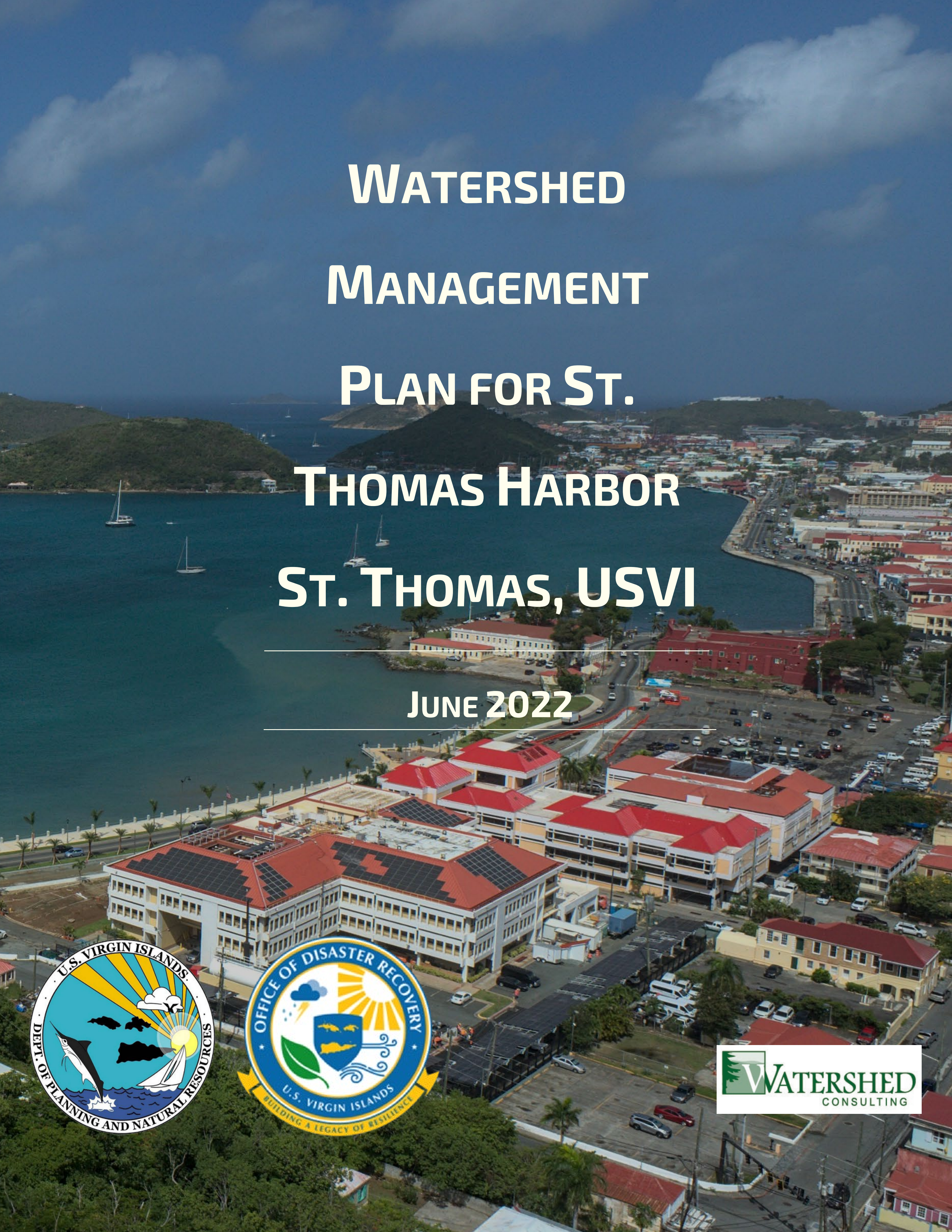
Watershed Management Plan for St. Thomas Harbor

St. Thomas, USVI

June 2022



ACKNOWLEDGEMENTS

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LIST OF ACRONYMS

APR	Area of Protection or Restoration
APC	Areas of Particular Concern
AU	Assessment Unit
BMP	Best Management Practice
CEKA	Cyril E. King Airport
CN	Curve Number
CWA	Federal Clean Water Act
CWP	Center for Watershed Protection, Inc.
DEM	Digital Elevation Model
DPNR	Department of Planning and Natural Resources
DPW	USVI Department of Public Works
DSM	Digital Surface Model
EPA	Environmental Protection Agency
FEMA	Federal Emergency Management Agency
GIS	Geographic Information System(s)
GSI	Green Stormwater Infrastructure
HMGP	Hazard Mitigation Grant Program
HUC	Hydrologic Unit Code
HSG	Hydrologic Soil Group
H&H	Hydrologic & Hydraulic
LID	Low Impact Development
MS4	Municipal Separate Storm Sewer System
MGD	Million Gallons per Day
nDSM	Normalized Digital Surface Model
NOAA	National Oceanic and Atmospheric Administration
NPDES	National Pollutant Discharge Elimination System
NRCS	National Resource Conservation Service
NWI	National Wetlands Inventory
OSDS	On-Site Disposal Systems
PAD-US	U.S. Geological Survey's Protected Areas Database

USGS	United States Geological Survey
USVI (or VI)	United States Virgin Islands
UVI	University of the Virgin Islands
SCS	Soil Conservation Service
SSO	Sanitary Sewer Overflow
STP	Sewage Treatment Plants
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
TPDES	Territorial Pollutant Discharge Elimination System
TSS	Total Suspended Solids
VIWMA	Virgin Islands Waste Management Authority
WAPA	USVI Water and Power Authority
WMP	Watershed Management Plan
WHPP	Wellhead Protection Plan
WTM	Watershed Treatment Model

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1 EXECUTIVE SUMMARY

The United States Virgin Islands Department of Planning and Natural Resources (USVI DPNR) obtained grant funding in 2019 through the Federal Emergency Management Authority Hazard Mitigation Grant Program (FEMA HMGP) to develop comprehensive Watershed Management Plans (WMPs) for eight high priority watersheds of concern, three on St. Thomas and five on St. Croix.

This watershed management plan (WMP) summarizes watershed-specific assessments and provides recommendations and design details to reduce flooding and improve water quality and resiliency. The three watersheds assessed on St. Thomas include Bolongo Bay, Cyril E. King Airport, and St. Thomas Harbor (Figure 1). The concurrent study on St. Croix includes the watersheds of Bethlehem, Diamond, Hovensa, Long Point Bay, and Salt River Bay.

This plan is intended to guide actions to:

1. Remedy current water quality issues,
2. Inform future development and improvement projects, and
3. Increase resiliency for existing and future land, water, and climate conditions.

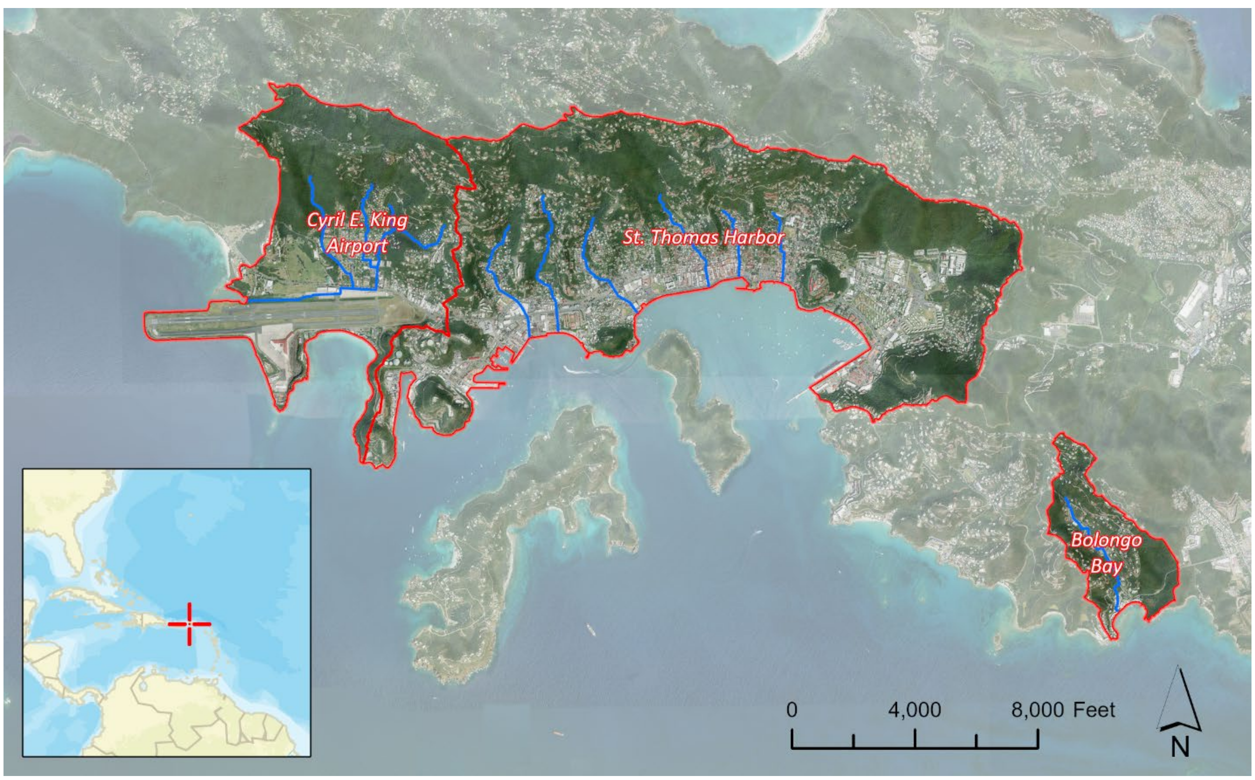


Figure 1. The three study watersheds on St. Thomas are outlined in red.

This WMP provides a detailed summary of existing regulations, policies, and programs related to water quality on St. Thomas. This is paired with a watershed-specific characterization that includes geology, hydrology, habitat, ecology, and demographics. To fully understand current watershed conditions, several datasets were developed or refined. Existing watershed boundaries and mapped guts were revised to better reflect drainage patterns. Stormwater infrastructure and existing stormwater best management practices were mapped and now reflect the most comprehensive dataset for the watershed. A detailed land cover dataset was developed utilizing high-resolution imagery from 2019. To identify areas of development change since the 2019 imagery was collected, an unmanned aircraft system (UAS) was flow over key areas in March 2022 to capture these areas and update the land cover dataset. This information was then used to predict future development through 2100. Within each of the priority watersheds, synoptic sampling of major guts during storm events was conducted to establish a baseline of water quality data. This gut monitoring is the most comprehensive assessment carried out in the territory and, in addition to characterizing the major guts, it also provided important information to guide future monitoring efforts.

The WMP also details the drivers of declining water quality and increasing flooding including a lack of stormwater best management practices (BMPs), unmaintained or absent stormwater infrastructure, unstable slopes, poorly planned development, failing wastewater infrastructure, solid and hazardous waste management, and climate change influenced changes in rainfall patterns. Other issues of concern are also summarized including point source pollution, sea level rise, mangrove health, coral health, air pollution, sargassum, and pollution from marinas.

A critical component in the development of this plan was community outreach and community and stakeholder input. A project website was developed so that easy to understand information, meeting invitations, and project deliverables could be shared. Several public outreach meetings were completed at pivotal stages of the development of this plan to inform and solicit feedback on areas of concern, utilizing critical local knowledge. As this WMP and other water quality driven efforts in the USVI span many years, it is important that the next generation take on the mantle of environmental stewardship. As such, a teaching curriculum was developed to educate students about watersheds, water quality issues, and green stormwater infrastructure. An in person and a remote teaching session with students on St. Thomas was carried out, completing the learning objectives from this curriculum. Likewise, a series of three educational videos were developed to educate a broad audience about these important topics. Finally, a more concise project summary website and print document were also created to convey the key information from this plan to a non-technical audience.

To improve water quality, reduce flooding, and improve resilience, a suite of recommendations was presented. A key component of the recommendations involved the identification, field and desktop assessment, water quality and hydrologic modeling, and ranking of stormwater BMPs. Preliminary (30%) engineering designs were advanced for two priority projects in the watershed and cost estimates were provided so that funding can be sought for final design and implementation. Other recommendations include changes to policies regarding solid waste management, watershed planning, site design, and stewardship. As this plan is meant to be actionable, financial and technical assistance needs, proposed timelines, and preliminary costs are also provided.

2 Project Overview

2.1 Introduction

The United States Virgin Islands Department of Planning and Natural Resources (USVI DPNR) obtained grant funding in 2019 through the Federal Emergency Management Authority Hazard Mitigation Grant Program (FEMA HMGP) to develop comprehensive Watershed Management Plans (WMPs) for:

- Three (3) high priority watersheds of concern on St. Thomas.
- Five (5) high priority watersheds of concern on St. Croix.

This watershed management plan (WMP) summarizes the assessment of the three high priority watersheds of concern on St. Thomas, specifically the Bolongo Bay, the Cyril E. King Airport, and St. Thomas Harbor watersheds (Figure 2). These watersheds encompass areas with critical infrastructure such as Cyril E. King Airport, major roadways such as Veterans Drive, commercial, residential, governmental, and agricultural areas.

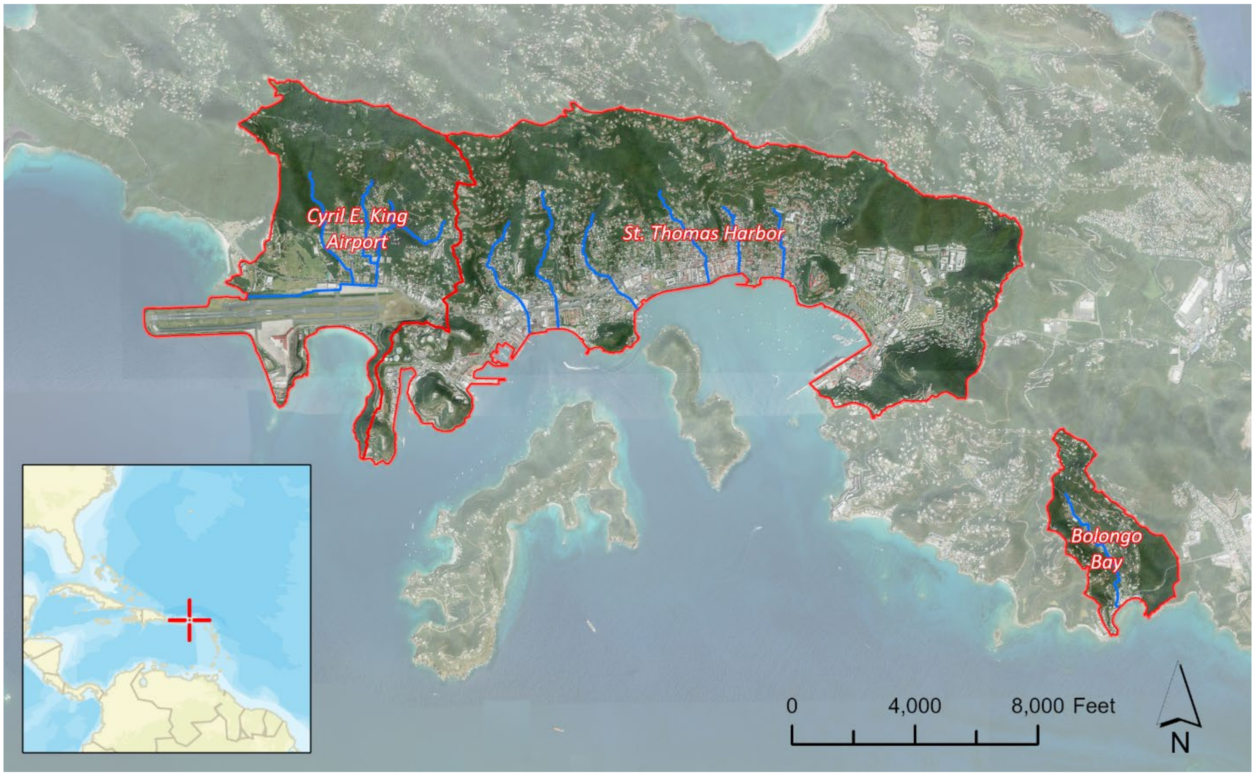


Figure 2. The three study watersheds on St. Thomas are outlined in red.

The high priority study watersheds were selected based on their importance to Virgin Islanders as places where the negative impacts of development (Figure 5) have led to decreasing water quality and increased flood risk. The recommendations of this report will equip the Virgin Islands with the means to reduce consequences of climate change as the region is expected to experience more intense rainfall events with long stretches of drought. The goal of this WMP is to summarize watershed-specific issues, propose attainable solutions to improve water quality and reduce flooding, outline the technical and financial resources required to do so, and create a proposed implementation timeline. This plan will be used to inform local agencies and institutions on site-specific options for flood reduction, stormwater management, and water reuse as well as larger programmatic changes that would improve water quality and resiliency.

Figure 3. Significant development on St. Thomas, such as the downtown St. Thomas Harbor area pictured, has impacted water quality and altered natural drainage patterns on the island.

2.2 BACKGROUND

2.2.1 Watersheds and Guts

A watershed is an area of land where rainfall drains to a common body of water such as a bay or harbor. There are 15 primary watersheds on St. Thomas, separated from each other by the crests of hills, ridgelines, and constructed infrastructure that guide the movement of water across the land (Figure 4). Each of these watersheds is made up of smaller drainage systems called subwatersheds that are also determined by topography and water flow.

Figure 4. Watersheds of St. Thomas.

A healthy watershed is one that conserves and cleans water, maintains aquatic ecosystems, supports healthy soils, and provides habitat for wildlife and plants. One of the most critical processes in maintaining healthy watersheds is infiltration, that is, the process by which water absorbed into the ground. This process provides many benefits, from recharging groundwater reservoirs to acting as a natural filtration system and removing pollutants. When the rate of rainfall exceeds the rate of infiltration, stormwater runoff is produced. This happens more readily and with smaller rainfall amounts when rain falls on impervious surfaces such as parking lots, roofs, roads, and driveways that do not allow water to soak into the ground (Figure 5). In its wake, stormwater runoff can scour the landscape, causing erosion and flooding that can damage local ecosystems and communities alike. This becomes more likely as native vegetation, which stabilizes and protects the native soil, is removed. As stormwater moves across the land, it can pick up harmful pollutants like trash, chemicals, nutrients, and excessive sediment before inevitably depositing these pollutants into St. Thomas's harbors and bays.

Figure 5. Runoff from impervious surfaces such as a road contributes to flooding and water quality problems.

The dominant water conveyance system within the watersheds of St. Thomas are guts and these waterways can also transport sediment and pollutants (Platenberg, 2006). A gut (occasionally spelled "ghut") is a stream with a reasonably well-defined channel (Figure 6). The guts of St. Thomas are ephemeral, flowing only when there has been enough rain for the accumulation of water within the defined gut channel. Historically, there were many guts that flowed year-round, fed by the groundwater reserves of the island. As recently as 1950, it was reported that a gut in Charlotte Amalie ran year-round (Moonlenaar & Paiewonsky, 2005). Now, guts primarily only flow following storm events, and this ephemeral nature has impacted the public perception of guts as only being useful as stormwater conveyances and not as a functional amenity of the island (Gardner et al., 2008).

Guts provide a variety of critical ecosystem services to St. Thomas. They provide habitats to many rare flora and fauna, are sources of food and recreational opportunities to members of the community, and provide fresh water for agricultural, industrial, and domestic purposes (Gardner et al., 2008). While other types of wetlands are present on St. Thomas and serve vital functions, the absence of large freshwater resources means that guts form the basis for watershed management in the territory (USVI DPNR, 2020).

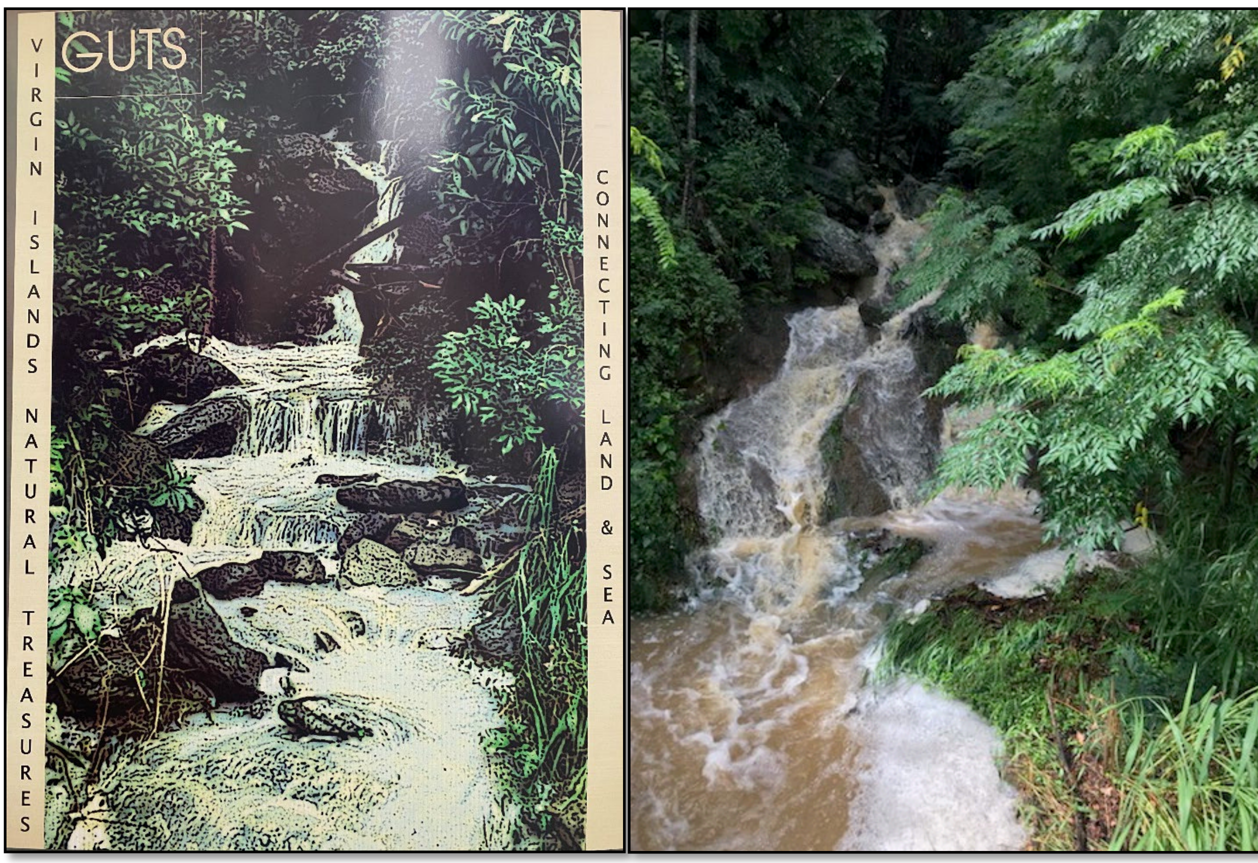


Figure 6. Illustration of a gut by the University of the Virgin Islands, Cooperative Extension Service (left) and picture of gut (right).

2.2.2 Watershed Management Planning

When Hurricane Irma hit the Virgin Islands in September of 2017, the impacts were devastating. High winds and flooding catastrophically damaged infrastructure across St. Thomas including homes, schools, hospitals, roads, and private businesses. Many residents were left with limited access to food, water, or electricity (Cox et al., 2019). The significant flooding also led to surges in nutrients and sediment entering the coastal ecosystems, causing serious damage to the coral reef communities (Hernández et al., 2020).

Events like these underline the need for proper watershed management, which is vital to maintaining healthy watersheds. There are many management practices that a community can employ to address stormwater runoff and prevent pollution at its source. Public education and outreach can be used to communicate the importance of responsible landscaping and proper use and storage of toxic household materials. Land use controls and/or incentives can be used to manage the development of impervious surfaces. Best management practices (BMPs) such as low impact development (LID) and green stormwater infrastructure (GSI) can be designed to clean and store stormwater.

At the heart of watershed management is the underlying philosophy that everything is interconnected. Every component of a watershed is interrelated and interdependent, bound together by the same shared water system. A successful watershed management framework supports partnerships and uses sound multi-disciplinary science to identify and complete well-planned, connected actions to achieve results.

In developing this WMP, the guidelines established in the U.S. Environmental Protection Agency's (EPA) *Handbook for Developing Watershed Plans to Restore and Protect our Waters* (the Handbook) were followed (U.S. EPA, 2008). The Handbook details a six-step process for watershed planning as outlined in Figure 7. The contents of this WMP are the product of Steps 1-4, that is, build partnerships (Step 1), characterize watersheds (Step 2), set goals and identify solutions (Step 3), and design an implementation program (Step 4). Recommendations for implementation of the WMP (Step 5) and measurement of progress and making adjustments as progress is made (Step 6) are also provided within this WMP. It is important to note that the process of watershed management is dynamic and iterative. As more information is collected and lessons are learned, the implementation program should be reassessed, refined, and modified accordingly.

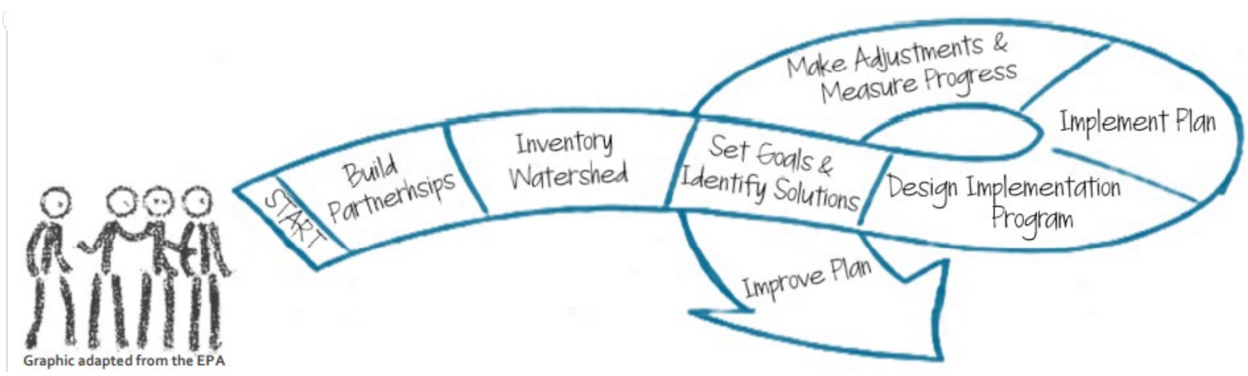


Figure 7. Conceptual drawing of the WMP and implementation process.

One key component of this process is its incorporation of the nine minimum elements from the Clean Water Act section 319 Nonpoint Source Program's funding guidelines. Each of these elements are embedded within the six-step process for watershed planning as shown in Figure 7. The nine elements are designated by the EPA as the most critical for an effective watershed planning process and are generally required for watershed projects funded under section 319. The nine elements, included in EPA's *Handbook for Developing Watershed Plans to Restore and Protect Our Waters* (2008), are:

1. Identify causes and sources of pollution
2. Estimate load reductions expected
3. Describe management measures and targeted critical areas
4. Estimate technical and financial assistance needed
5. Develop an information and education component
6. Develop a project schedule
7. Describe interim, measurable milestones
8. Identify indicators to measure progress
9. Develop a monitoring component

2.3 COMMUNITY OUTREACH

An essential component in the creation of this WMP is following the principles of community-driven development. Broad public education and engagement in the planning process is essential to the success of watershed management. This requires deliberate efforts to develop public participation in a shared analysis of both the problems and solutions for a given watershed. Communities most vulnerable to the effects of flooding and degraded water quality have relevant direct experience and can provide first-hand accounts and information not typically available by other means of investigation. It is also these same communities that are likely to be the most directly affected by the outcomes of the WMP. The more residents that are engaged in their own community solutions, the more effective those solutions will be.

In the development of this WMP, a variety of mediums were utilized for the purposes of community outreach and engagement. This included virtual meetings, site visits, social media engagement, short educational videos, and teaching sessions. One key component of community outreach was the development of a project website designed using the ESRI Story Map platform (Figure 8). The purpose of the Story Map is to provide a comprehensive resource for DPNR, partners, and community members to learn about the project, provide input, and access updates on project events and deliverables. One of the primary features of the Story Map is a tab that allows the public to submit reports of flooding or other water quality issues in a geographic format. This feature enables citizens to engage with the project continuously and to act as citizen scientists.

A link to the Story Map is provided here: Visioning Story Map. It can also be accessed and promoted via tinyurl.com/StormwaterUSVI.

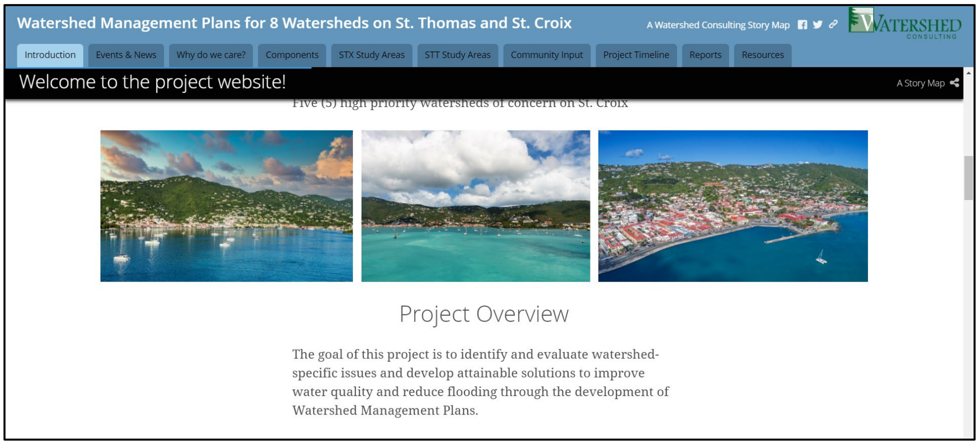


Figure 8. A screenshot from the Project overview section of the WMP Story Map.

2.3.1 Media Outreach

To inform community members about upcoming events and increase general awareness of the project, media outreach through radio, the DPNR website, and social media posts on the project's Facebook page was completed. The project piqued the interest of a number of local independent news organizations, resulting in several articles being written about the project. A summary of the press coverage and media outreach associated with project is summarized in Table 1.

Table 1 . A summary of the media outreach and press coverage for the project.

Media Outreach			
Medium	Organization	Date	Brief Description
Radio	NPR/WTJX / 93.1 FM	March 29th, 2021	Interview for promotion of community kickoff meetings
	WSTX/ 100.3 FM	March 29th, 2021	Interview for promotion of community kickoff meetings
	DaVybe/WLDV/107.9 FM	March 30th, 2021	Interview for promotion of community kickoff meetings
	Radio One / WVWI / 1000 AM	March 30th, 2021	Interview for promotion of community kickoff meetings
Phone Interviews	V.I. Daily News	April 8th, 2021	Interview
	V.I. Daily News	April 12th, 2021	Interview

Press Coverage			
Organization	Author	Date	Title & Link
U.S. Virgin Islands Hotel & Tourism Association	Laurel Kaufmann	April 1st, 2021	USVI Watershed Management Plan Town Hall Announcement
The Virgin Islands Consortium	Staff Consortium	April 6th, 2021	Town Halls to Discuss Impact of Stormwater Runoff on Local Communities Set for Wednesday and Thursday
The St. Thomas Source, US Virgin Islands	Susan Ellis	April 7th, 2021	Watershed Project Aims to Improve Water Quality in the Territory
The St. Thomas Source, US Virgin Islands	Sian Cobb	April 9th, 2020	Community's Input Sought for Watershed Plans
The Virgin Islands Daily News	Patricia Borns	April 14th, 2021	Stormwater USVI asks residents to identify territory water issues
The Virgin Islands Free Press	VI Free Press Staff	June 23rd, 2021	Town Hall Meeting On Long Point Watershed In St. Thomas Is Tonight
The St. Thomas Source, US Virgin Islands	Don Buchanan	June 30th, 2021	Rain Runoff Causes Problems, Project Seeks Solutions

2.3.2 Community Meetings

To engage with communities of St. Thomas, a combination of kickoff meetings, community visioning meetings and watershed-specific meetings were organized. The meetings were held virtually to maximize attendance and in consideration of the mitigating circumstances of the COVID-19 pandemic. The initial kickoff meeting (Kickoff Meeting #1) was intended to introduce USVI DPNR staff to the project, confirm goals and schedule, determine water quality sampling locations, and solicit general input. The second kickoff meeting (Kickoff Meeting #2) followed a similar format but was made available to all agencies and departments of the USVI territory government. In both meetings, project partners solicited important feedback on what can make a project of this nature successful and what important resources are available.

The intent of the community visioning meetings was to identify how individuals and agencies can lead, participate in, and collaborate on watershed improvements to achieve the goals of the WMP and the community vision for the future. Two community visioning meetings were held for the island of St. Thomas (Figure 9), one for residents and one for local business leaders. During these meetings, local stakeholders shared their perspective on environmental challenges within the study watersheds. Amongst business leaders, there was almost unanimous consensus that poor water quality and/or flooding has directly impacted their business and that they would benefit from a water quality friendly marketing campaign. This was echoed by several residents who have been directly impacted by the repercussions of storm-driven flood events. One resident detailed their firsthand account observing a large sediment plume in the bay after one particularly large rain event.

Figure 9. Two Virtual Town Hall meetings were held for St. Thomas.

Two watershed-specific community meetings were held for each of the study watersheds on St. Thomas (Table 2). In the first round of watershed-specific virtual town hall meetings (Figure 10), which occurred in the winter of 2021, the discussions were focused on key areas of concern and best management practice opportunities as they pertain to each individual watershed. It was during these meetings that stakeholders within the community identified specific locations that would benefit the most from improved stormwater management practices. Maps of the watersheds were presented, and community members pointed to specific locations where they have observed flooding or water quality issues firsthand. In Bolongo Bay for example, residents brought attention to the erosion of Water Gate Rd, which has been so significant that the road is now referred to by some residents as "pothole alley".

In the second round of town hall meetings, which occurred in the winter of 2022, the discussions focused on the progress of the project in the last year (Figure 11). This included presentations of the top ranked BMP practices and the processes that went into selecting them, as well as the water quality monitoring conducted and the final steps of the project that had not yet been completed at this time. Further discussions were held in these meetings about other potential areas of impact that should be assessed.

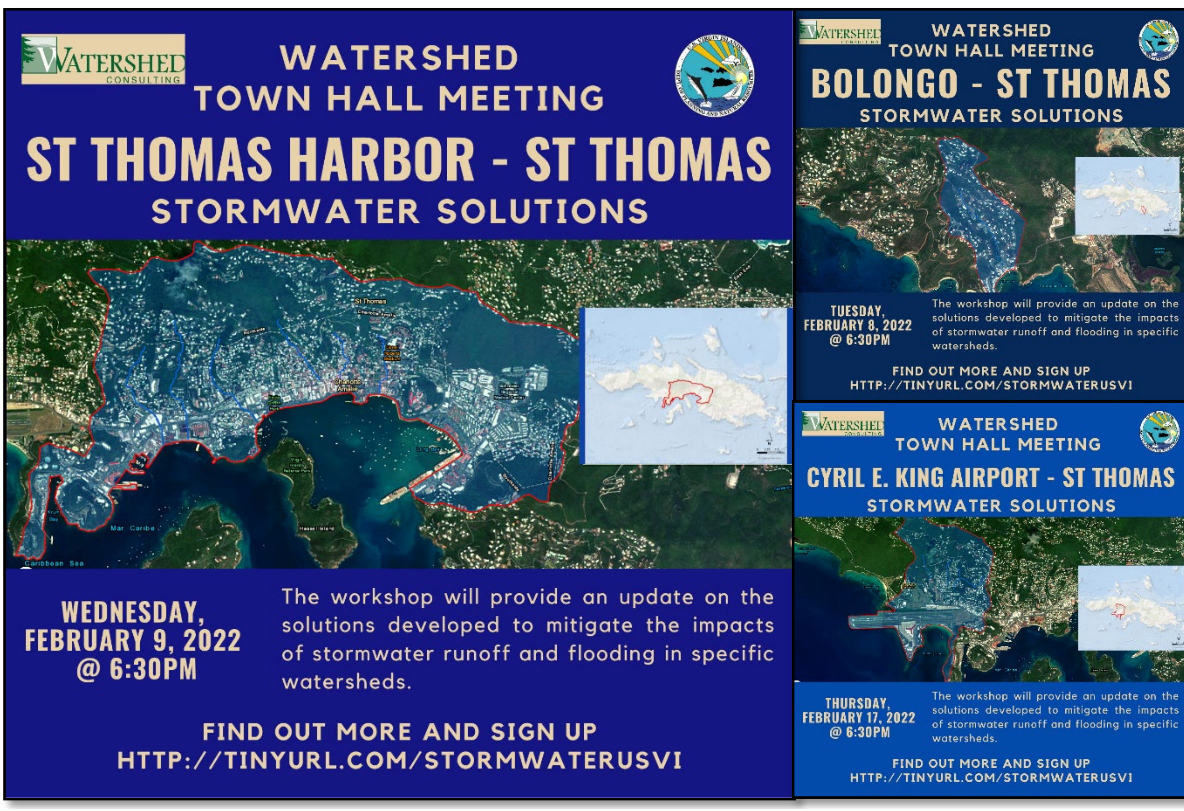


Figure 10. Flyers used to advertise the first watershed town hall meetings.

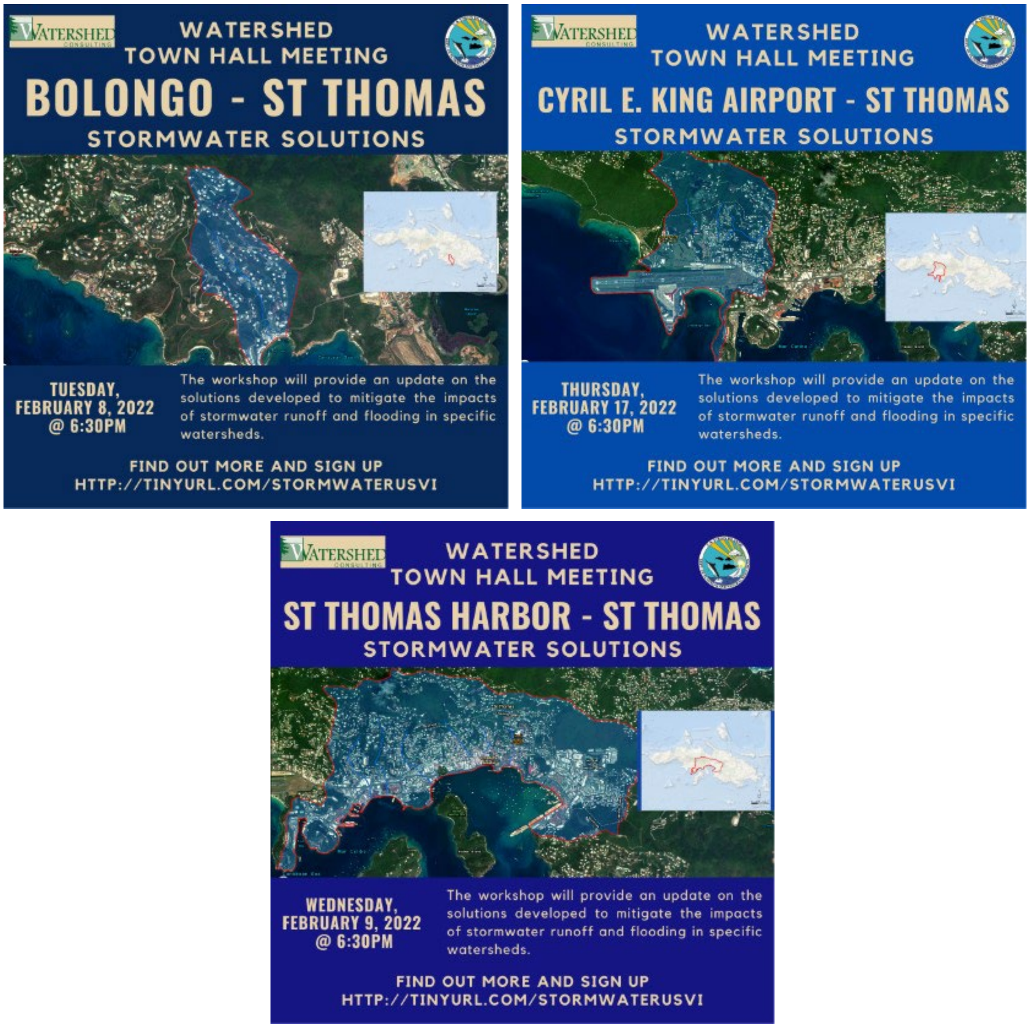


Figure 11. A second round of town hall meetings were held in February of 2022.

Table 2. A summary of community presentations and meetings.

<table>
<tr><th colspan="5">Presentations and Meetings</th></tr>
<tr><td colspan="2">Events</td><td colspan="2">Date</td><td>Brief Description</td></tr>
<tr><td rowspan="2">Project Kickoff Meetings</td><td>Project Kickoff Meeting #1 - USVI DPNR Stakeholders</td><td colspan="2">February 26th, 2021</td><td rowspan="2">The meetings were held to discuss the project, confirm project goals, confirm the project schedule, determine water quality sampling locations, and solicit general input.</td></tr>
<tr><td>Project Kickoff Meeting #2 - USVI Government Stakeholders</td><td colspan="2">March 3rd, 2021</td></tr>
<tr><td rowspan="2">Community Visioning Meetings</td><td>Community Visioning Meeting - Local Residents</td><td colspan="2">April 8th, 2021</td><td rowspan="2">The meetings were held to provide residents and businesses with an introduction to watershed management and project summary. An in-depth watershed discussion was held to identify high risk areas and address local concerns.</td></tr>
<tr><td>Community Visioning Meeting - Local Businesses</td><td colspan="2">April 8th, 2021</td></tr>
<tr><td colspan="2">Events</td><td>First Meeting Date</td><td>Second Meeting Date</td><td>Brief Description</td></tr>
<tr><td rowspan="3">Watershed Town Hall Meetings</td><td>Bolongo Bay Watershed Town Hall</td><td>June 3rd, 2021</td><td>February 8th, 2022</td><td rowspan="3">The meetings were held to discuss key areas of concern and best management practice opportunities as they pertain to each individual watershed. It was during these meetings that stakeholders within the community identified specific locations that would benefit the most from improved stormwater management practices.</td></tr>
<tr><td>St. Thomas Harbor Watershed Town Hall</td><td>June 7th, 2021</td><td>February 9th, 2022</td></tr>
<tr><td>Cyril E. King Airport Watershed Town Hall</td><td>June 9th, 2021</td><td>February 17th, 2022</td></tr>
</table>

2.3.3 Site Visits

Property damage and limited access to roadways caused by flooding and erosion were the most prevalent concerns brought up by community members (Figure 13). Locations identified as concerns by community members on the project website interactive map can be found in Figure 13. In response to many of those who contacted the project team or our partners about site specific issues, representatives from our team conducted site visits to assess the damage or issues, meet with community members in-person, and develop proposed solutions.

Often a relatively recent infrastructure development was cited as the source of aggravated flooding within a neighborhood or on a specific property. Community members noted how the construction of housing developments, walls, and sidewalks led to the flow of runoff being redirected onto their property. This highlights the need for careful planning that considers stormwater management in any type of development.

Figure 12. Photo of road erosion taken by resident on a road on the north side of St. Thomas.

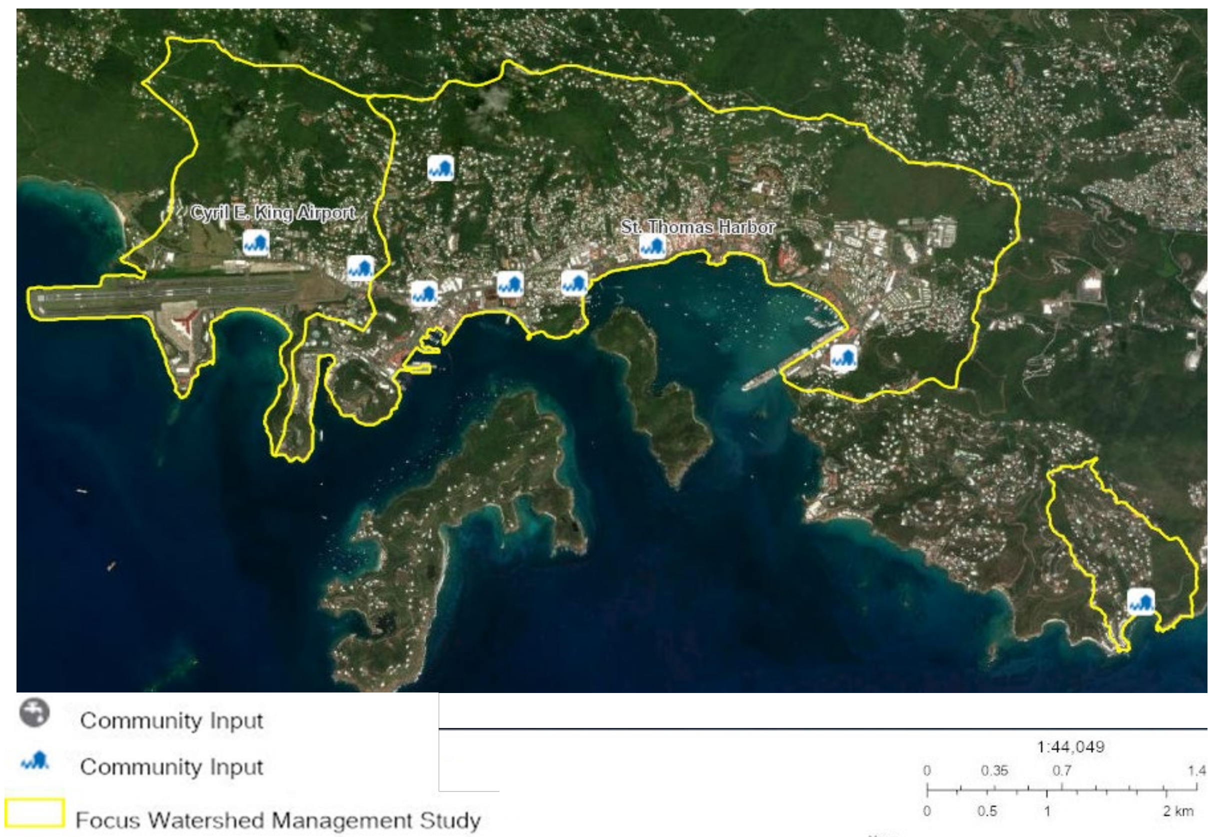


Figure 13. Flooding and water quality problem areas identified by community members .

In one specific incident, a community member detailed the excavation of old growth trees within an existing gut and along its banks (Figure 14). The community member noted how the trees used to provide shade and shelter to many species of mammals, birds, and reptiles. The area was once a place he would take his family to recreate. He stated that the excavation of the gut and its riparian buffer destroyed this ecosystem, and there has been no follow up to amend the environmental consequences of the destruction.

Figure 14. Photos of a gut taken by a resident before (left) and after (right) excavation.

2.3.4 Short Educational Videos

A series of three short educational videos were developed as a part of this project. The purpose in the development of these videos was to provide DPNR with educational outreach content that they could share on their social media and with local stakeholders.

Educational Video #1: An Introduction to Watersheds

This video provides an introduction to watersheds. The video introduces viewers to the fundamentals of watershed science, providing them with the knowledge to identify the basics of what constitutes a healthy watershed, and what potential threats may compromise that health. The video goes on to describe watershed management as a practice, why it is important and what that means for residents of a watershed. The narrator in this video is Olasee Davis, an assistant professor in the Natural Resources Program at the University of the Virgin Islands (UVI).

Educational Video #2: Threats to Watersheds and Potential Solutions

The second educational video dives a little deeper into the threats that watersheds in the Virgin Islands face and management strategies that can be used to address them. It provides an introduction to the specific water quality constituents (i.e., nutrients, sediment and bacteria) that threaten human and environmental health. This was followed by an introduction to hydrologic dynamics, specifically the methods of water movement including infiltration, interception, storage, and transport and how land use plays an influential role in these dynamics. The video summarizes common stormwater best management practices and explains how these practices utilize hydrologic dynamics to address pollutants of concern.

Educational Video #3: Community Action

The last video of the educational series focused on community action. Specifically, how local residents and businesses can engage in reducing contamination and improving the overall health of USVI watersheds. The primary premise of this video is that watershed protection is everyone's responsibility and there are impactful ways that individuals can contribute to improved watershed management. The first subject of focus is vegetation, emphasizing the value of utilizing vegetation to minimize erosion and reducing fertilizer and pesticide use to minimize nutrient pollution. This is followed by a discussion of hazardous chemicals and solid waste, and how residents can properly dispose of them. Next, the video describes the value in building a rain garden and keeping new structures out of flood zones. The video ends with a discussion of community action groups and local clean ups where community members can volunteer and get involved.

2.3.5 Educational Outreach

2.3.5.1 Curriculum Development

A teaching curriculum was developed to be used by educators in the Virgin Islands. The curriculum is divided into three sections that align with the learning objectives. In Section 1, students learn about stormwater and its movement through watersheds, and the types of pollutants that stormwater can carry to surface waters. In Section 2, students learn to monitor and measure stormwater, and they are introduced to green stormwater infrastructure as a mechanism to treat and reduce stormwater runoff from a property. Activities are designed to engage students to make recommendations about green stormwater infrastructure practices for their school grounds and local communities. In Section 3, students engage in a stormwater stewardship project.

Teachers have the option to carry out the curriculum in its entirety or to use guidance provided to engage students in any individual activity or grouping of activities. Each section includes an overview with guiding questions, student learning objectives, a list of activities and materials, preparation guidelines for educators, activity descriptions, resources for additional information, and background reading and worksheets for students. Key terms are listed in bolded red font and defined in a glossary at the end of the curriculum. Background information and worksheets designed for student use are provided within the document.

2.3.5.2 Teaching Sessions

Teaching Session 1:

An in person teaching session was held at the Ivanna Eudora Kean High School in mid-March 2022 (Figure 15). The project team met with Ms. Michealrose Ravalier's Physical Sciences class to complete the learning objectives for six of the ten activities found in the U.S. Virgin Islands Stormwater Education & Stewardship Curriculum (Appendix A). A seventh activity was partially completed. These activities, the learning objectives, and how they were completed are summarized below.

Figure 15. Students learned about concepts related to watershed planning and green stormwater infrastructure.

Activity 1.1B: **Knowledge Assessment**

This activity was focused on ensuring that students understand key terms and concepts about watersheds, impervious surfaces, stormwater runoff, and best management practices.

A question-and-answer activity was completed. The students were asked:

- What is a watershed?
- What is an impervious surface?
- What is a pervious surface?
- What is stormwater runoff?
- How does stormwater runoff and development impact water quality?
- What is a rain garden?

If students were unable to answer a question, the presenters helped guide them to the correct answers.

Activity 1.3: Delineating a Watershed

The goal of this activity is to understand how to delineate a watershed and understand a topographic map. At the teaching session, a location where a rain garden is proposed was assessed. The students walked to that location and a discussion was held about how water flows in that area. Students were asked to consider the area that drained to the point of interest.

Students were handed a printed map of the school area focused on the proposed rain garden area. They were then asked to draw the watershed they observed in the field (Figure 16).

Figure 16. Students draw the watershed for the proposed rain garden at their school.

Activity 1.4: Stormwater in Your Community

A discussion was held regarding pollutant sources, impervious surfaces, and pervious surfaces with a focus on the drainage area for the proposed rain garden at each school. A discussion was also held about what other harmful pollutants could be carried by stormwater like oil from cars or trash. Students were asked if they have seen "muddy" water flowing over the ground when it rains. The topics of erosion and sediment pollution were introduced. Students were asked to consider how pollutant sources while looking at the drainage area for the proposed rain garden outside and then while looking at their drainage area map.

Figure 17. Students discuss the location of impervious and pervious surfaces within the drainage area

Activity 1.5: Stormwater Flow Path Map

A discussion was held about how stormwater moves over land and how slope, and land cover, and soil compaction can impact that flow. Students discussed how the stormwater flows while looking at the site outside. They were then asked to draw arrows to indicate how the stormwater flows towards the proposed rain garden location within the watershed they have drawn.

Activity 1.6: Stormwater Pollution Map

A discussion was held regarding impervious surfaces and pervious surfaces with a focus on the drainage area for the proposed rain garden at each school. Students were asked to point out these areas outside and discuss the impacts of these land cover types. Students were asked to label the impervious and pervious surfaces on their drainage area map (Figure 17).

Activity 2.1: Getting to Know Green Stormwater Infrastructure (partial completion)

The topic of best management practices and green stormwater infrastructure (GSI) were introduced to students. As the school has a proposed rain garden, the discussion was focused on this one practice. A brief discussion on the benefits, the design, and the maintenance of rain gardens was held.

Activity 2.2: Recommend a GSI Practice

A rain garden was recommended by the school group for their school property. A discussion was held regarding the practice design, how to direct water to the practice, and what issues the rain garden will address. Considerations include the size of the practice, plants to be installed, maintenance, and aesthetics. The group also discussed the importance of designing the rain garden to be an appropriate size for the drainage area.

Teaching Session 2:

A second remote teaching session was held in May 2022. Some adaptations from the curriculum were necessary given the remote teaching session format and the goal of making the content as useful as possible for the students.

Activity 1.2 – Watershed in a Box

The goal of this activity is to understand watersheds and their connection to stormwater runoff. Since this session was remote, this goal was completed by demonstrating how watersheds impact stormwater runoff in HydroCAD, a modeling program commonly used for this type of analysis. A model for the school property for a location of interest for a proposed rain garden proposed by the school was modeled.

Activity 2.1: Getting to Know Green Stormwater Infrastructure (partial completion)

In the previous in-person teaching session, the Green Stormwater Infrastructure (GSI) practice discussion focused on rain gardens. During the Zoom session, a review of other common GSI practice types was completed in a brief presentation with photo examples.

Activity 3.1 – Maintenance of Rain Gardens

A discussion of maintenance requirements for rain gardens was held, which was selected given the proposed rain garden at the school and will serve as a stewardship activity. Topics included:

- What needs to be done?
- How often is maintenance required?
- What tools are required?

Section 1 Recap:

It was confirmed that the students were able to:

- Describe a watershed.
- Describe stormwater and how it impacts watersheds.
- Identify examples of nonpoint source pollution, discuss how it occurs, and compare and contrast it with point source pollution.

This completes the student learning objectives for Section 1.

Section 2 Recap:

The student learning objectives for Section 2 are:

- Students will learn about green stormwater infrastructure design solutions.
- Students will be able to calculate impervious area and volume estimates for stormwater design.
- Students will identify design criteria and make recommendations.

These objectives have been met with a combination of the in-person and the remote Zoom teaching sessions. Students learned about rain gardens and impervious surfaces as well as some of the considerations for design in the in-person teaching session. In the Zoom session, students learned about additional types of GSI and the considerations for those practices.

This completes the student learning objectives for Section 2.

Section 3 Recap:

Stewardship activities will be completed in the future through rain garden maintenance education.

This completes the student learning objectives for Section 3.

2.4 Existing Regulations, Policies & Programs

Existing regulations, policies, and programs related to water quality have a profound impact on the success of current and future watershed planning efforts. Strong regulations and programs provide a solid base for watershed planning efforts and can establish potential sources of funding for staffing and training. As part of this WMP, an evaluation of current codes and a survey of staff to better understand current challenges for staff and where code language may be adjusted to enhance water quality and protect natural resources was conducted. The complete methods and findings from the evaluation are documented in the U.S. Virgin Island Regulatory Review Report found in Appendix A. A summary of this information targeted at DPNR staff is also provided in Appendix A.

2.4.1 Current Policies & Legal Framework

In the USVI, both federal and local policies and procedures are in place for environmental protection. The USVI government implements or enforces the following federally mandated environmental programs:

- Clean Water Act (CWA)
  - Ambient Water Quality Monitoring
  - Section 319 Nonpoint Source Pollution
  - Section 402 Territorial Pollutant Discharge Elimination System (TPDES)
  - Beaches Environmental Assessment and Coastal Health (BEACH) Act
- Safe Drinking Water Act (SDWA)
- Clean Air Act (CAA)
  - Air Pollution Prevention and Control
  - Title V Operating Permits
  - New Source Performance Standards
  - Risk Management Program (RMP)
  - Section 112 Air Toxics, including National Emission Standards for Hazardous Air Pollutants
- Energy Policy Act of 2005

The Virgin Islands Code currently contains the policies for water resources management and watershed planning in the USVI. The 2019 Code includes measures to ensure that some level of protection is provided for available water resources since development activities on land can result in direct impacts on coastal waters and marine resources due to the islands physiography. The USVI has several watershed protection codes in place (i.e., buffers, erosion, and sediment control) but are still experiencing negative water quality impacts. The surveys conducted through this regulatory audit and needs/capabilities assessment helped to identify how implementation of the codes could be improved. The regulatory review (see Appendix A, report Table 1) highlights the sections of the Virgin Islands Code that have direct influence on water resources and watershed planning efforts.

2.4.2 USVI Regulatory Agencies

The institutions with regulatory responsibilities related to watershed management and planning in the USVI are as follows:

2.4.2.1 Department of Planning & Natural Resources (DPNR)

The Department of Planning and Natural Resources (DPNR) was established in 1987 and serves as the agency responsible for the administration and enforcement of all laws pertaining to the preservation and conservation of fish and wildlife, trees and vegetation, coastal zones, cultural and historical resources, water resources, and other environmental concerns. Prior to 1987 the agency was known as the Department of Conservation and Cultural Affairs. The responsibilities of the DPNR include oversight and compliance for land subdivision, development and building permits, code enforcement, earth change permits, zoning administration in the coastal zone, boat registration, and mooring and anchoring of vessels within territorial waters. DPNR is comprised of ten primary operating divisions, each with its own regulatory mandate. The divisions with responsibilities relevant to watershed management can be found in Appendix A's regulatory review.

2.4.2.2 VI Department of Agriculture (VIDA)

The Virgin Islands Department of Agriculture (VIDA) is responsible for soil conservation practices on agricultural lands including maintaining buffer zones along guts. VIDA exercises its authority for earth change activities conducted on sites over which they have authority They also support the activities of the Virgin Islands Conservation District (VICD) to provide for the conservation and development of the soil, water, and other natural resources of the Virgin Islands.

2.4.2.3 Department of Public Works (DPW)

The Department of Public Works (DPW) routinely impacts watershed health and planning efforts through several program areas including:

1. Infrastructure Maintenance: DPW is mandated to plan, construct and maintain public roads, highways, storm drainage systems, buildings, transportation systems, parking facilities, and cemeteries.
2. Gut Cleaning Program: DPW operates a program to clean guts to avoid nuisance flooding especially during the hurricane season. Guts are cleared and maintained in accordance with the guidelines stipulated by the DPNR and may involve bushing the sides of the guts and removal of solid waste. DPW has also partnered with the Waste Management Authority (WMA) to address guts that have been affected by sewage.
3. Flood Mitigation: DPW undertakes flood mitigation work for roads, as well as general flood mitigation for properties in floodplains. Examples include the Smith Bay Road stormwater mitigation project[1] and the St. Andrews Flood Mitigation Project[2].

[1] https://www.usviodr.com/dpw-receives-award-to-address-chronic-flooding-in-smith-bay/
[2] https://www.fema.gov/case-study/successful-storm-sewer-system-improvement

2.4.2.4 Waste Management Authority (WMA)

This agency provides waste collection, treatment, and disposal services to protect public health and preserve the environment of the USVI. They regulate the landfills, convenience centers, and bin locations where solid waste is collected. The agency is also responsible for the public sewer system and addressing sanitary sewer overflows (SSOs) and combined sewer overflows (CSOs).

2.4.2.5 Water and Power Authority (WAPA)

This agency produces and distributes electricity and drinking water to residential and commercial customers in the territory. This includes the islands' wells that may be impacted by pollutants from runoff. The DPNR DEP's groundwater program also has a role in in drinking water through their public water systems supervision program that regulates well management and new well drilling.

2.4.3 Coastal Zone Management Tier Structure

The entirety of the USVI is in the coastal zone because they are small islands. For planning and permitting considerations, the coastal zone is divided into two tiers: Tier 1 and Tier 2. Tier 1 extends landward from the outer limit of the territorial sea, including all offshore islands and bays, to distances inland as specified in an approved map that was first developed in 1979 (NOAA, 2018). Figure 18 shows the extent of the Tier 1 areas for St. Thomas as provided by the Coastal Zone Management (CZM) program. Tier 2 includes the remainder of the USVI - interior portions of the Islands of St. Thomas, St. John, and St. Croix, including all watersheds and adjacent land areas not included in Tier 1.

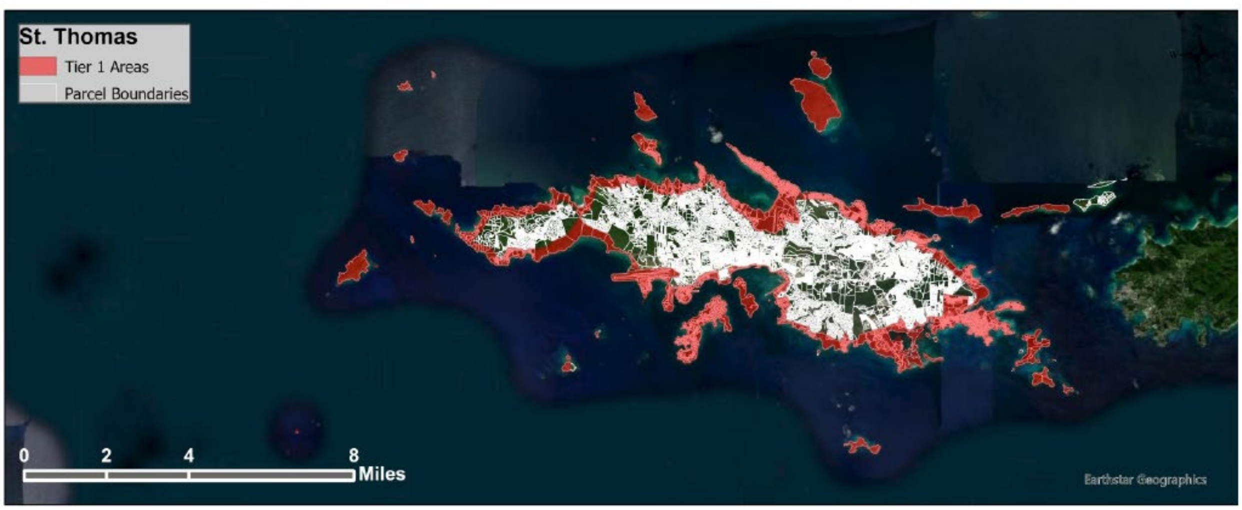


Figure 18. CZM Tier 1 areas (courtesy of CZM).

Areas designated as Tier 1 have a more stringent permitting process than those in Tier 2. Permits for development can be for either minor activities or major activities and permitting development responsibilities are assigned based on the activity type. The DPNR Commissioner issues permits for all minor activities. A Coastal Zone Management Commission committee for each of the three major islands issues all permits for major activities within Tier 1. A more comprehensive coastal zone permit process is focused only on proposals in Tier 1, and Section 906 of the VICZMA is focused on specific policies applicable to the tier. Major construction permit applications for Tier 1 projects are reviewed by CZM staff who then issue a report with recommendations that trigger a public hearing process. After the public hearing, the project must be approved by the local Coastal Zone Management Commission committee for the specific island, and then by the USVI legislature and the governor.

Tier 2 permit applications have fewer requirements for applicants during the DPNR review process and are handled entirely by DPNR. The Division of Building Permits issues permits for activities under the Earth Change law, while the Division of Planning issues zoning and subdivision permits. No public hearing is currently required for Tier 2 projects unless a zoning change is required. Although development projects in Tier 2 are required to be consistent with the goals of the VICZMA and reviewed by the relevant authorities, compliance monitoring and enforcement by DPNR personnel is typically limited to permitted activities within Tier 1 only.

2.4.4 Survey

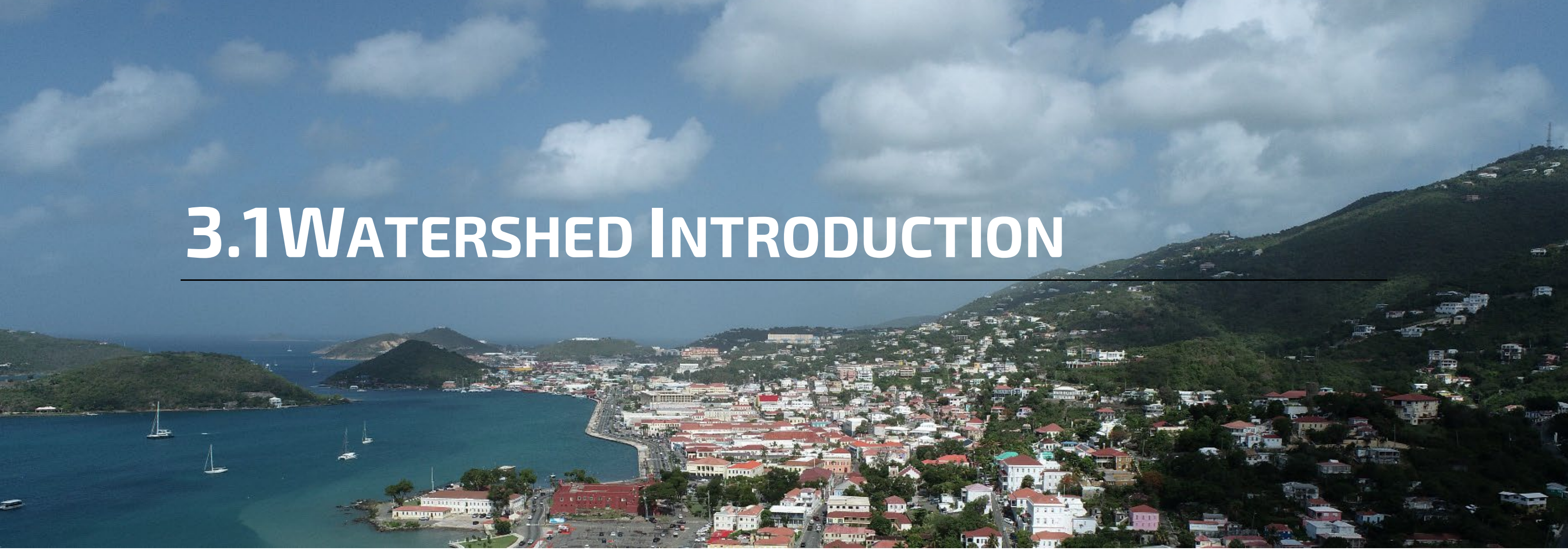
DPNR staff were surveyed to identify programmatic strengths and gaps in watershed protection strategies. The review used multiple online survey tools to best understand current practices and procedures and to allow staff an opportunity to weigh in on programmatic issues they encounter while performing their jobs. The review was conducted to document current conditions, not as a critique of past management efforts.

The results of the surveys informed the watershed plan recommendations and were instrumental in developing optimum management standards and strategies to reduce the impacts of urbanization and new development. Understanding the current state of development strategies and practices allows for an assessment of strengths and weaknesses, guides future watershed planning strategies, and highlights changes and additions to current codes that help design effective watershed plans and protect important water resources. A total of four surveys were completed by DPNR and WMA staff. They included:

1. **Eight Tools of Watershed Protection Audit**
   This audit tool, developed by CWP, identifies programmatic strengths and gaps in watershed protection strategies and helps inform watershed planning recommendations.
2. **Needs and Capabilities Assessment**
   The Needs and Capabilities Assessment explores programmatic needs and existing capacity pertaining to the process of plan reviews and inspection of stormwater Best Management Practices (BMPs).
3. **Future Land Use Questions**
   These questions were designed to obtain more information on future watershed development. It was intended to answer questions about planned future projects and the protections provided to certain land uses and physical topographies to reduce the impact of development.
4. **Better Site Design Questions for WMA**
   Other agencies outside of DPNR also have programs or practices that influence watershed protection planning. A set of questions was provided to WMA staff to provide their insight into how their current practices influence watershed resources.

The links to three of the surveys were provided to DPNR staff in early May 2021 and respondents were given several weeks to provide input. All survey instruments were closed on May 28th, 2021 to allow time for processing. Some tools had better response rates than others, and some questions received no response since the preceding question was answered with a no or a response that that meant there was no additional information. The Needs and Capabilities Assessment had four responses (compared to eight responses to the Eight Tools Audit survey), but the responses did provide additional input from staff on the development review process. Appendix A includes the results of the assessment. There was no response to the Post-Construction Management questions, which may indicate that post construction inspection and maintenance may be a tool that should be adopted in the future.

3 St. Thomas Harbor Watershed



3.1 Watershed Introduction

St. Thomas Harbor is a 3.94 sq. mile watershed located on the southern coast of St. Thomas (Figure 19). The watershed encompasses the capital city of the USVI, Charlotte Amalie, as well as the surrounding neighborhoods. Charlotte Amalie is the largest city on St. Thomas with a population of approximately 18,481 according to the 2010 US Census. It is a hot spot of tourism and trade with multiple active cruise ship and shipping ports along the hardened shoreline.

The watershed contains 4.1 miles of guts and 6.7 miles of shoreline. It includes 5.1 acres of wetlands, all of which are classified as riverine. Soils generally have a slow rate of infiltration and a high runoff potential. The total impervious cover of the watershed is approximately 34%, and the watershed has 51% tree canopy cover. The primary zoning categories are low-density residential (37.7%) and medium-density residential (28.3%). Housing development in the watershed primarily occurred during the 1960s and 1970s. Data from the U.S. Virgin Islands Department of Planning and Natural Resources (DPNR) ambient and beach water quality monitoring programs categorizes assessment units as either Class B or Class C, with impairments for oil and grease, dissolved oxygen, enterococcus/fecal coliform, and turbidity. See Appendix B1 for the complete watershed characterization.

Figure 19. Overview map of the watershed.

3.2 PHYSICAL & NATURAL FEATURES

3.2.1 Soils & Topography

3.2.1.1 Soils

When rain falls over land, a portion runs into guts, the ocean, and the stormwater system while the remaining infiltrates into the soil or evaporates into the atmosphere. The hydrologic soil group (HSG) is a soil property that represents the rate at which water infiltrates into a type of soil. Soils are classified into seven soil groups, including four HSGs (A, B, C, and D) based on the soil's infiltration capacity, and three "dual classifications" (A/D, B/D, and C/D) where a soil's infiltration capacity is influenced by a perched water table (Table 3). Data was obtained from the USVI Department of Planning and Natural Resources (DPNR) soil boundaries and the gridded National Soil Survey Geographic Database (gNATSGO), which is developed and maintained by the U.S. Department of Agriculture's Natural Resource Conservation Service (USDA NRCS).

Table 3. Overview of Hydrologic Soil Groups (HSG)[1].

Hydrologic Soil Group (HSG)	Description
HSG-A	HSG-A soils consist of deep, well-drained sands or gravelly sands with high infiltration and low runoff rates.
HSG-B	HSG-B soils consist of deep, well-drained soils with a moderately fine to moderately coarse texture and a moderate rate of infiltration and runoff.
HSG-C	HSG-C consists of soils with a layer that impedes the downward movement of water or fine-textured soils and a slow rate of infiltration.
HSG-D	HSG-D consists of soils with a very slow infiltration rate and high runoff potential. This group is composed of clays that have a high shrink-swell potential, soils with a high-water table, soils that have a clay pan or clay layer at or near the surface, and soils that are shallow over nearly impervious material.
HSG-A/D	HSG-A/D soils naturally have a very slow infiltration rate due to a high-water table, but they will have high infiltration and low runoff rates if drained.
HSG-B/D	HSG-B/D soils naturally have a very slow infiltration rate due to a high-water table, but they will have a moderate rate of infiltration and runoff if drained.
HSG-C/D	HSG-C/D soils naturally have a very slow infiltration rate due to a high-water table, but they will have a slow rate of infiltration if drained.
No HSG Assigned[2]	Data not available in gNATSGO.

[1] Source: NRCS, 2007 https://directives.sc.egov.usda.gov/OpenNonWebContent.aspx?content=17757.wba
[2] Indicates HSG data was not available within a particular soil boundary.

Figure 20 shows the distribution of HSG classes within the St Thomas Harbor watershed and Table 4 provides a breakdown of the acres and percentages. The watershed consists predominantly of low infiltration soils, with 57.2% HSG-D soils. There is a small percentage (13.1%) of moderately well-draining HSG-B soils in the upper most reaches. Much of the flatter, more developed areas in the watershed have no HSG classification (29.3%). This is likely because the development altered the native soil conditions or the abundance of impervious surfaces complicated accurate mapping. As shown in Table 4, the percentage of total area attributed to HSG classes amounts to 99.7% of the watershed. The final 0.3% can be attributed to surface water in the watershed.

Table 4. Hydrologic Soil Groups (HSG) in the watershed.

Hydrologic Soil Group (HSG)	Area in Watershed (acres)	Percentage of Total Area (%)
A	0.0	0.0%
B	330.3	13.1%
C	0.0	0.0%
D	1442.8	57.2%
A/D	0.0	0.0%
C/D	0.0	0.0%
No HSG Assigned	739.8	29.3%
Total	*2,513.0*	*99.7%*

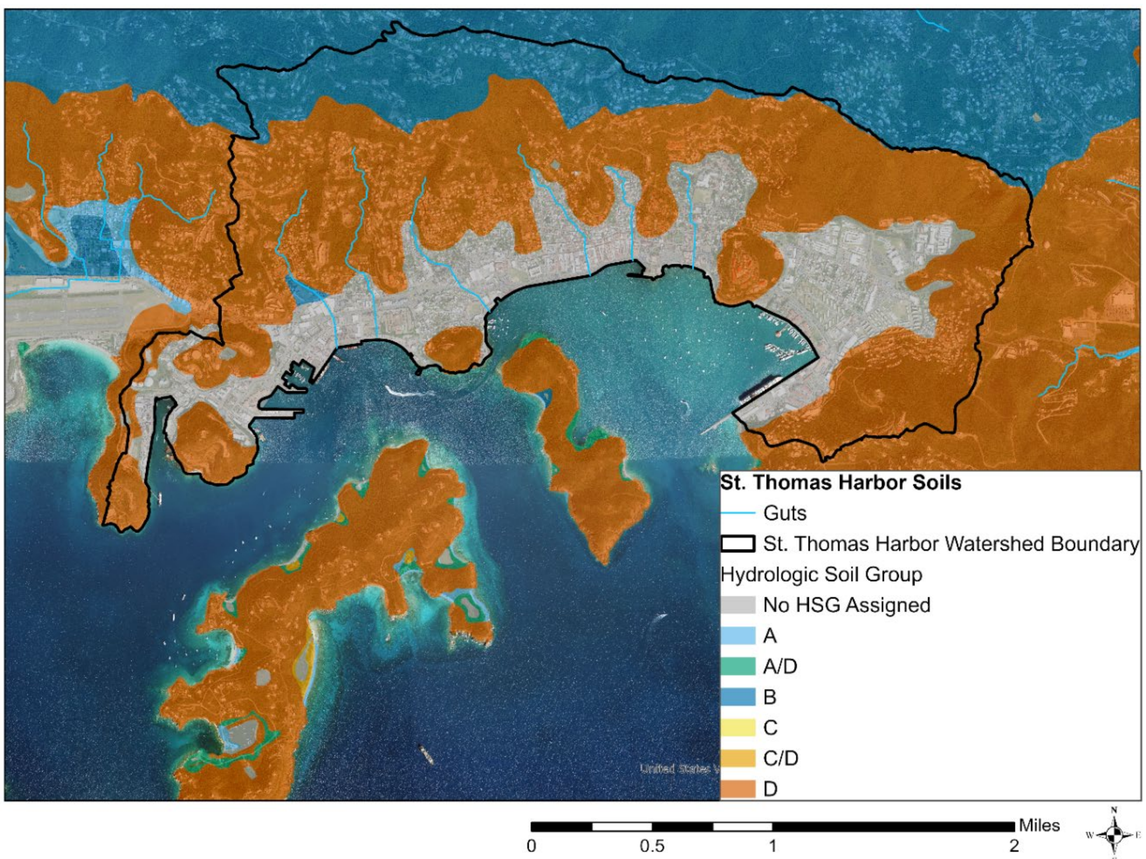


Figure 20. Hydrologic Soil Groups (HSG) in the watershed.

3.2.1.2 Topography

Development on steep slopes is highly susceptible to erosion that carries sediment to nearby waterways and ultimately local bays. In excess, sediment has harmful impacts on aquatic ecosystems, including but not limited to 1) reduced light penetration, which inhibits coral and seagrass growth, 2) clogging of gills and filters in fish and shellfish, and 3) decline of commercial and recreation fishing success (Schueler, 1987). Sediment deposition in coastal waters smothers seagrass beds and coral reefs, increases sedimentation of channels and harbors (requiring more frequent dredging), changes bottom composition, and leads to loss of use for recreational purposes like swimming and snorkeling (U.S. EPA, 1993). To date, there is no steep slope ordinance in the USVI to limit development on steep slopes and ensure adequate soil and erosion control practices are used.

Soil surveys produced by the U.S. Department of Agriculture categorize soil types, in part, based on typical slope ranges shown in Table 5 below. These ranges, along with a slope data layer developed for this project using 2018 topographical data, were used to summarize slopes in the St Thomas Harbor watershed (summarized in Table 5 and displayed on Figure 21). Slopes in the watershed are predominantly either less than 3% or between 16-50%. Figure 21 shows that the greatest slopes are in the northern portion of the watershed associated with the watershed boundary and guts. The soils associated with the steeper slopes have low infiltration and high runoff potential. During a rain event, the runoff flows down these slopes to the floodplain below, often resulting in flooding. Figure 25 below shows the locations of floodplains in the St Thomas Harbor watershed.

Figure 21 shows the location of the developed areas in relation to the slope percentages. Development areas, based on data from 2019, were defined as areas containing greater than 20% impervious cover. There are approximately 1,540 acres of developed area in the St Thomas Harbor watershed, which equates to 61% of the total watershed area. Most development has occurred in areas with flatter slopes located along the in the southern portion of the watershed. However, there is also some low-density residential development located along the steep slopes in the northern portion of the watershed.

Table 5. Slope percentages in the St. Thomas Harbor watershed.

Slope Percentage	Area in Watershed (acres)	Percentage of Total Area (%)
0% – 3%	541.7	21.5%
4% – 8%	332.4	13.2%
9% – 15%	312.7	12.4%
16% – 25%	568.7	22.6%
26% – 50%	722.0	28.6%
> 51%	42.8	1.7%
Total	*2,520.3*	*100%*

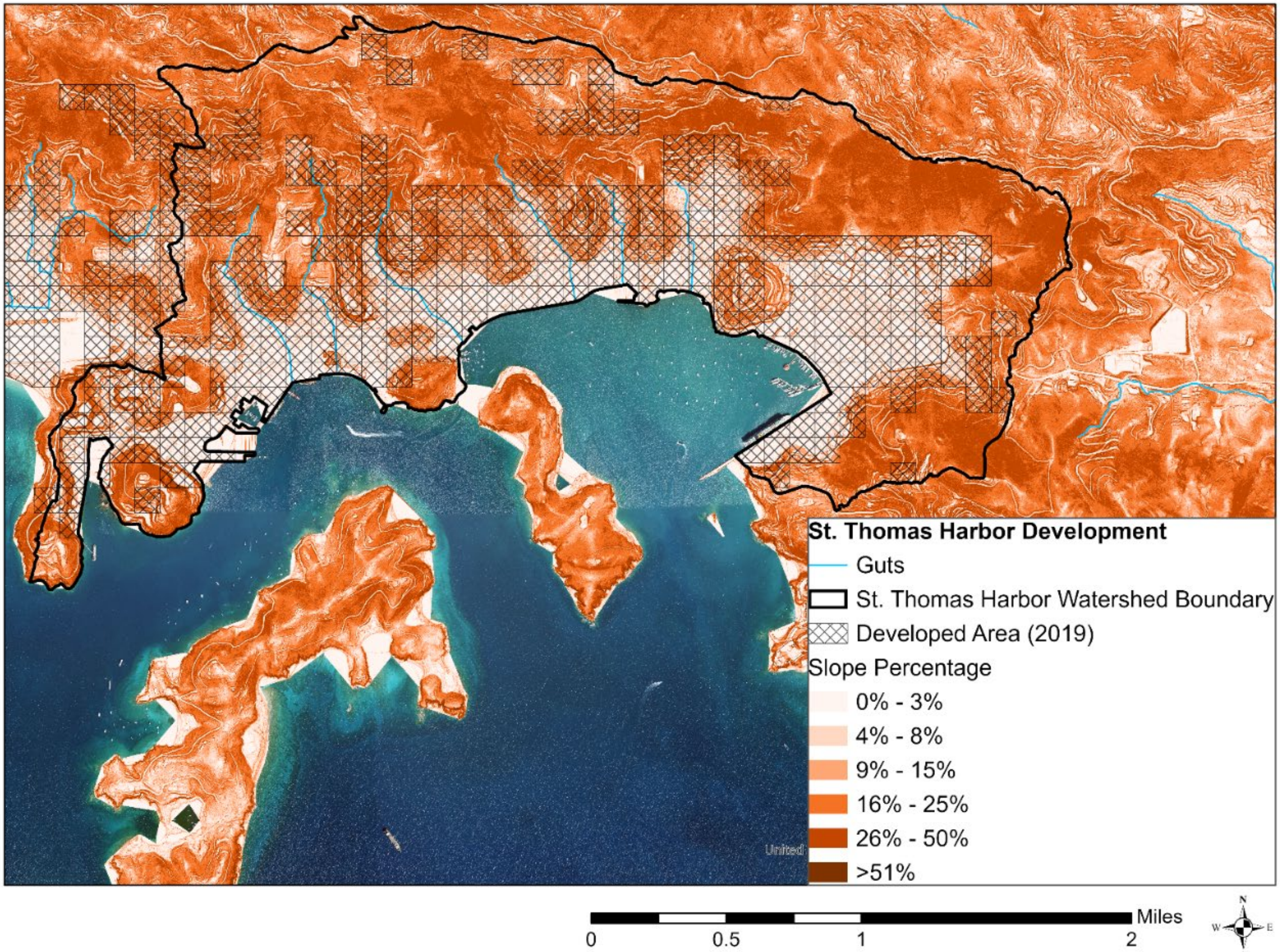


Figure 21 . Developed areas and slope percentages in the St. Thomas Harbor watershed.

3.2.2 Hydrology

3.2.2.1 Rainfall

Rainfall in the watershed is primarily dominated by weather systems that arrive from the east in the summer and from the northwest in winter. The average annual rainfall on St. Thomas is approximately 38 inches. Most of this rainfall comes during the wettest months, typically between September and November. The driest months on the island are generally February to March. Rainfall patterns vary significantly from year to year, with above average precipitation and flooding one year and drought or near-drought conditions the following year (RMSI Private Limited, 2021).

3.2.2.2 Surface Water Features

Within the watershed, there are 4.1 miles of guts, 0.5 acres of freshwater ponds, and 6.7 miles of shoreline along the Caribbean Sea (Figure 22). Surface water data were obtained from USVI DPNR and from the National Wetlands Inventory (NWI) dataset.

The guts of St. Thomas currently flow only after heavy rainfall or during the rainy season. Portions of the guts are piped underground to allow for development. In the 18th and 19th centuries, guts served as the primary drinking water source on St. Thomas; they also served as a drinking water source to a limited degree in the 20th century through the 1960s but are no longer used for drinking water (Gardner et al., 2008). Guts were also used for hunting, freshwater fishing, bathing, and hiking (Gardner et al., 2008).

Guts with permanent pools of freshwater can serve as habitat for rare species of aquatic animals (e.g., Mountain Mullet and American Eel). In addition, guts form corridors that facilitate the movement of wildlife species (Gardner et al., 2008). Over time, increased development led to their degradation as they were seen as dumping grounds. Today, they are still used as a source of freshwater for agriculture and to recharge groundwater. Due to the ephemeral nature of guts, the water quality monitoring programs in the U.S. Virgin Islands focus on coastal waters and beaches, so information concerning water quality in guts is sparse.

There are three guts of interest in the St. Thomas Harbor watershed, the Contant Gut, deJongh Gut, and Savan Gut. The Savan Gut, (also known historically as Brower's Gut and Jigget Gut) is the lower portion of the deJongh Gut. This gut was historically used by the Savanneroes to catch and roast "jumbo shrimps" from the upper reaches of the gut (Gardner et al., 2008). The gut's headwaters begin in the mountainous and heavily vegetated region north of the St Thomas Harbor watershed. The gut drains into the harbor, traveling through vegetated areas to a combination of an intermixed lined and unlined degraded concrete channel from the Jane E. Tuitt Elementary School (flowing under the school and the schools' basketball court) to the intersection of Guttets Gade and Norte Gade. The Savan section of Charlotte Amalie has extremely high runoff rates due to the steep slopes in the upper basin. Flash floods from intense thunderstorms are a common event affecting this area and can occur anytime during the year (Gardner et al., 2008).

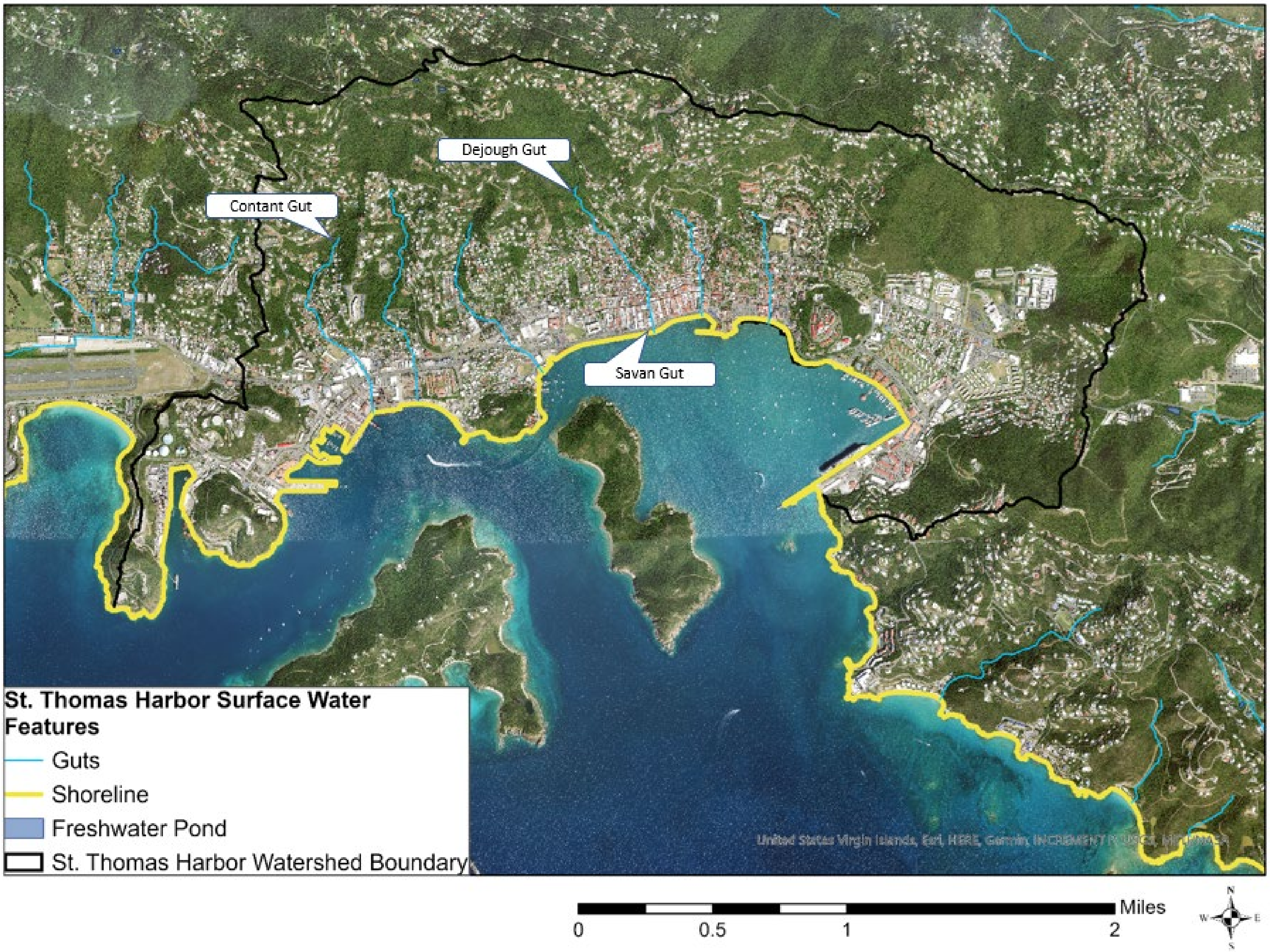


Figure 22. Surface water features in the St. Thomas Harbor watershed.

3.2.2.3 Riparian Zones

Existing land cover was summarized within a 25-foot buffer surrounding the guts in the watershed. These buffers are commonly referred to as riparian zones, transitional areas occurring between guts and the neighboring land. Riparian zones are characterized by distinctive hydrology, soil, and biotic conditions, and while they are often proportionally a small component of a watershed, they play a significant role in ecosystem process and local fauna composition (Heartsill-Scalley, 2021).

In the St. Thomas Harbor watershed, 52% of the existing land-cover within the riparian buffer zone is composed of tree canopy. In addition, it is noteworthy that 35% of the riparian buffer zone consists of impervious cover (buildings, roads, and other paved areas), indicating development directly along the guts (Figure *23*).

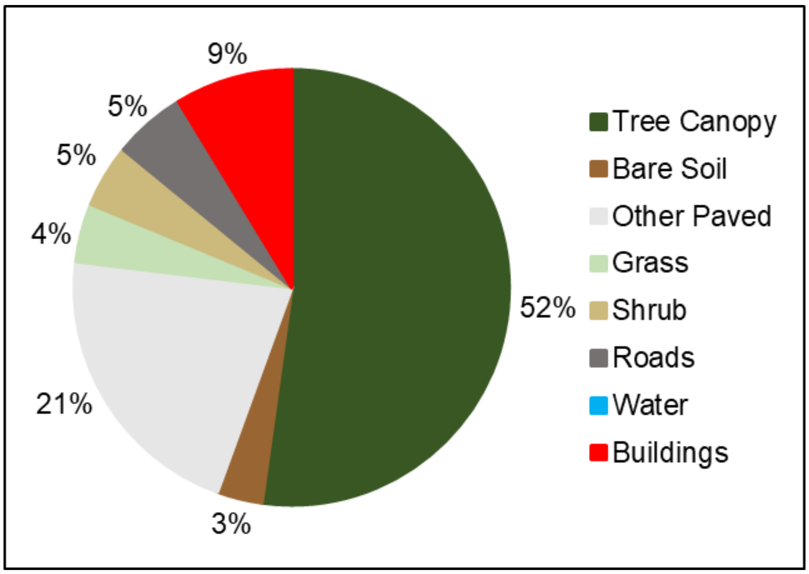


Figure 23. Existing land cover within a 25-foot buffer of guts in the St. Thomas Harbor watershed.

3.2.2.4 Wetlands

According to the National Wetlands Inventory (NWI), there are no estuarine and marine wetlands, fresh water emergent wetlands, freshwater forested/shrub wetlands, or lacustrine wetlands within the St. Thomas Harbor watershed. The NWI classifies guts as riverine wetlands, of which there are 5.1 aces

3.2.2.5 Freshwater Resources

Freshwater is a scarce resource in the USVI. Water is supplied to housing units through a combination of the public water supply, cisterns, and personally owned reverse osmosis production systems, in addition to bottled water purchased by residents. Figure 24 shows the distribution of water sources (public, cistern, or other) by estate based on 2010 U.S. Census data. The public water supply is provided by the USVI Water and Power Authority (WAPA), which operates the Randolph Harley desalination plant. This facility can produce 2.3 million gallons per day of potable water using energy efficient reverse osmosis. The WAPA pipe distribution system serves 45% of the island and has not yet been expanded to provide service to the western and northern parts of the island. Many of the water main pipes that deliver water to residents are old and fragile ductile iron types installed as far back as the 1940s. This has resulted in leaks in the system with approximately 10 percent of water lost in the distribution system on St. Thomas (USVI Hurricane Recovery and Resilience Task Force, 2018).

Most of the island's population uses cisterns to collect rainwater for general use and purchases bottled water for drinking. Bottled water is predominantly derived from WAPA, bottled, and certified by the Department of Health. The USVI Code Title 29 Chapter 5 requires that all buildings except commercial development dwellings and single unit apartments already connected to potable water systems be constructed with a self-sustaining water system such as a cistern or other water collection system (USVI, 2019). This includes a requirement to have a certain minimum usable capacity of gallons per square foot of roof area based on building type.

Cisterns are either concrete holding tanks lined in waterproof coating and placed underground or plastic tanks located either above ground or buried. Electric pumps are used to connect to the existing plumbing system and provide water used for toilets, sinks, dishwashers, washing machines, and showers. Generally, they are not used for drinking water as they are typically not sealed and subject to contamination. Mesh screens are used to keep out larger animals and debris, but mosquitoes and frogs are often found in cisterns. Cistern water is commonly treated with chlorine bleach to kill any animals, insects, or pathogens as recommended by CDC guidelines.

Several drinking water treatment technologies are available for household use including treatment of cistern water that include filtration, reverse osmosis systems, distillation systems, and ultraviolet treatment systems (CDC, n.d.). During a drought, residents purchase water from WAPA or a private water hauler to fill their cisterns (USVI Hurricane Recovery and Resilience Task Force, 2018). From the late 1960s to the early 1980s, WAPA used several wells near the St. Thomas Hospital in Sugar Estate. These wells are no longer in production (USVI DPNR, 2018).

Many hotels and condominiums in the USVI use small reverse osmosis units to produce their own water (USVI Hurricane Recovery and Resilience Task Force, 2018). Private water haulers also purchase potable water from WAPA, and several have built their own reverse osmosis production system (Alderson et al., 2018).

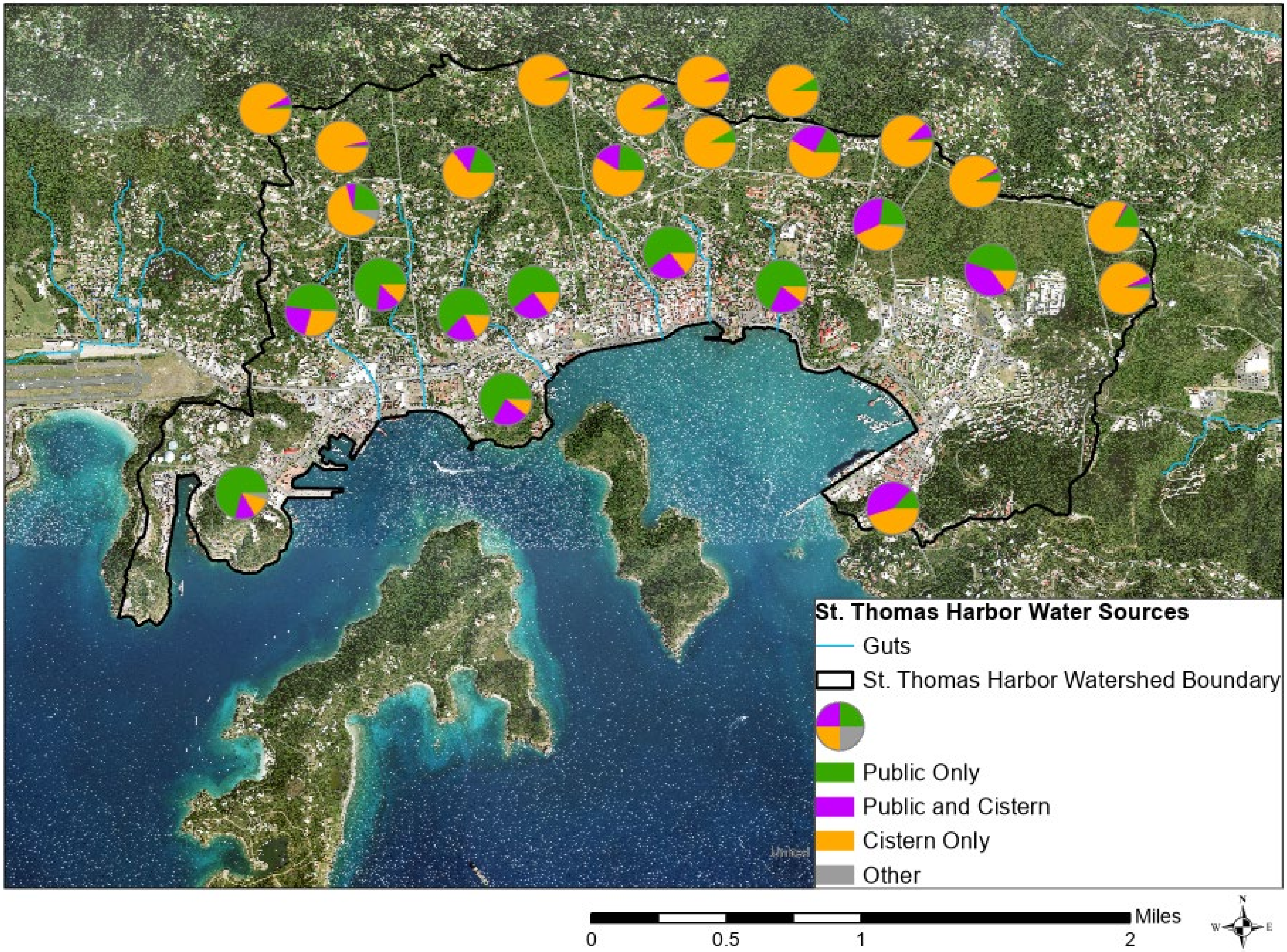


Figure 24. Housing unit water sources by estate in the St. Thomas Harbor watershed (Source: 2010 U.S. Census data).

3.2.2.6 Flood Zones

Flood zones in the USVI are characterized by the impact associated with the 100-year and 500-year flood events (Table 6). As indicated in Table 6, most of the mapped flood zones are in the "AO" zone located in the southwestern portion of the watershed. The "A" zone is associated with the gut floodplains and the "AE" zone is located along the shoreline (Figure 25). No data are available for the 10-, 25-, or 50-year flood events on the U.S. Virgin Islands.

Table 6. Flood zone types and areas in watershed.

Flood Zone	Definition*		Area in Watershed (acres)
A	Areas subject to inundation by the 1-percent-annual-chance (100-year) flood event where no hydraulic analyses have been performed.		92.7
AE	Areas subject to inundation by the 1-percent-annual-chance (100-year) flood event where hydraulic analyses have been performed.		98.1
AO	Areas subject to inundation by the 1-percent-annual-chance (100-year) shallow flooding where average depths are between one and three feet.		143.4
VE	Areas subject to inundation by the 1-percent-annual-chance (100-year) food event with additional hazards due to storm-induced velocity wave action.		34.3
X	An area of minimal to moderate flood hazard that is outside of the Special Flood Hazard Area and either 1) between the limits of the base flood and the 0.2-percent-annual chance (500-year) flood, or 2) above the elevation of the 0.2-percent-annual-chance (or 500-year) flood.		5.5
*Definitions adapted from https://floodpartners.com/flood-zones/		Total:	374

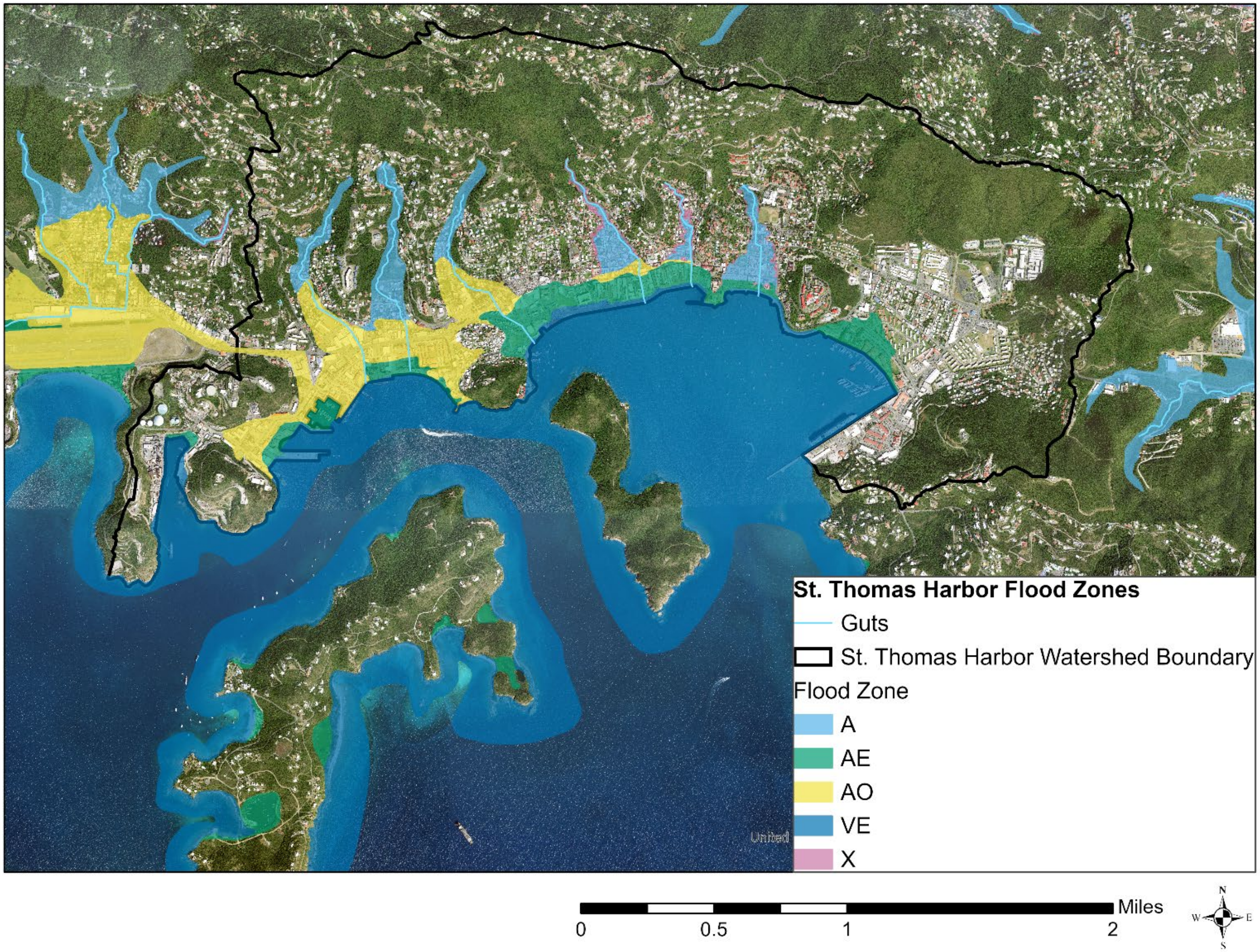


Figure 25. Flood zones in the St. Thomas Harbor watershed.

3.2.3 Habitat & Ecology

St. Thomas is home to many species of protected and endangered plants, birds, fish, reptiles, mammals, and coral. The U.S. Endangered Species Act of 1973 provides for the conservation of endangered or threatened species and all or portions of their required habitats and ecosystems. A species is considered 'endangered' if it is likely to become extinct in a significant portion of its range. A species is considered 'threatened' if it is likely to become endangered in the near future (UVI, 2009).

Coral reefs consist of a community of coral polyps that form some of the most diverse ecosystems and provide habitat for at least 25% of all marine species (UVI, 2009). Global stressors to the reefs include ocean warming and other impacts related to climate change. Local threats include pollutants associated with runoff from development, unsustainable land use and fishing pressure, physical damage from anchors, boat groundings, and marine debris. Strategic priorities for coral reef management are documented in Rothenberger & Henderson (2019).

Coral reefs are important to the USVI economy; they provide food, jobs, recreation, and culture, as reef products are incorporated in streets and buildings. Corals also provide a natural defense for coastal property and protect the islands from hurricane-induced flooding, providing an estimated $47 million dollars in annual flood protection benefits (Storlazzi et al., 2019). They also help support recreation, as they contribute to swimmable and aesthetic bays and beaches as well as diving locations for tourists.

According to the U.S. Fish and Wildlife Service's spatial datasets, the St Thomas Harbor watershed does not contain critical habitat for rare, threatened, or endangered species. No spatial datasets for wildlife corridors, Areas of Protection or Restoration (APR), or coral reef management locations were available for the island of St. Thomas. These areas may exist on the island, and possibly within this watershed; however, data was unable to be obtained.

A spatial dataset of Areas of Particular Concern (APCs), including APCs specific to coral reefs, was provided by DPNR. Within the St. Thomas Harbor watershed, there are no coral reef-specific APCs; however, 337 acres of the "St. Thomas Harbor and Waterfront" and "Magens Bay and Watersheds" APCs are within the St. Thomas Harbor watershed. Figure 26 below illustrates the APCs within and surrounding the St. Thomas Harbor watershed.

Protected areas on St. Thomas are available from the U.S. Geological Survey's (USGS) Protected Areas Database (PAD-US). The PAD-US is a national inventory of protected areas including areas dedicated to the preservation of biological diversity, and other natural uses—such as recreational or cultural uses, including extraction—managed for these purposes through legal or other effective means. Based on USGS PAD-US data, there are no protected areas in the St. Thomas Harbor watershed. Figure 26 illustrates the protected areas surrounding the St. Thomas Harbor watershed. Mangrove areas surrounding the St. Thomas Harbor watershed (the data for which was provided by USVI DPNR) are also displayed on Figure 27.

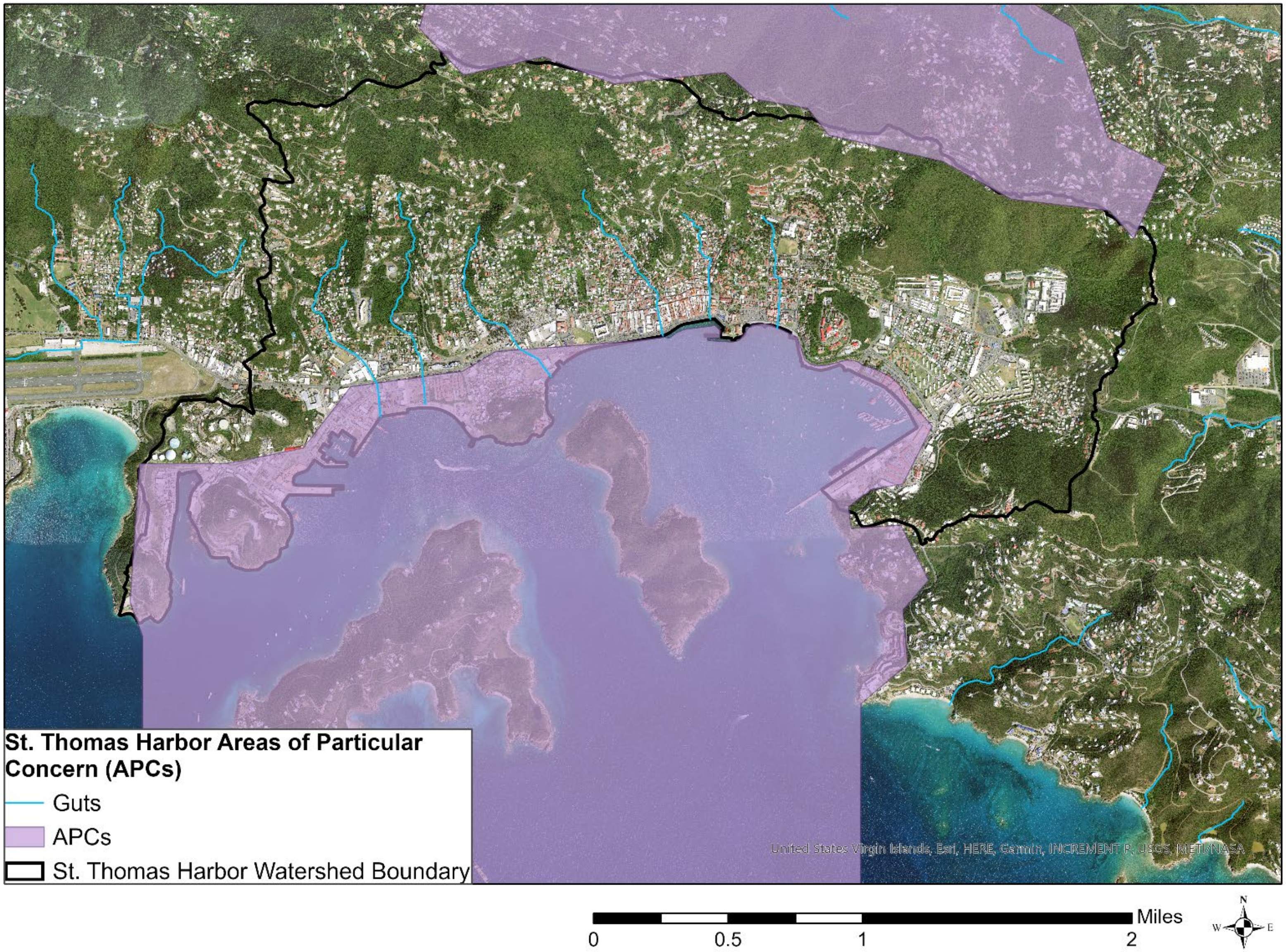


Figure 26. Areas of Particular Concern (APCs) within and surrounding the St. Thomas Harbor watershed.

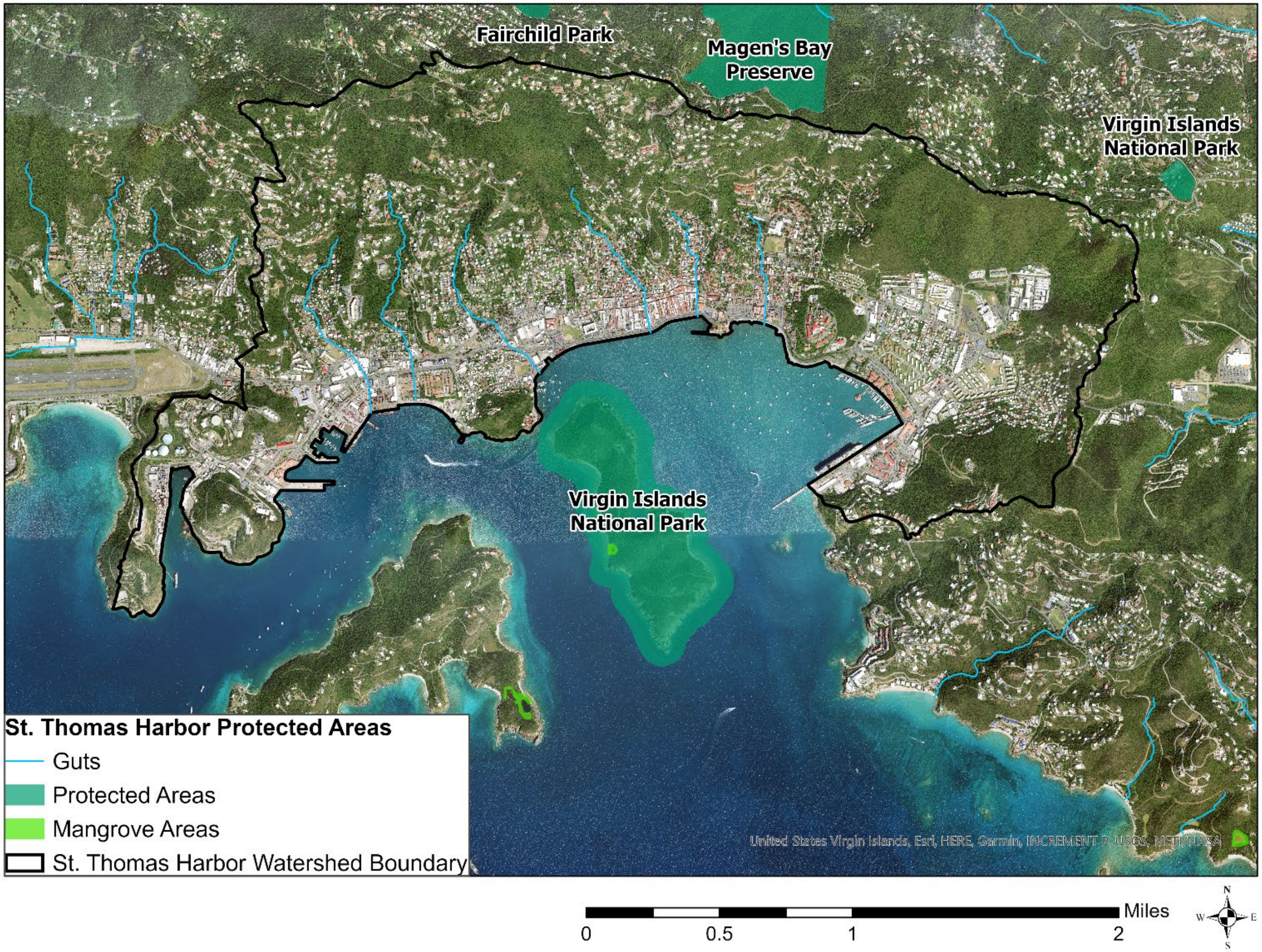


Figure 27. Protected areas and mangroves within and surrounding the St. Thomas Harbor watershed.

3.3 Population Characteristics & Land Cover

3.3.1 Watershed Demographics

Various demographics were summarized for the study watersheds using 2010 U.S. Census data because 2020 Census data was not yet released for the USVI at the time of this report. Data was obtained from the U.S. Census Bureau's Virgin Islands webpage and summarized by USVI estate boundaries. Estates that intersected watershed boundaries were summarized according to the proportion of each estate within the study watershed. The demographic data categories include:

- Total Population
    - Total number of people of any age.
    - This value was adjusted to account for the proportion of the estate that is contained within the study watershed.
- Percent Minority
    - Percentage of population with a racial status other than white alone and/or non-Hispanic or Latino (i.e., all people other than non-Hispanic-or-Latino, white-alone individuals). The minority population in the USVI is primarily African American and West Indian.
- Percent Linguistically Isolated
    - Percentage of population over 5 years old who speak a language other than English and who speak English less than "very well"
- Percent Low Income
    - Percent of families with income in 2009 below the poverty level
- Percentage of occupied households with no vehicles

Table 7 provides a summary of the above-listed demographics in the St Thomas Harbor watershed. Approximately 31.7% of the total population of St. Thomas is located within the St Thomas Harbor watershed, a majority of which are minorities. The Census data at the estate scale indicates differences between different portions of the watershed in terms of population density, minority percentage, linguistic isolation, poverty, and mobility (see Figure 28 and Figure 29 below).

Table 7. Overview of selected 2010 U.S. Census demographics data summarized for estates in the watershed.

Demographic	Value
Total Population*	16,376
Percent Minority**	87.7%
Percent Linguistically Isolated**	10.6%
Percent Low Income**	15.6%
Average Number of Vehicles per Occupied Household**	1.0

** This is the area-adjusted total, which accounts for portions of some estates being not entirely within the St Thomas Harbor watershed boundary.*
*** These values are averages weighted by estate area.*

Figure 28 below illustrates the population density of the estates in the St Thomas Harbor watershed. Populations are shown in people per square mile. The most densely populated areas are located across the south-central portion of the watershed corresponding to medium-density residential and commercial development.

Figure 29 below illustrates (A) the percent minority of the population of each estate, (B) the percent of the population in each estate that is linguistically isolated, (C) the percent of the families whose 2009 earnings were below the poverty line and (D) the percentage of occupied households with zero vehicles in the estates within the St. Thomas Harbor watershed. The estate with gray fill has a population of zero, and therefore has no associated metrics. Low-income families make up a large proportion of residents within the main downtown urban development of Charlotte Amalie. These regions also coincide with a large percentage of minority populations, those who are linguistically isolated, and households with zero vehicles.

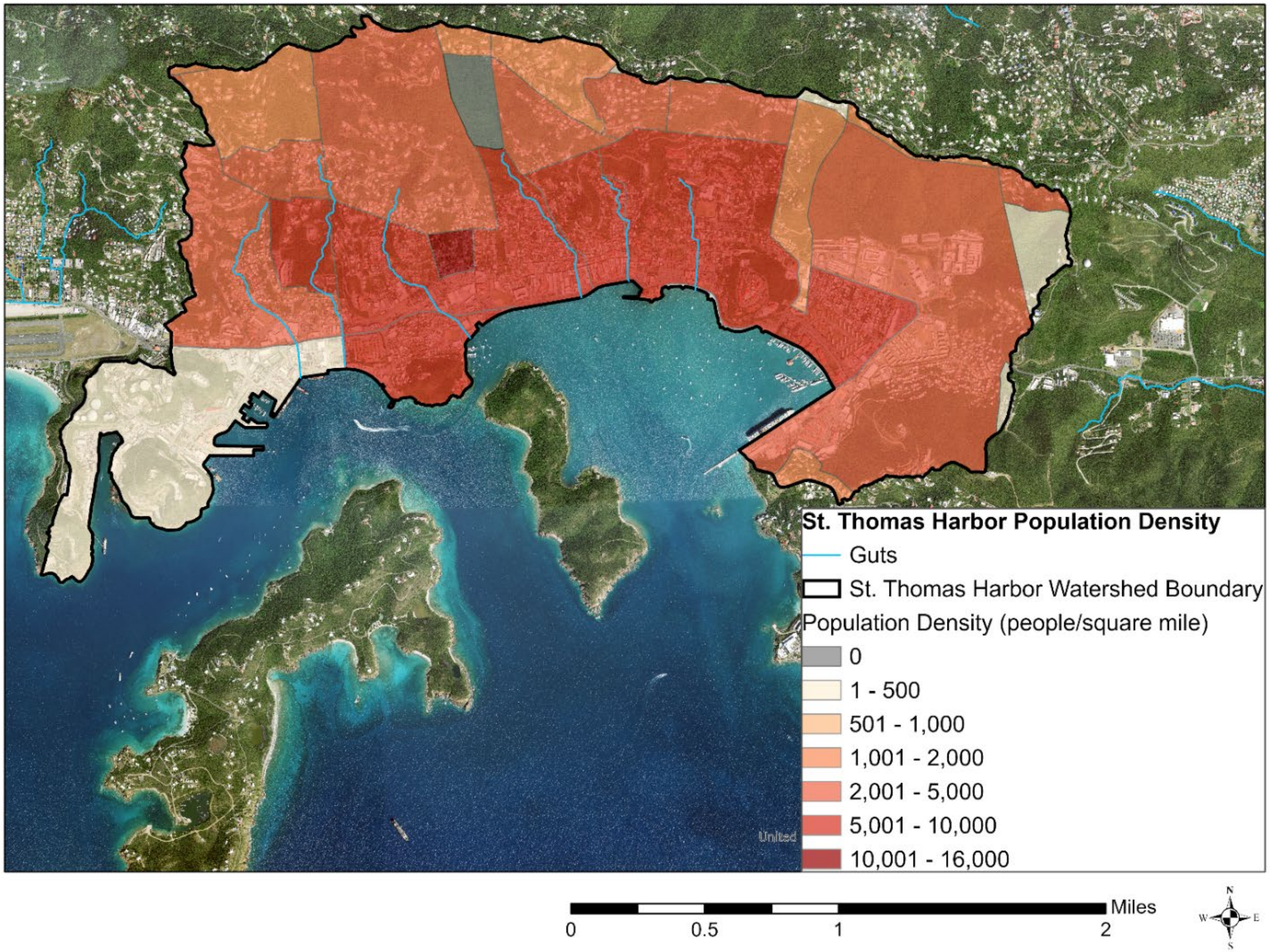


Figure 28. Population density (people per square mile) in estates within the St. Thomas Harbor watershed.

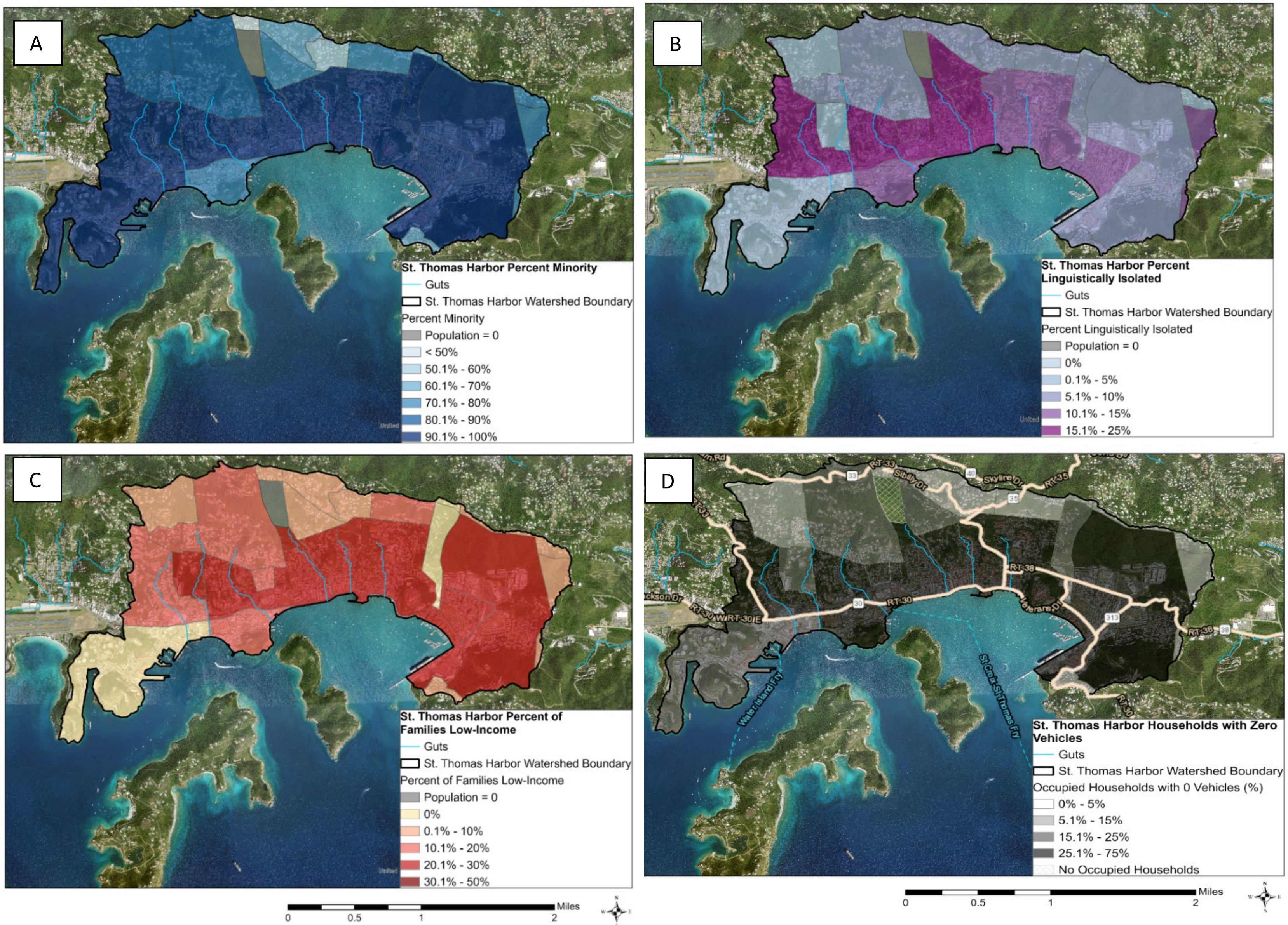


Figure 29. Minority (A), linguistically isolated (B), low-income (C), and zero vehicle household (D) demographics in estates within the St. Thomas Harbor watershed.

3.3.2 Land Cover Mapping

Land cover was mapped from high-resolution, remotely sensed data yielding the most complete, precise, and accurate mapping ever carried out for the USVI. The primary source data sets used consisted of aerial imagery obtained through the Hexagon imagery program and publicly available LiDAR sourced from NOAA Digital Coast. The aerial imagery, collected in 2019, had a spatial resolution of 15 cm with spectral coverage in the blue, green, red, and near-infrared portions of the electromagnetic spectrum. The LiDAR data, which was collected in 2018 using a discrete return sensor, had a point spacing that exceeded 90 points per square meter in some locations. Supplementing these remotely sensed data sets were vector layers representing roads and hydrologic features.

The imagery data were processed to create seamless mosaics for each island. The LiDAR was processed to create normalized and classified point clouds in addition to raster surface models. The surface models consisted of a Digital Elevation Model (DEM), Digital Surface Model (DSM), and a Normalized Digital Surface Model (nDSM). The DEM was derived from the LiDAR ground classified points, with each pixel value representing the ground surface topographic elevation relative to sea level. The DSM was derived from the LiDAR first returns, with each pixel representing the height of features relative to sea level. The nDSM was obtained by subtracting the DEM from the DSM, yielding a model in which each pixel represented the height above ground. All raster surface models were produced at a resolution of 0.5 meters. Some editing was performed on the vector data sets to improve their consistency and quality prior to incorporating them into the land cover mapping.

Land cover feature extraction was carried out using a semi-automated process at a resolution of 0.5 meters. The automated part of the mapping centered on an object-based feature extraction approach that incorporated the imagery, LiDAR point clouds, LiDAR surface models, and supporting vector data sets to map land cover features using a combination of artificial intelligence and expert systems. The output from the automated workflow was then manually reviewed by technicians at a scale of 1:1000 to correct visible errors. The final landcover data set contained eight classes: 1) bare soil, 2) buildings, 3) grass/herbaceous vegetation, 4) other paved/impervious surfaces, 5) roads, 6) shrubs, 7) tree canopy, and 8) water. The height threshold for tree canopy was 2 meters. See Figure 30 below for an example of the imagery, nDSM, and land cover classifications for an example area on St. Thomas.

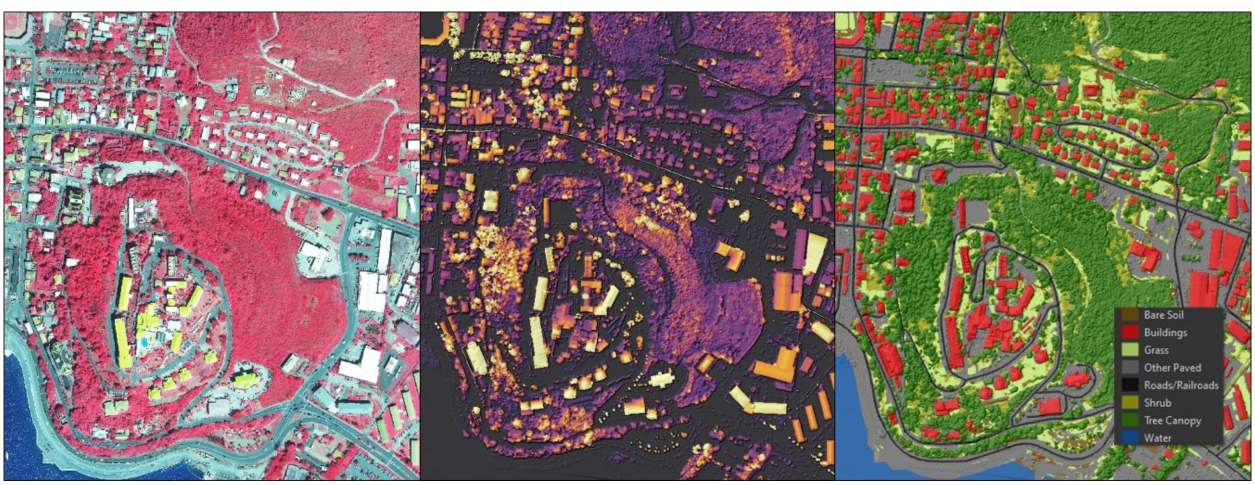


Figure 30. Imagery displayed as color infrared (left), LiDAR nDSM (center), and resulting land cover (right) on an example area in St. Thomas.

The existing land cover in the St Thomas Harbor watershed is predominantly tree canopy (51.0%), grass shrub (cumulatively 11.7%), and impervious surfaces other than roads and buildings (21.7%). Figure 31 and Table 8 present the existing land cover within the St Thomas Harbor watershed.

Total impervious cover is approximately 34%, placing the watershed in the “Non-Supporting” category, based on the Impervious Cover Model. According to this classification system, non-supporting watersheds have between 25% and 60% impervious cover. Within this range, the watershed no longer supports its designated uses in terms of hydrology, channel stability, habitat, water quality, or biological diversity; additionally, the watershed can become so degraded that it may be difficult or impossible to fully recover predevelopment stream function and diversity (Schueler et al., 2009).

Table 8. Existing land cover in the watershed.

Land Cover Category	Area in St. Thomas Harbor Watershed (acres)	Percentage of Total Area
Bare Soil	67.3	2.7%
Buildings	307.2	12.2%
Grass	146.3	5.8%
Other Paved	476.3	18.9%
Roads	87.5	3.5%
Shrub	148.0	5.9%
Tree Canopy	1,286.8	51.0%
Water	2.4	0.1%
Total	*2,521.8*	*100%*

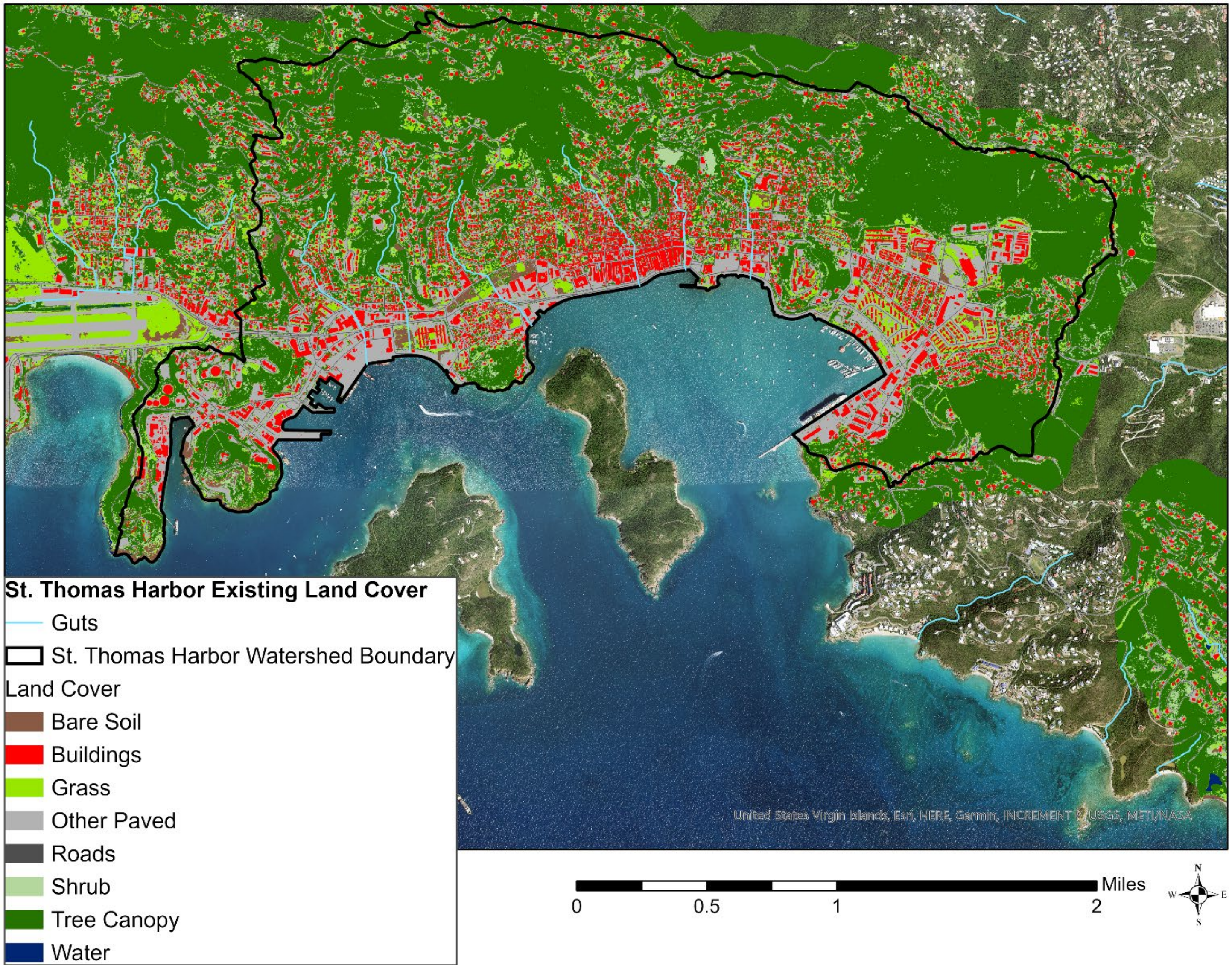


Figure 31. Existing land cover in the St. Thomas Harbor watershed.

3.3.3 Zoning

The USVI Zoning Code defines how property in specific zones can be used. The document details whether specific geographic zones are acceptable for residential, commercial, or industrial purposes. Zoning codes may regulate lot size, placement, density, setbacks, acceptable uses, and the height of structures. The U.S. Virgin Islands have 18 distinct zoning districts: two agricultural districts, five residential districts, four business districts, one commercial district, two industrial districts, two waterfront districts, one public district, and one special district.

Zoning information is available for the USVI as part of a parcel layer that contains the current, previous, and proposed zoning districts. However, the zoning districts in the spatial dataset do not match those in DPNR's "Virgin Islands Zoning District Requirements" document, which can be found on their website.

The zoning districts in the spatial dataset were revised to represent land use categories that are: 1) more meaningful from a planning sense, and 2) more consistent with the Watershed Treatment Model, which will be used in later phases of plan development for the St. Thomas Harbor watershed. In general, the zoning districts were categorized based on the use category (e.g., all agricultural zones characterized as "Agricultural"). Residential zoning districts were subdivided based on their densities, with "Waterfront Pleasure" classified as Low Density Residential due to the zoning density being the same as the Low-Density Residential category. Figure 32 illustrates the breakdown of the revised zoning districts throughout the parcels in the St. Thomas Harbor watershed. Most of the watershed is characterized as low-density residential (37.7%) and medium density residential (28.3%).

It is important to note that neither the revised zoning districts, nor the original zoning districts on which they are based, are necessarily reflective of all uses occurring in the parcel. Original zoning districts appear to be designated based on the parcel's majority use. As such, a parcel may contain areas that do not match its overall zoning district. Zoning districts defined as "Other" refer to zoning districts that were originally blank, or defined as "PAD", "S Special" or "NL".

The pie charts in Figure 33 below summarizes the relationship between existing land cover and area of the revised zoning districts in the St. Thomas Harbor watershed. Most of the land-use in residential development zoning areas is green space, most notably in low-density developments and to a lesser degree in medium and high-density developments. Business zoning areas also show to be predominated by green space, roughly as much so as medium-density developments. Industrial, commercial, and public zoning areas in contrast are dominated by impervious surfaces. Land cover mapping and predicted future land cover can be found in Sections 3.3.2 and 3.3.6 respectively.

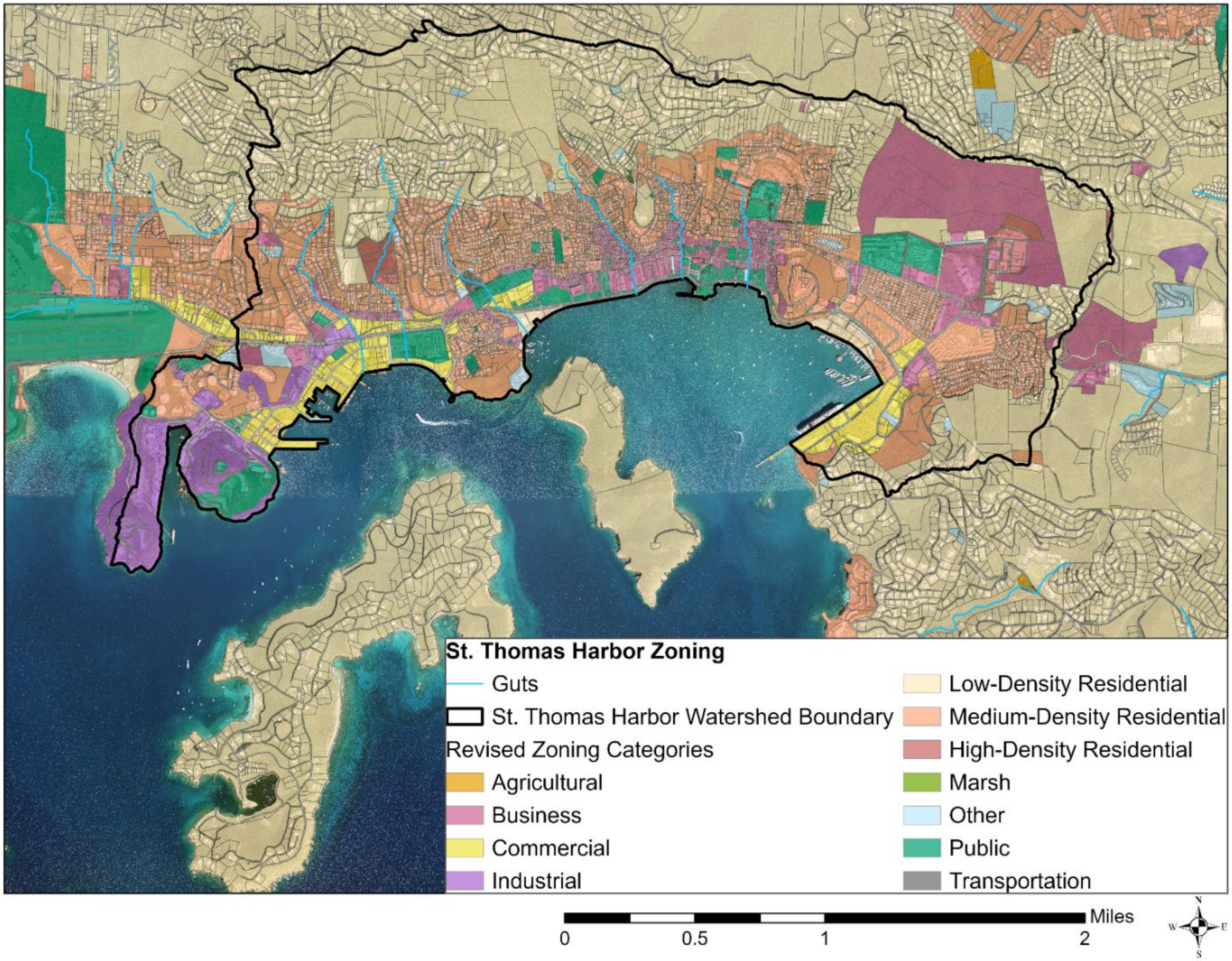


Figure 32. Revised zoning districts within the St. Thomas Harbor watershed.

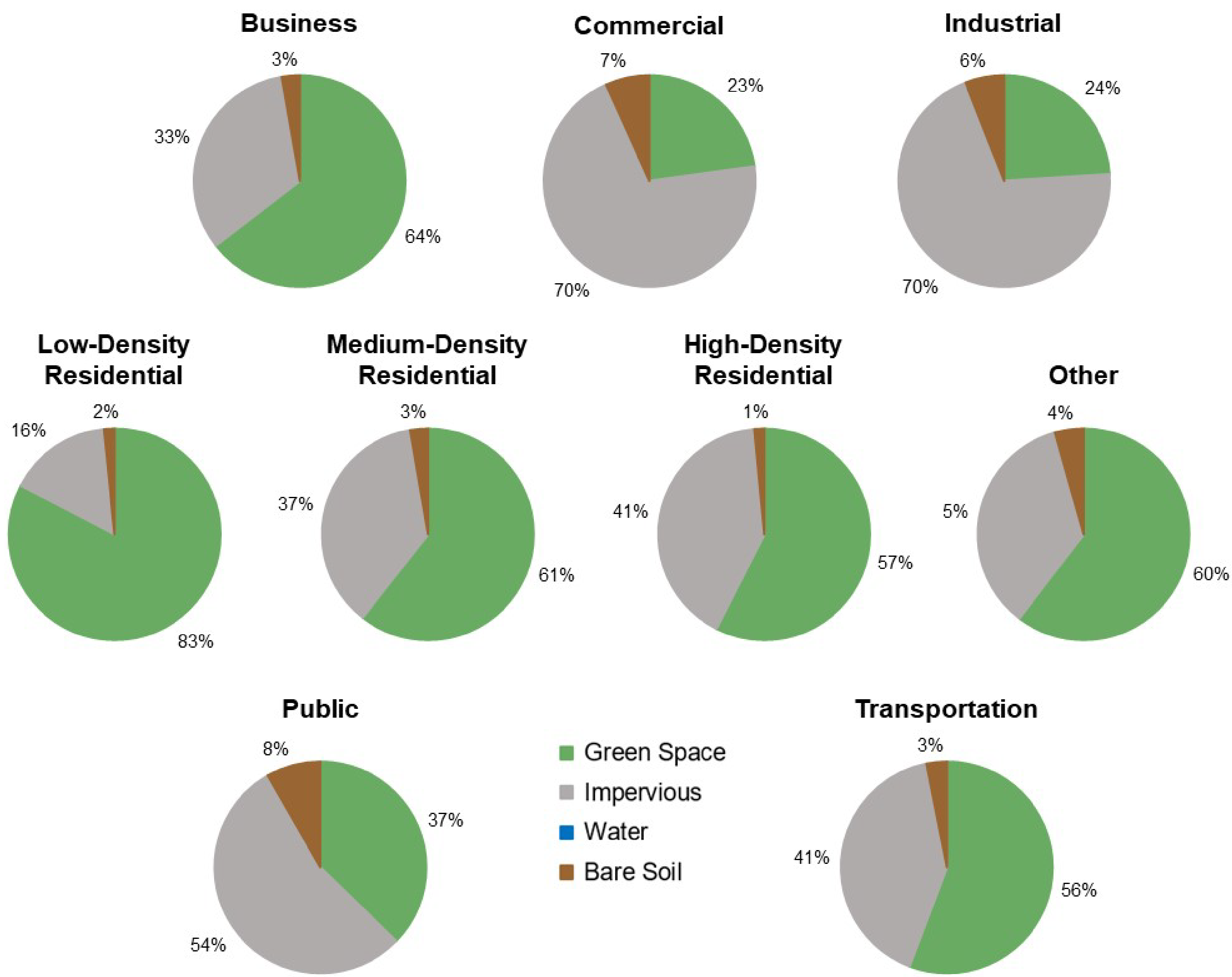


Figure 33. Land cover in revised zoning districts in the watershed.

3.3.4 Housing Development Age

Median decade of housing unit development by estate in the St. Thomas Harbor watershed was sourced from the 2010 U.S. Census data. As shown in Figure 34, the predominant decades of residential development in the St. Thomas Harbor watershed were the 1960s and 1970s.

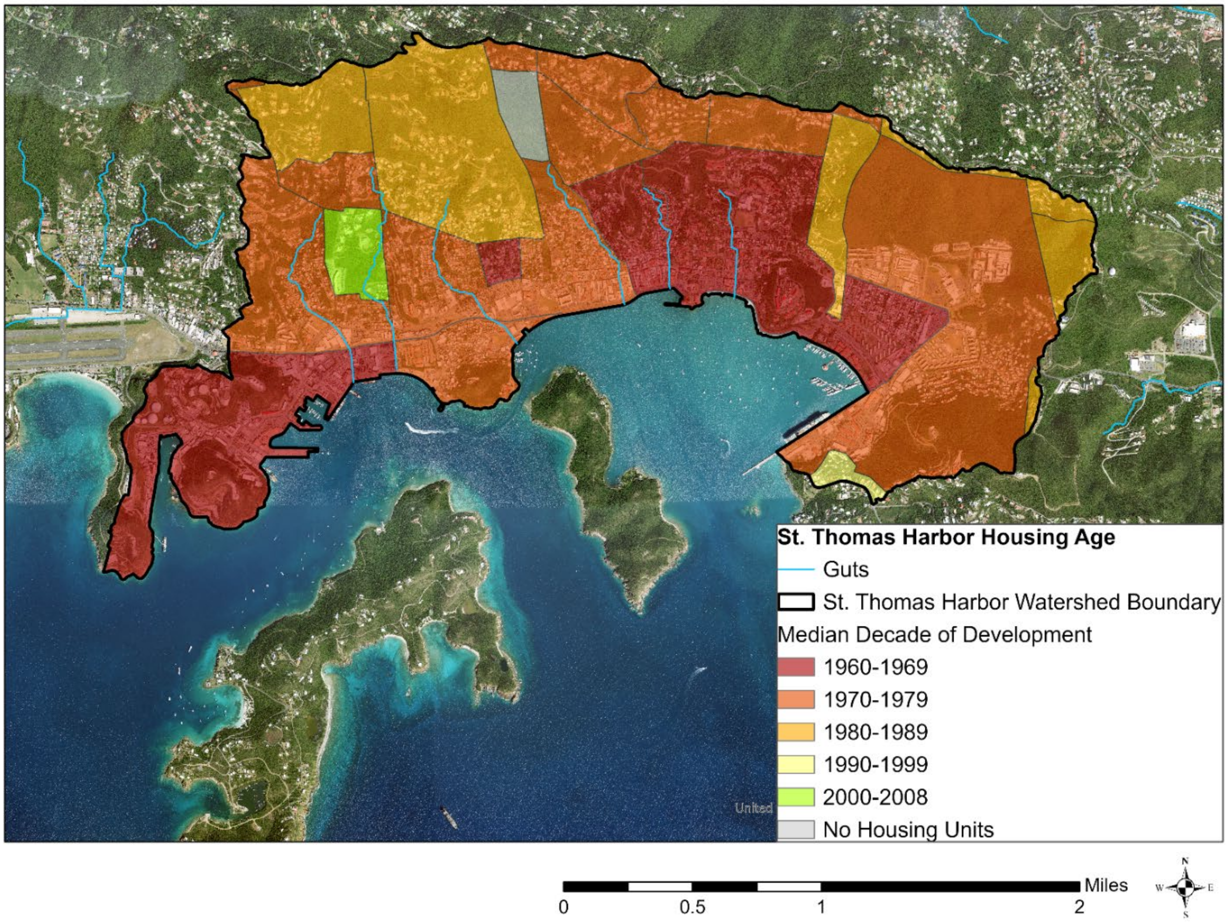


Figure 34. Median decade of housing unit development by estate in the St. Thomas Harbor watershed (Source: 2010 U.S. Census data).

3.3.5 Publicly Owned Land

Figure 35 and Table 9 below display the federal- and USVI- owned areas within the St Thomas Harbor watershed on St. Thomas. Most of the USVI-owned parcels are owned by the Government of the Virgin Islands, the Virgin Islands Housing Finance Authority, or the Virgin Islands Port Authority. Most of the federal-owned parcels are owned by the Federal Government or the United States of America Forest Service.

Table 9. Area of parcels owned by federal and USVI government entities.

Ownership Category	Area in Watershed (acres)	Percentage of Area in Watershed (%)
Federal	7.9	0.3%
USVI	467.2	19.3%
Other	1,793.8	73.9%
None Listed	157.5	6.5%

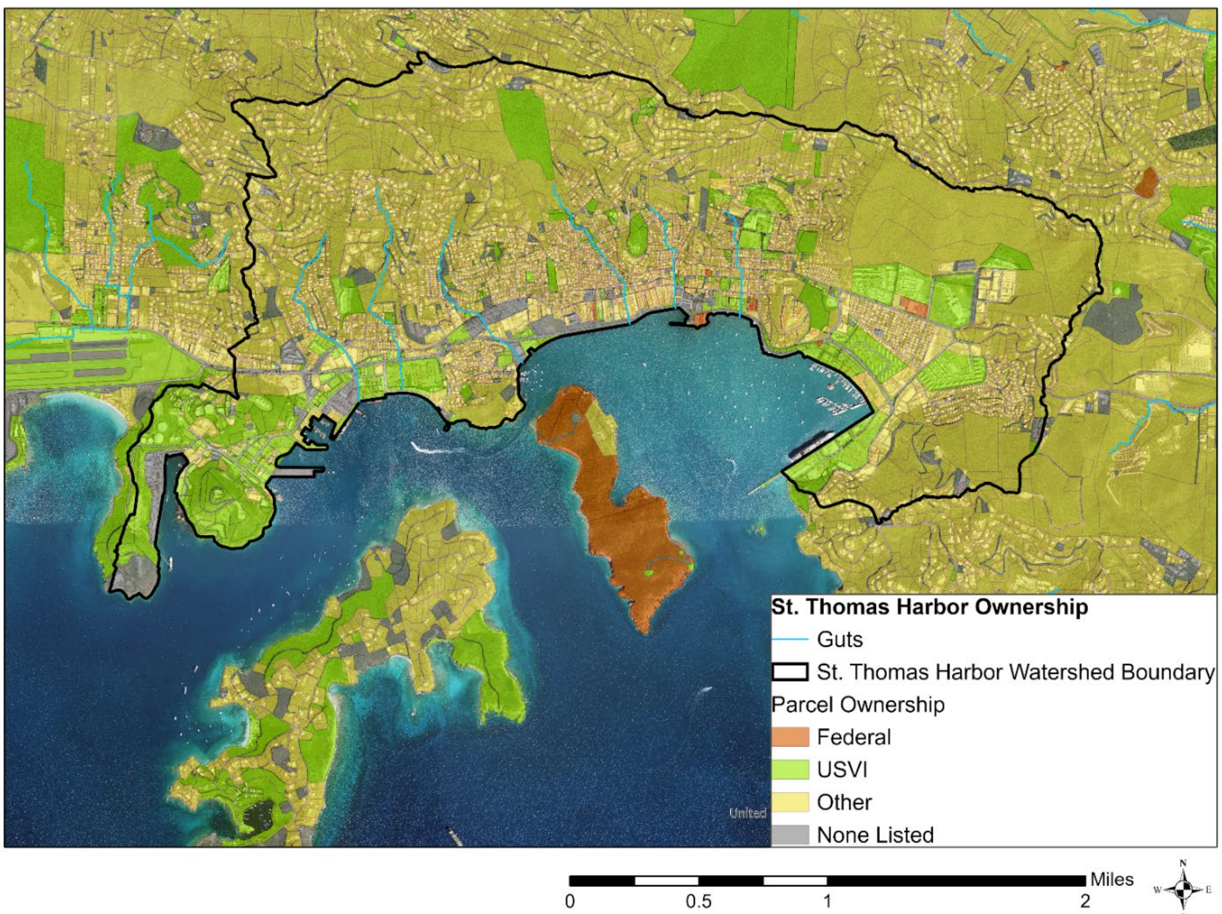


Figure 35. Federal and USVI-owned parcels in the St. Thomas Harbor watershed.

3.3.6 Predicted Future Land Cover

Future land cover scenarios for 2030, 2050, 2080, and 2100 were developed based upon 2019 land cover data (see Section 3.3.2) and predicted development based on past trends within the watershed to assess the impacts of this growth. Feature engineering was employed to predict where this future development will occur based on observed development patterns.

The study watershed was divided into grid cells, each representing 5.56 acres. Grid Cells with 20% impervious surface or more were defined as “Urban”, and all other grid cells were defined as “Other”. Land cover change between the 2012 and 2019 data was calculated to identify regions where change occurred during the specified time frame. This step was repeated to identify regions where development change occurred between 2002 and 2019.

An exploratory analysis was performed to identify common characteristics associated with the grid cells experiencing development change. Characteristics explored included population density, income, distance to tourist attractions, distance from highway, zoning designation, distance to previously urban areas, elevation, slope, flood zone designation, distance to shoreline, watershed designation, parcel size, percent of previous agriculture land use in each grid cell, percent previous impervious land cover in each grid cell, percent previous wetland in each grid cell, and percent previous bare soil in each grid cell.

The following notable findings were found during the feature engineering process across the eight watersheds assessed during this analysis:

1. Distance to shoreline does not appear to play a factor in the current development pattern while distance to highways was a more significant in predictor of where development will occur.
2. A large majority of newly created impervious surface is occurring in residential zoning designations
3. Most of recent development tends to occur at lower elevations.
4. 20.8% of grid cells designated as “new development” intersect a FEMA designated Flood zone.

Features associated with development change were inserted into a logistic regression model. Features were removed if they were directly correlated to another feature in the model. The logistic regression model was used to predict development change between 2012-2019 and 2002-2019. Within the model, the dependent variable was binary, representing if a grid cell experienced development gain or not. At a 10% probability threshold, the 2012-2019 model’s overall accuracy is calculated at 96.8%. The 2002-2019 model’s overall accuracy is calculated at 89.5%.

The 2012-2019 model was generalized to 10 years, distributing the new projected development across the study area. A 10% probability threshold was defined, which can be interpreted as having a 10% risk of development between 2019 and 2030. This same process was repeated for the 2002-2019 model, which was generalized to 20 years, to retrieve development risk predictions for 2040. The model was run iteratively on both the 10-year and 20-year model outputs to retrieve predictions for 2050, 2080, and 2100. The model’s features were updated where applicable. Lastly, the model output was manually corrected for any discrepancies between models.

Each grid cell identified as at-risk for development was assigned a predicted amount of impervious surface if development were to occur. The amount of impervious was calculated as the mean percent impervious surface in the current urban grid cells bordering a given grid cell identified as at risk for development. The assumption is that the new development grid cells reflect the land use composition of nearby grid cells. The calculation was repeated for forest cover, shrub cover, grass cover, and bare cover.

The future land cover model makes several assumptions. First and most significantly, the model assumes that the development pattern in the future will be consistent with the development pattern observed in present day. Significant changes in climate and the development market over the next 80 years can significantly impact future development patterns. Additionally, USVI's population trajectory is highly dependent on the territory's ability to mitigate future environmental damage. The model does not guarantee that any individual grid cell will be further developed. Instead, each identified grid cell should be thought of as being at risk for development and may require additional monitoring for development in the future. The longer the model's time frame, the higher the error potential. The new land cover for each newly defined urban grid cell is assumed to have the same land use composition as the urban grid cells surrounding each newly developed cell. Second, the model assumes that all currently classified urban grid cells will remain urban and grid cells not predicted to be developed will have the same land use composition as present day. Hence, a presently developed grid cell will remain developed in the future with a similar land use composition while undeveloped grid cells that are expected to remain undeveloped will have similar future land use composition as present day. Third, aggregating data into grid cells may result in discrepancies in the land use composition of grid cells bordering the watershed's edge. Since each grid cell is assigned a percentage for each land use type, the land use composition of each grid cell is assumed to be spatially dispersed across the grid cell. Finally, the model fails to account for conserved areas, meaning that development may be predicted in conservation regions.

New development is predicted to be most likely to occur to the north in the St. Thomas Harbor watershed. Much of the southern portion of the watershed is already developed, surpassing the 20% impervious land cover threshold. Many low-density residential communities are at risk for increased densification over time, leading to more impervious surfaces in these regions. The future development predictions indicate risk of a sprawling development pattern in St. Thomas Harbor, densifying regions farther away from the city center.

The land cover area in each grid cell was summarized within the St Thomas Harbor watershed boundary. In 2019, the watershed had 34% impervious cover. These impervious surfaces in the watershed are predicted to increase by approximately 4% by 2100 to a total of 38%. In comparison, green space is expected to decrease by 4% from the existing condition (63% green space in 2019 to 59% in 2100). The land cover summary for the existing and future scenarios is provided in Figure 36. There is an inverse relationship between impervious cover and green space; as impervious cover increases, green space decreases as shown in Figure 37.

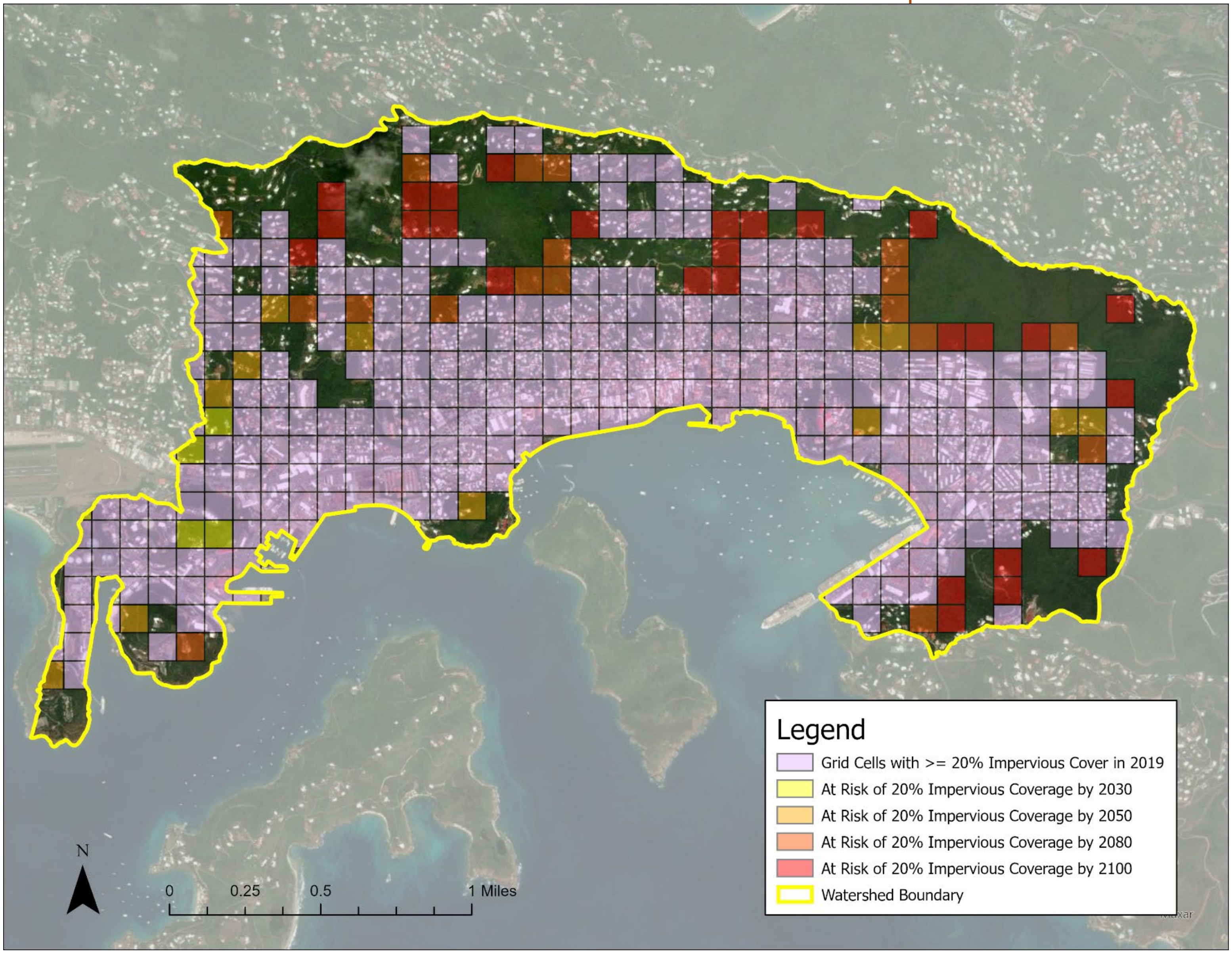


Figure 36. Grid Cells at risk of development in 2030, 2050, 2080 and 2100.

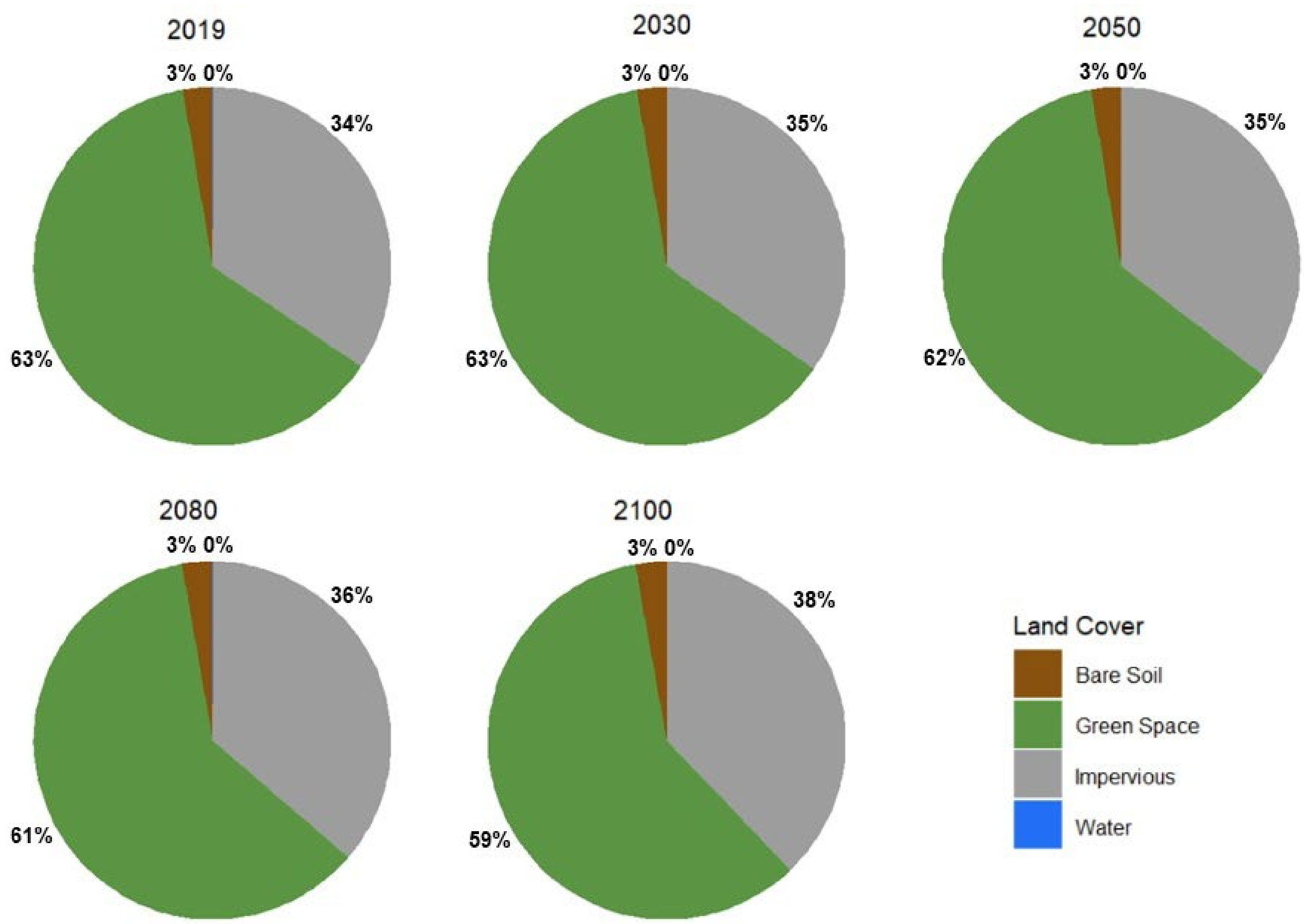


Figure 37. Existing land cover (2019) and future land cover (2030, 2050, 2080, and 2100) in the St Thomas Harbor watershed.

3.4 PROBLEM DEFINITIONS

3.4.1 Impaired Waterbodies

USVI DPNR is responsible for implementing and enforcing territorial water quality standards and pollution control laws under the federal Clean Water Act. To meets these goals, DPNR administers two water quality monitoring programs, the coastal water quality monitoring program and the beach water quality program. The coastal water quality monitoring program is the primary mechanism for monitoring the U.S. Virgin Islands coastal water quality. In this program, delineated waterbodies referred to as assessment units (AUs) are sampled for a variety of water quality indicators on a quarterly basis. In the beach water quality monitoring program, designated beaches throughout the territory are sampled for water quality indicators on a weekly basis. Due to the ephemeral nature of guts, water quality monitoring programs focus on coastal waters and beaches. Data collected by these programs is used to protect public health and provide notification of beach closures. The data also determines effluent permit limits and develops waterbody impairment listings for the 303(d) list. This list is used to establish priorities for the implementation of water quality improvement measures including the development of TMDLs.

According to the current U.S. Virgin Islands water quality standards, the waters of the U.S. Virgin Islands exist in one of four classes: I, A, B, and C. Standards as defined in the 2020 Integrated Water Quality Monitoring and Assessment Report can be found in Table 10.

- Class I waters include either inland surface waters or inland groundwaters are therefore excluded from the water quality monitoring program at this time.
- Class A waters (or Outstanding National Resource Waters) are marine and coastal water with exceptional recreational, environmental, or ecological significance to be preserved. They are designated for maintenance and propagation of desirable species of aquatic life (including threatened, endangered, and indigenous species), for primary contact recreation, and for use as potable water sources.
- Class B waters encompass all marine and coastal waters not classified as Class A or Class C. As with Class A waters, they are designated for maintenance and propagation of desirable species of aquatic life, for primary contact recreation, and for use as potable water sources.
- Class C waters are those waters which are located in industrial harbors and ports. They have less stringent water quality standards for certain parameters and are designated for the maintenance and propagation of desirable species of aquatic life, primary contact recreation, industrial water supplies, shipping, navigation, and for use as potable water sources for those waters being used currently or that could be used in the future as potable water sources.

Table 10. Water quality and assessment criteria (USVI DPNR, 2020).

Parameter	Source Data Type	Assessment Method
Enterococcus	Ambient, Beach	The 30-day geometric mean for enterococcus shall not exceed 30 colony-forming units/100 mL and no more than 10 percent of the samples collected in the same 30 days shall exceed 110 colony-forming units/100 mL.
Turbidity	Ambient, Beach	A maximum nephelometric turbidity unit reading of three (3) shall be permissible, and secchi disk reading of minimum of 1 meter.
Clarity	Ambient, Beach	***For areas where coral reef ecosystems are located**, a maximum nephelometric turbidity unit reading of one (1) shall be permissible, and secchi disk reading of minimum of 1 meter.
Total Phosphorus	Ambient	Shall not exceed 50 µg/l
pH	Ambient	Class A, B: Range shall not be outside 7.0 to 8.3 standard units Class C: Range shall not be outside 6.7 to 8.5 standard units
Dissolved Oxygen	Ambient	Class A, B: Shall be no less than 5.5 mg/L Class C: Shall be no less than 5.0 mg/L
Temperature	Ambient	Shall not exceed 32 degrees Celsius at any time, nor as a result of waste discharge to be greater than 1.0°C above natural conditions. ***For areas where coral reef ecosystems are located**, shall not exceed 25-29°C at any time, nor as a result of waste discharge to be greater than 1.0°C above natural.

*Areas that contain coral reef ecosystems are determined based on Benthic Habitat Mapping in Puerto Rico and the U.S. Virgin Islands (NCCOS, 2002)

The St Thomas Harbor watershed includes four (4) assessment units (AUs), with representative data taken from fifteen water quality monitoring stations (Figure 38). The AUs are classified as either Class B or Class C, with impairments for oil and grease, dissolved oxygen, Enterococcus/fecal coliform, and turbidity (Table 11). The oil and grease, dissolved oxygen, and Enterococcus/fecal coliform impairments all have established TMDLs, and the turbidity impairments are classified as "Low Priority" for TMDL development.

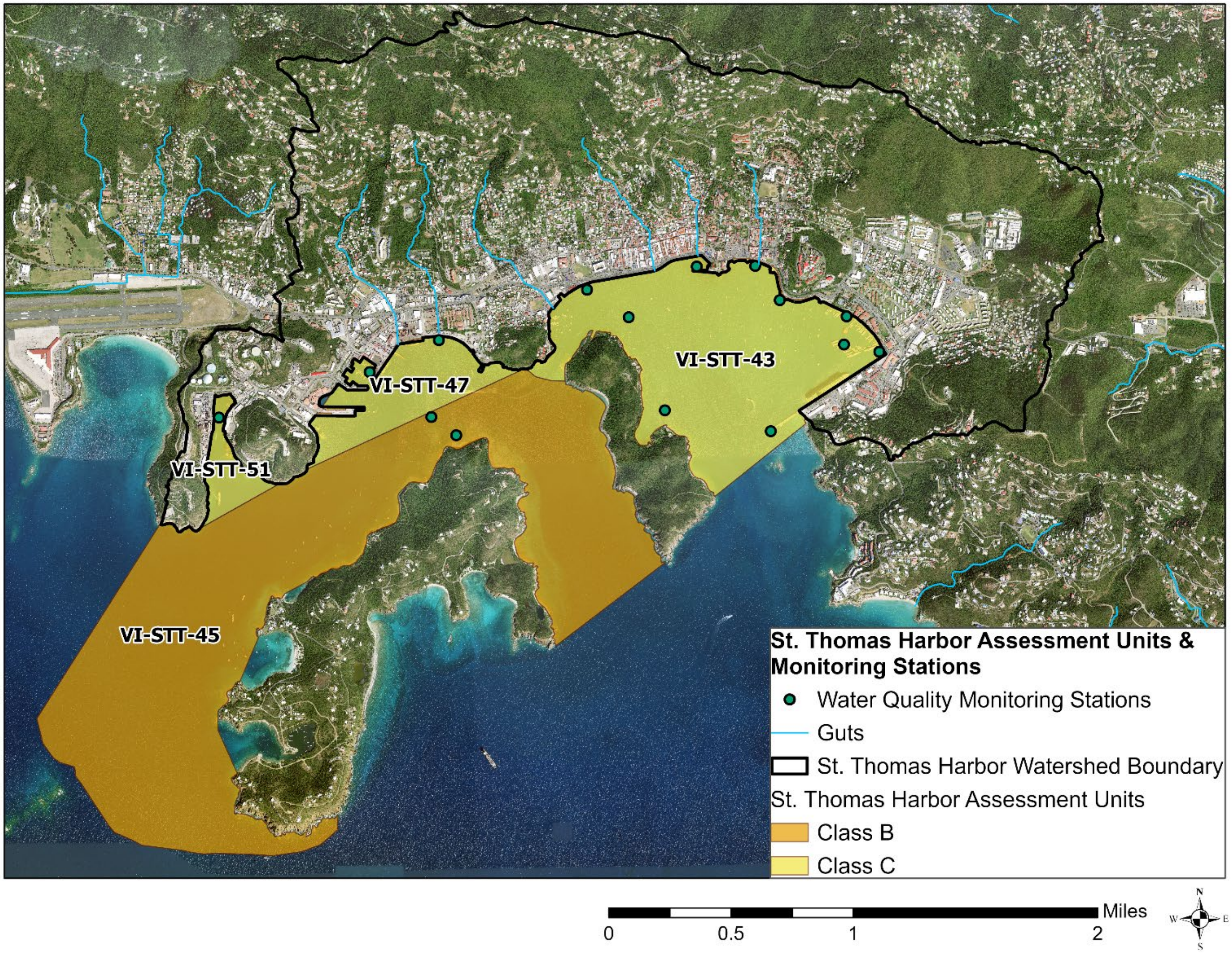


Figure 38. Assessment units and water quality monitoring stations in the watershed.

Table 11. Assessment units (AUs) with 303(d) listing in the watershed (USVI DPNR, 2020).

AU ID	AU Name	Associated Monitoring Stations	Priority	Class	Impairment	Years Impaired	TMDL Completion
VI-STT-43	St. Thomas Harbor, inner	STT-31B, STT-31C, STT-32A, STT-32B, STT-33A, STT-33B, STT-34, STT-35, STT-36, STT-37	Medium	C	Turbidity	2010, 2012, 2014, 2016, 2020	2024
VI-STT-45	Gregerie Channel	STT-1, STT-39	Current TMDL	B	Dissolved Oxygen (TMDL established for Biological Oxygen Demand & Sediment Oxygen Demand),	N/A	Completed
VI-STT-45	Gregerie Channel	STT-1, STT-39	Current TMDL	B	Enterococcus & Fecal Coliform	N/A	Completed
VI-STT-47	Hassel Island at Haulover Cut to Regis Point	STT-2, STT-3	Current TMDL	C	Dissolved Oxygen (TMDL established for Biological Oxygen Demand & Sediment Oxygen Demand)	N/A	Completed
VI-STT-47	Hassel Island at Haulover Cut to Regis Point	STT-2, STT-3	Current TMDL	C	Enterococcus, Fecal Coliform	N/A	Completed
VI-STT-47	Hassel Island at Haulover Cut to Regis Point	STT-2, STT-3	Current TMDL	C	Oil and Grease	N/A	Completed
VI-STT-51	Krum Bay	STT-4	Current TMDL	C	Dissolved Oxygen (TMDL established for Biological Oxygen Demand & Sediment Oxygen Demand)	N/A	Completed
VI-STT-51	Krum Bay	STT-4	Current TMDL	C	Enterococcus, Fecal Coliform	N/A	Completed
VI-STT-51	Krum Bay	STT-4	Low	C	Turbidity	2016, 2018	2034

3.4.2 Stormwater

3.4.2.1 Lack of Management Practices

Stormwater BMPs improve the water quality of stormwater runoff both by removing pollutants through filtering or settling and by controlling both the volume and rate of flow of runoff entering guts and coastal waters. As detailed in Section 3.5.2, the St. Thomas Harbor watershed has seven existing stormwater practices that have a cumulative drainage area of 104.6 acres, covering approximately 4.1% of the total watershed area. This leaves the majority of the watershed presently untreated (95.9% unmanaged).

As land development continues in the USVI, stormwater management practices will play an important role in reducing flooding and improving water quality by infiltrating a greater amount of water into the groundwater, and detaining stormwater to reduce peak discharge rates, more nearly approximating the pre-developed hydrology.

3.4.2.2 Deteriorated & Absent Stormwater Conveyance

Failure to manage stormwater runoff from roads, most notably unpaved roads, is one of the primary land based sources of pollution in the USVI (U.S. Virgin Islands, 2020). There are approximately 78.6 miles of roads in the watershed. To minimize surface water contamination and reduce flooding, roadway stormwater infrastructure such as culverts, swales, and surface crossings are utilized to intercept flows and convey water. Many of the roads of St. Thomas either do not have adequate infrastructure or the existing infrastructure is not functioning properly (i.e., clogged or damaged). This can result in ponding and flooding within and along the roadway and can result in erosion in other areas due to the increased stormwater volume and velocity (Figure 39). This presents both a public safety hazard and maintenance burden.

Figure 39. Road erosion (left) and undermined roadway due to unmanaged stormwater (right).

Many of the stormwater drainage structures needed maintenance as of 2021 field observations. Some structures needed structural repairs while many were obstructed and/or plugged with sediment, debris, and trash. Field crews in June 2021 encountered several DPW crews clearing and cleaning guts near structures. However, there is a need for a structured program that ensures routine and post-storm event maintenance, as local property owners often indicated that maintenance was an issue. Regularly scheduled maintenance would help alleviate some of the localized flooding problems by removing obstructions from the guts and roadway swales.

One way of assessing adequate drainage infrastructure in the watershed is to determine how far road segments are from drainage structures. Of the 78.6 miles of roads in the St. Thomas Harbor watershed, only 19.6 miles (24.9%) are within 50 feet of a drainage structure (Figure 40). This indicates that in these locations, stormwater must travel overland for long distances prior to accessing a drainage relief structure, often resulting in large volumes of concentrated stormwater flow.

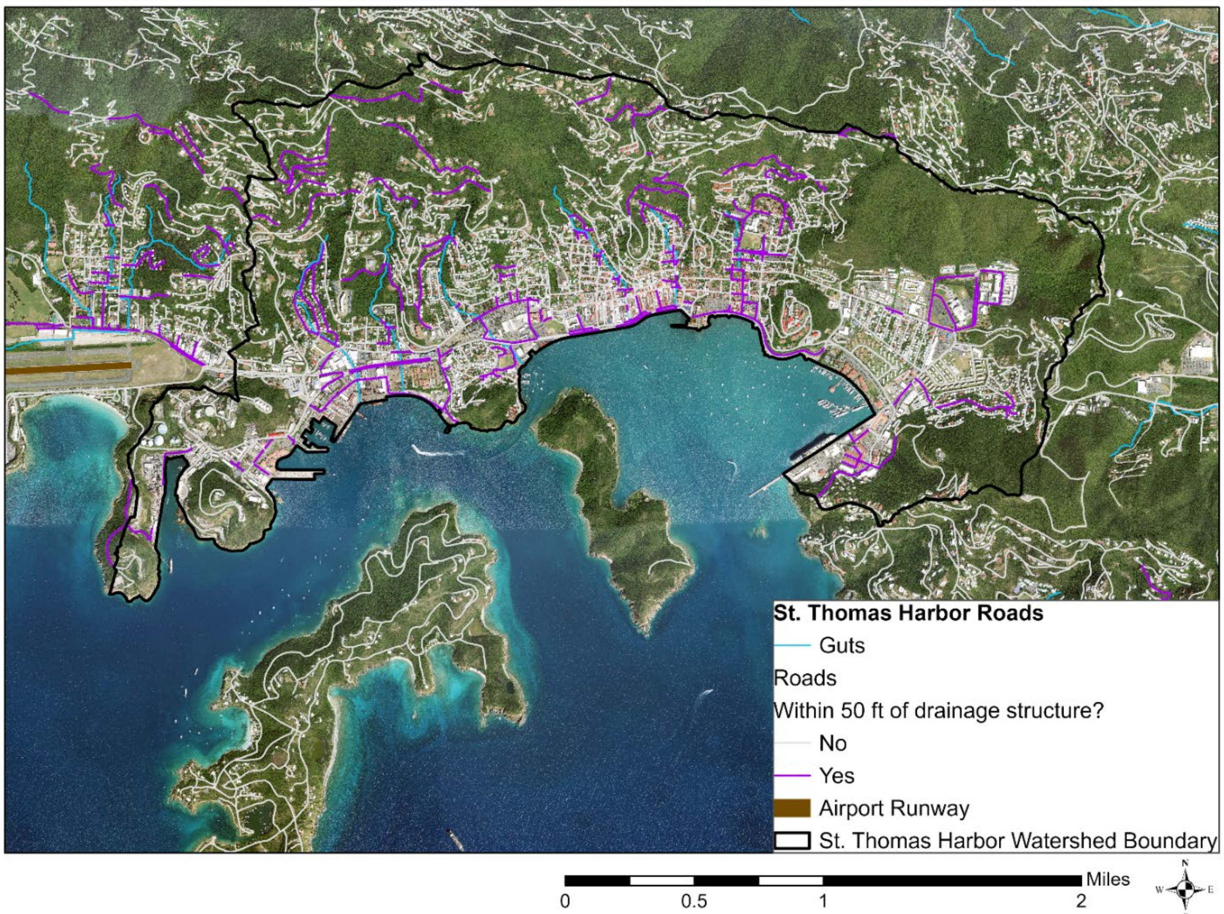


Figure 40. Roads in the watershed and a classification of distance to nearest drainage structure.

3.4.3 Wastewater

Wastewater including leaking, broken, or disconnected wastewater and septic system pipes pose a significant threat to the watershed. In the watershed, wastewater pipes are often outdated and infrequently maintained. Consequently, illicit discharges from leaking, broken, or disconnected sewer or damaged or malfunctioning septic systems may run-off into the region's stormwater system, leading to increased pollution and contamination. Wastewater can pose human health risks and contains high bacteria and nutrient loads.

Wastewater treatment for the USVI is provided by either the public wastewater treatment system or by private on-site disposal (septic) systems (OSDS). Septic system use can be constrained by a number of factors, including poor suitability of soils for conventional systems. A study of OSDS applicability in the Virgin Islands found that much of land area in the USVI is unsuitable for septic soil absorption systems, including conventional and some alternatives (The Cadmus Group, 2011). As such, leaking septic systems are an issue of concern for the entire USVI. Proper inspection and maintenance of OSDS are critical to ensure effectiveness and to verify that systems are not damaged and leaking.

Figure 42 shows the percentage of housing units in the St. Thomas Harbor watershed with a septic tank or cesspool as well as the sanitary sewer system. According to the VIWMA, the agency provides wastewater services including collection, pumping, treatment, and disposal to an estimated 60% of the Virgin Islands residents (VIWMA, 2021). The agency and system are funded in part by an annual wastewater user fee of $110.77 per equivalent residential unit that support the operations, maintenance, and capital investment plan (RAND, 2020).

The current sewer system in the USVI consists of eight wastewater treatment plants, 31 pump stations, and hundreds of miles of buried wastewater lines. More than 4.5 million gallons of wastewater are collected daily (VIWMA, n.d.). Of the eight plants run by the agency, five are on St. Thomas, one is located on St. Croix, and the remaining two are on St. John. There are several major and minor pumping station facilities within the St. Thomas Harbor watershed boundary (Figure 42). The sewer system includes combined sewer where wastewater and rainwater are collected. Since many of the wastewater lines are located along the intermittent waterways (guts) that carry stormwater runoff, they may be subject to possible sanitary sewer overflows (SSOs) that can result in untreated sewage being introduced into stormwater flows. No data for SSOs is currently available at the time of this report development.

Possible illicit discharges due to failing or misconnected infrastructure was a major issue identified by field crews. Illicit discharges can contribute both pollutants and bacteria to surface waters and the storm drain system through leaking pipes, illegal connections, and unexpected overflows during storm events and pose a public health risk (Figure 41). Field crews observed leaking sewer lines during field visits, suggesting that illicit discharges may be a significant issue in the islands.

Figure 41. Suspected illicit discharge in gut.

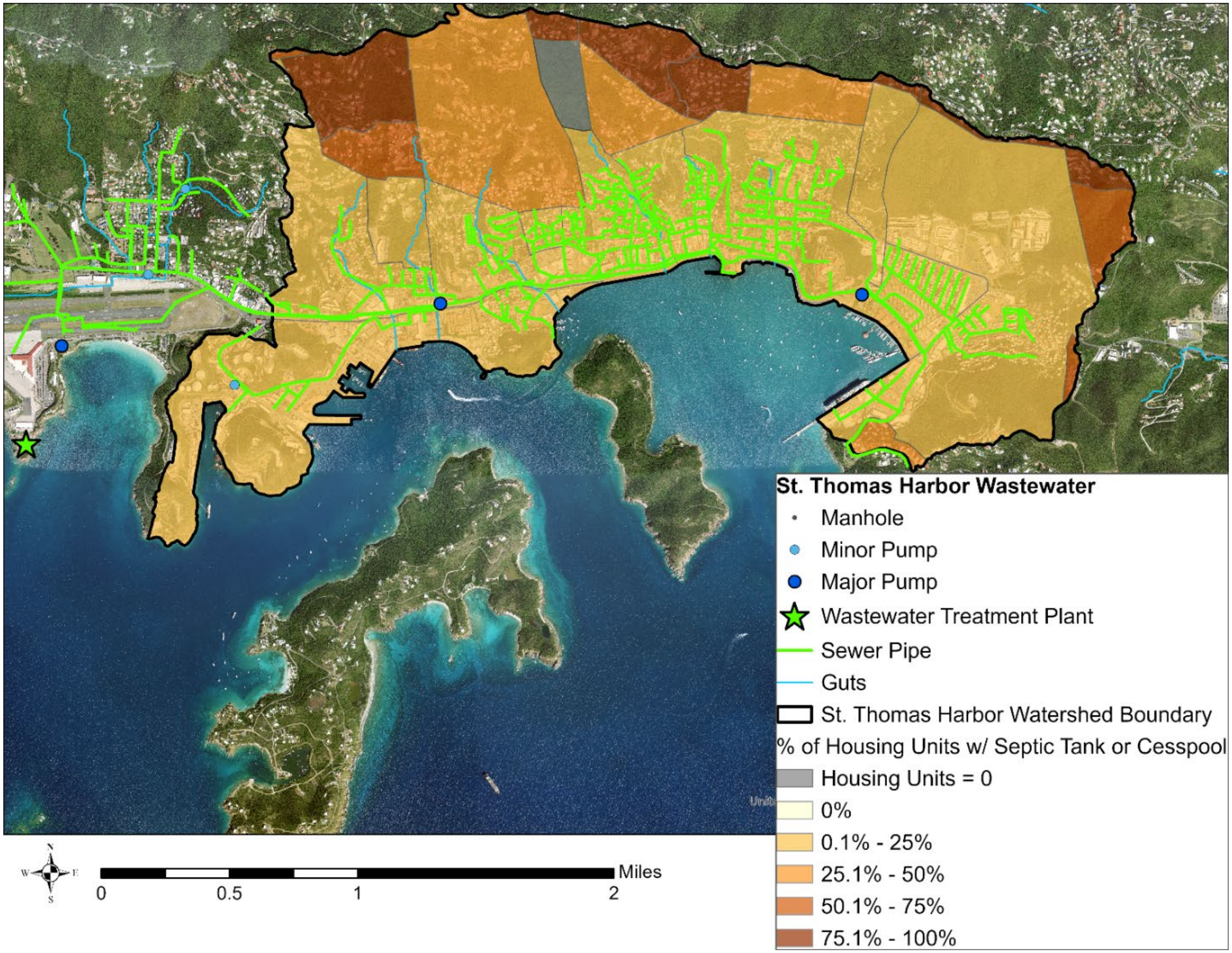


Figure 42. Sanitary sewer system and percent of housing units by estate with septic tanks or cesspools in the watershed (Sources: 2010 U.S. Census data, VIWMA).

3.4.4 Point Source Pollution

In addition to the infrastructure system and associated pollutants that are introduced due to age or failure, other pollutant sources include permitted industrial and municipal discharges. The National Pollutant Discharge Elimination System (NPDES) program requires stormwater discharges from certain municipal separate storm sewer systems (MS4s), industrial activities, and construction sites to be permitted. USVI DPNR is the delegated authority to implement the NPDES Program, and it does so through its own Territorial Pollutant Discharge Elimination System (TPDES) Program. The program issues regulatory permits associated with the management of stormwater discharges from construction activities and industrial facilities. TPDES permits have terms no longer than five years and permittees that wish to continue discharging must apply for permit renewal at least 180 days prior to the expiration date of their permit. If the permitting authority has a complete application but does not reissue the permit prior to the expiration date, the existing permit is "administratively" continued. As of the writing of this report, two TPDES permits are active in the St. Thomas Harbor watershed (Figure 43; Table 12). The violation identified was from January of 2019, and no further violations have been identified.

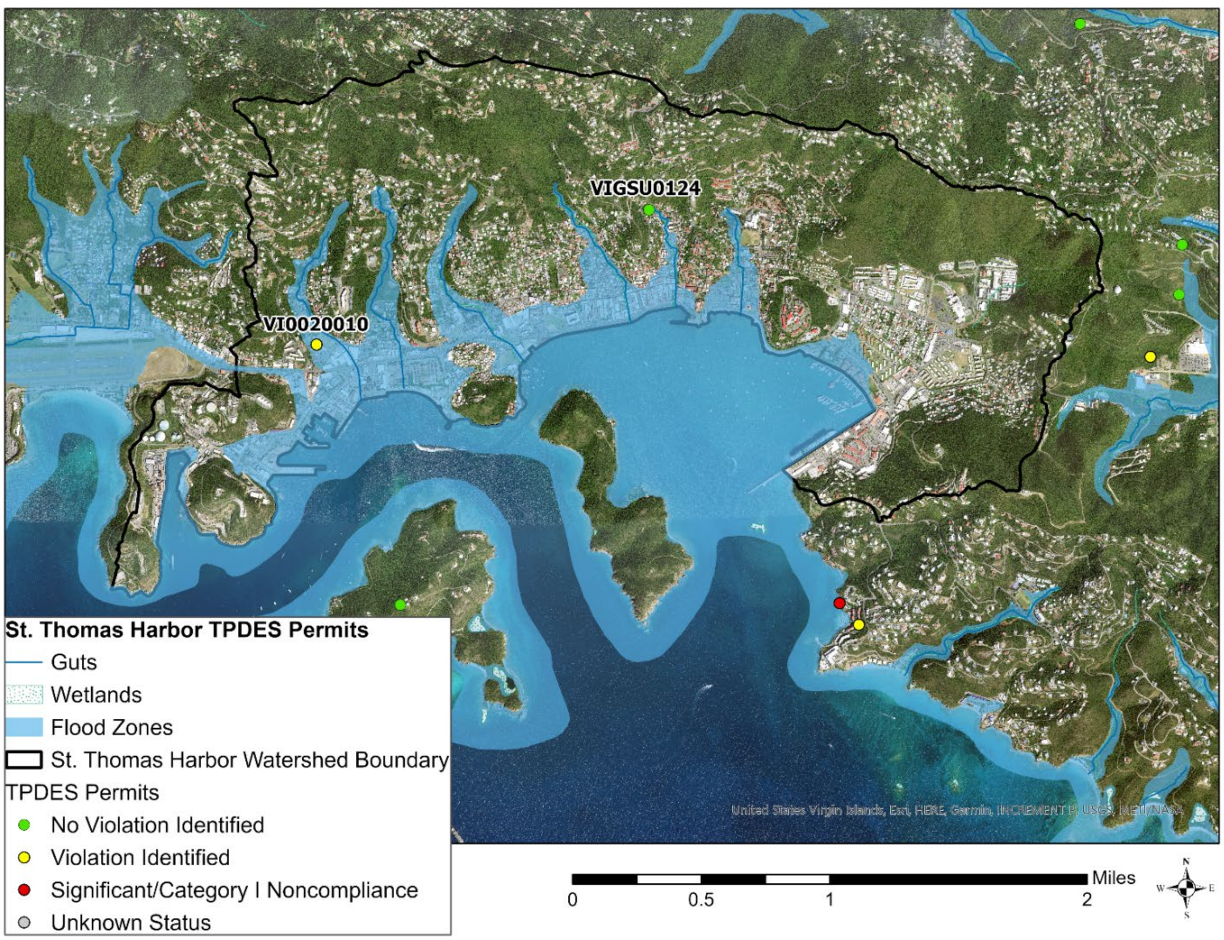


Figure 43. Facilities with TPDES permits in the watershed.

Table 12. Facilities with TDPES permits in the watershed.

Facility Name	Source ID	Permit Type	Effective – Expiry Date	Status
Estate Tutu Apartments Development	VIGSU0124	General Permit Covered Facility	10/06/2020 – 11/30/2022	No Violation Identified
Chevron Puerto Rico, LLC	VI0020010	NPDES Individual Permit	11/01/2016 – 10/31/2021	Violation Identified

3.4.5 Solid Waste Management

The Virgin Islands Waste Management Authority (VIWMA) is responsible for all waste disposal in the territory. The organization has made efforts to start and sustain various recycling and composting efforts, but the organization is historically underfunded and markets for recycled materials are difficult to access.

The USVI has one unlined landfill on the island of St. Thomas, the Bovoni Landfill, that accepts residential, commercial, and industrial waste. This landfill is near capacity and have been operating under EPA consent decrees since 2012 and 2013 for various violations including leaching of toxic waste into the nearby mangrove (Culbertson et al., 2020). Most residents bring their solid waste to collection bins at roadside locations, to staffed convenience centers, or directly to the landfill. In addition, VIWMA also provides some residential collection service, either directly or through contracts with permitted service providers. Businesses directly contract waste removal with permitted waste haulers.

3.4.5.1 Improper Waste Disposal

It was observed during site visits that solid waste such as trash and debris is abundant alongside roadways and at dumpster sites around waste bins. This is most often caused by improper household waste disposal (Figure 44). Signs directing the proper disposal of waste are abundant throughout the island but are often ignored. Dumpster sites often overflow with waste, leading to a significant amount of garbage accumulating adjacent to the dumpsters.

Improper solid waste management presents risks to public and environmental health and reduces aesthetics. It can increase the risk of disease, water and air pollution, leachate, trash odors, and scavenger animals. When improperly contained and managed, trash, especially plastic waste, can also become floatable debris, an issue of international concern. Trash can also enter and clog stormwater systems, limiting the infrastructure's functionality within the watershed and causing localized flooding.

Figure 44. Examples of illegal dumping adjacent to dumpsters and a posted no dumping sign.

3.4.5.2 Hazardous Waste

Hazardous waste is directly harmful to human health and the environment. Household hazardous waste may include cleaning supplies, furniture polish, fertilizers, motor oil, paint supplies, nail polish remover, lighter fluid, and other chemicals. Industrial sites often produce hazardous waste as well. In the St. Thomas Harbor watershed, shipyards, manufacturing companies, boat repair, and automobile shops may use hazardous waste such as grease and gasoline that are toxic. Improper handling and storage of these wastes can pose a significant risk to human health and wildlife habitat.

Although they were not the focus of field assessments, solid waste management and hazardous waste management sites were documented when observed (Figure 45). Seven sites within the St. Thomas Harbor watershed were identified, four within southwestern St. Thomas Harbor watershed and three within southeastern St. Thomas Harbor watershed (Figure 46). These sites do not represent a complete inventory of solid or hazardous waste issues.

Figure 45. Open containers of used motor oil were observed placed uphill of a gut (left) and used motor and cooking oil are placed in open areas in insecure containers for collection (right).

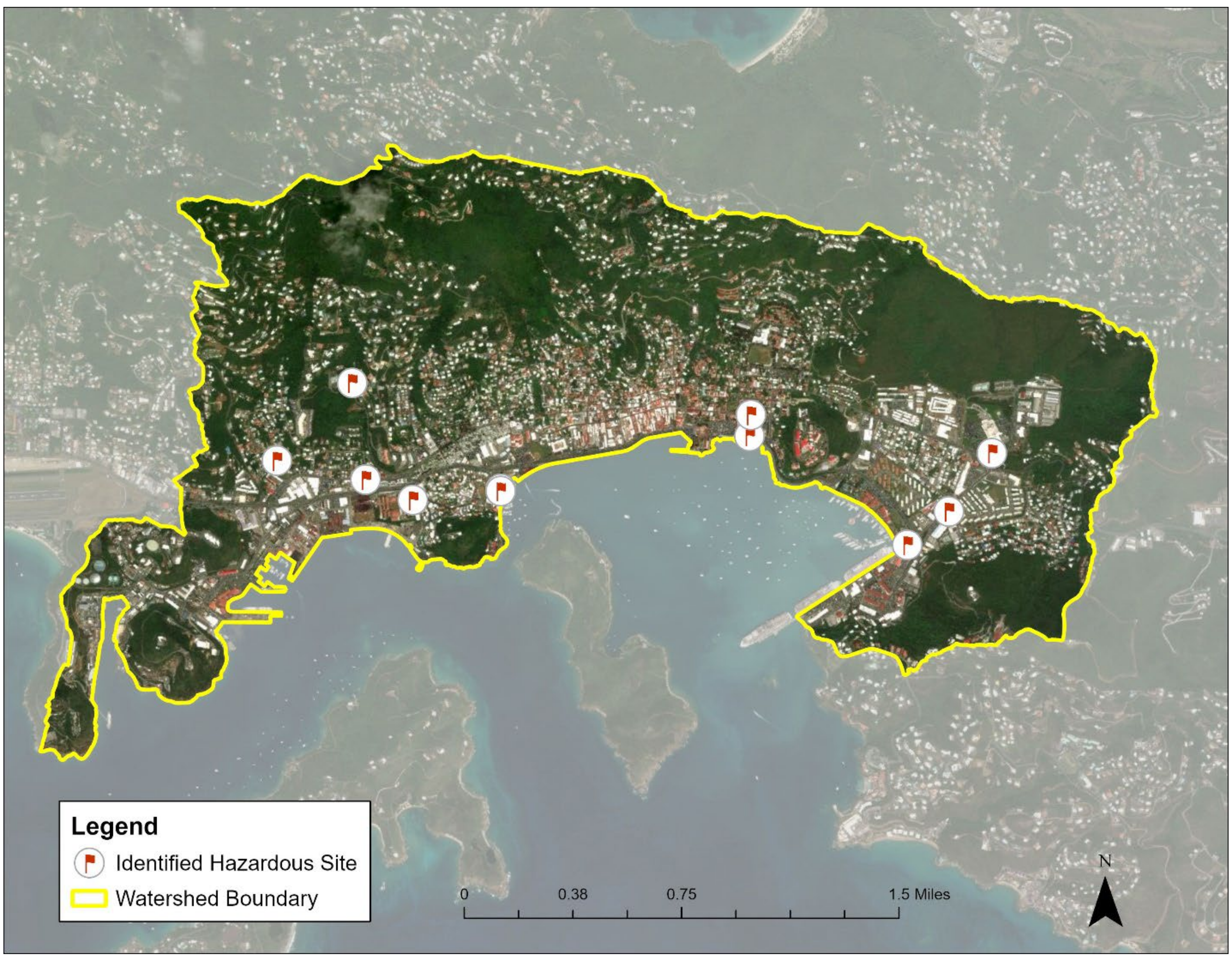


Figure 46. Seven hazardous or solid waste problem sites were identified for mitigation during field investigations in June 2021.

3.4.5.3 Damaged & Abandoned Vehicles

In the USVI, there is an abundance of abandoned vehicles. Options for disposing of these vehicles are limited and require both time and, in some cases, a fee to hire a tow truck to transport the vehicle for disposal. Vehicles can be brought to the Bovoni Landfill on St. Thomas for free disposal Monday through Saturday (as of January 2022). The Office of the Administrator launched an Abandoned Vehicle Taskforce in 2019 to mark and dispose of abandoned vehicles and as of May 2019, approximately 175 abandoned vehicles were removed on St. Thomas. Although abandoned vehicles are subject to a minimum $1,000 fine (Figure 47), these fines are rarely enforced.

During field visits, an accident was observed where potentially hazardous fluids were leaking from a damaged vehicle (Figure 47). Although emergency services were on the scene of the accident, no spill response measures were applied to these leaking fluids. The fluids were draining towards stormwater infrastructure that is directly connected to the ocean.

Figure 47. Warning sign regarding a fine for abandoned vehicles (left) and vehicle damaged in an accident with fluids spilling on the ground (right).

3.4.6 Other Issues of Concern

3.4.6.1 Sea Level Rise

Climate changed influenced sea level rise is an issue of concern for the USVI. Due to the melting of polar ice caps and thermal expansion of ocean waters, sea level rise poses a significant risk to the island in the form of shoreland erosion, infrastructure degradation, and the contamination of groundwater aquifers, wetlands, and estuaries.

Data provided by the Sea Level Rise and Coastal Flood Hazard Scenarios and Tools Interagency Task Force suggests that sea level rise proximal to St. Thomas will be between approximately 3.38 ft by 2100, with a high estimate of 6.79 ft and a low estimate of 1.21 ft depending on the modeled scenario (Sweet et al., 2022). This is of notable concern as many of the critical harbors and bays surrounding St. Thomas are within a few feet of sea level. Interactive sea level rise projection maps can be found at: https://sealevel.nasa.gov/task-force-scenario-tool.

Figure 48. Coastal erosion due to sea level rise threatens stability of homes near the coast.

3.4.6.2 Mangrove Health

Mangroves provide important coastal protections from storm surges, store and filter stormwater, and provide wildlife habitat. Mangroves are threatened by development pressures, pollution especially from marine debris and from polluted stormwater, and climate change impacts including sea level rise.

Figure 49. Mangroves provide critical habitats and hydrologic functions to the islands of USVI.

3.4.6.3 Coral Health

Coral reefs provide coastal protection from storm surges and damage, aquatic habitat for critical local food sources and biodiversity, and economic contributions as a draw for tourism and recreation. On an economic scale, the total value of the USVI coral reefs is an estimated $187 million (Brander & Van Beukering, 2013). The island's coral reefs are at risk due to climate change driven temperature increases, increased hurricane storm intensity, ocean acidification, bleaching, reduction in reef predators and herbivores, pollution from human activity, and increased sedimentation from land-based sources of pollution including development. Stony coral tissue loss disease (SCTLD) is another threat to coral reefs, and this often-fatal disease has been detected in the USVI.

3.4.6.4 Air Pollution

Although air quality in the USVI is generally good, air quality can be degraded by Saharan dust events, industrial pollutants, and vehicle emissions. Dust from storms occurring in Africa can be transported by prevailing winds from the North African desert over the Atlantic Ocean and to the USVI. These dust events can cause issues for people with respiratory conditions (Platenburg, 2018). The USVI is heavily reliant on passenger vehicles and public transportation is not well utilized. As such, vehicle emissions are especially concentrated in the urban areas that can cause reductions in air quality (Shirley et al., 2012).

3.4.6.5 Sargassum

Since 2011, sargassum seaweed has periodically washed ashore in large quantities. Prior to this time, only small amounts of the seaweed would wash ashore. As it decomposes near shore, it can kill seagrass through shading and deoxygenation, prevent turtle nesting, and smother coral. Sargassum also creates hydrogen sulfide, a foul smelling and toxic gas that can irritate lungs and eyes. It also poses a significant economic issue for the region both in a reduction in tourism and in the cost to remove and dispose of the seaweed as it washes up on beaches.

Figure 50. Sargassum build up on a beach in USVI.

3.4.6.6 Marinas

Marinas can be a source of pollutants due to dumping from boats or leaking pumping stations. This direct discharge of fuel or sewage can result in bacteria and toxic pollutants in near shore waters that can affect important coastal habitat. There are two marinas within the St. Thomas Harbor watershed, the Crown Bay Marina and the Yacht Haven Grande.

3.5 Data Collection

3.5.1 Stormwater Infrastructure Mapping

Accurately mapping the existing stormwater infrastructure is critical to understanding the connectedness of these systems to plan for future stormwater upgrades to improve resiliency. Stormwater best management practices (BMPs) improve water quality both by removing pollutants through filtration, infiltration, or settling, and by reducing the volume and velocity of runoff entering guts and coastal waters. As land development continues in the USVI and precipitation patterns are impacted by climate change, stormwater management practices will play an even more important role in reducing flooding, protecting water quality and marine ecosystem health, reducing peak discharge rates, and more nearly approximating the hydrology of undeveloped lands.

An inventory of stormwater infrastructure including features like catchbasins, paved swales, grass swales, and culverts was conducted and evaluated as part of field investigations for this Plan. Prior to this, very limited digitized stormwater infrastructure data existed for St. Thomas. No publicly available centralized GIS repository of stormwater infrastructure currently exists for the territory. This lack of infrastructure data presents a several of challenges to watershed planners. Without knowing what stormwater infrastructure is present, determining hydraulic flow paths through watersheds can often be unclear, in turn making it difficult to accurately delineate contributing drainage areas of existing or proposed stormwater treatment practices. Furthermore, a lack of data on the condition and effectiveness of existing infrastructure makes planning for regular maintenance, repairs, or upgrades inefficient.

Figure 51. Examples of stormwater infrastructure. A catch basin (left) and a paved swale (right).

The infrastructure mapping effort for this Plan was split into field and desktop phases. Field data was collected with handheld GNSS equipment (primarily a Trimble TSC7) using the mobile data collection app ArcGIS Collector. Most field data was collected from March to early May 2021. Photo attachments were included for all data points if feasible. Notes were added about each feature such as the number and direction of pipe connections, condition, if maintenance was needed, and size if possible. The desktop mapping stage focused on quality control and completeness of the map data. Pipe connections were drawn where field notes described, cross culverts were completed with inlet/outlet pairs, and additional infrastructure visible from satellite imagery or LiDAR topography was added. Finally, during field visits in June 2021, additional verification was performed on previously mapped infrastructure. A limited amount of new data was collected during these visits as well, particularly around potential BMP sites.

Figure 52. Inspection of existing stormwater infrastructure during field assessments (above) and an

example of the maps produced (below).

This dataset is the most complete and accurate mapping of the stormwater infrastructure within the watershed. However, no mapping of this scale can capture all infrastructure. There are many private areas that were unable to be accessed in the field. It is also expected that there is some infrastructure that has become buried with sediment over time and is unable to be identified. Additionally, as-built plans were unavailable for much of St. Thomas, so in areas where field investigations were unable to be completed or where pipe connections were unclear, this data was unable to be captured. Additional steps to clarify connections or identify additional infrastructure such as feeding cameras through the stormlines or utilizing a pipe locator were not within the scope of this project.

At lower elevations within the densely developed areas of Charlotte Amalie, the drainage network is dominated by sub-surface box culverts. Many of St. Thomas Harbor's guts make their way from natural channels to open concrete channels then to these box culverts, finally draining into the Harbor. A network of catchbasins and stormlines propagate through these systems as well. Many stormlines are damaged, clogged with trash or debris, or otherwise not functioning. This information was included in the infrastructure database provided to DPNR so that repairs and/ or maintenance can be targeted for these locations.

In total, 652 point, 215 line, and 3 polygon features were mapped within the watershed for a total of 870 features. The largest numbers of infrastructure types collected were catchbasins, culvert inlets, storm lines, and culvert outlets. A breakdown of the number of features identified by infrastructure type are included in Table 13 below.

Table 13. Summary of infrastructure data collected by type in the watershed.

Feature Type	Infrastructure Type	Quantity
Point Features	Catch basin	305
	Culvert inlet	117
	Culvert outlet	112
	Stormwater manhole	38
	Information point	32
	Outfall	16
	Sanitary manhole	13
	Grate curb inlet	12
	Surface crossings	7
Line Features	Storm line	114
	Paved swale	54
	Swale	21
	Storm tunnel	19
	Trench drain	6
	Surface flow	1
Polygon Features	Stormwater treatment practice	3
	Total	**870**

3.5.2 Existing Stormwater BMPs

Stormwater best management practices (BMPs) improve water quality both by removing pollutants through filtration, infiltration, or settling, and by reducing the volume and velocity of runoff entering guts and coastal waters. As land development continues in the USVI and precipitation patterns are impacted by climate change, stormwater management practices will play an even more important role in reducing flooding, protecting water quality and marine ecosystem health, reducing peak discharge rates, and more nearly approximating the hydrology of undeveloped lands.

Understanding where current BMPs exist is critical to properly allocate stormwater resources across the watershed. For example, if a neighborhood or region within a watershed is already being treated by a current BMP practice, a new BMP may be better served elsewhere within the watershed. The existing BMPs will also play a significant role in the hydrologic and water quality modeling completed for this project since these BMPs reduce pollutants and stormwater volume and velocity entering guts and coastal regions. BMPs were previously scarcely mapped, and BMP locations were generally unknown.

Existing BMPs were identified using a combination of field observations, site plans, Hexagon imagery, and LiDAR topography data. They were then digitized into a GIS database. This identification process focused on the identification of structural BMPs, such as bioretention cells, infiltration basins, treatment wetlands and wet ponds. Non-structural practices, such as disconnections to filter strips and vegetated buffers as well as reforestation efforts could not be feasibly identified. It is possible that some existing BMPs remain unidentified due to a lack of access to private property, lack of comprehensive site plans, or their small size rendering them undetectable in the available data sources. In total, seven BMPs were mapped in the watershed; two BMPs in Southwest St. Thomas Harbor, four BMPs in South-Central St. Thomas Harbor, and one BMP in Northeast St. Thomas Harbor (Figure 53). The seven identified BMPs in the watershed, including a brief description of the BMPs, can be found in Table 14 below.

Table 14. Summary table of existing BMPs identified in the St. Thomas Harbor watershed.

Map ID	BMP Type	BMP Description
1	Oil/Water separator	Underground Swirl Separator.
2	Oil/Water separator	Underground Swirl Separator.
3	Oil/Water separator	Underground Swirl Separator.
4	Oil/Water separator	Underground Swirl Separator.
5	Basin	Surface basin with minimal infiltration.
6	Basin	Surface basin with minimal infiltration.
7	Basin	Surface basin with minimal infiltration.

Drainage areas for each existing BMP were delineated utilizing one-foot contours derived from LiDAR elevation data and mapped infrastructure. These drainage areas are shown in Figure 53 below in yellow. In general, the drainage areas for the existing BMPs were fairly small (average of 14.9 acres for a total of 104.6 managed acres) as they were often designed to treat stormwater runoff from a single or a few properties rather than a larger scale project. Based on available data, the majority of the watershed is presently untreated (95.9% unmanaged), further highlighting the need for watershed-scale planning.

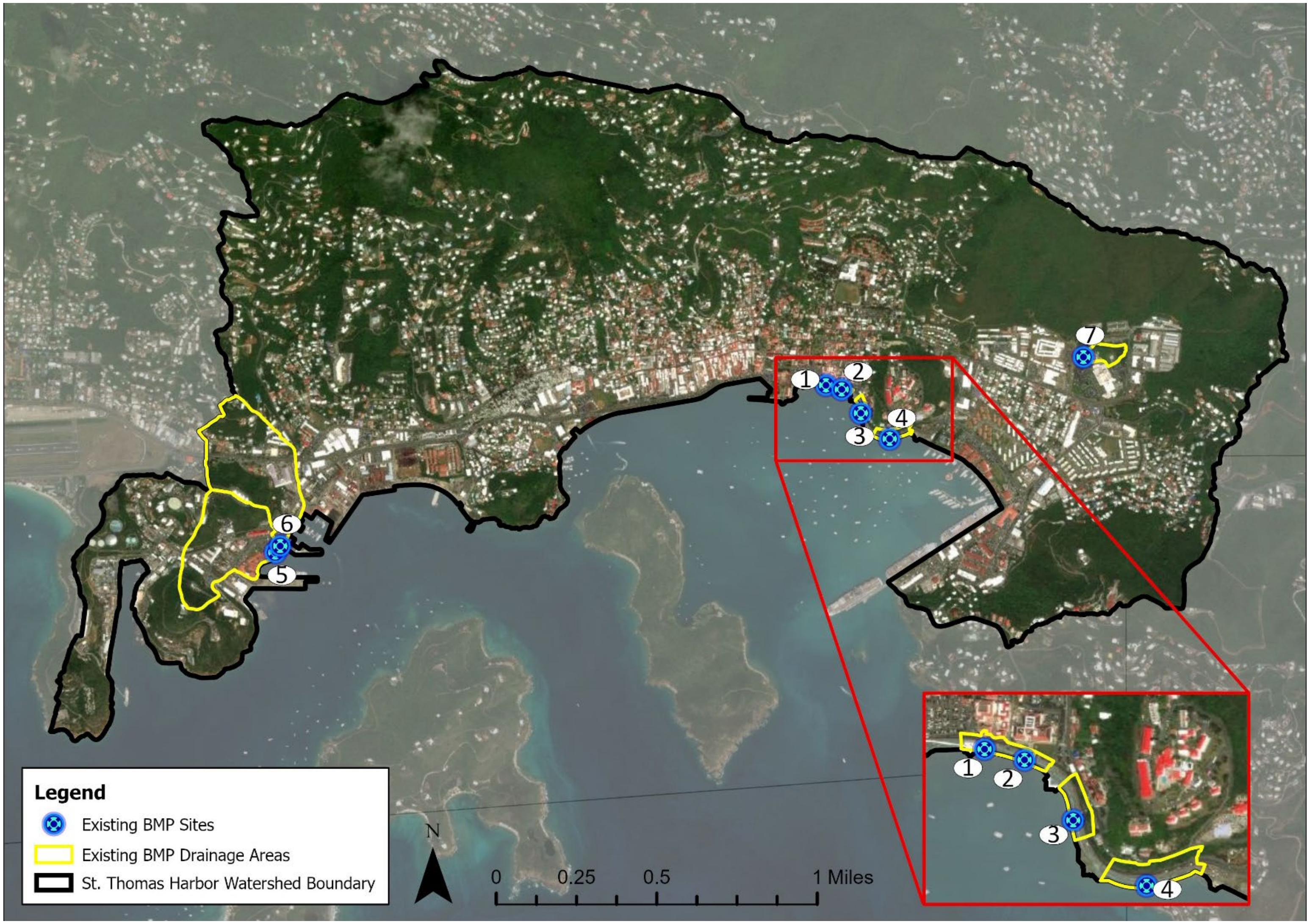


Figure 53. Existing stormwater BMPs identified within the St. Thomas Harbor watershed.

Figure 54. Existing basins BMP ID 5 (above) and BMP ID 7 (below) in the St. Thomas Harbor watershed.

3.5.3 Updates to Existing Data

DPNR-provided watershed boundaries and FEMA-provided gut layers for the watershed was revised utilizing newly available data including LiDAR-derived elevation data (USGS, 2018), Hexagon imagery (0.15m, 2019), and stormwater infrastructure mapped as a part of this project. Mapped infrastructure such as surface crossings, culverts, and stormwater pipes as well as assumed flow confinement from roadways and buildings were also considered during drainage area delineation. This new data allowed for a better understanding of topography and drainage patterns including the impacts of previously unmapped stormwater infrastructure. For the St. Thomas Harbor watershed, the updates to the watershed boundary resulted in a net watershed area change of 24.5 acres (0.98% of the watershed).

3.5.4 UAS Data Collection

Figure 55. WingtraOne Gen II UAS utilized to collect data in the study watersheds.

Land cover data (see Section 3.3.2) was created using 2019 Hexagon imagery as the primary source. However, in the last three years there may have been significant changes in land cover that could impact stormwater flows including the construction of new commercial or residential developments or clearing of forested areas. To understand potential development changes, an unmanned aircraft system (UAS) was flow over key areas in March 2022 to capture up to date very high-resolution imagery (≤5 cm). The areas of suspected change were identified based on information regarding current and recent known development and shared with DPNR. DPNR stakeholders reviewed the proposed areas and recommended several additional areas to collect data to ensure that any known areas of change were covered by these UAS flights. Where possible, given Federal Aviation Administration (FAA) flight height restrictions around airports, a fixed wing WingtraOne Gen II UAS was utilized (Figure 55). Where flight height restrictions prevented the use of the Wingtra UAS, a DJI Phantom quadcopter UAS was utilized. The collected data was used to assess the level of development change in the watershed and update the land cover data used to model the selected stormwater management practice concept designs (see Section 3.7.4). In addition, topographic information derived using photogrammetry was generated for areas flown with the Wingtra UAS. This data will be provided to DPNR for use in other projects. In this watershed, data was collected for approximately 80 acres.

3.6 WATER QUALITY MONITORING OF GUTS

3.6.1 Monitoring Overview

Efficient management and monitoring of natural resources requires informative data derived from areas of interest. The guts of St. Thomas are the primary source and conveyance system of fresh water on the island. Likewise, they are also the main conduit through which chemical pollutants and sediment from the watersheds of St. Thomas reach the ocean (Platenburg, 2006). Despite their importance, the guts of St. Thomas have not been monitored with consistency and their terrestrial sources of pollutants are not well understood. The guts on the island are ephemeral, only flowing following rainfall, and this makes sampling of the guts very challenging. This study represents the most widespread and comprehensive sampling of guts in the USVI. This monitoring effort also serves as a pilot project and the lessons learned during this effort can be used to guide future monitoring and can also be used to identify pollutant sources and guide efforts to improve water quality.

In this study, synoptic sampling of major guts during storm events was conducted to establish a baseline of water quality data and to assist in the prioritization of sub-watersheds for further assessment. Synoptic sampling is a form of water quality sampling in which surface water is collected from many sites across a watershed in a short period of time. It is a common method for exploring the relationships between land-use and water quality, providing a brief “snapshot” of stream (or gut) health (Wayland et. al, 2003). The sampling completed under the scope of this WMP consisted of four main components:

1. Rainfall monitoring
2. Grab sampling
3. Flow measurements
4. Sediment sampling

Each of these four elements is described in detail below. The locations for these monitoring points are shown in Figure 56 below.

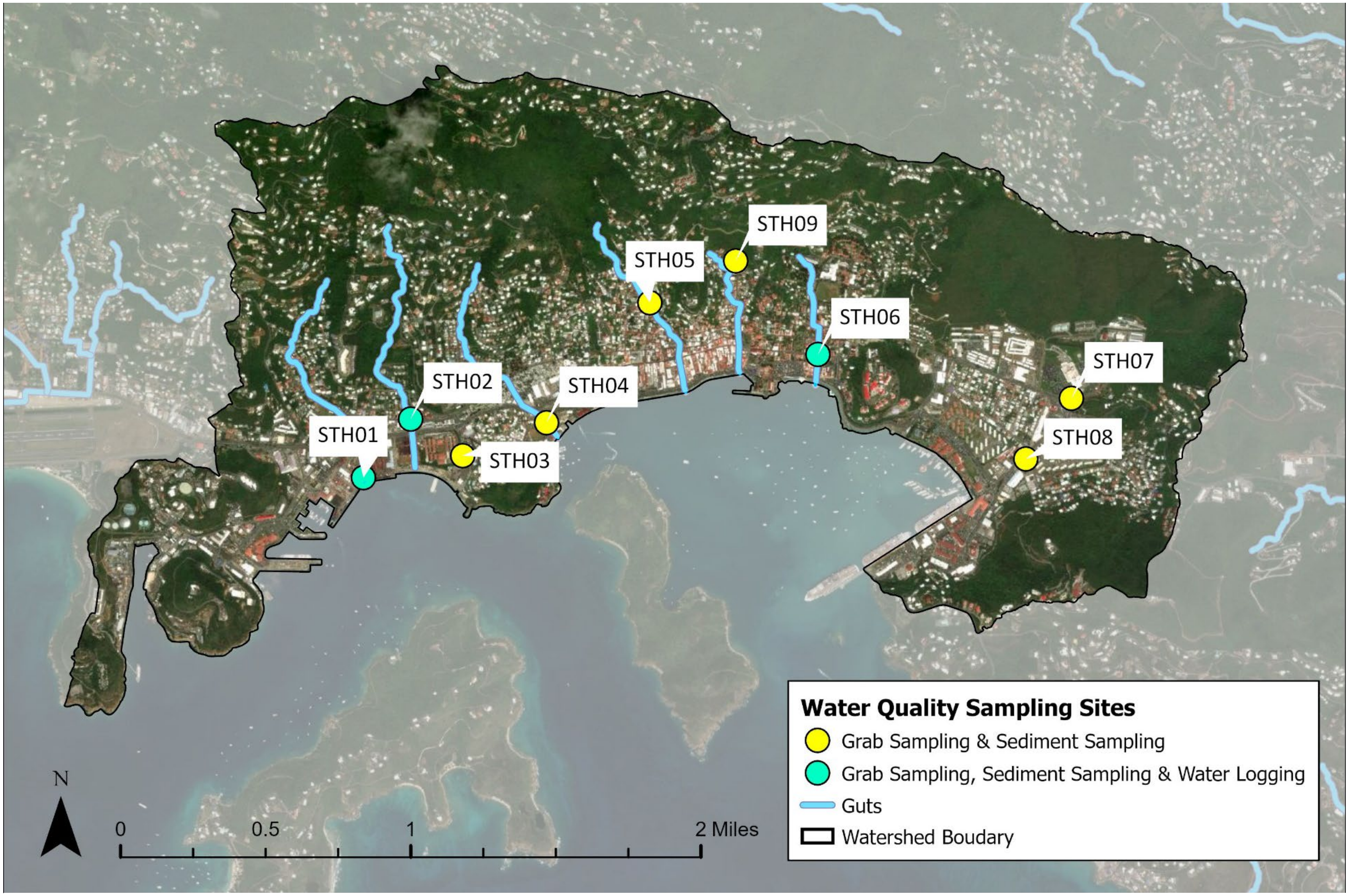


Figure 56. Grab sampling, sediment sampling, and water logging locations.

3.6.2 Rainfall Monitoring

Given the ephemeral nature of the guts on St. Thomas, the focus of the monitoring effort was on sampling during and following and storm events, understanding rainfall patterns, and collecting rainfall data. This crucial component of the study is greatly influenced by rainfall patterns, which vary across the island of St. Thomas. The different geographic regions are referred to as microclimates and they experience unique patterns of rainfall intensity or duration (Bowden, 2021). In this study, rainfall was monitored with two rain gauges installed during this project, gauges operated by the Community Collaborative Rain, Hail, and Snow Network (CoCoRaHS), and Water Resources Research Institute (WRRI) at the University of the Virgin Islands (UVI) (Figure 58). The two gauges installed by the project team were RG3 HOBO Data Logging Rain Gauges, a widely used tipping bucket rain gauge (Figure 57). These gauges were deployed in locations that ensured that spatial variability in precipitation across the watersheds of St. Thomas were accounted for.

Figure 57. Watergate rain gauge (left) and Altona rain gauge (right).

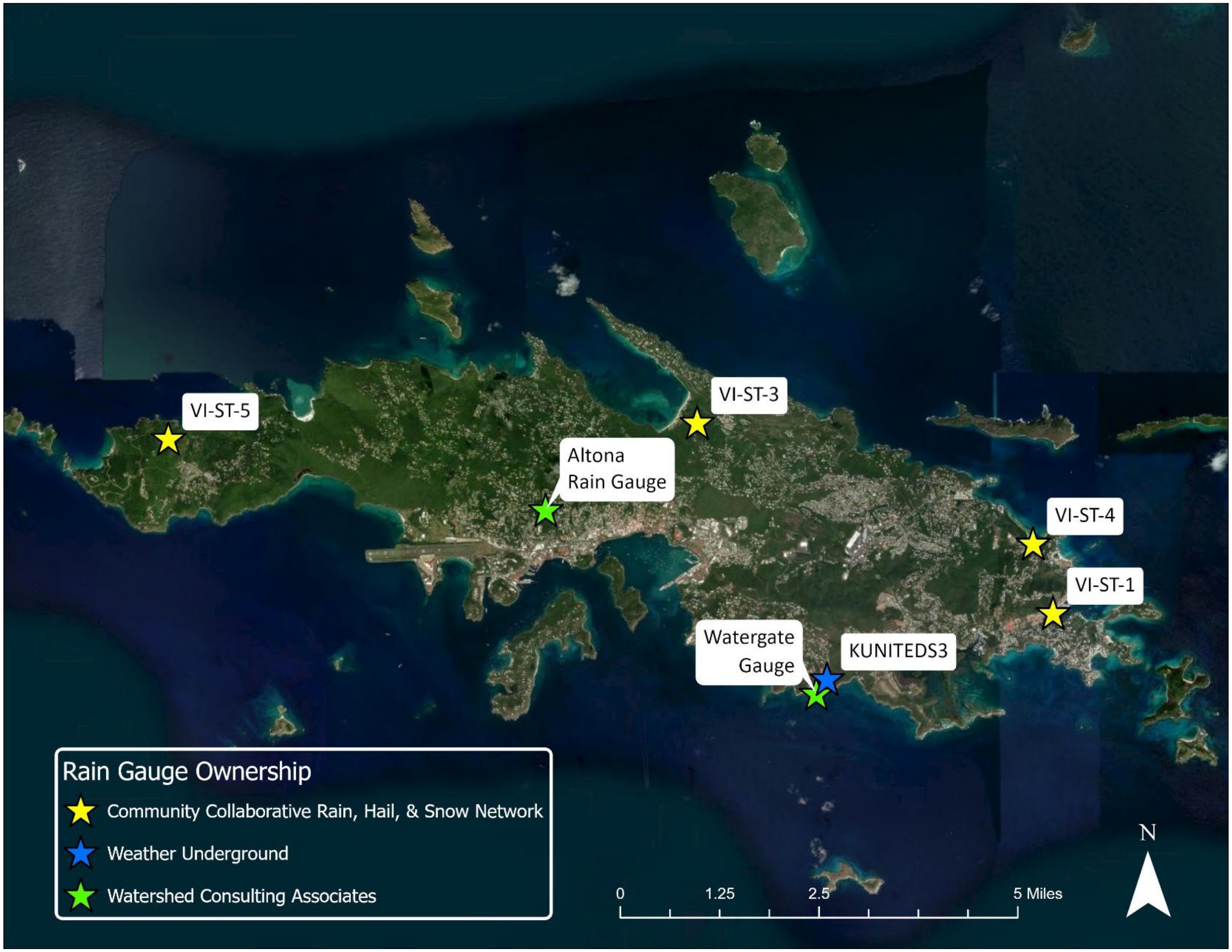


Figure 58. Rain gauge locations on St. Thomas.

3.6.3 Grab Sampling

Grab samples, samples collected at a discrete point in time, were taken during storm events exceeding 0.25 inches of rain in a quarter hour from nine gut sampling locations across the St. Thomas Harbor watershed (Figure 59). Most of the sampling locations (STH01, STH02, STH03, STH04, STH06, STH08) were chosen at the lowest elevation point in a major open channel gut just before the gut becomes subterranean, entering the underground tunnels beneath Charlotte Amalie before discharging into the bay. Sampling location STH05 was selected because of the notable erosion undermining the neighboring road just above the Jane E. Tuitt Elementary School. Erosion stabilization and stormwater storage best management practices have been proposed for this location, highlighting the need to understand the state of existing water quality conditions. Sampling location STH09 was chosen due to its proximity to a proposed intersection repair project being proposed by the USVI Department of Public Works (DPW). Sampling location STH07 was chosen as the drainage area to the sampling location is primarily forested with the exception of the roads, buildings, and parking lots surrounding Scheider Regional Medical Center. This sampling location will provide a comparison data point to the more developed sampling locations. Grab samples were analyzed for a number of pollutants that are indicative of gut health. The specific pollutants monitored and their impact on gut health is summarized in Table 15.

For sampling locations where no flow was observed during two qualifying storm events, this lack of flow was recorded. The lack of flow was confirmed either by visual observation or by the installed HOBO water level loggers. This lack of gut flow was an important finding as it indicated that characteristics of the upstream drainage area caused the lack of gut flow at this rainfall threshold. There are several watershed-specific characteristics that are likely to result in this observation including but not limited to:

1. Soil composition in the watershed allows for infiltration of rainfall at least up to the observed rainfall threshold, taking into account antecedent soil moisture.
2. Significant storage upstream of the monitoring point such that enough detention is taking place to eliminate flow at this location. Storage could include natural depressions and manmade ponding areas.
3. Alteration of natural drainage patterns to the extent that enough drainage is directed away and disconnected from the gut that the contributing area is effectively much smaller than it would be otherwise. This could include inadvertent rerouting of stormwater down driveways and along roadways or intentional collection of stormwater via infrastructure and discharge to the bay or downstream of the monitoring point in the gut.

For these monitoring locations without flow, an assessment was made of the contributing drainage area to determine the probable cause of this observation. The assessment focused on mapped soils, topography, and mapped stormwater infrastructure. A summary of this analysis is provided for each monitoring location without measurable flow.

Figure 59. Grab sample collection from sampling sites STH06 (left) & STH07 (right).

Table 15. Water quality monitoring parameters measured via grab sampling.

Water Quality Class	Water Quality Parameters	Description
Nutrients	Total Phosphorus (TP) & Total Kjeldahl Nitrogen (TKN)	TP and TKN are two of the most frequently monitored elements in water quality studies throughout the United States due to their role in promoting eutrophication (Bowman, 1982). TP and TKN are commonly derived from agricultural runoff during and following major storm events. Other sources include human and animal waste, septic systems, and fertilized lawns.
Bacteria	Escherichia coli (E. coli) & Enterococci	E. coli and enterococci are two forms of fecal coliform bacteria derived from the digestive tract of humans and other warm-blooded animals. The presence of these fecal coliform bacteria in water is a strong indication of recent sewage or animal waste contamination.
Sediment & Organic Matter	Total suspended solids (TSS)	TSS is a measurement of the total waterborne material that exceeds 2 microns in size, primarily comprised of mineral and organic matter. Minerals and organic matter play an important role in the transportation of nutrients and contaminants in water. TSS is often derived from erosion, which can be exacerbated by impervious surfaces, poor agricultural practices, and other forms of human activity.
Volatile Organic Compounds (VOCs)	Acetone, Carbon Disulfide, Dichloromethane, Trichloroethylene, & Tetrachloroethylene	VOCs are chemicals that have the ability to both dissolve in water and vaporize into the air. VOCs have notable adverse effects on human health and are dangerous to the environment. Common sources of VOCs include industrial spills and leaks as well as the dumping of household cleaning products.
Inorganic Contaminants	Orthophosphate, Nitrate, Nitrite, Bromide, Sulfate, Fluoride, & Chlorine.	Inorganic contaminants in water can range across a variety of chemicals from a variety of different sources. In this study we focus on inorganic contaminants primarily derived from the production of fertilizers and drinking water.
Total petroleum hydrocarbons (TPHs)	Automotive Gasoline, Fuel Oils, Benzene, Toluene, & Naphthalene	TPHs are a family of chemicals derived from crude oil. The presence of oil in guts has detrimental effects on human, aquatic, and environmental health. In this study, we measure the most common chemicals within the TPH family.
Heavy Metals	Lead, Cadmium, Arsenic, Mercury, Chromium, & Copper	Heavy metals, while usually present in only trace amounts, can be incredibly toxic and cause severe issues for human, aquatic, and environmental health. Heavy metals occur naturally in rocks, however excess heavy metal concentrations found in water is usually the byproduct of anthropogenic activity.

3.6.4 Flow Measurements

Gut discharge (i.e., flow) is a key parameter in understanding gut hydrology and water quality. In this study, gut discharge was monitored at three locations as shown in Figure 56 (STH01, STH02, and STH06). Discharge was measured using Onset HOBO U20 Water Level Loggers (Figure 60). Pressure measurements derived from the logger during storm events were converted to discharge measurements by correcting for changes in barometric pressure in the air and using Manning's equation to determine channel roughness. To use Manning's equation, channel geometry, slope, and friction coefficient for each of the flow measurement locations were determined. Channel geometry was determined by direct measurements in the field. Channel slope was determined by taking the slope of LIDAR-derived elevation data 10m above and below the deployment location. In the case where channel became subterranean within 10m of the gauge downstream, the slope was measured from the point of subterranean entrance and a point 20m upstream. Friction coefficient was determined by channel material. Full details of sampling method can be found in Appendix B2.

Figure 60. Field crew member setting up an Onset HOBO U20 Water Level Logger at gauge station (left) and water flowing through the gut following a rain event (right) at STH 01.

3.6.5 Sediment Sampling

Sediment deposited in guts was collected and analyzed for grain size and contaminants. Sediment sampling occurred once at all grab sampling locations (see Figure 56) unless it was infeasible because 1) there is no sediment to sample, a possibility in some concrete channels, or 2) the sampling personnel were unable to safely access the channel. Some of the drainage ways at the point of sampling are concrete lined while others are not lined and over natural ground.

Upon arrival at the site, the sampling site was photographed. A measuring tape was stretched across the drainage way and photographed to document the various sediment deposition types across the channel. Probes were made at each variation of sediment type (i.e., gravel, fines, mixed sediment) and depths of loose or lightly compacted sediment were measured at each point and recorded. A small diameter metal rod was used to estimate deposition depth. The rod was driven in with the rubber mallet and when resistance changed, a core was taken to resistance or 2 inches below that depth where a notable resistance change was noted. The 4 inch plexiglass core was cut into lengths 6 inches longer than the estimated deposited soil depths. The rubber mallet was used to drive the core to the depth of the estimated deposition.

Once the core was completely in, a thin metal sheet (approximately 6 inches in width) was placed beneath the core by excavating adjacent to the core to clear an area to slide it beneath. The core with the metal sheet on the bottom was lifted vertically and placed upright. The depths of the various visible layers were measured with a metered tape adjacent to the core. Once measured and photographed, the core was dumped into a labeled sample bag. This was repeated at each identified soil type change. Once all samples were collected, a subsample of each sample was taken into the compositing container and well mixed and apportioned into the appropriate laboratory provided sample bottles. Samples were taken to Ocean Systems Laboratory for grain size analysis according to ASTM Standards. The complete methods used for the collection of deposited sediment from each of these environments can be found in Appendix B2. Field photos can be found in Figure 61.

Figure 61. Field crew member measuring the depth of deposition (left) and collecting a subsample of the various sediment types across the cross-section of the gut channel (right).

3.6.6 Results & Discussion

3.6.6.1 Rainfall & Flow Measurements

In the USVI, rainfall can be unpredictable and occur over a small geographic area and have varying intensity over a very short period of time. This makes it challenging to correlate rainfall data collected in rain gauges, even when gauges are distributed across the island, to in-gut flow. As such, the flow measurements shown below often do not coincide with the rainfall data over time. In some cases, the rainfall may occur at the rain gauge after the flow is observed in the gut because of the path of the storm event over the island. It would be challenging to accurately pair these measurements as even a rain gauge positioned at each monitoring location may not capture the rainfall that produced the stormwater flowing through the gut when an isolated high intensity storm occurs upstream of the gut location. This is a limitation of the study design but also highlights the difficulty of monitoring both flow and rainfall in the USVI.

One water level logger located in the STH01 gut channel near the MSI/Ports captured the first qualifying rain event of the monitoring period on December 4, 2021. The peak rainfall rate of 0.32 in. per 0.25 hour started at 12:04 pm with a total rainfall accumulation of 0.20 inches for the duration of the entire rain event. During this monitored event, the peak flow rate of the STH01 gut discharge was 2.0 cfs. The total discharge volume that flowed through STH01 was 21,336.55 cf (Figure 62). The Altona rain gauge, located further upstream of the STH01 site, did not log any rainfall accumulation. The KCHARLOT2 rain gauge, located south of STH01 on Water Island, started to log rainfall accumulation between 11:00 am and 12:00 pm. However, the STH01 water level logger recorded peak flow rate between 8:00 am and 9:00 am, *before* the KCHARLOT2 gauge logged rainfall. The peak flow rate likely corresponded with a microburst of rainfall that took place over a small portion of the gut and was not logged by either of the upstream or downstream rain gauges. In a future expanded monitoring effort, placement of additional rain gauges along the gut channel can supplement flow data due to the highly variable and sporadic nature of rainfall patterns within the watershed and even within smaller fragments of the gut.

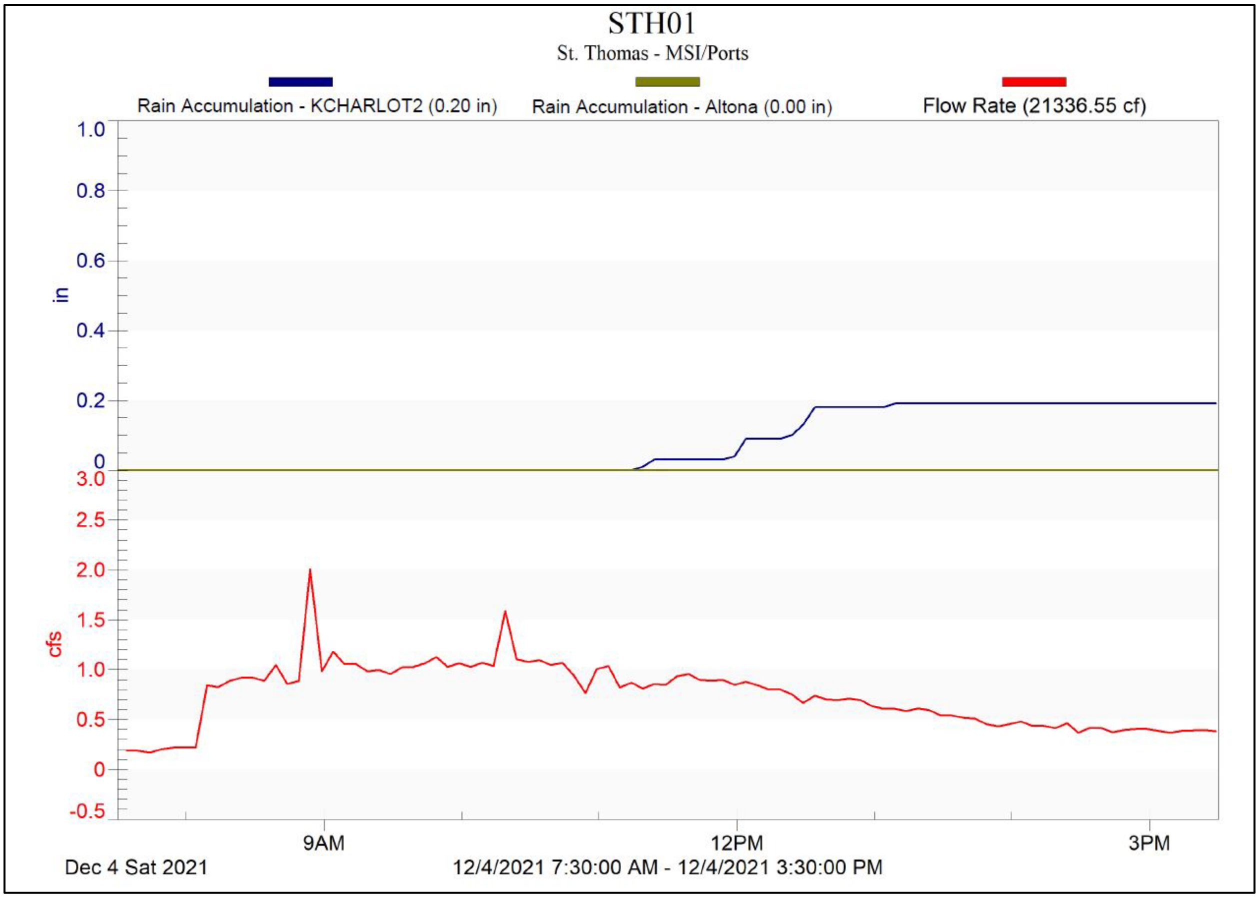


Figure 62. A hydrograph displaying the peak flow rate of the discharge through the STH01 gut monitoring site (2.0 cfs) and the corresponding rain accumulation for the storm event (0.20 in.) that occurred on December 4, 2021.

The second qualifying rain event of the STH01 monitoring period occurred on December 15, 2021. The peak rainfall rate of 1.15 in. per 0.25 hour started shortly after 11:00 am at the KCHARLOT2 rain gauge that is south of STH01 on Water Island. The Altona rain gauge upstream of STH01 began logging rainfall shortly after, between 11:00 am and 12:00 pm. During this monitored event, the peak flow rate of 0.55 cfs occurred at 12:00 pm. With this peak flow occurring within one hour after rainfall began in both rain gauge locations, this indicates that this particular storm event may have covered a larger area of the watershed than the previously logged storm event in order to trigger flow that closely corresponded to the timing of the peak rainfall rate of the storm event. The total discharge volume that flowed through STH01 was 15,643.97 cf (Figure 63).

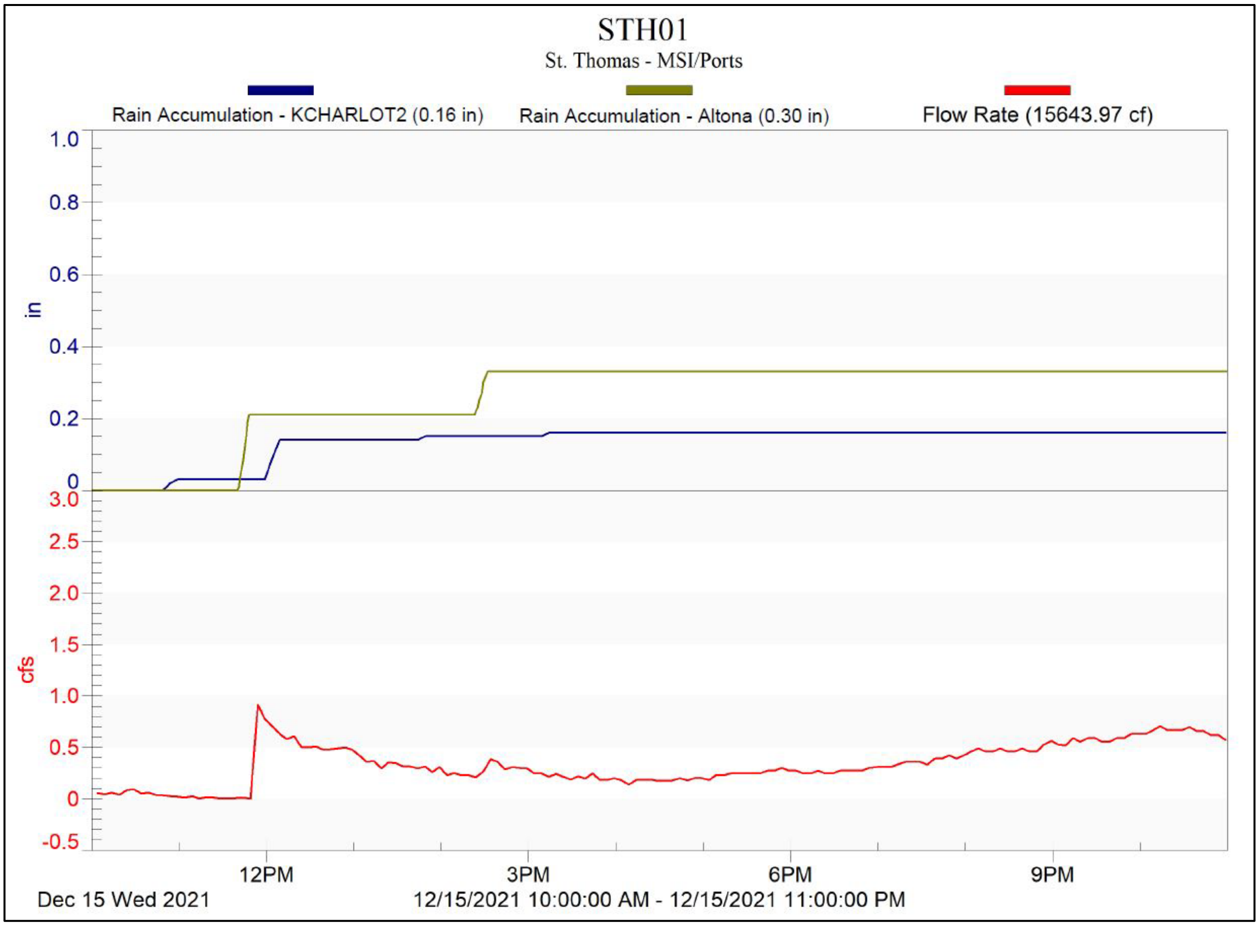


Figure 63. A hydrograph displaying the peak flow rate of the discharge through STH01 (0.55 cfs) and the corresponding rain accumulations for the storm event that occurred on December 15th, 2021. The Altona rain gauge that is upstream of STH01 logged 0.3 inches of rainfall and the KCHARLOT2 rain gauge that is south of STH01 on Water Island logged 0.16 inches of rainfall.

One water level logger located in the STH02 gut channel, close to Altona, captured the first qualifying rain event of the monitoring period on December 20, 2021. The peak rainfall rate of 0.27 inches per 0.25 hour started between 10:00 am and 11:00 am. The ICHARL167 rain gauge did not log any rainfall accumulation. The Altona rain gauge logged a total rainfall of 0.22 inches. A total of 16,089 cf of stormwater discharge flowed through STH02 with the two peak flows occurring directly after the peak rainfall threshold was achieved (Figure 64). The first peak flow point was achieved at the STH02 location within a 15-minute interval of the peak rainfall intensity occurring at approximately 11:00 am.

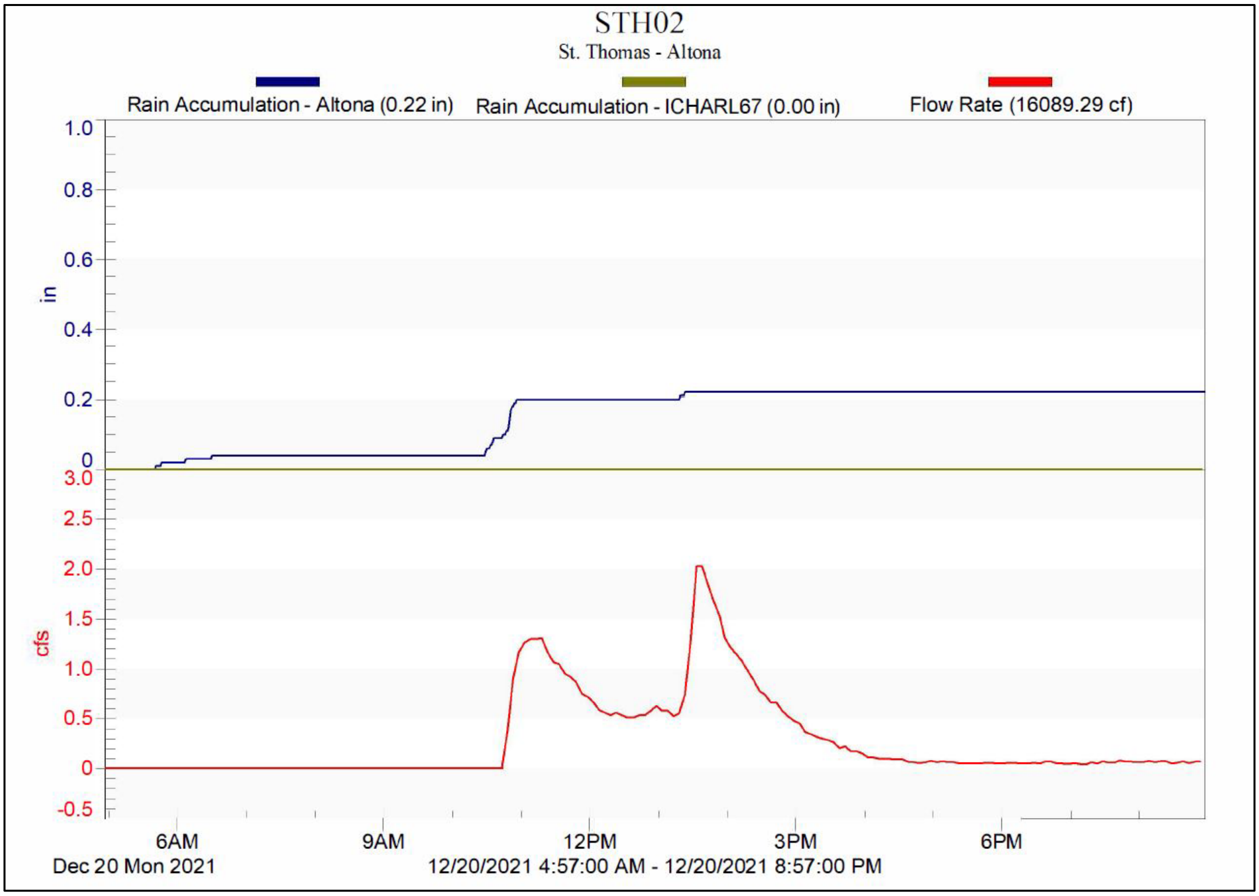


Figure 64. A hydrograph displaying the peak flow rate of the discharge through STH02 (2.05 cfs) and the corresponding rain accumulations for the storm event that occurred on December 20, 2021. The Altona and ICHARL167 rain gauges are both upstream of STH02. Altona is northwest of STH02 and ICHARL167 is northeast of STH02.

The second qualifying storm event of the STH02 monitoring period occurred on January 8th, 2022. The peak rainfall rate of at least 0.25 inches per 0.25 hour was achieved between 9:00 am and 10:00 am at the Altona rain gauge. The ICHARL167 rain gauge did not log any rainfall accumulation. The Altona rain gauge logged a total rainfall of 0.23 inches. A total of 18,130 cf of stormwater discharge flowed through STH02 with the one peak flow occurring directly after the peak rainfall threshold was achieved (Figure *65*). Similar to the previous storm event, the first peak flow point was achieved at the STH02 location within a 15-minute interval of the peak rainfall intensity occurring shortly after 9:00 am. The two monitored storm events at STH02 both demonstrate how its location within the gut has direct hydrologic connectivity to upland impervious surfaces that produce runoff almost immediately upon a rainfall intensity of at least 0.25 inches per 0.25 hour. Factors such as the topography, underlying soils, and land cover within the STH02 drainage area are likely to be prevailing factors in the hydrologic connectivity of this location. Additional study on the STH02 contributing drainage area can provide context as to the magnitude and temporal performance of gut flow at this location.

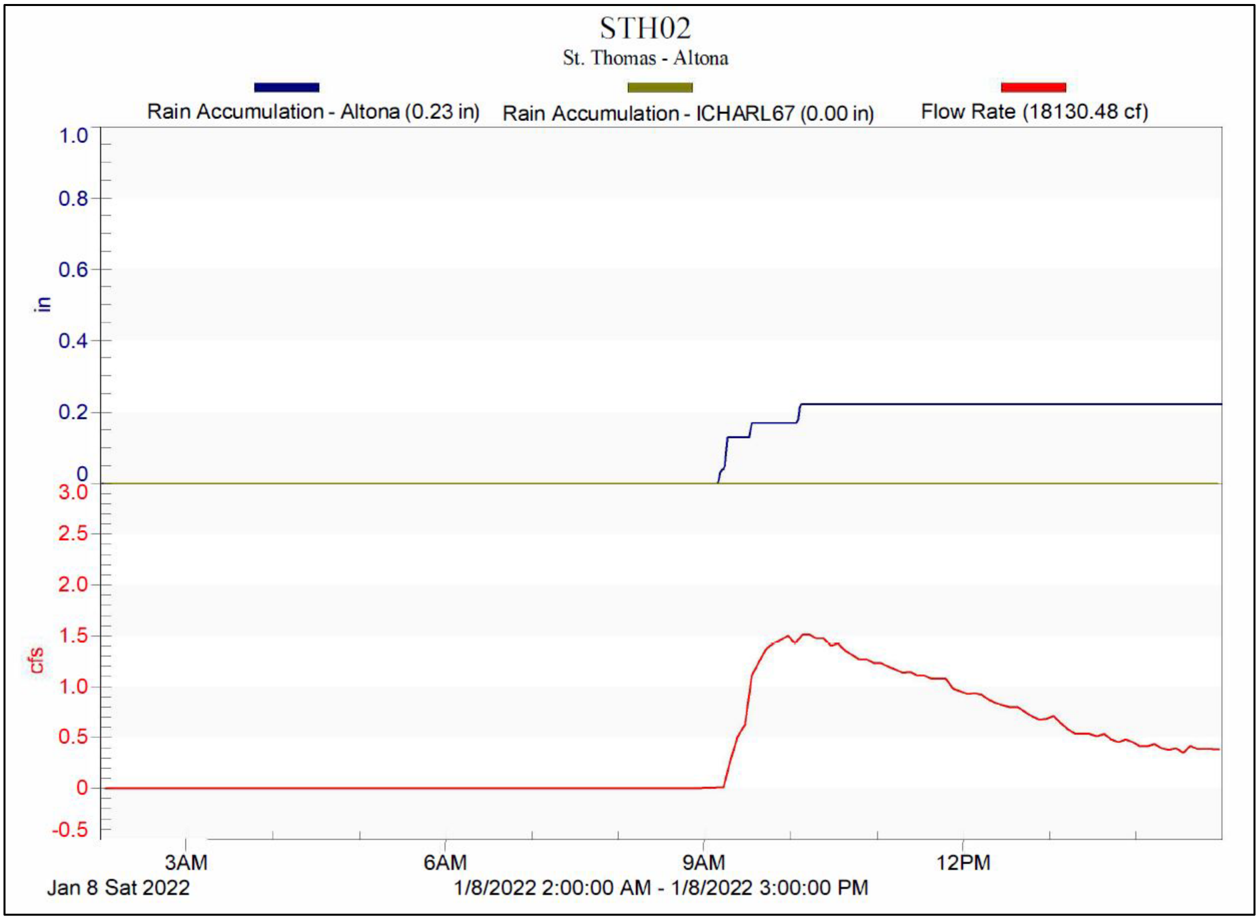


Figure 65. A hydrograph displaying the peak flow rate of the discharge through STH02 (1.55 cfs) and the corresponding rain accumulations for the storm event that occurred on January 8, 2022. The Altona and ICHARL167 rain gauges are both upstream of STH02. Altona is northwest of STH02 and ICHARL167 is northeast of STH02.

One water level logger located in the STH06 gut channel, captured the first qualifying rain event of the monitoring period on November 25th, 2021. The peak rainfall rate of 1.86 inches per hour started between 10:30 am and 11:30 am at the ICHARL149 rain gauge. The ICHARL149 rain gauge logged 0.41 inches of rainfall and the ICHARL25 rain gauge logged 0.43 inches of rainfall. A total of 2,374 cf of stormwater discharge flowed through STH06 with the one peak flow occurring between 9:00 am and 10:00 am, before the peak rainfall threshold was achieved (Figure 66). There was no measurable peak flow logged at STH06 after the peak rainfall threshold was achieved at the ICHARL149 and ICHARL25 rain gauges.

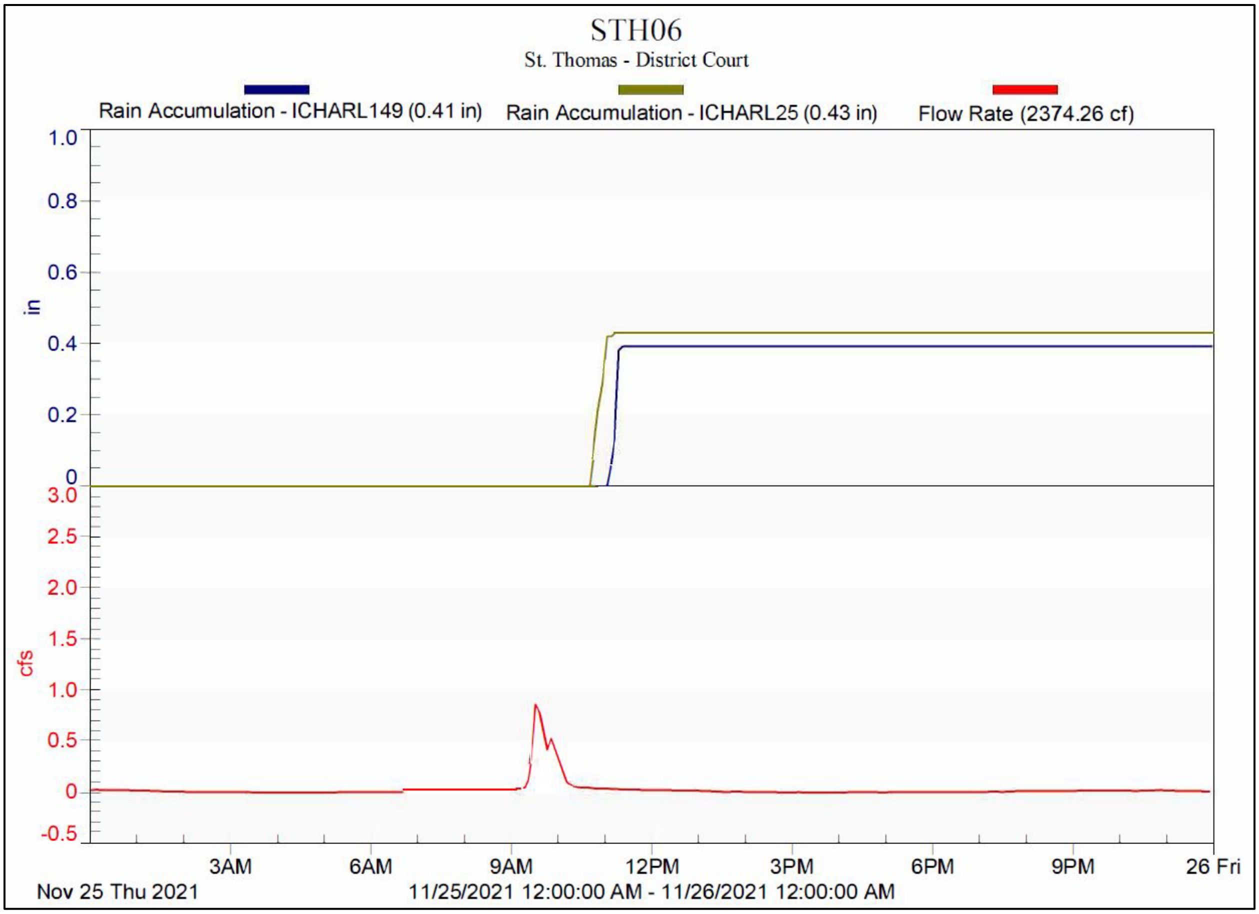


Figure 66. A hydrograph displays the peak flow rate of the discharge through STH06 (2.05 cfs) and the corresponding rain accumulations for the storm event that occurred on November 25, 2021. The ICHARL149 rain gauge is southeast of STH06 and the ICHARL25 rain gauge is northeast of STH06.

The second qualifying storm event of the STH06 monitoring period occurred on December 4th, 2021. The peak rainfall rate of 0.96 inches per hour was achieved between 3:30 pm and 4:30 pm at the ICHARL149 rain gauge. The ICHARL149 rain gauge logged a total rainfall of 0.53 inches and the ICHARL25 rain gauge did not log any rainfall accumulation. A total of 4,963 cf of stormwater discharge flowed through STH06 with no measurable peak flow logged (Figure 67). The two monitored storm events at STH06 do not demonstrate a direct hydrologic connectivity between the STH06 gut location and its upland impervious surfaces. While there were measurable volumes of flow recorded at STH06, they were not correlated with the occurrence of the peak rainfall rate observed at surrounding rain gauges. Factors such as the topography, underlying soils, and land cover within the STH06 drainage area are likely to be prevailing factors in the lack of direct hydrologic connectivity of this location that limits the occurrence of a significant peak flow rate at this monitoring location. Additional study on the STH06 contributing drainage area can provide context as to the magnitude and temporal performance of gut flow relative to rainfall patterns in this area.

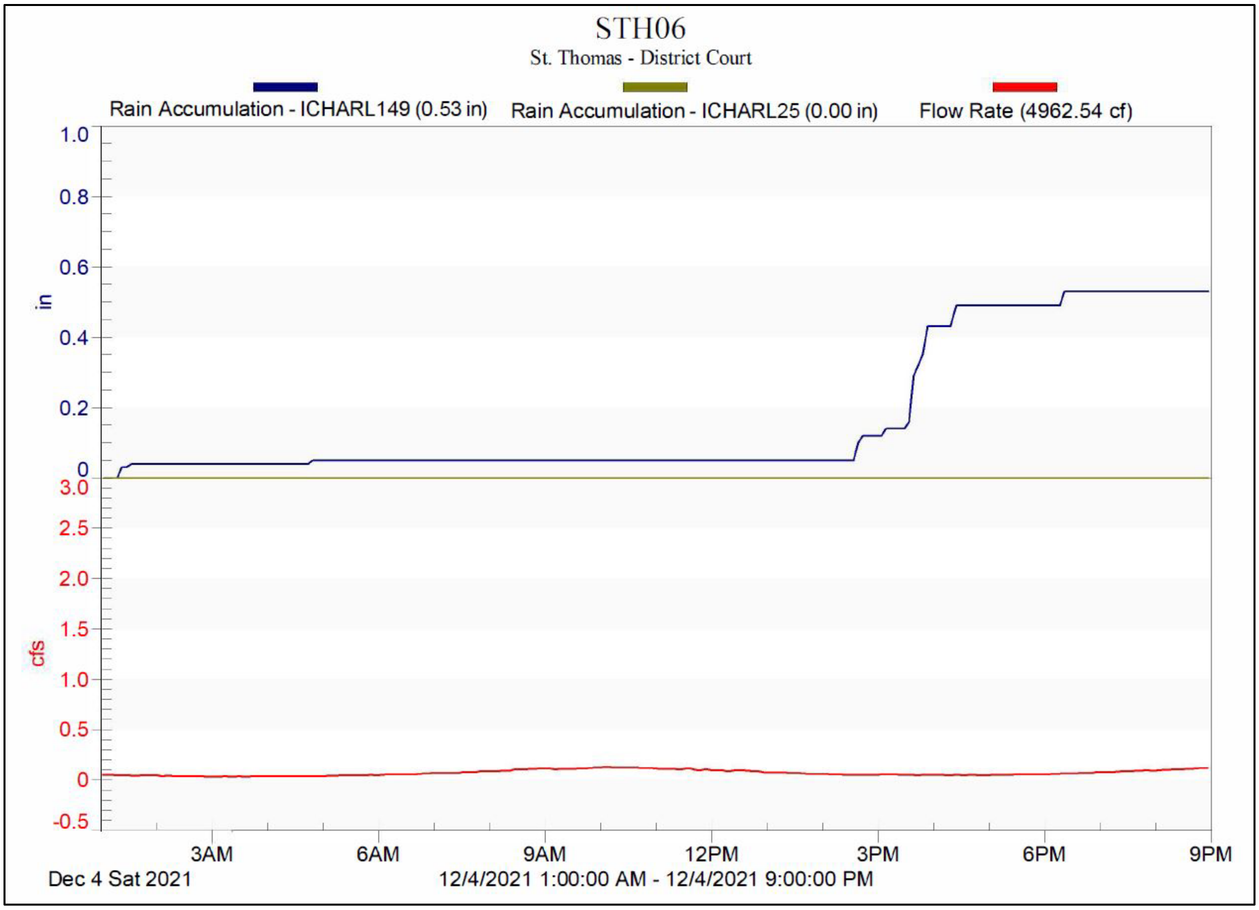


Figure 67. A hydrograph displays the peak flow rate of the discharge through STH06 (0.13 cfs) and the corresponding rain accumulations for the storm event that occurred on December 4, 2021. The ICHARL149 rain gauge is southeast of STH06 and the ICHARL25 rain gauge is northeast of STH06.

3.6.6.2 Water Quality Data

Water quality results for the two grab samples at each sampling location across the St. Thomas Harbor watershed could not be compared to each other as they represent a discrete point in time during two different storm events. However, the collective set of preliminary results was compared to various water quality standards established by the EPA and the USVI DPNR to determine which pollutants are of concern and will likely require extended monitoring in the St. Thomas Harbor watershed guts if detected at acute concentrations in this preliminary monitoring study.

The water quality standards used for comparison were based on the assumption that the two grab samples each taken from STH01 and STH04 were entirely comprised of brackish water and grab samples taken from the remaining six sites were entirely comprised of freshwater due to site specific characteristics. The Amended 2019 USVI Water Quality Standards for inland brackish water and freshwater were used to determine pollutant exceedances for the corresponding surface water type at each monitoring location. Within the 2019 USVI Water Quality Standards, if there was no inland freshwater or brackish water standard defined for a measured parameter, the standard for the receiving water body of all eight monitoring sites – Class C coastal waters – was used alternatively. If there was no comparable standard provided in the 2019 USVI Water Quality Standards, the EPA National Primary and Secondary Drinking Water Regulations (NPDWRs and NSDWRs) were used to understand the magnitude of particular pollutant concentrations such as bromide, fluoride, mercury, and sulfate in the grab samples. Within the EPA NPDWRs and NSDWRs, it is understood that these regulations are for human consumption of water and therefore are highly stringent compared to regulations for non-potable freshwater. However, for grab sample water quality results that exceed the EPA NPDWRs and NSDWRs, they will be acknowledged for being held to these higher standards due to the standard for non-potable gut discharge being undefined.

There are no federal regulations or advisories for the concentration of petroleum range organics or acetone in surface waters to protect aquatic or human health. Raw data results for these parameters are presented in Table 16 through Table 23 but could not be applied to any established standard from the EPA or USVI DPNR. However, water quality standards for specific pollutants within the class of TPHs that are measures of petroleum constituents, including benzene, naphthalene, and toluene were provided for grab samples containing these pollutants. The primary pollutants of concern based upon consistent exceedances of the Amended 2019 USVI Water Quality standards across the St. Thomas Harbor watershed:

1. E. coli
2. Enterococci
3. Sediment
4. Total Nitrogen (TN)
5. Total Phosphorus (TP)
6. Copper
7. Bromide
8. Sulfate

E. coli and Enterococci: The acute concentration of fecal coliform bacteria, specifically E. coli and enterococci, in all grab samples across the St. Thomas Harbor indicates that there were significant amounts of sewage and/or animal waste contaminating the monitored portions of the gut channels. The water quality standards used to measure the magnitude of fecal coliform bacteria is based on consistent sampling over a 30-day period which is not representative of the sampling conditions of this study. However, this standard provides context that an essential, long-term water quality goal is to prioritize the prevention of human or animal fecal matter entering waterways at any time. Consistent sampling of gut flow in all rain events within a 30-day period is needed to confirm whether this acute water quality exceedance is consistent over a longer duration.

Sediment: The USVI DPNR's standard for turbidity (<3.0 NTU) was exceeded in all grab samples across the watershed. As there was no empirical standard for turbidity of TSS provided for inland freshwater, this value is the standard for the receiving waters of the eight monitoring sites, Class C coastal waters (Table 16 through Table 23). These results indicate there is a high concentration of mineral and organic matter that may be sourced from erosion, agricultural fields, or other land uses. Additional study on the land use acreages of these sites respective drainage areas can determine the hierarchy of sources contributing to this exceedance of sediment in the St. Thomas Harbor gut channels.

TP and TN: The USVI DPNR's standards for TP (<0.05 mg/L) and TN (<0.207 mg/L) were exceeded in all grab samples. As there was no empirical standard for TP and TN provided for inland freshwater, both values are standards for the receiving waters of the eight monitoring sites, Class C coastal waters. All TP results were in exceedance of the receiving coastal water standard. The TN standard is based on consistent sampling of coastal waters over a three-year period which is not representative of the sampling conditions of this study (Table 16 through Table 23). While the TN results are not directly comparable to this standard due to the limited sampling conditions of this preliminary study, it provides the basis to extend monitoring of this location, when possible, to focus on the dynamics of TN (and TP) over a longer temporal scale to determine how this gut is performing in its nutrient dynamics. Extended monitoring could also be advanced to determine loading values of TN and TP along the St. Thomas gut channels to determine the source and magnitude of these nutrients in this watershed.

Copper: The USVI DPNR's standard for acute copper concentrations in the monitoring sites' receiving waters, Class C coastal waters (<4.8 ug/L), were exceeded in all grab samples (Table 16 through Table 23). Copper is typically found in natural surface waters at low concentrations, however acute concentrations of this metal can have adverse effects on aquatic life by inhibiting their survival, growth, reproduction, and more (Kapustka et al., 2004). Continued monitoring of all eight monitoring sites is recommended to determine the source of acute copper concentrations and if they are consistently exceeding the water quality standard for St. Thomas Harbor's receiving coastal waters as was demonstrated in the preliminary results.

Bromide: The bromide concentration in six out of the eight monitoring sites' grab sample sets exceeded the EPA primary drinking water quality standards (Table 16 through Table 23). While more restrictive, the EPA standard for bromide concentrations was used for preliminary comparison as there was no standard defined for USVI waters. Bromide is typically observed at low concentrations in the natural environment. However, if found in high concentrations in surface waters, it is likely associated with fossil fuels and coal-associated wastewaters (VanBriesen, 2014). Extended monitoring of the bromide concentrations in these key locations is recommended to understand the chronic performance of this pollutant.

Sulfate: The sulfate concentration in STH01 and STH04 grab samples exceeded the EPA primary drinking water quality standards by at least 96% (Table 16 and Table 19). While more restrictive, the EPA standard for sulfate concentrations was used for preliminary comparison as there was no standard defined for USVI waters. Sulfate can be sourced from both natural and anthropogenic sources. Natural sources include but are not limited to combustion of organic matter, sea spray aerosols, and mineral weathering. Examples of anthropogenic sources of sulfate pollution include agricultural and industrial wastewater runoff and rising of seawater levels into freshwater bodies (Zak, 2021). Given that both STH01 and STH04 are in locations that receive both tidal flow from the ocean and freshwater from highly developed areas (i.e., brackish water), it is likely that there were both natural and anthropogenic sources of sulfate pollution within their grab samples.

Table 16. Water quality monitoring parameters measured via grab sampling at STH01 on December 4 and 15, 2021. Red cells demonstrate a water quality exceedance of the Amended 2019 USVI Water Quality Standards (USVI, 2019) for inland brackish water. Orange cells demonstrate a water quality exceedance of the EPA NPDWRs. Yellow cells demonstrate a water quality exceedance of the EPA NSDWRs.

Water Quality Class	Water Quality Parameter	STH01 (12/04/21)	STH01 (12/15/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
Inland Brackish Water	pH	7.73	8.32	Between 6.7-8.5[A]	N/A	N/A
	Salinity (psu)	11.16	0.09	0.5-35 psu	N/A	N/A
	Temperature (°C)	27.0	26.7	<32°C	N/A	N/A
	Dissolved Oxygen (mg/L)	-	7.73	>5.50 mg/L	N/A	N/A
Sediment	Turbidity (NTUs)	55.80	96.30	>3.0 NTU[B]	N/A	N/A
	Total Suspended Solids (mg/L)	88.0	23.0	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters.	N/A	N/A
Bacteria	E. Coli	Positive	Positive	Negative	N/A	N/A
	Enterococci	Positive	Positive	Negative	N/A	N/A
	Enterococci MPN per 100 mL	10,112	10,112	<30 CFU/100 mL[C] <110 CFU/100mL[D]	N/A	N/A
Total Petroleum Hydrocarbons (TPHs)	Petroleum Range Organics (mg/L)	1.7	3.2	-	-	-
	Benzene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Naphthalene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Toluene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Heavy Metals	Arsenic (ug/L)	6.5	Undetected	<69 ug/L (acute), <36 ug/L (chronic)	N/A	N/A
	Cadmium (ug/L)	0.66	Undetected	<33 ug/L (acute), <7.9 ug/L (chronic)	N/A	N/A
	Chromium (ug/L)	4.7	8.7	<1,100 ug/L (acute), <50 ug/L (chronic)	N/A	N/A
	Copper (ug/L)	23.4	24.4	<4.8 ug/L (acute),	N/A	N/A

Water Quality Class	Water Quality Parameter	STH01 (12/04/21)	STH01 (12/15/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
				<3.1 ug/L (chronic)		
	Lead (ug/L)	Undetected	6.5	<210 ug/L (acute), <8.1 ug/L (chronic)	N/A	N/A
	Mercury (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Volatile Organic Compounds (VOCs)	Acetone (ug/L)	6.7	9.5	-	-	-
	Carbon Disulfide (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Methylene Chloride (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Tetrachloroethane (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Trichloroethene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Inorganic Pollutants	Bromide (mg/L)	20.8	0.11	N/A	<0.1 mg/L[C]	N/A
	Chloride (mg/L)	5,740	27.9	N/A (saltwater)	N/A	N/A
	Fluoride (mg/L)	0.6	0.057	N/A	N/A	<2.0 mg/L
	Sulfate (mg/L)	711	7.3	N/A	N/A	<250 mg/L
Nutrients	Total Nitrogen – Kjeldahl (mg/L)	1.2	1.4	<0.207 mg/L[E]	N/A	N/A
	Total Phosphorus (mg/L)	0.17	0.18	<0.05 mg/L[B]	N/A	N/A

[A] When discharging to class C coastal waters.
[B] In marine or coastal waters.
[C] 30-day geometric mean.
[D] No more than 10% of the samples collected in the same 30 days.
[E] In more than 10% of samples over a three-year period in estuarine, marine, and coastal waters.

Table 17. Water quality monitoring parameters measured via grab sampling at STH02 on December 20, 2021, and January 8, 2022. Red cells demonstrate a water quality exceedance of the Amended 2019 USVI Water Quality Standards for inland freshwater. Orange cells demonstrate a water quality exceedance of the EPA NPDWRs. Yellow cells demonstrate a water quality exceedance of the EPA NSDWRs.

Water Quality Class	Water Quality Parameter	STH02 (12/20/21)	STH02 (01/08/22)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
Inland Freshwater	pH	7.11	7.53	Between 6.7-8.5[A]	N/A	N/A
	Salinity (psu)	0.23	0.17	<0.50 psu	N/A	N/A
	Temperature (°C)	27.20	26.63	<32°C	N/A	N/A
	Dissolved Oxygen (mg/L)	-	4.87	>5.50 mg/L	N/A	N/A
Sediment	Turbidity (NTUs)	54.45	77.80	>3.0 NTU[B]	N/A	N/A
	Total Suspended Solids (mg/L)	57.65	26.13	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters.	N/A	N/A
Bacteria	E. Coli	Positive	Positive	Negative	N/A	N/A
	Enterococci	Positive	Positive	Negative	N/A	N/A
	Enterococci MPN per 100 mL	10,112	10,112	<30 CFU/100 mL[C] <110 CFU/100mL[D]	N/A	N/A
Total Petroleum Hydrocarbons (TPHs)	Petroleum Range Organics (mg/L)	3.1	5.3	-	-	-
	Benzene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Naphthalene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Toluene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Heavy Metals	Arsenic (ug/L)	3.8	Undetected	<340 ug/L (acute), <150 ug/L (chronic)	N/A	N/A
	Cadmium (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Chromium (ug/L)	8.45	42.6	<16 ug/L (acute), <11 ug/L (chronic)	N/A	N/A

Water Quality Class	Water Quality Parameter	STH02 (12/20/21)	STH02 (01/08/22)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
	Copper (ug/L)	40.7	29.0	<4.8 ug/L (acute)[A], <3.1 ug/L (chronic)[A]	N/A	N/A
	Lead (ug/L)	10.5	Undetected	<65 ug/L (acute), <2.5 ug/L (chronic)	N/A	N/A
	Mercury (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Volatile Organic Compounds (VOCs)	Acetone (ug/L)	26.3	9.7	-	-	-
	Carbon Disulfide (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Methylene Chloride (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Tetrachloroethane (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Trichloroethene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Inorganic Pollutants	Bromide (mg/L)	0.08	0.086	N/A	<0.1 mg/L[C]	N/A
	Chloride (mg/L)	36.5	36.6	<860 mg/L (acute), <230 mg/L (chronic)	N/A	N/A
	Fluoride (mg/L)	0.071	0.081	N/A	N/A	<2.0 mg/L
	Sulfate (mg/L)	41.85	41.6	N/A	N/A	<250 mg/L
Nutrients	Total Nitrogen – Kjeldahl (mg/L)	7.2	1.8	<0.207 mg/L[E]	N/A	N/A
	Total Phosphorus (mg/L)	0.18	0.28	<0.05 mg/L[B]	N/A	N/A

[A] When discharging to class C coastal waters.
[B] In marine or coastal waters.
[C] 30-day geometric mean.
[D] No more than 10% of the samples collected in the same 30 days.
[E] In more than 10% of samples over a three-year period in estuarine, marine, and coastal waters.

Table 18. Water quality monitoring parameters measured via grab sampling at STH03 on December 15 and 20, 2021. Red cells demonstrate a water quality exceedance of the Amended 2019 USVI Water Quality Standards for inland freshwater. Orange cells demonstrate a water quality exceedance of the EPA NPDWRs. Yellow cells demonstrate a water quality exceedance of the EPA NSDWRs.

Water Quality Class	Water Quality Parameter	STH03 (12/15/21)	STH03 (12/20/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
Inland Freshwater	pH	7.66	7.31	Between 6.7-8.5[A]	N/A	N/A
	Salinity (psu)	0.33	0.24	<0.50 psu	N/A	N/A
	Temperature (°C)	27.44	28.20	<32°C	N/A	N/A
	Dissolved Oxygen (mg/L)	7.03	-	>5.50 mg/L	N/A	N/A
Sediment	Turbidity (NTUs)	103.0	224.0	>3.0 NTU[B]	N/A	N/A
	Total Suspended Solids (mg/L)	23.5	210.0	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters.	N/A	N/A
Bacteria	E. Coli	Positive	Positive	Negative	N/A	N/A
	Enterococci	Positive	Positive	Negative	N/A	N/A
	Enterococci MPN per 100 mL	10,112	10,112	<30 CFU/100 mL[C] <110 CFU/100mL[D]	N/A	N/A
Total Petroleum Hydrocarbons (TPHs)	Petroleum Range Organics (mg/L)	3.4	3.3	-	-	-
	Benzene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Naphthalene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Toluene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Heavy Metals	Arsenic (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Cadmium (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Chromium (ug/L)	7.7	7.5	<16 ug/L (acute), <11 ug/L (chronic)	N/A	N/A
	Copper (ug/L)	29.5	43.8	<4.8 ug/L (acute)[A], <3.1 ug/L (chronic)[A]	N/A	N/A

Water Quality Class	Water Quality Parameter	STH03 (12/15/21)	STH03 (12/20/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
	Lead (ug/L)	Undetected	9.2	<65 ug/L (acute), <2.5 ug/L (chronic)	N/A	N/A
	Mercury (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Volatile Organic Compounds (VOCs)	Acetone (ug/L)	7.0	Undetected	-	-	-
	Carbon Disulfide (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Methylene Chloride (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Tetrachloroethane (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Trichloroethene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Inorganic Pollutants	Bromide (mg/L)	0.46	0.23	N/A	<0.1 mg/L[C]	N/A
	Chloride (mg/L)	128	64.4	<860 mg/L (acute), <230 mg/L (chronic)	N/A	N/A
	Fluoride (mg/L)	0.067	0.084	N/A	N/A	<2.0 mg/L
	Sulfate (mg/L)	21.2	12.9	N/A	N/A	<250 mg/L
Nutrients	Total Nitrogen – Kjeldahl (mg/L)	1.7	3.9	<0.207 mg/L[E]	N/A	N/A
	Total Phosphorus (mg/L)	0.25	0.39	<0.05 mg/L[B]	N/A	N/A

[A] When discharging to class C coastal waters.
[B] In marine or coastal waters.
[C] 30-day geometric mean.
[D] No more than 10% of the samples collected in the same 30 days.
[E] In more than 10% of samples over a three-year period in estuarine, marine, and coastal waters.

Table 19. Water quality monitoring parameters measured via grab sampling at STH04 on December 4 and 15, 2021. Red cells demonstrate a water quality exceedance of the Amended 2019 USVI Water Quality Standards for inland brackish water. Orange cells demonstrate a water quality exceedance of the EPA NPDWRs. Yellow cells demonstrate a water quality exceedance of the EPA NSDWRs.

Water Quality Class	Water Quality Parameter	STH04 (12/04/21)	STH04 (12/15/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
Inland Brackish Water	pH	7.60	7.85	Between 6.7-8.5[A]	N/A	N/A
	Salinity (psu)	31.42	0.25	0.5-35 psu	N/A	N/A
	Temperature (°C)	27.40	27.37	<32°C	N/A	N/A
	Dissolved Oxygen (mg/L)	-	7.57	>5.50 mg/L	N/A	N/A
Sediment	Turbidity (NTUs)	3.85	188.0	>3.0 NTU[B]	N/A	N/A
	Total Suspended Solids (mg/L)	78.0	107.33	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters.	N/A	N/A
Bacteria	E. Coli	Positive	Positive	Negative	N/A	N/A
	Enterococci	Positive	Positive	Negative	N/A	N/A
	Enterococci MPN per 100 mL	5,383	10,112	<30 CFU/100 mL[C] <110 CFU/100mL[D]	N/A	N/A
Total Petroleum Hydrocarbons (TPHs)	Petroleum Range Organics (mg/L)	0.85	4.5	-	-	-
	Benzene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Naphthalene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Toluene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Heavy Metals	Arsenic (ug/L)	17.0	Undetected	<69 ug/L (acute), <36 ug/L (chronic)	N/A	N/A
	Cadmium (ug/L)	1.6	Undetected	<33 ug/L (acute), <7.9 ug/L (chronic)	N/A	N/A
	Chromium (ug/L)	8.5	12.6	<1,100 ug/L (acute), <50 ug/L (chronic)	N/A	N/A

Water Quality Class	Water Quality Parameter	STH04 (12/04/21)	STH04 (12/15/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
	Copper (ug/L)	13.0	24.6	<4.8 ug/L (acute), <3.1 ug/L (chronic)	N/A	N/A
	Lead (ug/L)	23.0	7.6	<210 ug/L (acute), <8.1 ug/L (chronic)	N/A	N/A
	Mercury (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Volatile Organic Compounds (VOCs)	Acetone (ug/L)	7.45	9.3	-	-	-
	Carbon Disulfide (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Methylene Chloride (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Tetrachloroethane (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Trichloroethene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Inorganic Pollutants	Bromide (mg/L)	62.3	1.2	N/A	<0.1 mg/L[C]	N/A
	Chloride (mg/L)	18,900	358	N/A (saltwater)	N/A	N/A
	Fluoride (mg/L)	1.45	0.1	N/A	N/A	<2.0 mg/L
	Sulfate (mg/L)	2,415	52.3	N/A	N/A	<250 mg/L
Nutrients	Total Nitrogen – Kjeldahl (mg/L)	0.95	1.4	<0.207 mg/L[E]	N/A	N/A
	Total Phosphorus (mg/L)	0.19	0.25	<0.05 mg/L[B]	N/A	N/A

[A] When discharging to class C coastal waters.
[B] In marine or coastal waters.
[C] 30-day geometric mean.
[D] No more than 10% of the samples collected in the same 30 days.
[E] In more than 10% of samples over a three-year period in estuarine, marine, and coastal waters.

Table 20. Water quality monitoring parameters measured via grab sampling at STH05 on January 8th and 12th, 2022. Red cells demonstrate a water quality exceedance of the Amended 2019 USVI Water Quality Standards for inland freshwater. Orange cells demonstrate a water quality exceedance of the EPA NPDWRs. Yellow cells demonstrate a water quality exceedance of the EPA NSDWRs.

Water Quality Class	Water Quality Parameter	STH05 (01/08/22)	STH05 (01/12/22)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
Inland Freshwater	pH	7.54	7.81	Between 6.7-8.5[A]	N/A	N/A
	Salinity (psu)	0.50	0.10	<0.50 psu	N/A	N/A
	Temperature (°C)	27.81	25.61	<32°C	N/A	N/A
	Dissolved Oxygen (mg/L)	4.07	8.47	>5.50 mg/L	N/A	N/A
Sediment	Turbidity (NTUs)	137.0	94.4	>3.0 NTU[B]	N/A	N/A
	Total Suspended Solids (mg/L)	78.0	107.3	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters.	N/A	N/A
Bacteria	E. Coli	Positive	Positive	Negative	N/A	N/A
	Enterococci	Positive	Positive	Negative	N/A	N/A
	Enterococci MPN per 100 mL	10,112	10,112	<30 CFU/100 mL[C] <110 CFU/100mL[D]	N/A	N/A
Total Petroleum Hydrocarbons (TPHs)	Petroleum Range Organics (mg/L)	16.2	2.4	-	-	-
	Benzene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Naphthalene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Toluene (ug/L)	3.9	4.0	<57 ug/L[E], <520 ug/L[F]	N/A	N/A
Heavy Metals	Arsenic (ug/L)	Undetected	3.7	<340 ug/L (acute), <150 ug/L (chronic)	N/A	N/A
	Cadmium (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Chromium (ug/L)	2.1	6.5	<16 ug/L (acute), <11 ug/L (chronic)	N/A	N/A
	Copper (ug/L)	22.9	28.6	<4.8 ug/L (acute)[A],	N/A	N/A

Water Quality Class	Water Quality Parameter	STH05 (01/08/22)	STH05 (01/12/22)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
				<3.1 ug/L (chronic) [A]		
	Lead (ug/L)	Undetected	26.2	<65 ug/L (acute), <2.5 ug/L (chronic)	N/A	N/A
	Mercury (ug/L)	0.11	0.11	N/A	<2.0	N/A
Volatile Organic Compounds (VOCs)	Acetone (ug/L)	72.8	Undetected	-	-	-
	Carbon Disulfide (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Methylene Chloride (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Tetrachloroethane (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Trichloroethene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Inorganic Pollutants	Bromide (mg/L)	0.40	0.043	N/A	<0.1 mg/L [C]	N/A
	Chloride (mg/L)	144	14.6	<860 mg/L (acute), <230 mg/L (chronic)	N/A	N/A
	Fluoride (mg/L)	0.095	0.076	N/A	N/A	<2.0 mg/L
	Sulfate (mg/L)	18.2	8.0	N/A	N/A	<250 mg/L
Nutrients	Total Nitrogen – Kjeldahl (mg/L)	47.6	1.9	<0.207 mg/L [G]	N/A	N/A
	Total Phosphorus (mg/L)	6.0	0.33	<0.05 mg/L [B]	N/A	N/A

[A] When discharging to class C coastal waters.
[B] In marine or coastal waters.
[C] 30-day geometric mean.
[D] No more than 10% of the samples collected in the same 30 days.
[E] Human health for the consumption of water and organisms – apply to all waters except ones designated and currently being used as a potable water source.
[F] Human health for the consumption of organisms only – apply to all waters except ones designated and currently being used as a potable water source.
[G] In more than 10% of samples over a three-year period in estuarine, marine, and coastal waters.

Table 21. Water quality monitoring parameters measured via grab sampling at STH06 on November 25th and December 4th, 2021. Red cells demonstrate a water quality exceedance of the Amended 2019 USVI Water Quality Standards for inland freshwater. Orange cells demonstrate a water quality exceedance of the EPA NPDWRs. Yellow cells demonstrate a water quality exceedance of the EPA NSDWRs.

Water Quality Class	Water Quality Parameter	STH06 (11/25/21)	STH06 (12/04/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
Inland Freshwater	pH	7.10	7.25	Between 6.7-8.5[A]	N/A	N/A
	Salinity (psu)	0.21	0.64	<0.50 psu	N/A	N/A
	Temperature (°C)	22.7	28.4	<32°C	N/A	N/A
	Dissolved Oxygen (mg/L)	-	-	>5.50 mg/L	N/A	N/A
Sediment	Turbidity (NTUs)	38.0	22.7	>3.0 NTU[B]	N/A	N/A
	Total Suspended Solids (mg/L)	20.0	16.8	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters.	N/A	N/A
Bacteria	E. Coli	Positive	Positive	Negative	N/A	N/A
	Enterococci	Positive	Positive	Negative	N/A	N/A
	Enterococci MPN per 100 mL	10,112	10,112	<30 CFU/100 mL[C] <110 CFU/100mL[D]	N/A	N/A
Total Petroleum Hydrocarbons (TPHs)	Petroleum Range Organics (mg/L)	1.2	5.0	-	-	-
	Benzene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Naphthalene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Toluene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Heavy Metals	Arsenic (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Cadmium (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Chromium (ug/L)	3.1	Undetected	<16 ug/L (acute), <11 ug/L (chronic)	N/A	N/A
	Copper (ug/L)	10.5	6.6	<4.8 ug/L (acute)[A], <3.1 ug/L (chronic)[A]	N/A	N/A

Water Quality Class	Water Quality Parameter	STH06 (11/25/21)	STH06 (12/04/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
	Lead (ug/L)	6.0	Undetected	<65 ug/L (acute), <2.5 ug/L (chronic)	N/A	N/A
	Mercury (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Volatile Organic Compounds (VOCs)	Acetone (ug/L)	6.4	Undetected	-	-	-
	Carbon Disulfide (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Methylene Chloride (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Tetrachloroethane (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Trichloroethene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Inorganic Pollutants	Bromide (mg/L)	0.09	0.52	N/A	<0.1 mg/L[C]	N/A
	Chloride (mg/L)	29.4	173	<860 mg/L (acute), <230 mg/L (chronic)	N/A	N/A
	Fluoride (mg/L)	0.12	0.34	N/A	N/A	<2.0 mg/L
	Sulfate (mg/L)	10.7	12.3	N/A	N/A	<250 mg/L
Nutrients	Total Nitrogen – Kjeldahl (mg/L)	3.3	26.2	<0.207 mg/L[E]	N/A	N/A
	Total Phosphorus (mg/L)	0.40	3.7	<0.05 mg/L[B]	N/A	N/A

[A] When discharging to class C coastal waters.
[B] In marine or coastal waters.
[C] 30-day geometric mean.
[D] No more than 10% of the samples collected in the same 30 days.
[E] In more than 10% of samples over a three-year period in estuarine, marine, and coastal waters.

Table 22. Water quality monitoring parameters measured via grab sampling at STH07 on November 25th and December 5th, 2021. Red cells demonstrate a water quality exceedance of the Amended 2019 USVI Water Quality Standards for inland freshwater. Orange cells demonstrate a water quality exceedance of the EPA NPDWRs.

Water Quality Class	Water Quality Parameter	STH07 (11/25/21)	STH07 (12/05/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
Inland Freshwater	pH	7.23	6.85	Between 6.7-8.5[A]	N/A	N/A
	Salinity (psu)	0.21	0.13	<0.50 psu	N/A	N/A
	Temperature (°C)	23.5	30.2	<32°C	N/A	N/A
	Dissolved Oxygen (mg/L)	-	-	>5.50 mg/L	N/A	N/A
Sediment	Turbidity (NTUs)	13.1	11.1	>3.0 NTU[B]	N/A	N/A
	Total Suspended Solids (mg/L)	7.7	12.7	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters.	N/A	N/A
Bacteria	E. Coli	Positive	Positive	Negative	N/A	N/A
	Enterococci	Positive	Positive	Negative	N/A	N/A
	Enterococci MPN per 100 mL	8,501	10,112	<30 CFU/100 mL[C] <110 CFU/100mL[D]	N/A	N/A
Total Petroleum Hydrocarbons (TPHs)	Petroleum Range Organics (mg/L)	1.2	0.84	-	-	-
	Benzene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Naphthalene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Toluene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Heavy Metals	Arsenic (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Cadmium (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Chromium (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Copper (ug/L)	9.4	19.2	<4.8 ug/L (acute)[A], <3.1 ug/L (chronic)[A]	N/A	N/A
	Lead (ug/L)	Undetected	Undetected	N/A	N/A	N/A

Water Quality Class	Water Quality Parameter	STH07 (11/25/21)	STH07 (12/05/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
	Mercury (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Volatile Organic Compounds (VOCs)	Acetone (ug/L)	Undetected	Undetected	-	-	-
	Carbon Disulfide (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Methylene Chloride (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Tetrachloroethane (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Trichloroethene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Inorganic Pollutants	Bromide (mg/L)	0.074	0.205	N/A	<0.1 mg/L[C]	N/A
	Chloride (mg/L)	21.75	18.25	<860 mg/L (acute), <230 mg/L (chronic)	N/A	N/A
	Fluoride (mg/L)	0.036	0.05	N/A	N/A	<2.0 mg/L
	Sulfate (mg/L)	9.8	4.0	N/A	N/A	<250 mg/L
Nutrients	Total Nitrogen – Kjeldahl (mg/L)	0.865	0.705	<0.207 mg/L[E]	N/A	N/A
	Total Phosphorus (mg/L)	0.26	0.22	<0.05 mg/L[B]	N/A	N/A

[A] When discharging to class C coastal waters.
[B] In marine or coastal waters.
[C] 30-day geometric mean.
[D] No more than 10% of the samples collected in the same 30 days.
[E] In more than 10% of samples over a three-year period in estuarine, marine, and coastal waters.

Table 23. Water quality monitoring parameters measured via grab sampling at STH08 on December 4th and 15th, 2021. Red cells demonstrate a water quality exceedance of the Amended 2019 USVI Water Quality Standards for inland freshwater. Orange cells demonstrate a water quality exceedance of the EPA NPDWRs. Yellow cells demonstrate a water quality exceedance of the EPA NSDWRs.

Water Quality Class	Water Quality Parameter	STH08 (12/04/21)	STH08 (12/15/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
Inland Freshwater	pH	7.28	8.37	Between 6.7-8.5[A]	N/A	N/A
	Salinity (psu)	0.64	0.04	<0.50 psu	N/A	N/A
	Temperature (°C)	28.5	26.9	<32°C	N/A	N/A
	Dissolved Oxygen (mg/L)	-	8.16	>5.50 mg/L	N/A	N/A
Sediment	Turbidity (NTUs)	38.3	296.0	>3.0 NTU[B]	N/A	N/A
	Total Suspended Solids (mg/L)	34.4	26.0	None from wastewater sources which will cause disposition or be deleterious for the designated uses shall be present in any waters.	N/A	N/A
Bacteria	E. Coli	Positive	Positive	Negative	N/A	N/A
	Enterococci	Positive	Positive	Negative	N/A	N/A
	Enterococci MPN per 100 mL	10,112	10,112	<30 CFU/100 mL[C] <110 CFU/100mL[D]	N/A	N/A
Total Petroleum Hydrocarbons (TPHs)	Petroleum Range Organics (mg/L)	2.1	3.3	-	-	-
	Benzene (ug/L)	0.3	0.3	0.58-2.1[E], 16-58[F]	N/A	N/A
	Naphthalene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Toluene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Heavy Metals	Arsenic (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Cadmium (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Chromium (ug/L)	3.8	6.4	<16 ug/L (acute), <11 ug/L (chronic)	N/A	N/A
	Copper (ug/L)	22.4	31.3	<4.8 ug/L (acute)[A], <3.1 ug/L (chronic)[A]	N/A	N/A

Water Quality Class	Water Quality Parameter	STH08 (12/04/21)	STH08 (12/15/21)	2019 USVI Water Quality Standard	EPA National Primary Drinking Water Regulations (NPDWRs)	EPA National Secondary Drinking Water Regulations (NSDWRs)
	Lead (ug/L)	Undetected	6.5	<65 ug/L (acute), <2.5 ug/L (chronic)	N/A	N/A
	Mercury (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Volatile Organic Compounds (VOCs)	Acetone (ug/L)	245	6.4	-	-	-
	Carbon Disulfide (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Methylene Chloride (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Tetrachloroethane (ug/L)	Undetected	Undetected	N/A	N/A	N/A
	Trichloroethene (ug/L)	Undetected	Undetected	N/A	N/A	N/A
Inorganic Pollutants	Bromide (mg/L)	Undetected	0.064	N/A	<0.1 mg/L[C]	N/A
	Chloride (mg/L)	16.8	16.8	<860 mg/L (acute), <230 mg/L (chronic)	N/A	N/A
	Fluoride (mg/L)	0.066	0.053	N/A	N/A	<2.0 mg/L
	Sulfate (mg/L)	6.6	7.3	N/A	N/A	<250 mg/L
Nutrients	Total Nitrogen – Kjeldahl (mg/L)	1.8	1.9	<0.207 mg/L[G]	N/A	N/A
	Total Phosphorus (mg/L)	0.39	0.29	<0.05 mg/L[B]	N/A	N/A

[A] When discharging to class C coastal waters.
[B] In marine or coastal waters.
[C] 30-day geometric mean.
[D] No more than 10% of the samples collected in the same 30 days.
[E] Human health for the consumption of water and organisms – only applicable to waters designated and currently being used a potable water source.
[F] Human health for the consumption of organisms only – apply to all waters except ones designated and currently being used as a potable water source.
[G] In more than 10% of samples over a three-year period in estuarine, marine, and coastal waters.

3.6.6.3 "No Flow" Analysis

During two qualifying rain events on December 4, 2021, and January 8, 2022, visual inspection by field crew members verified the lack of flow at the STH09 monitoring site during the storm events (Figure 68).

Grab samples could not be collected in either event and subsequently, a "no flow" desktop analysis was conducted to determine what environmental factors likely contributed to the lack of flow including slope, soil type, land cover classes within the STH09 drainage area, and the presence of stormwater infrastructure to divert runoff away from the gut channel. Figure 69 provides a map of where the STH09 site is located along the gut and delineates its drainage area within the watershed.

Figure 68. No active storm flow was observed at the STH09 monitoring location during a qualifying storm event.

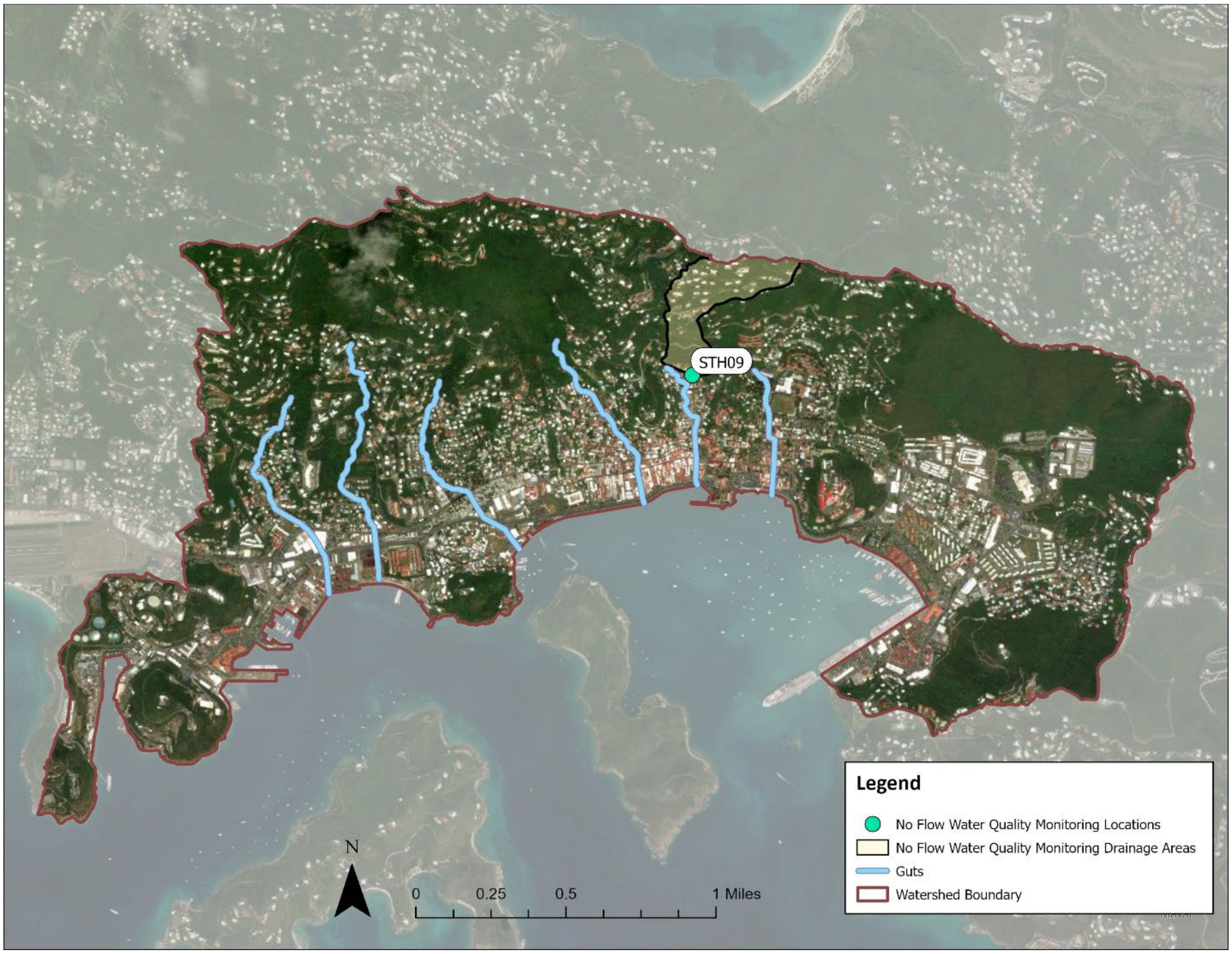


Figure 69. The STH09 monitoring location was confirmed to have no gut flow during two qualifying rain events in December 2021 and January 2022. The drainage area of this site is delineated in light yellow.

The desktop analysis demonstrated that the two most salient factors likely contributing to the absence of flow through the gut, specifically at the STH09 site, was a high green space composition of 76.3% in its drainage area (Figure 70) and a high composition of Hydrologic Soil Group (HSG) B soils in its drainage area at 54.7% (Figure 71). This finding was expected as previous research has shown that healthy vegetated areas have a significant capacity to absorb and slow stormwater flows. Soils within the HSG B group are defined as having a “moderately low runoff potential when thoroughly wet”. These soils are typically comprised of 50-90% sand, which provides a higher saturated hydraulic conductivity (i.e., infiltration capacity) than soils in groups C and D. There was 0.20 inches of total rainfall accumulation on December 4, 2021, and 0.19 inches of rainfall on January 8, 2022, closest to the STH09 site. In both storm events, the rainfall accumulation was insufficient to produce flow due to the combination of high green space composition and distribution of Class B soils within the STH09 drainage area infiltrating the runoff before it reached the gut channel. It is also likely that the dry conditions prior to these rain events reduced the amount of runoff during these storms as there was more pore space within the soil to store water.

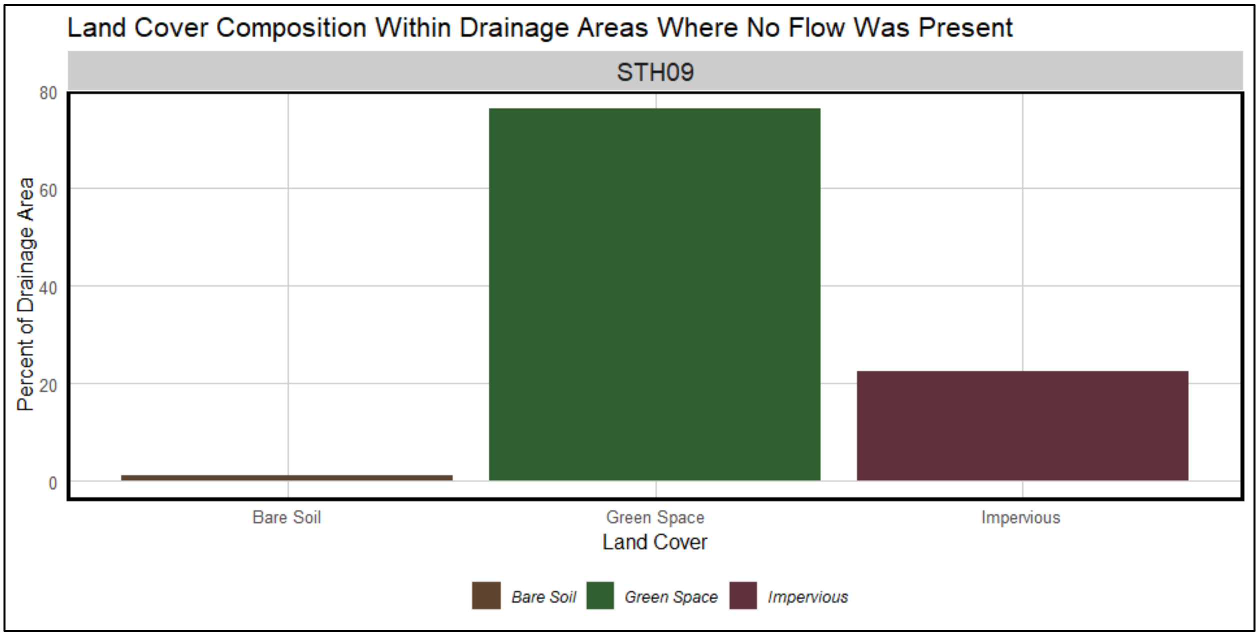


Figure 70. The land cover composition of the STH09 drainage area is predominately green space (76.3%).

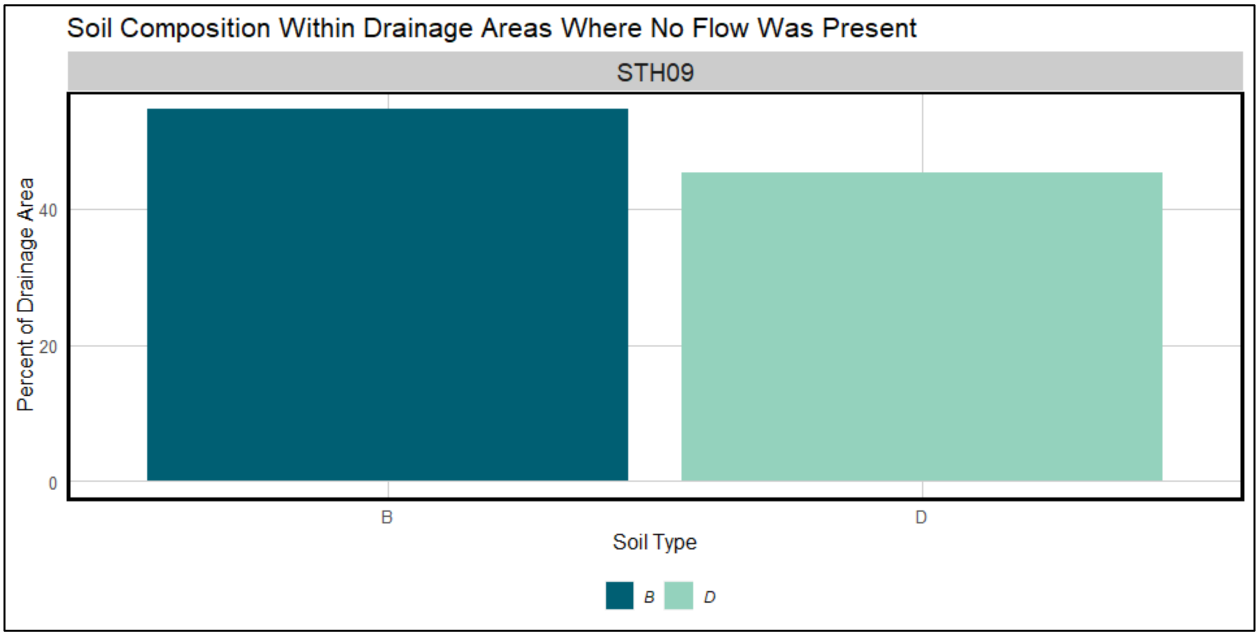


Figure 71. The majority of the soil within the STH09 drainage area is Class B (54.7%).

3.6.6.4 Sediment Sampling

Sediment sampling occurred once at all nine monitoring sites in the St. Thomas Harbor Watershed on November 13, 2021. At STH01, a composite of loose sediment scraped from the first 1.0-inch layer of debris inside the concrete culvert was collected. The material was described as dark, brown-black sandy and silty soil with organic material and green algal cover during field collection (Munsell Notation = 5Y 2.5/1, wet). The organic detritus and oil in the sediment produced a strong odor. The sampled sediment was likely deposited from both tidal and inland freshwater flow in the gut as STH01 is a source for both classes of water.

The composited sediment was analyzed for grain size distribution and composition. Grain sizes were separated into seven categories:

- <63 microns (clay particles and very fine to coarse silt)
- 63-125 microns (very fine sand)
- 125-250 microns (very fine to fine sand)
- 250-500 microns (medium sand)
- 500-2,000 microns (coarse to very coarse sand)
- 2,000-4,000 microns (very fine pebbles)
- >4,000 microns (fine to very coarse pebbles, cobbles, and boulders)

These grains often wash into gut channels from both impervious and pervious surfaces in the contributing drainage areas of the gut channels. Developed surfaces including roadways, sidewalks, rooftops, and active construction sites within commercial, industrial, and residential regions and even undeveloped, vegetated surfaces can be eroded by stormwater runoff. Traveling at fast enough velocities, stormwater runoff is highly effective at displacing sediment at various sizes, from fine clay particles all the way to boulders, and depositing them along gut channels. The individual sediment grains each have the surface area that provides space for pollutants to chemically or physically bind onto the sediment. If high volumes of sediment are washed into waterways during storm events, it is likely that the sediment is carrying additional pollutants with it. The combined surface areas from the individual grains provides the capacity to carry potentially high pollutant loads of nutrients, oils, and metals, and therefore sediment can be considered a separate pollutant category for this reason. Additionally, too much sediment can simply clog stormwater infrastructure and natural waterways to the extent that it can alter the original drainage paths and cause ponding, puddling, and even flooding issues. Identifying solutions to limit or prevent sediment pollution into natural waterways will subsequently aid in limiting other pollutants from entering waterways and reducing the chance of ponding and flooding events.

Results from the grain size analysis demonstrated that the composition of sediment within the two largest grain size categories – between 2,000 and 4,000 microns and larger than 4,000 microns – was 66% (Figure 72). Within this fraction, most of the sediment was larger than 4,000 microns. This indicates that most of the sediment sample was comprised of fine to very coarse pebbles and cobbles. Approximately 19% of the sediment within the sample was under 500 microns which is comprised of very small particles – fine sand, silt, and clay. The 15% of the remaining sample was in between 500 and 2,000 microns which is made up of coarse to very coarse sand.

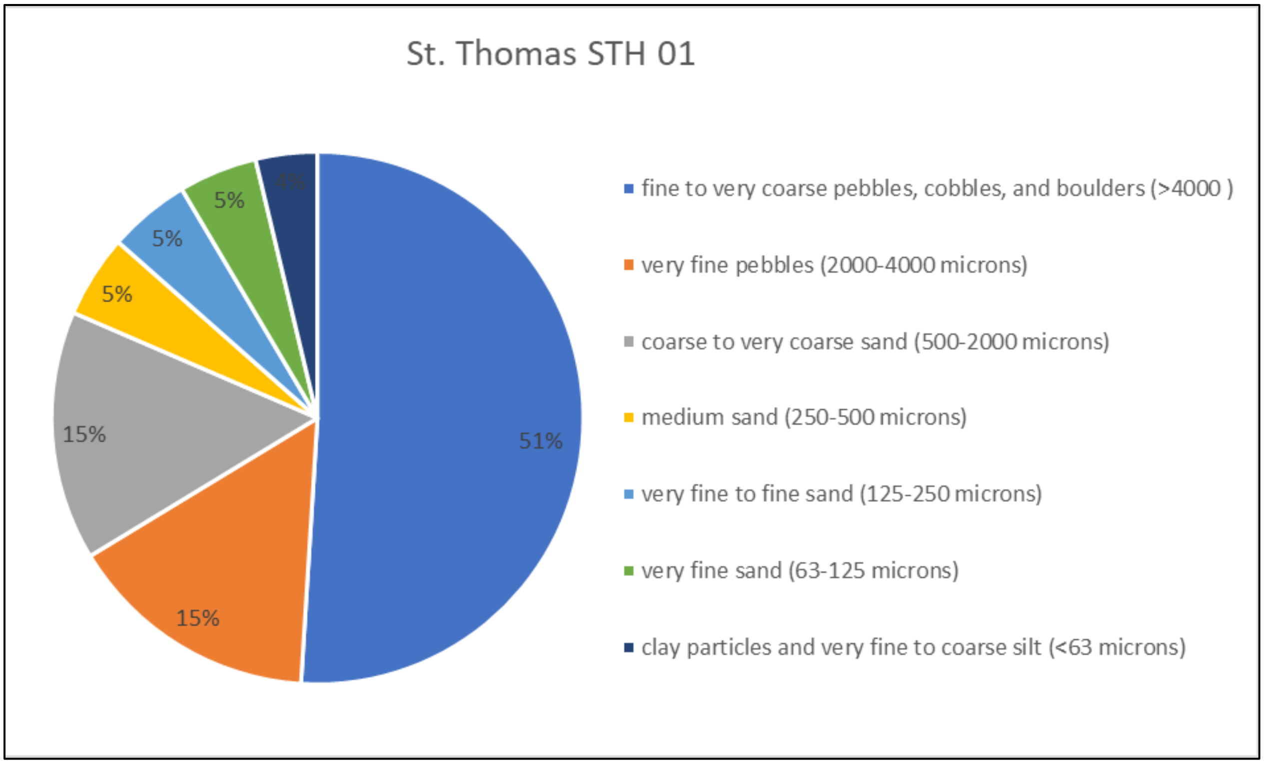


Figure 72. The percent composition of the seven grain size categories within the STH01 sediment sample.

At STH02, a composite of two samples of loose sediment scraped from the top 2.0-inch and 5.0-inch layers of debris inside of the concrete culvert was collected. The composite material was described as dark brown sandy and gravelly soil with strong odors of organic material and human refuse during field collection (Munsell Notation = 10YR 3/3, wet). Results from the grain size analysis demonstrated that the composition of sediment within the largest grain size category – greater than 4,000 microns – was 34% (Figure *73*). Approximately 59% of the sample fell within two grain size categories – 500-2,000 microns and 2,000-4,000 microns which is likely made up of coarse sand to fine pebbles. Only a very small fraction (7%) of the sample was comprised of fine particles less than 500 microns in size.

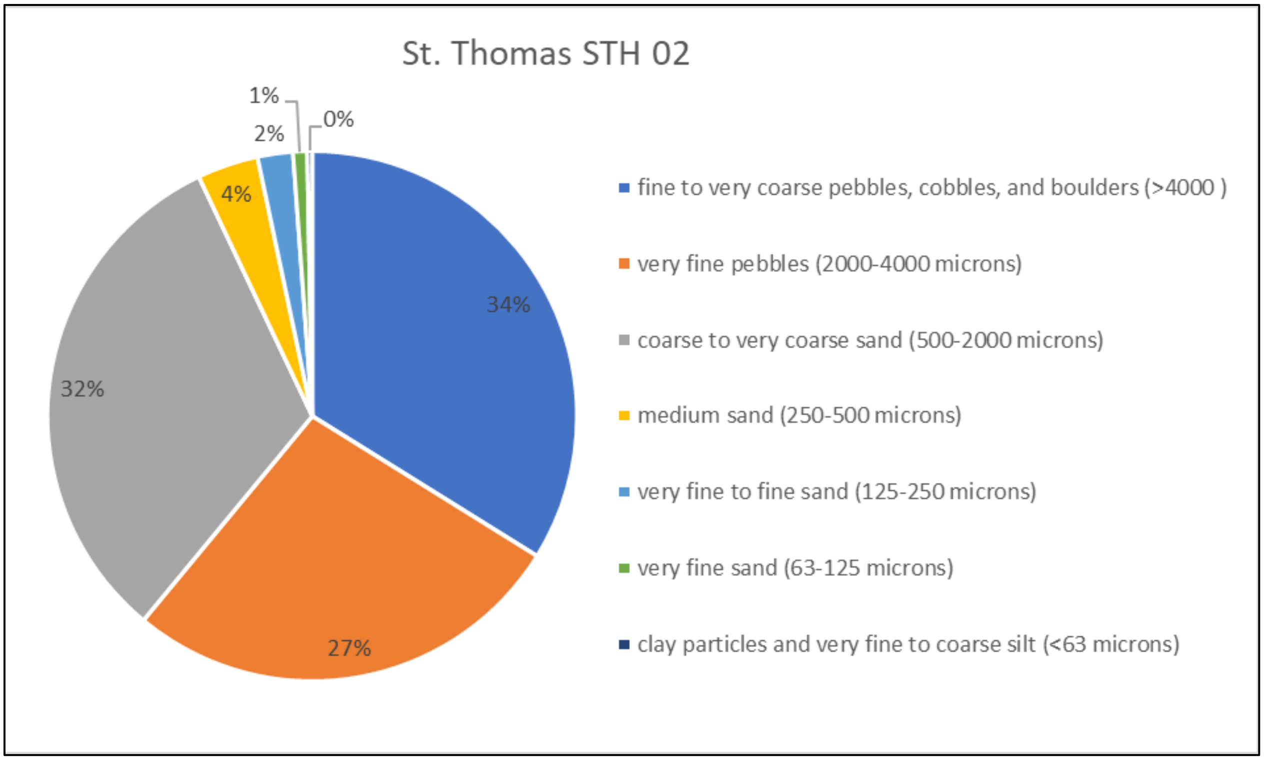


Figure 73. The percent composition of the seven grain size categories within the STH02 sediment sample.

At STH03, a composite of two samples of loose sediment, each scraped from the top 5.0-inch layer of debris inside of the concrete culvert, was collected. The first sample was described as a gray-brown, gravelly sand (Munsell Notation = 10YR 4/6, moist) and the second sample was described as a dark brown silty sediment containing green algae and organic material during field collection (Munsell Notation = 5Y 4/1, wet). Results from the grain size analysis demonstrated that the most prominent grain size in the composite was sediment 500-2,000 microns in size, at 30%. However, the sample was fairly equally distributed across the remaining grain size categories (Figure 74).

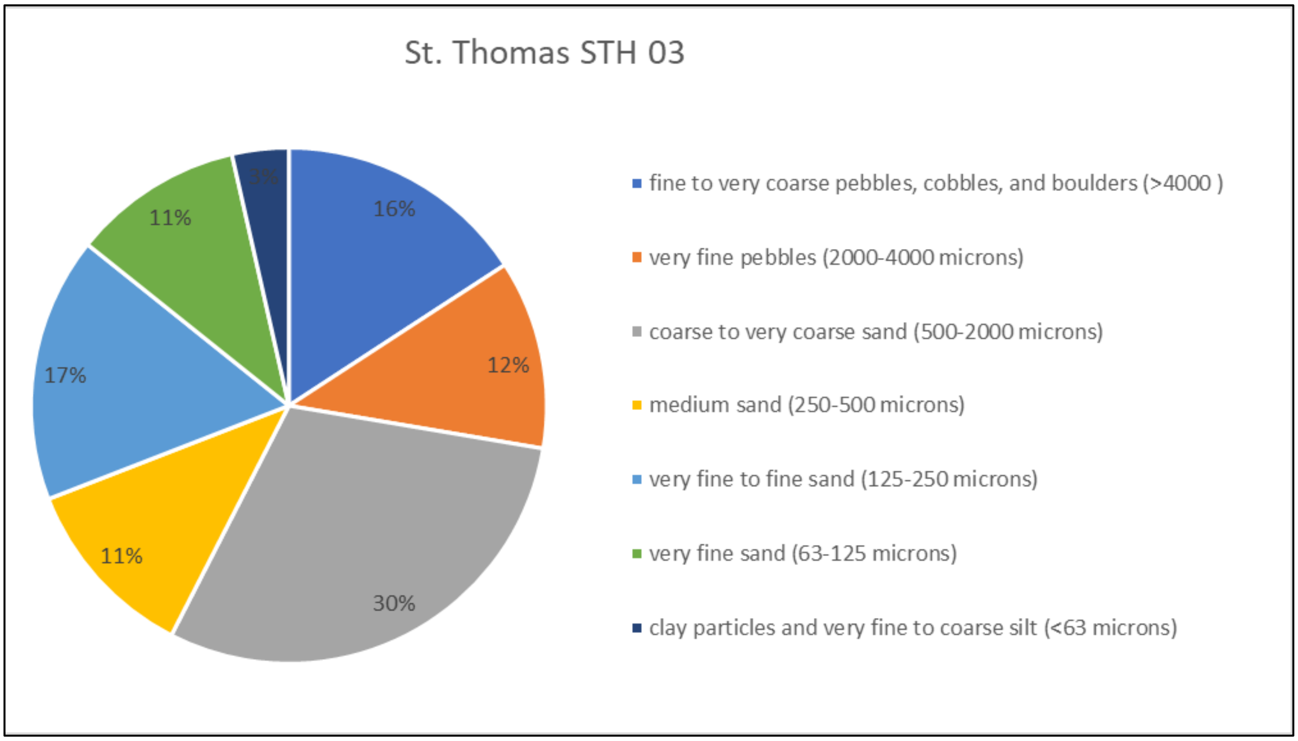


Figure 74. The percent composition of the seven grain size categories within the STH03 sediment sample.

At STH04, a composite of two samples of loose sediment, each scraped from the top 10.0-inch layer of debris inside of the concrete culvert, was collected. The composite sample was described as a dark green and black sand and silt material during field collection (Munsell Notation = 5Y 3/2, wet). The sediment in the channel had an anaerobic odor and was superimposed with a layer of oil, hexane. Results from the grain size analysis demonstrated that the composite sample was mostly comprised of sediment 500-2,000 microns in size (29%). This sample was fairly equally distributed across the remaining grain size categories (Figure 75).

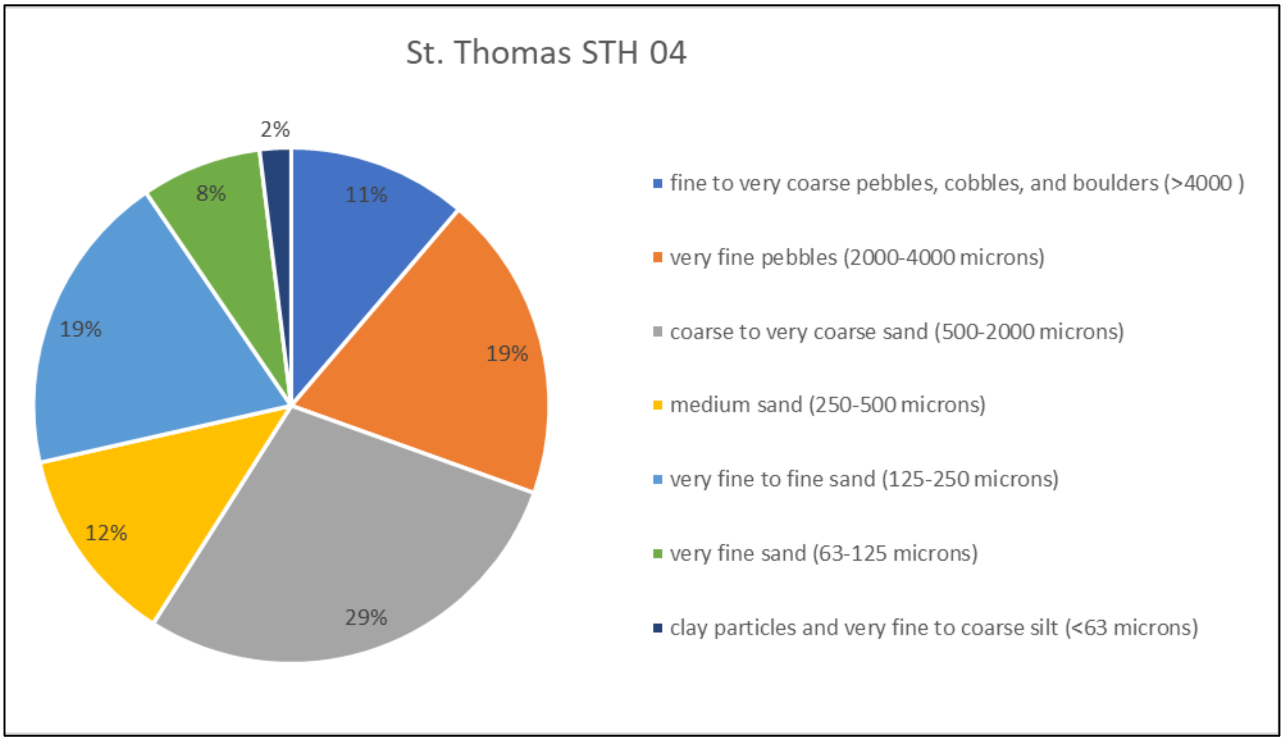


Figure 75. The percent composition of the seven grain size categories within the STH04 sediment sample.

At STH05, a composite of three samples of loose sediment was collected from the inside of the concrete culvert and the earthen gut channel. The composite sample was described as a dark brown soil mostly made of gravelly sand during field collection (Munsell Notation = 10YR 4/2, dry). Results from the grain size analysis demonstrated that more than half of the composite sample was made up of sediment larger than 4,000 microns (52%), which indicates most of the sample was comprised of pebbles and cobbles and only a small fraction (4%) of the sample was comprised of finer particles such as silt and clay (Figure 76).

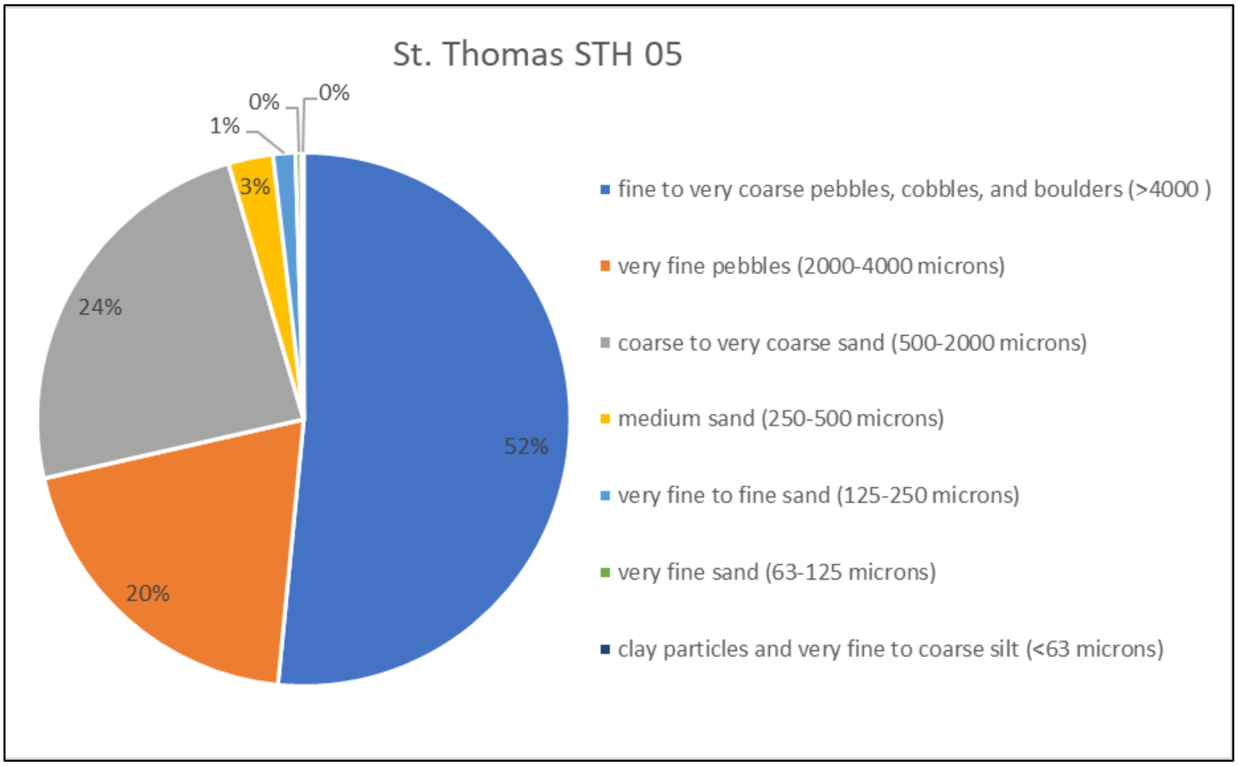


Figure 76. The percent composition of the seven grain size categories within the STH05 sediment sample.

At STH06, a single sample of sediment was scraped from the top 2.1-inch layer of debris inside of the concrete culvert. The sampled material was described as dark brown sandy soil with observation of organic material during field collection (Munsell Notation = 10YR 4/6, wet). The organic material had a strong, foul odor. Results from the grain size analysis demonstrated that most of the sample was comprised of sediment 500-2,000 microns in size (28%) and the remaining fraction was distributed between the other grain size categories (Figure 77).

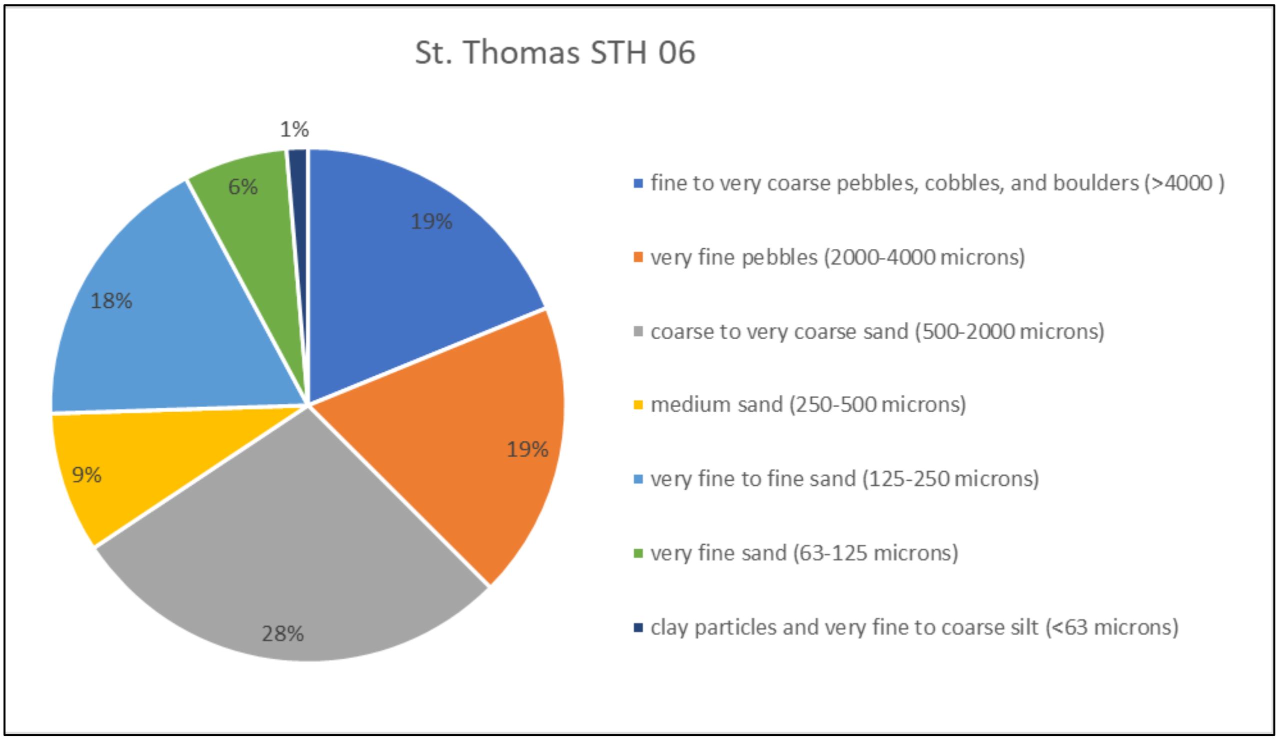


Figure 77. The percent composition of the seven grain size categories within the STH06 sediment sample.

At STH07, one sample of sediment was scraped from the top 4.5-inch layer of debris inside of the concrete culvert. The sample was described as brown soil containing gravelly sand during field collection (Munsell Notation = 10YR 4/6, wet). Results from the grain size analysis demonstrated that approximately 37% of the sediment within the sample was greater than 4,000 microns, indicative of pebbles and cobbles. A majority of the sediment was within 500-4,000 microns (33%) which is comprised of coarse sand to very fine pebbles. Only a small fraction (7%) of the sediment was comprised of fine particles such as very fine sand, silt, and clay (Figure 78).

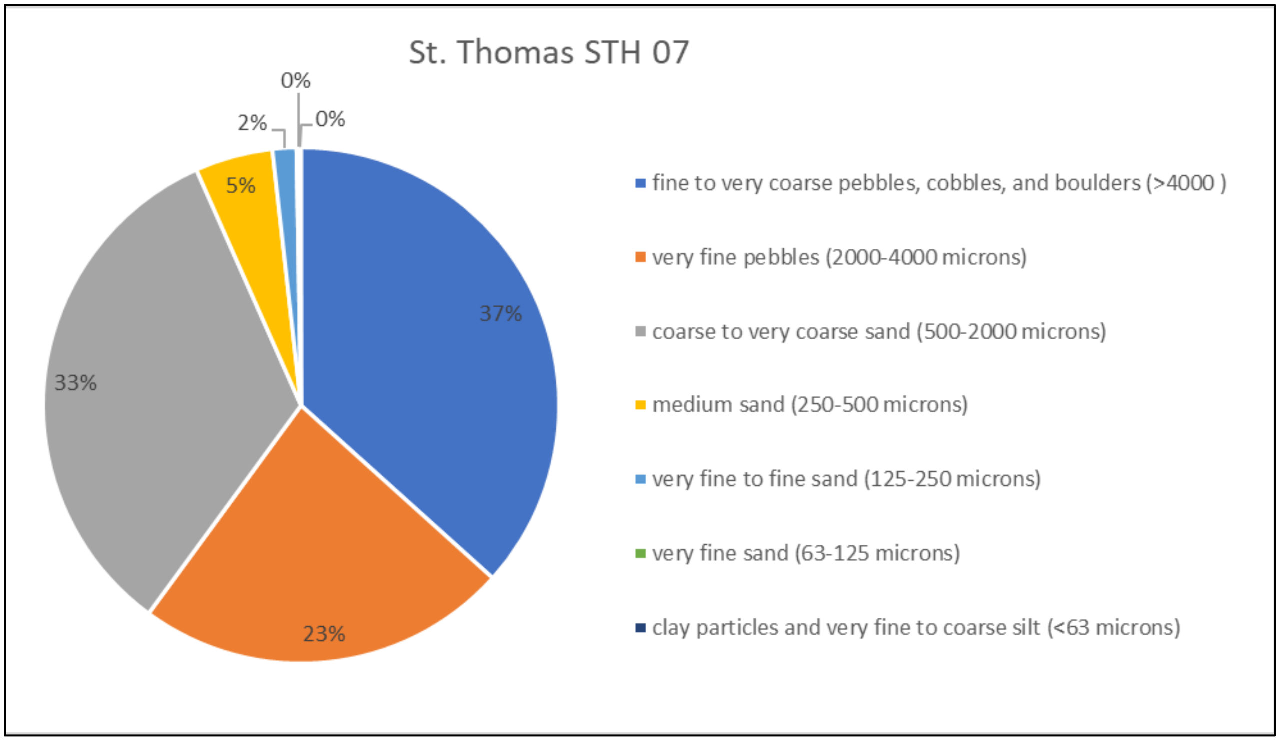


Figure 78. The percent composition of the seven grain size categories within the STH07 sediment sample.

At STH08, a composite of two samples scraped from two locations close to the concrete culvert was collected. The first sample was collected upstream of the culvert and the second sample was taken directly in front of the culvert's grate. The composite sample was described as a mix of organic material and sandy, gravelly soil with flecks of grey and white during field collection (Munsell Notation = 10YR 3/1, dry). Results from the grain size analysis demonstrated that a majority of the sediment fell within two grain size categories – 500-2,000 microns and 2,000-4,000 microns. Collectively, these grain sizes made up 73% of the sample which represents coarse to very coarse sand and fine pebbles. Only 9% of the sample was comprised of fine particles of fine sand, silt, and clay. The remaining 18% of the sediment was larger than 4,000 microns (Figure 79).

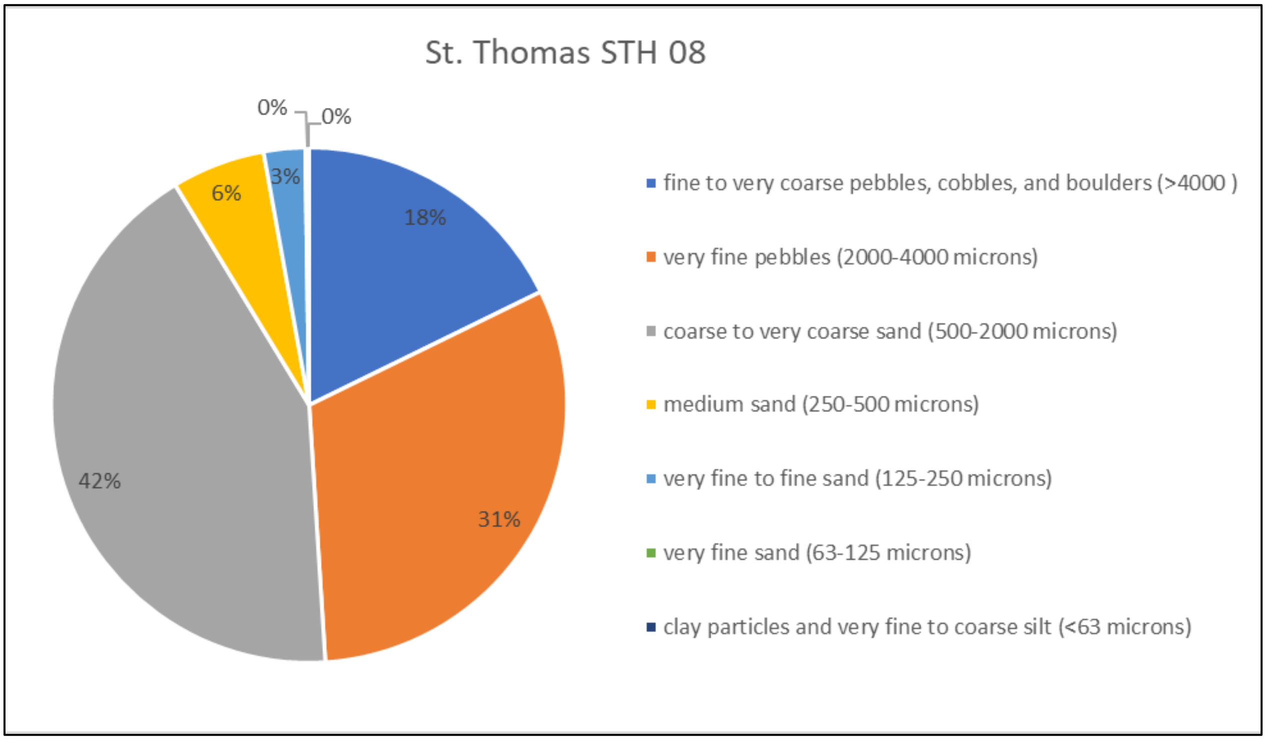


Figure 79. The percent composition of the seven grain size categories within the STH08 sediment sample.

At STH09, a composite of two scrapings were collected from inside of the concrete culvert, each from the top 1.5-inch and 3.0-inch layers of the debris. The material was described as a mix of organic material and sandy and gravelly soil that was dark brown in color (Munsell Notation = 10YR 4/2, moist). Results from the grain size analysis demonstrated that a majority of the sediment fell within two grain size categories – 500-2,000 microns and 2,000-4,000 microns. Collectively, these grain sizes made up 58% of the sample which represents coarse to very coarse sand and fine pebbles. Only 12% of the sample was comprised of fine particles of fine sand, silt, and clay. The remaining 26% of the sediment was larger than 4,000 microns (Figure 80).

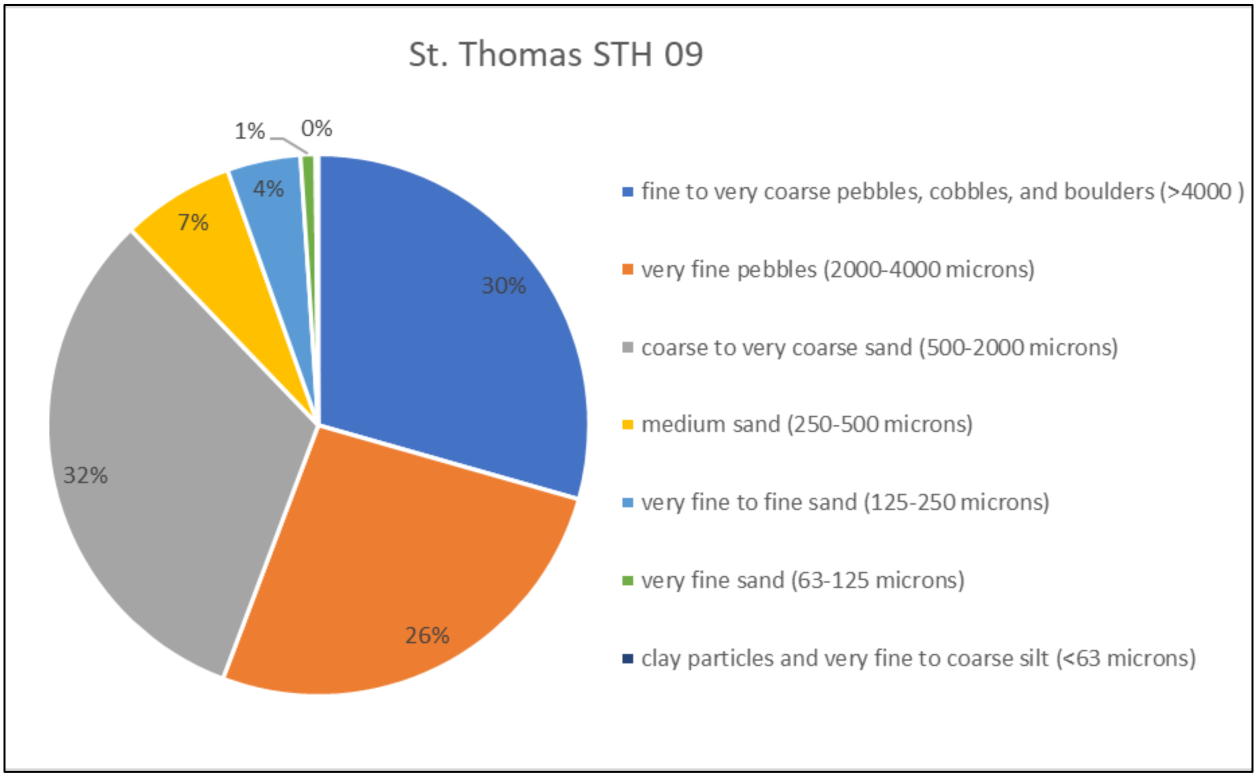


Figure 80. The percent composition of the seven grain size categories within the STH09 sediment sample.

3.7 Identification and Ranking of Stormwater BMPs

3.7.1 Stormwater and Flooding Best Management Practices

3.7.1.1 Desktop Assessment

A desktop assessment was completed to identify 32 sites for potential stormwater management and flooding mitigation best management practices (BMPs). This process involved a thorough review of GIS resources and associated attribute data. Data included, but was not limited to, stormwater infrastructure data collected during this project (see Section 3.5.1), soils classifications, parcel data, topography, and guts. Assessments also considered areas of concern identified by project stakeholders and collected during and following public meeting input. This data was used to identify and map areas of water quality and flooding concern as well as areas where opportunities for potential BMP implementation were located. A point location was created for each identified site or area for assessment in the field (Figure 81).

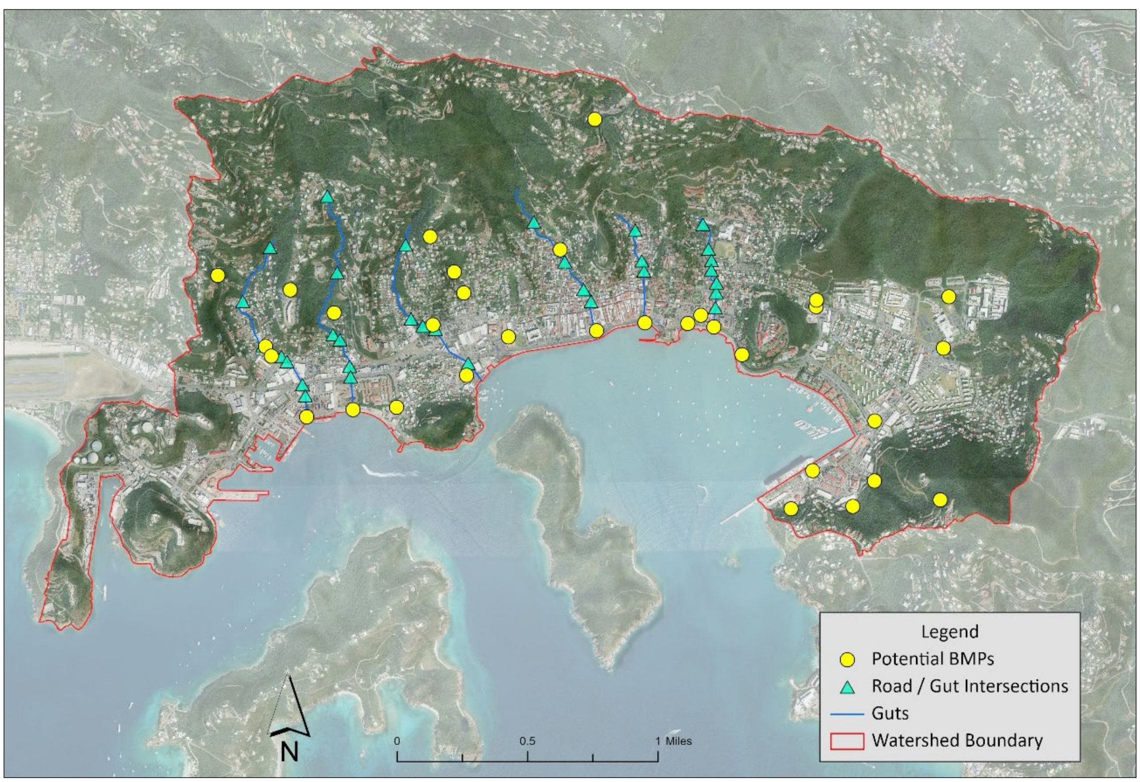


Figure 81. Overview map of desktop identified potential BMPs and road / gut intersections.

Also identified were 33 locations at which the mapped gut intersected roads. These points were identified as easy-access locations to assess bank erosion and the general health of the guts. Shown on the map in Figure 81 are desktop-identified potential BMP points as well as road/gut intersection points.

3.7.1.2 Field Assessments

Targeted field assessments were completed in June 2021 and were focused on BMP assessment (Figure 82). These areas were prioritized prior to field work to further focus these efforts. In order to maximize efficiency in the field and better understand site-specific conditions, digital base maps were created. The maps show guts, watersheds, and stormwater infrastructure. This information was used in the field to assess potential feasibility issues for proposed practices and to better identify preliminary BMP locations. The base layers were pre-loaded into a project-specific mobile app that was customized for this project using the Fulcrum platform (Figure 82). The app was also pre-loaded with the point locations identified during the desktop assessment. These points allowed for easy site location and data collection in the field.

Of the 32-initial desktop-identified potential BMP locations, 21 were visited and assessed in the field. These are shown in Figure 83 below in orange. Additionally, during the course of field investigations, 21 new BMP locations were identified. These are shown in Figure 83 below in purple. Road/gut intersections were assessed in the field if they were reasonably accessible during the priority BMP assessments. The nine assessed intersections are shown below in Figure 83 in green. One potential BMP was identified after the field visits.

At each site, the customized mobile data collection app was used to collect information including site suitability, photographic documentation, proposed BMP practice, hydrologic connectivity, operations and maintenance issues, follow-up notes, and other pertinent data. All collected data was securely uploaded to the Cloud for later use.

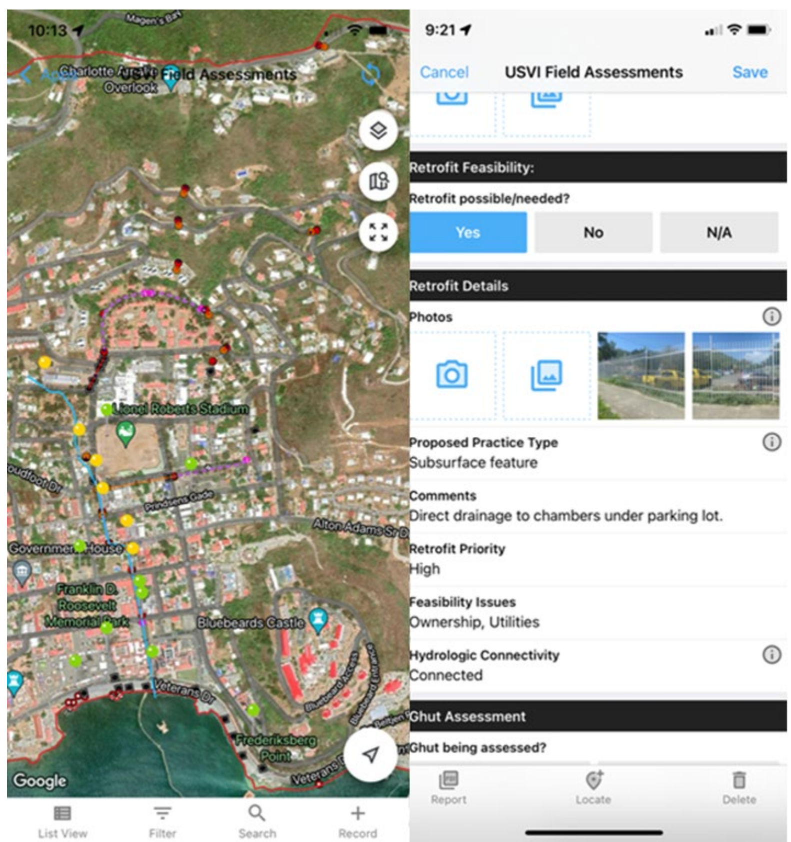


Figure 82. Fulcrum app interface used for field assessments.

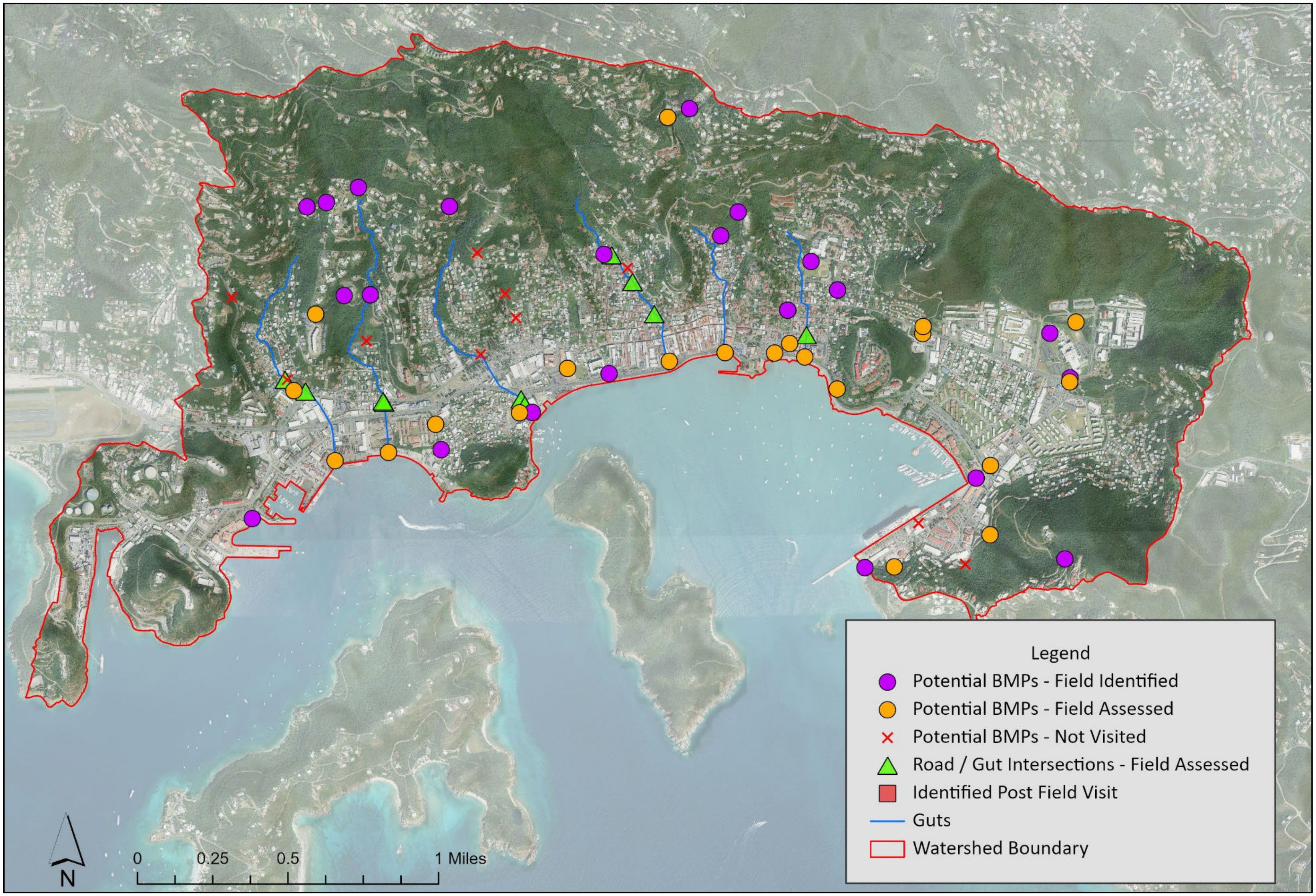


Figure 83. Overview of map of potential BMP locations and road / gut intersections assessed in the field including new field identified locations.

3.7.2 Preliminary Ranking of BMP Project Sites

To help determine which practices would be most effective and feasible, a preliminary prioritization process was applied to the list of potential sites. The goal of this preliminary ranking was to assess each identified project site for its associated benefits and feasibility issues and narrow down a large list of projects to a more manageable list of 10 projects that will be impactful in terms of water quality benefits and quantity. This process is important because both time and resources are limited and can only be allocated to a limited number of practices at one time. Once the feasible top 10 projects are implemented, the next highest ranked projects should be further assessed and moved forward to additional design and eventually implementation.

As a result of the desktop and field assessments, a total of 53 sites for potential stormwater best management practices (BMPs) were identified in the St. Thomas Harbor watershed. BMPs in the field or desktop assessments that were either in close proximity to anther BMP or were not viable BMP candidates were excluded from the ranking. In total twenty newly identified BMPs, nineteen field assessed BMPs, seven assessed road-gut intersections, eleven desktop identified (not field visited) sites, and one BMP added after field assessments were included in the ranking. Five hazardous or solid waste sites were later removed from the ranking as the appropriate mitigation of these sites was not a stormwater BMP.

The preliminary ranking considered the following factors, scoring on qualitative scales:

1) **Impervious cover managed:** If a large percentage of the estimated drainage area was impervious surface, a "High" rank was applied. Some small practices, for example parking lot treatment systems, may have had a small *total* area of impervious cover within their drainage areas but received a "High" rank as the impervious cover represented a high percentage of the drainage area.
2) **Drainage area size:** Practices that would treat large areas, relative to the other proposed practices within the watershed, received "High" scores. This included practices that would treat guts directly as guts often drain larger areas.
3) **Potential water quality benefits:** Ranking for this metric considered nearby land use and existing known water quality issues (for example, documented turbid runoff or road erosion). Nearby industrial, commercial, or high-density residential land use were generally considered to pose greater water quality risks than lower density development. If an area lacked existing stormwater treatment features, the potential water quality benefits were considered greater than if the proposed practice would retrofit or supplement existing stormwater features.
4) **Potential for flood mitigation:** If the proposed practice would help store and slow a large quantity of runoff during storm events, a "High" score was assigned. Practices located upstream of high-density development areas were generally considered to have higher potential flood mitigation benefit as they directly impacted the communities downstream.
5) **Difficulty of design/construction:** The available space, scale of project, and density of surrounding development were all considered for this metric. Proposed BMPs that would require potentially complicated overflow and routing systems to tie with existing infrastructure were considered higher difficulty and thus scored lower. These types of complications were often linked to concerns with construction access, land ownership, topography, and other similar limiting factors.
6) **Site of particular concern?:** This metric was either "Yes" or "No". If a site had documented water quality, erosion, or flooding concerns based on local knowledge or field investigation, it was marked "Yes".

Table 24. BMP preliminary ranking metric scores.

Metric	Ranking Option	Scores
Impervious cover managed	Low	1
	Medium	2
	High	3
Drainage area size	Small	1
	Medium	2
	Large	3
Potential water quality benefits	Low	1
	Medium	2
	High	3
Potential flood mitigation	Low	1
	Medium	2
	High	3
Difficulty of design/construction	Low	1
	Medium	2
	Complex	3
Site of particular concern?	No	0
	Yes	1

The sum of the numeric qualitative rankings represented each BMP's preliminary prioritization score. A maximum score of 16 was possible for each assessed BMP, and the closer to that score, the higher the rank (Table 24). The scores can be found in Table *25*. These top 10 ranked sites are spatially distributed across the watershed, covering a total drainage area of 1,301 areas, (51.6% of the watershed area; Figure 84). Consequently, the selected BMPs project sites treat a variety of regions and neighborhoods throughout St. Thomas Harbor Watershed. The ranking determined that these sites are capable of treating a large amount of impervious surface, improving water quality, and reducing flood potential within the watershed. Additionally, the chosen BMP locations have minimal known barriers to implementation.

The 10 highest ranking proposed BMPs were reviewed by project stakeholders at DPNR to ensure there was not any site-specific information that the project team were unaware of were that would impact implementation. Following this review, the 10 projects were advanced to the next round of prioritization, the final ranking. Complete preliminary ranking information and the point locations of these projects are included in Appendix B3. One-page BMP summary sheets were created for each of the 10 highest ranking proposed BMPs, which can also be found in Appendix B3.

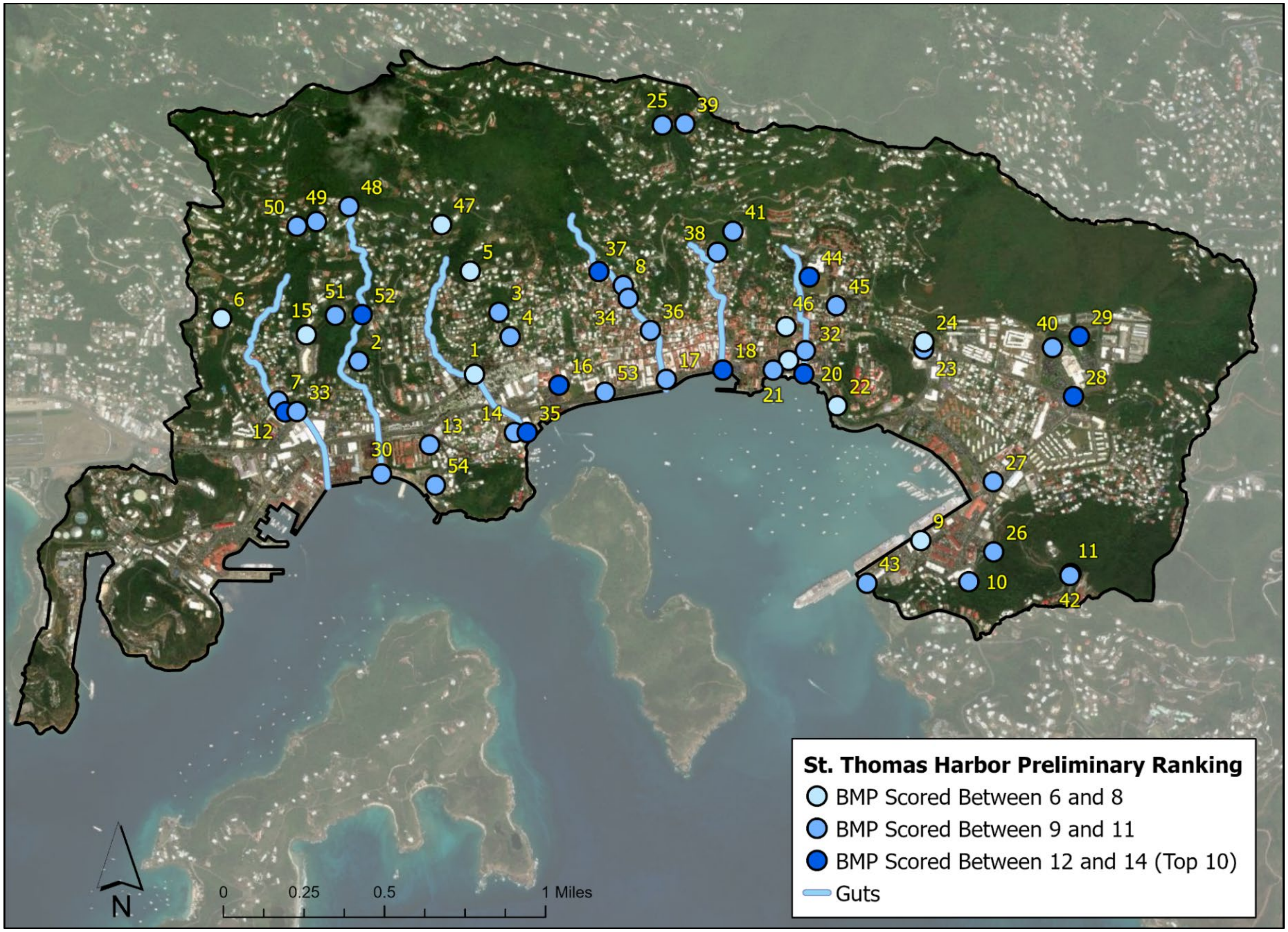


Figure 84. Map of proposed BMP points and preliminary ranking results for the Saint Thomas Harbor watershed.

Table 25. Summary table of preliminary BMP ranking results.

ID	Description	Final Score
12*	Potential to provide storage under green space. Area is fenced with razor wire, so no access was possible. Gut is in poor condition with significant trash and dumping.	14
28*	Potential for a surface or subsurface feature in green space adjacent across crossroad.	14
37*	Gut is eroded and undermining road. Erosion also noted in gut. Provide formalized storage, stabilize road.	14
44*	Direct gut to chambers under ballfield through entry gate.	14
52*	Potential to provide storage in gut with large basin. There is bedrock visible in gut. Gabions or check dams would be another less desirable option. Culvert and drainage to culvert is in poor condition. Could be stabilized and check dams added on outlet side.	14
16*	Potential to add catch basins in parking lot and redirect swale along road to chambers under ball field. Parking lot and ballfield are in poor condition. There is a clogged pipe with trash adjacent to parking area and this drainage could be incorporated into the practice.	12
18*	CDS for gut	12
20*	CDS for gut	12
29*	Potential for linear surface basin along road; could be integrated into development of lot. Direct drainage from the east and north to the basin. Treatment could be subsurface. Basin in green space adjacent to drainage to the east could also be an option.	12
35*	CDS for gut; improve hazardous storage.	12
7	Dumpster location with significant trash spilling into gut; relocate trash storage and stabilize gut erosion	11
13	There is a dumpster location adjacent, and they are collecting used motor oil and cooking oil. Collection should be improved and moved away from gut. CDS recommended in lower gut, but this could be an alternative location.	11
17	CDS for Savan Gut.	11
27	CDS for gut	11
30	CDS for gut (Note: could not access area)	11
32	Add walking path to connect roads and check dams	11
34	Gut restoration and historic preservation; known project by ACOE in this location.	11
40	Potential to direct gut to basin and expand basin	11
51	Regrade parking lot to direct drainage to green space adjacent to entrance and manage and surface basin. There is a swale that runs along the parking lot already and the swale should be directed to the basin.	11
53	Flooding issues and WQ issues; CDS system.	11
54	CDS for gut	11
4	Install new collection system in this location to better manage stormwater flows.	10
8	Potential for subsurface chambers to manage contributing area (not entire gut due to space constraints).	10
23	Install subsurface chambers for road to east and south. Multi use building proposed.	10
33	Potential to deepen gut and install gabions.	10
36	Potential to install gabions.	10
38	DPW is working to complete a repair - clean out opening, fix top, maybe a debris guard. Lots of water comes through here. Considered enlarging but not enough capacity downstream.	10
41	Potential for water storage in existing tank pending engineering feasibility.	10
43	Likely drains most of the hillside. Provide surface storage in greenspace and/or CDS for gut.	10
45	Direct drainage to chambers under parking lot.	10
2	Potential for surface storage for hill and gut if feasible given elevations.	9
3	Potential for surface storage upstream of culvert.	9
10	Potential for surface storage in greenspace.	9

ID	Description	Final Score
14	Redirect catch basin line to chambers under field. May be challenging due to sea level.	9
21	Bioretention opportunity. Confirm redevelopment of this area.	9
25	Potential for a surface basin to manage parking lot and uphill road drainage.	9
26	Sediment trap / CDS system at gut outlet	9
39	Small surface feature to take a few parking spaces, discharge to CB	9
42	Continue ditch on uphill side of road and direct to sediment trap. Could be done on each switchback. Add additional cross drainage.	9
48	Potential to make a sediment trap prior to gut	9
49	Stabilize and add sediment traps before gut. Shoulders of road are eroding.	9
50	Direct water to subsurface chambers under parking lot	9
6	Good location for surface crossing and diffuser	8
9	Generally good opportunity for GSI and/or CDS system. Need site plans to determine CB network.	8
11	Potential for surface storage uphill of road.	8
15	Large basin possible in depressed green space. Potential to direct drainage to this area, but elevations may be limiting.	8
19	Potential to direct drainage from paved swale under parking lot	8
46	Potential to redirect road drainage under parking area and manage in chamber system.	8
47	Potential to close or narrow this section of road between residential areas and convert to storm water treatment area	8
1	Potential small storage opportunity.	7
5	Potential for surface storage in green space.	7
22	Potential for a small bioretention.	6
24	Potential small storage opportunity.	6
*Top 10 site		

3.7.3 Final Ranking of BMP Project Sites

3.7.3.1 Methods & Materials

Once the 10 highest ranking proposed BMPs were determined, a more comprehensive rating methodology was utilized to establish a final ranking of the top 10 BMPs. The ranking is designed to account for the highest priorities that should be pursued for concept and final design implementation described in Table 26 below. The ranking accounts for twenty factors, including both qualitative and quantitative metrics.

There are 15 quantitative factors. Quantitative factors were scored on a range of one to five using Jenks Natural Breaks Classification, a classification method designed to find natural groupings in the data to group similar values together. Classes in Jenks Natural Breaks Classification are divided where there are relatively large differences in the data values. Only values of the top 10 BMPs within St. Thomas Harbor were factored into the classification. Scores associated with pollutant load reductions and hydrologic properties were based on the water quality modeling and hydrologic and hydraulic modeling described in the following sections.

There are five qualitative categories: community input, severity of water quality discharge violations, feasibility concerns, ancillary benefits, and expert opinion. Each of these categories have a unique scoring and classification system individualized to each qualitative variable being scored

All scores were summed, yielding a final score for each BMP. The BMPs were then ranked from highest score (rank 1) to lowest score (rank 10).

Table 26. Metrics included in the final ranking and their respective score ranges.

Metric	Description	Scoring
Impervious Surfaces	The total area of impervious surface in each identified Drainage Area (m^2)	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Development Potential	The percentage of area at risk of development by 2050 within each identified drainage area as defined by the future land use model.	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Industrial Zoning	The percentage of industrial zoning designations within each drainage area	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Public Zoning	The percentage of public zoning designations within each drainage area	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Riparian Forest Cover	The percentage forested area within 100 ft of a gut within each drainage area	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Gut Density	The gut density in each drainage area (m/m^2)	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Outfall Density	The infrastructure density in each drainage area (m/m^2)	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Flooding Severity	The percentage of 100-year floodplain zones as defined by FEMA within each drainage area	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Bank Erosion Severity	Number of locations identified as Medium to High erosion severity in each drainage area during field assessments.	Given a score 1-5 determined by Jenks Natural Breaks Classification.

Metric	Description	Scoring
Road Gut Crossings	Count of road/gut crossings in each drainage area	Given a score 1-5 determined by Jenks Natural Breaks Classification.
Total Nitrogen	Total Nitrogen (TN)	Given a score 1-5 determined by Jenks Natural Breaks Classification
Total Phosphorus	Total Phosphorous (TP)	Given a score 1-5 determined by Jenks Natural Breaks Classification
Total Suspended Solids	Total Suspended Solids (TSS)	Given a score 1-5 determined by Jenks Natural Breaks Classification
Fecal Coliform Reductions	Fecal Coliform Reductions (lbs./year)	Given a score 1-5 determined by Jenks Natural Breaks Classification
BMP Storage Volume	The amount of water the bmp would be sized to hold (ft^3)	Given a score 1-5 determined by Jenks Natural Breaks Classification
Community Input	Whether or not there is voiced community concern within the drainage area.	Given a score 1 or 5 determined by if there was a voiced community concern within the BMP's drainage area
Severity of Water Quality Violations in Discharge	Ranked based on the severity of water quality violations in BMP discharge points as defined by the 2020 USVI Water Quality Report (USVI, 2020).	Ranked from 1-5: 1 – Not of Concern 3 – Low Concern 4 – Moderate Concern 5 – High Concern
Feasibility Concerns?	What is the magnitude of feasibility concerns in putting a BMP at the location? BMP feasibility concerns may include, but are not limited to ownership, space, high cost, lack of public support, etc.	Ranked from 0-30: 0 – High Concern 15 – Moderate Concern 30 – Minimal Concern
Ancillary Benefits	Any significant benefits of BMP outside of metrics in ranking? Benefits may include aesthetics, educational, healthy vegetation, etc.	Ranked from 1-5: 1 – None 3 – Some 5 - Many
Expert Opinion	How highly regarded is the site by experts in the field?	Ranked from 0-30: 0 – Recommended 15 – Recommended Moderately 30 – Recommended Highly

3.7.3.2 Final Ranking Results

The final ranking of BMP project sites can be found below in Table 27. Scores of the top 10 BMPs ranged from 48 to 102 with BMP Numbers 44 and 12 receiving the two highest scores in the final ranking. Figure 85 displays the spatial distribution of the final scores and each BMP's associated drainage area. The top two ranked BMPs, 44 and 12, were selected for additional design and the development of 30% concept plans.

Table 27. Top 10 recommended BMPs in the watershed.

BMP ID	Rank	BMP Description	Drainage Area (Acres)	Impervious Area (Acres)	Storage Volume (ft^3)	Total Nitrogen Removed (lb./year)	Total Phosphorus Removed (lb./year)	Total Suspended Solids Removed (lb./year)
44	1	Subsurface Chambers	59.7	15.0	376,221	29	7	5,886
12	2	Subsurface Chambers	236.8	52.4	76,618	105	24	21,183
37	3	Stabilization and storage within gut, basin	144.3	12.9	82,584	35	8	7,056
20	4	CDS Unit	237.7	68.0	0	94	21	19,134
35	5	Relocate hazardous storage, CDS Unit	117.6	30.6	0	56	13	11,345
18	6	CDS Unit	153.4	41.8	0	76	17	15,367
52	7	Floodplain / Gut Restoration, Stabilization, Cross drainage / infrastructure, Basin	81.1	12.8	45,094	28	6	5,664
16	8	Subsurface Chambers	50.9	22.0	188,122	39	9	7,860
28	9	Basin, Subsurface feature	140.9	21.4	39,648	45	10	9,143
29	10	Basin	33.6	3.7	33,396	9	2	1,860

Figure 85. Top 10 high priority BMPs, relative ranking of each BMP, and the associated BMP drainage area for the St. Thomas Harbor watershed. Note that drainage areas for BMPs 44 and 20 overlap.

3.7.4 30% Design Sites

3.7.4.1 Infiltration Chambers (Proposed BMP 12)

This 30% design includes 558 Stormtech MC-4500 infiltration chambers located beneath the Ulla F. Muller Elementary School yard off Trankilo Road in Charlotte Amalie, St. Thomas (Figure 86). A 12-foot Contech CDS unit is proposed in the existing gut channel to provide trash and debris removal before diverting flow into the chamber system for detention and infiltration. Site constraints include numerous existing utilities beneath Trankilo Road and on school property.

The complete 30% design plans can be found in Appendix B4. A map of the drainage area for this proposed system can be found below in Figure 87.

Figure 86. Example photo of subsurface infiltration chambers (above) and Ulla F. Muller Elementary School yard off (below).

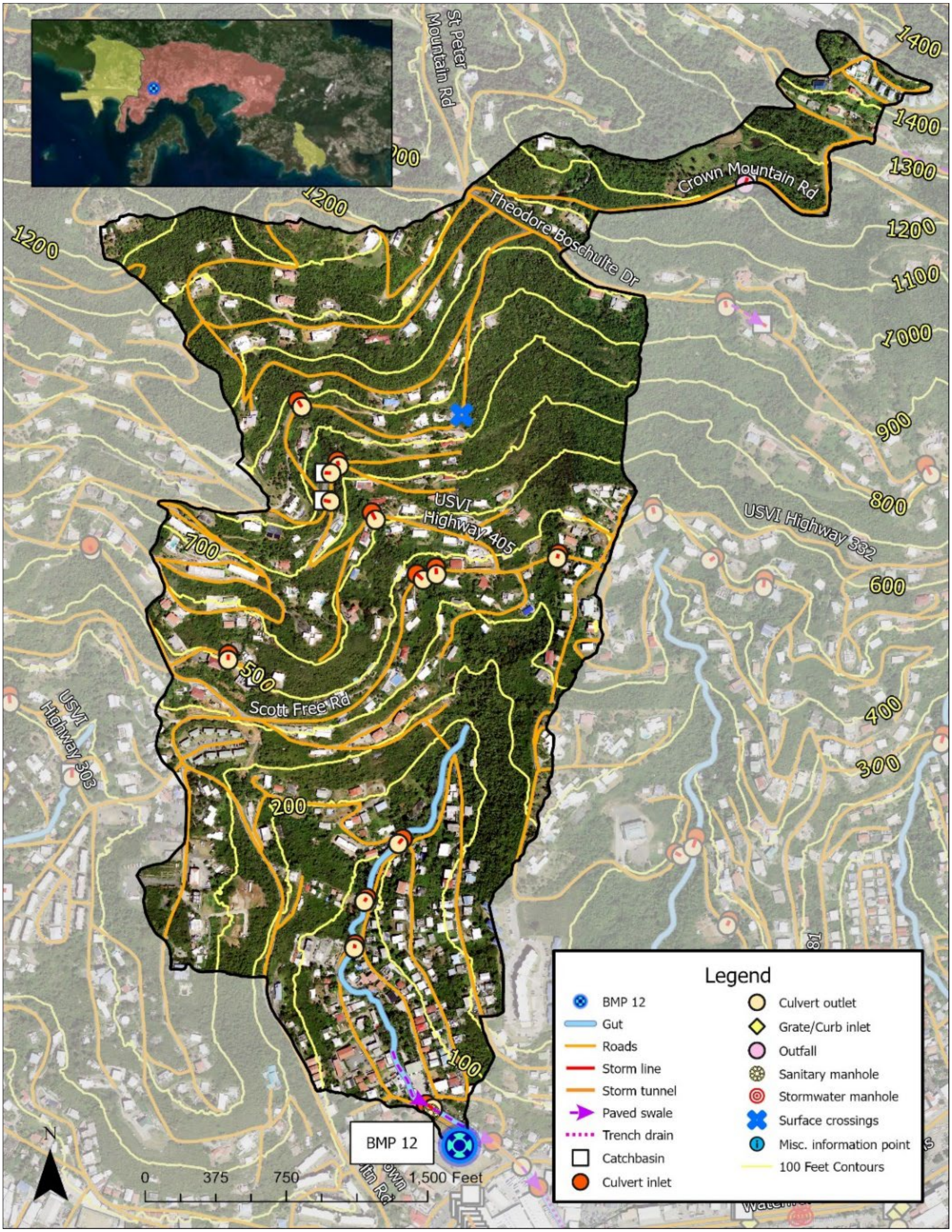


Figure 87. Drainage area to BMP 12.

3.7.4.2 Infiltration Chambers (Proposed BMP 44)

This 30% design includes 2450 Stormtech MC-4500 infiltration chambers located beneath Lionel Roberts Stadium in Charlotte Amalie (Figure 88). A nearby gut is diverted beneath Hospital Ground Road to a 12-foot Contech CDS unit. The CDS unit provides trash and debris removal before diverting flow into the chamber system for detention and infiltration up to the 1-year rain event.

The complete 30% design plans can be found in Appendix B4. A map of the drainage area for this proposed system can be found below in Figure 89.

Figure 88. Example photo of subsurface infiltration chambers.

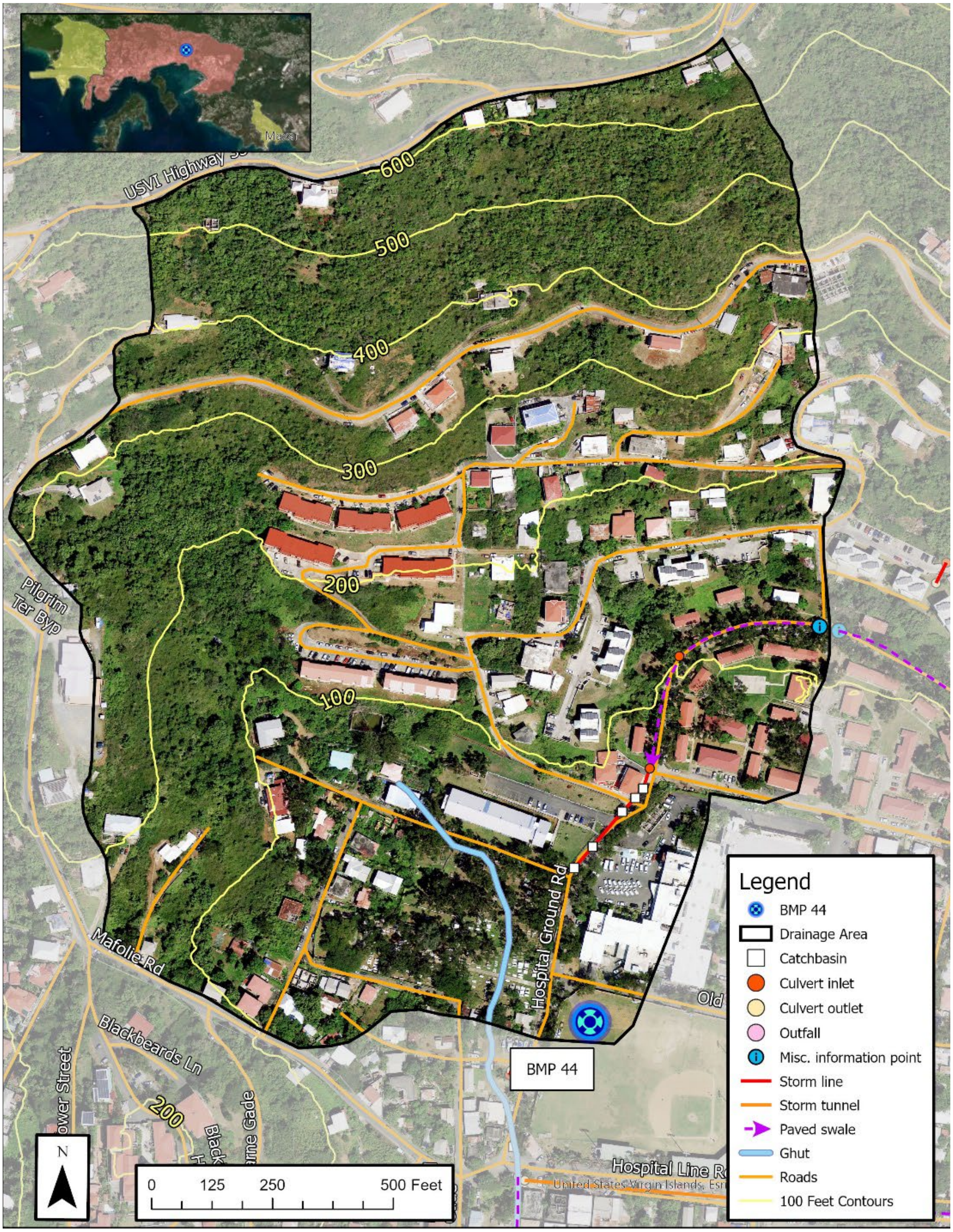
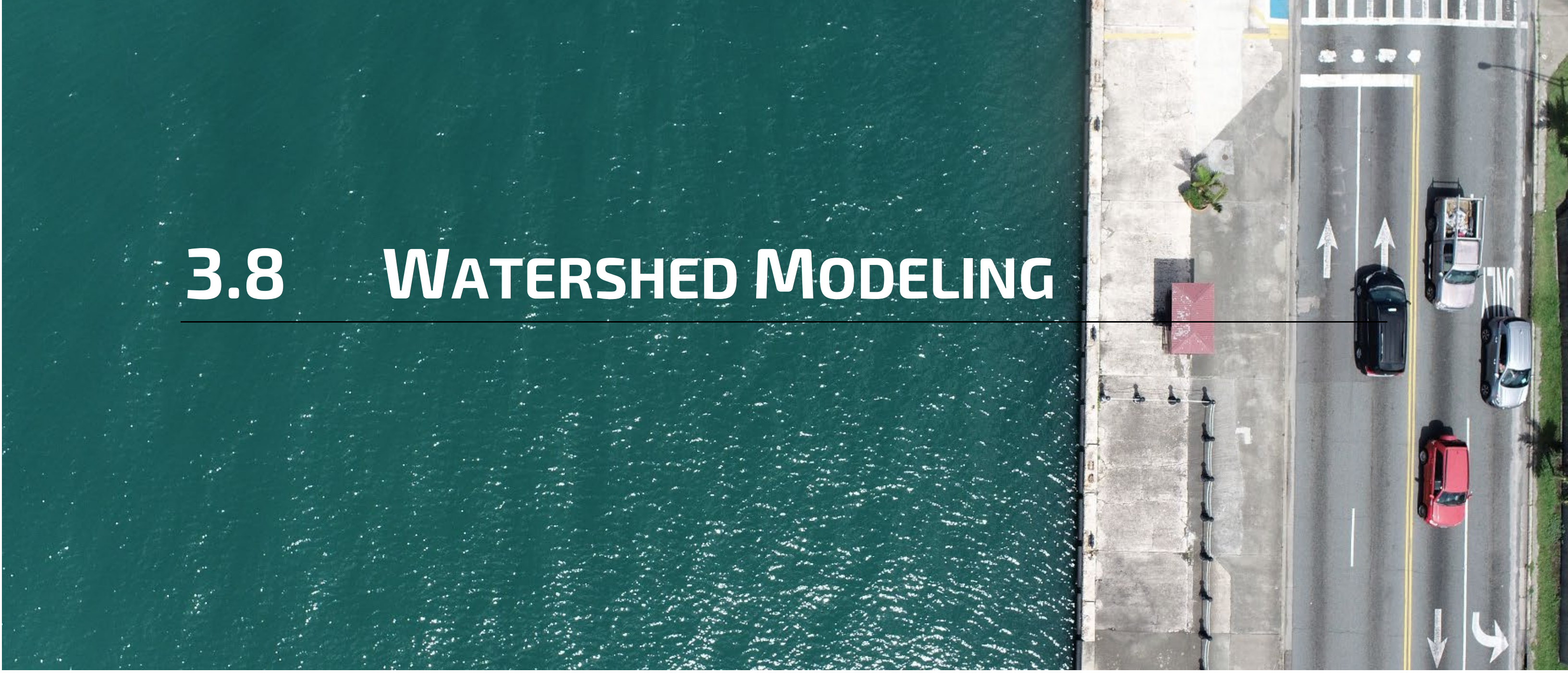


Figure 89. Drainage area to BMP 44.



3.8 Watershed Modeling

3.8.1 Modeling Overview

Water quality and hydrologic and hydraulic (H&H) modeling were completed to meet several objectives. Limited technical information regarding modeling methodologies is included in this section to improve readability and allow for more discussion of modeling results. Complete modeling methodology and complete modeling results are included as Appendix B5 AND B6.

Watershed scale and individual BMP scale modeling was completed to assess four primary scenarios:

1. Existing watershed conditions: Assess watershed-scale water quality and hydrology taking existing BMPs into account.
2. Existing watershed conditions with future development: Assess watershed-scale water quality and hydrology taking existing BMPs into account through future predicted land cover scenarios in the years 2030, 2050, 2080, and 2100.
3. Proposed watershed conditions: Assess watershed-scale water quality and hydrology taking any existing BMPs into account and the proposed Top 10 ranked BMPs.
4. Proposed watershed conditions with future development: Assess watershed-scale water quality and hydrology taking existing BMPs into account and the proposed Top 10 ranked BMPs through future predicted land cover scenarios (2030, 2050, 2080, and 2100).

Water quality modeling was completed using the Watershed Treatment Model (WTM), a spreadsheet-based tool developed by the Center for Watershed Protection that calculates total nitrogen (TN), total phosphorus (TP), total suspended solid (TSS), and fecal coliform (FC) loads based on several drainage area sources including land use, soil type, sewage use and disposal, stream channel erosion and nutrient concentration, and marina characteristics.

Hydrologic and hydraulic (H&H) modeling was completed using HydroCAD, a software most commonly used to model stormwater runoff and design stormwater management systems. Models were developed in HydroCAD to estimate peak flow rates and model volumes, as well as to assess the peak flow rate reduction benefits of existing and proposed BMPs.

Peak flow is measured in cubic feet per second (cfs) and is indicative of how quickly water flows through a watershed. High peak flows are problematic because they exacerbate erosion and flooding as stormwater flows in fast-moving, concentrated channels down a slope. Generally, watersheds or drainage areas with a high peak flow are likely to have had land cover and/or land use changes occur, altering the natural state. Land cover is a key determinant of peak flow, although underlying soil conditions, topography, and drainage area also can play significant roles. The implementation of stormwater BMPs can reduce and delay the timing of the peak flow, which more closely mimics an undeveloped watershed (Figure 90).

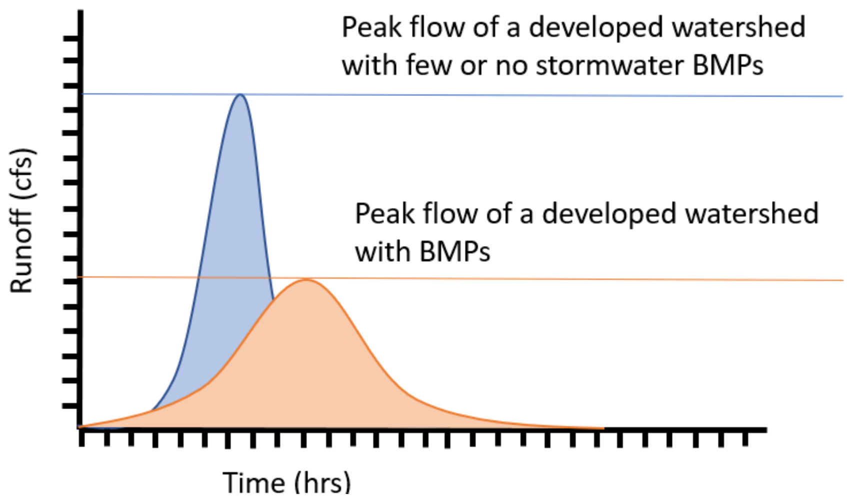


Figure 90. Illustrative hydrographs demonstrating the peak flow reduction value of implementing BMPs.

Data and information inputs to the H&H models were:

- Drainage areas for existing and proposed best management practices (source: delineated in GIS utilizing topography, imagery, mapped stormwater infrastructure, and limited field verification),
- Time of concentration, defined as the time required for a drop of water to travel from the most hydrologically remote place in a drainage area to the point of collection (source: digitized in GIS as the longest flow length),
- Hydrologic soil group (HSG) (source: National Resource Conservation Service (NRCS) soil data),
- Existing and future land use (source: developed for this project as described in Sections 3.3.2 and 3.3.6), and
- Rainfall depth and distribution (source: NOAA Atlas 14 Point Precipitation Frequency Estimates, and a Type II storm distribution is used in accordance with the Soil Conservation Service (SCS) 24-hour Rainfall Distribution).

Additional details about HydroCAD modeling methodologies can be found in Appendix B5.

3.1.1 Existing Conditions

The Saint Thomas Harbor watershed contains seven existing BMPs that were identified during this project (see Section 3.5.2 for more discussion on the identification and location of these practices). The parameters listed above were imported into HydroCAD. The SCS TR-20 runoff method (most commonly used in this type of HydroCAD assessment) was used to generate a total runoff hydrograph for each study watershed drainage area and each BMP drainage area. Runoff volume was calculated separately for each combination of land cover and soil type, known as a curve number (CN). The runoff was then summed to calculate the total runoff from each drainage area node. This approach preserves the runoff volume from each subarea within the drainage area node and thus is called the flow-weighted or "Weighted-Q" method.

Storage volume measured to the first overflow outlet of each BMP was defined in HydroCAD using GIS measurement tools, existing stormwater infrastructure, and elevation contour layers. Table 28 below describes each of the practices, the storage volume associated with the practice, and the assumptions that were incorporated into the water quality and hydrologic modeling scenarios. Taken together, stormwater BMPs included oil/water separators capturing 3.5 acres of impervious cover and basins capturing 46 acres of impervious cover.

Table 28. Storage volume and assumptions of existing BMPs.

Existing ID	BMP Type	Storage Volume (cf)	BMP Description and Assumptions
1	Oil/Water separator	0	Underground Swirl Separator. Drains portions of Veterans Drive. No storage, flow-through structure. No infiltration.
2	Oil/Water separator	0	Underground Swirl Separator. Drains portions of Veterans Drive. No storage, flow-through structure. No infiltration.
3	Oil/Water separator	0	Underground Swirl Separator. Drains portions of Veterans Drive. No storage, flow-through structure. No infiltration.
4	Oil/Water separator	0	Underground Swirl Separator. Drains portions of Veterans Drive. No storage, flow-through structure. No infiltration.
5	Basin	628	Volume measured to road. 24" concrete culvert and distributed flow over road discharges to harbor. Surface areas estimated from contours. No available site plans. 0.21 in/hour infiltration rate from NRCS soil data.
6	Basin	1,030	Volume measured up to horizontal grate overflow. 24x24 grate overflow to 30" pipe, and distributed flow over road discharging to harbor. Surface areas estimated from contours. No available site plans. 0.21 in/hour infiltration rate from NRCS soil data.
7	Basin	3,896	Volume measured up to low berm overflow. Surface areas estimated from contours. No available site plans. 0.21 in/hour infiltration rate from NRCS soil data.

3.8.1.1 Hydrologic Modeling Results of Existing Conditions

Although seven BMPs were identified, four of the practices (BMP IDs 1 through 4) do not provide any flow detention or infiltration and are designed only for water quality as flow-through structures. BMPs 5, 6, and 7 contribute to peak flow reductions at the watershed outlet.

To determine the hydrologic impact of the existing BMPs in the watershed, the model was also run with the existing BMPs removed. During the 1-year storm event, peak flow was 3,407 cfs in both scenarios.

3.8.1.2 Water Quality Modeling Results of Existing Conditions

Existing pollutant loads, summarized by major land use categories, are presented in Table 29. In this watershed, urban land has the highest estimated loads for TN and TP. TSS loads were predominantly caused by channel erosion, which was estimated from the length of guts in the watershed. The estimated contribution from all sewage sources—sanitary sewer overflows (SSOs), illicit discharges, and septic systems—represented the majority of the fecal coliform loading.

Table 29. Existing pollutant loads to surface waters in the watershed.

Land Use	TN (lbs./year)	TP (lbs./year)	TSS (lbs./year)	Fecal Coliform (billion/year)
Urban Land	15,184	2,216	441,213	667,983
Active Construction	11	2	7,360	0
Channel Erosion	1,801	720	1,440,780	0
Forest	2,323	186	92,932	11,152
Rural Land	0	0	0	0
Point Sources	0	0	0	0
Onsite Sewage	5,043	841	33,621	71,533
SSOs and Illicit Discharges	8,245	1,374	54,969	6,239,023
Open Water	16	1	198	0
Total	**32,624**	**5,340**	**2,071,073**	**6,989,690**

3.8.2 Existing Conditions with Future Development

The seven existing BMPs were modeled to assess the existing watershed-scale conditions along with the future predicted land cover scenarios in order to determine the impacts of increased development without the construction of any additional stormwater BMPs. The models were created to assess each of the four future land cover scenarios: 2030, 2050, 2080, and 2100. A summary of the land cover changes from the present condition to these future conditions are summarized in Table 30 below. Over the projected time periods, changes are minimal but in general green space decreases while impervious cover and bare soil increase.

Note that land cover information for 2019 differs slightly in the future land cover modeling because the data had to be aggregated to grid cell format to be compared with the future land cover projections that were developed using this grid cell format.

Table 30. Future land cover summary table.

Land Cover Category	Acres				
	2019	2030	2050	2080	2100
Bare Soil	67.1	67.4	68.5	69.1	71.3
Green Space	1,587.1	1,580.2	1,560.8	1,537.3	1,496.0
Impervious Cover	866.0	872.7	890.9	913.9	953.0
Water	1.4	1.4	1.4	1.4	1.4

3.8.2.1 *Hydrologic Modeling Results of Existing Conditions with Future Development*

Over time, as projected impervious cover increases and green space decreases, the watershed-scale peak flow rate increases. This trend can be observed in Figure 91 below.

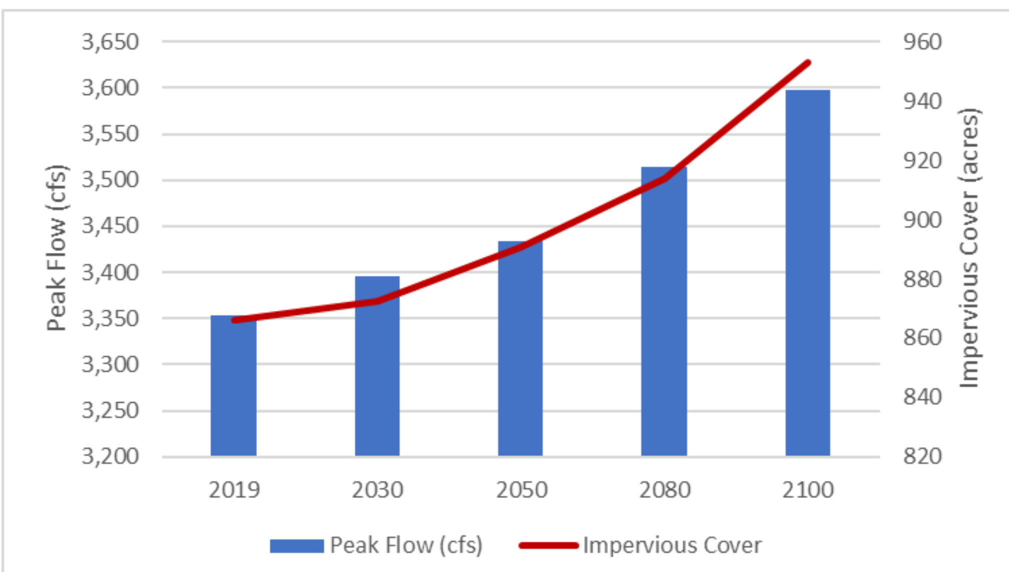


Figure 91. Relationship between watershed scale peak flow (blue) and the predicted impervious cover (red) over time.

3.8.2.2 Water Quality Modeling Results of Existing Conditions with Future Development

The water quality modeling results for the projected future land cover mirror the results observed in the hydrologic modeling (Figure 91). Over time, as impervious cover increases and green space decreases, each of the four pollutants of concern that were modeled increase (Figure 92).

Figure 92. Relationship between watershed-scale pollutant loading for TN (yellow), TSS (blue), TP (green), and Fecal Coliform (orange) and the predicted impervious cover increase (red) over time.

3.8.3 Top 10 Proposed BMPs

The top 10 proposed BMPs identified in Section 3.7.3 were modeled to ensure that they are adequately sized and to assess their impact on watershed-scale peak flow and water quality. Drainage areas for each of these 10 BMPs were delineated and BMPs were designed to maximize peak discharge reduction during the 1-year storm event, provide infiltration, improve water quality, reduce downstream flooding impacts, and build resiliency to flooding. A summary of the model assumptions and storage volumes of proposed BMPs can be found in Table 31. The location of the top 10 BMPs can be found in Figure 85.

Table 31. Model assumptions and storage volumes of proposed BMPs.

Proposed BMP ID	BMP Type	Storage Volume (cf)	Assumptions	Total Drainage Area (Acres)	Impervious Area (Acres)
12	Subsurface Chambers	76,618	Sized for detention of 1-year event. 7 in/hour infiltration rate from NRCS soil data.	236.80	52.43
52	Basin	45,094	Sized for detention of 1-year event. 1 in/hour infiltration rate from NRCS soil data.	81.11	12.78
37	Basin	82,584	Sized for detention of 1-year event. 1 in/hour infiltration rate from NRCS soil data.	144.32	12.89
28	Basin	39,648	Sized for detention of WQ (1.05") event. 1 in/hour infiltration rate from NRCS soil data.	140.94	21.41
35	CDS Unit	-	Flow-through CDS Unit	117.62	30.57
16	Subsurface Chambers	188,122	Sized for detention of 1-year event. Sand filter layer assumed limiting infiltration rate (3.5 in/hr.).	50.85	22.04
44	Subsurface Chambers	376,221	Sized for detention of 1-year event. Sand filter layer assumed limiting infiltration rate (3.5 in/hr.).	59.71	15.00
20	CDS Unit	-	Flow-through CDS Unit	177.98	52.98
29	Basin	33,396	Sized for detention of 1-year event. 1 in/hour infiltration rate from NRCS soil data.	33.57	3.71
18	CDS Unit	-	Flow-through CDS Unit	153.43	41.82

With exception of “flow-through” water quality treatment structures designed only to provide trash and sediment removal (known as a “CDS Unit”), each BMP is represented in HydroCAD by a Pond node with storage and outlets. Flow-through structures are modeled as nodes with insignificant storage, which provide velocity information used to size the structures.

The storage volume for each BMP was defined in HydroCAD, using the available surface area at each site as the primary constraint. A series of outlets were defined for each BMP, typically with a smaller, low-flow orifice located at the bottom of the pond or structure, a larger overflow orifice one to three feet from the bottom, usually in the form of a riser, and a long overflow emergency spillway weir three to four feet from the bottom (Figure 93). Each proposed BMP node is designed to maximize peak discharge reduction benefits during the 1-year rain event within the available space. For sites where space constraints preclude the storage volume from providing the necessary volume for detention of the 1-year rain event, the BMP is sized for the “water quality volume” (WQv) storm event, which typically transports the majority of stormwater pollutants. See Appendix B5 for further discussion of the water quality volume. Any flow that exceeds the storage capacity of the BMP nodes is automatically routed to the next downstream node which is either a reach node, another BMP node, or directly to the watershed outlet. All flow is routed to a single node representing the watershed outlet, where flows are summed into a hydrograph.

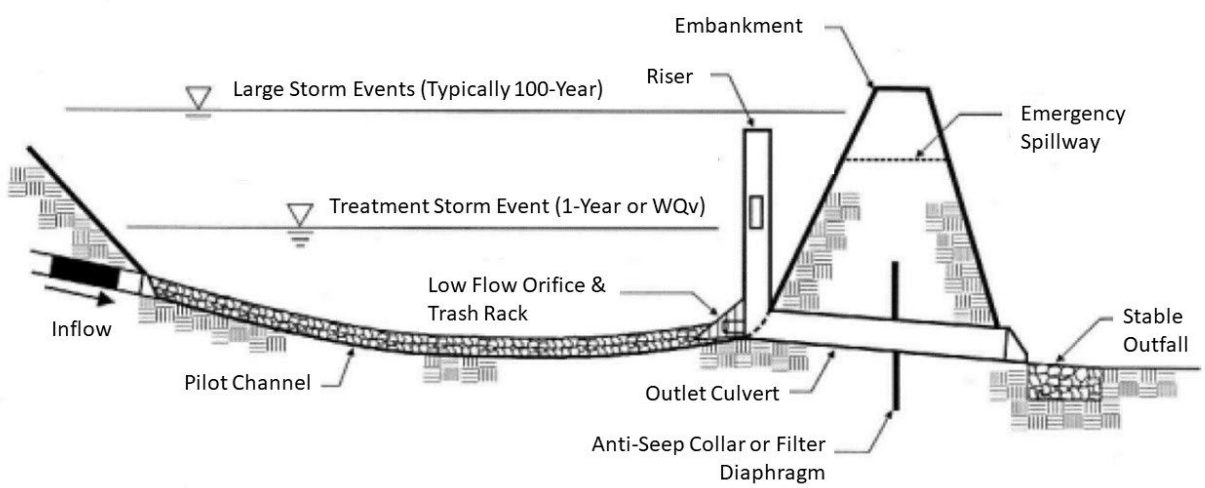


Figure 93. Dry detention basin design. Graphic adapted from the 2017 Vermont Stormwater Management Manual Rule and Design Guidance (Vermont ANR, 2017).

3.8.3.1 Hydrologic Modeling Results of Proposed BMPs

Using current land-use conditions, it was determined that the 10 proposed BMPs reduced the modeled peak flow by 12.26% at the Saint Thomas Harbor watershed outlet during the 1-year storm event, from 3,401 cfs to 2,984 cfs (Figure 94). This is a substantial reduction in peak flow and would likely lead to profound reductions in erosion and flooding.

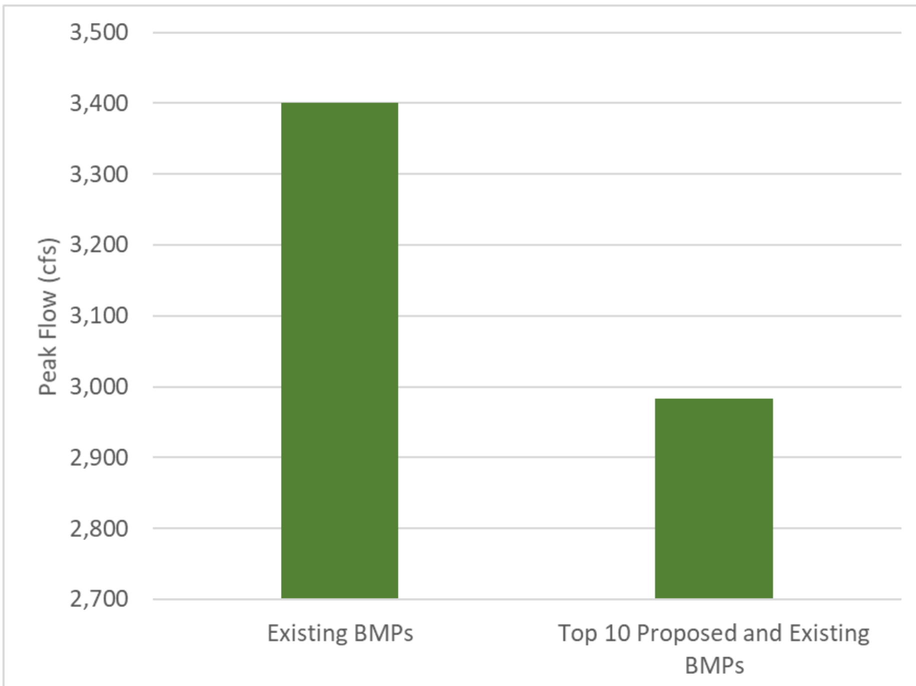


Figure 94. Peak flow was reduced at the watershed outlet from 3,401 cfs with existing BMPs to 2,984 cfs with addition of the Top 10 proposed BMPs.

3.8.3.2 Water Quality Modeling Results of Proposed BMPs

The pollutant load reductions from the Top 10 BMPs proposed in the watershed can be found in Table 32. The proposed practices are effective at reducing pollutants associated with sediment and erosion (TN, TP, and TSS), however are not effective at treating pollution associated with wastewater (Fecal Coliform). Collectively, the 10 proposed BMPs are estimated to remove 516 lbs. of TN, 118 lbs. of TP, and 104,499 lbs. of TSS annually. The model showed no reductions in Fecal Coliform loading. It is important to note that of the pollutants in the WTM, fecal coliform is the most difficult to characterize. Research has shown that stormwater treatment practices such as those proposed can be effective at treating fecal coliform from surface water, so it is feasible that this potential reduction was not captured in the model (Mallin, 2016).

Table 32. Estimated water quality benefits of each proposed retrofit.

Proposed BMP Practice ID	TN (lbs./year)	TP (lbs./year)	TSS (lbs./year)
12	105	24	21,183
52	28	7	5,664
37	35	8	7,056
28	45	10	9,143
35	56	13	11,345
16	39	9	7,860
44	29	7	5,886
20	94	21	19,134
29	9	2	1,860
18	76	17	15,367
Total	***516***	***118***	***104,498***

As noted above, the WTM includes several different sources of pollutant loading for the watershed as a whole, including:

- Surface Runoff (Urban, Rural, and Forest),
- Active Construction,
- Channel Erosion,
- Point Sources,
- Onsite Sewage,
- SSOs and Illicit Discharges, and
- Open Water.

The proposed BMPs account for reductions to the Surface Runoff (Urban, Rural, and Forest) category exclusively. The 10 BMPs reduce Surface Runoff associated TN loads by 3%, TP loads by 5%, and TSS loads by 20% annually. However, when considering the other six modeled pollutant loading sources, these annual reductions for TN, TP, and TSS are reduced to 2%, 2%, and 5% respectively (Figure 95). The watershed-scale pollutant loads including all modeled sources are summarized in Table 33 below.

Table 33. Estimated pollutant loads in the watershed for the existing conditions and with reductions associated with the Top 10 proposed BMPs.

Time Frame	TN (lbs./year)	TP (lbs./year)	TSS (lbs./year)	Fecal Coliform (billion/year)
Existing Conditions	32,624	5,340	2,071,073	6,989,690
Existing Conditions with Top 10 Proposed BMPs	32,108	5,222	1,966,575	6,989,690
Difference Between Existing and Proposed Conditions	**516**	**118**	**104,499**	**0**

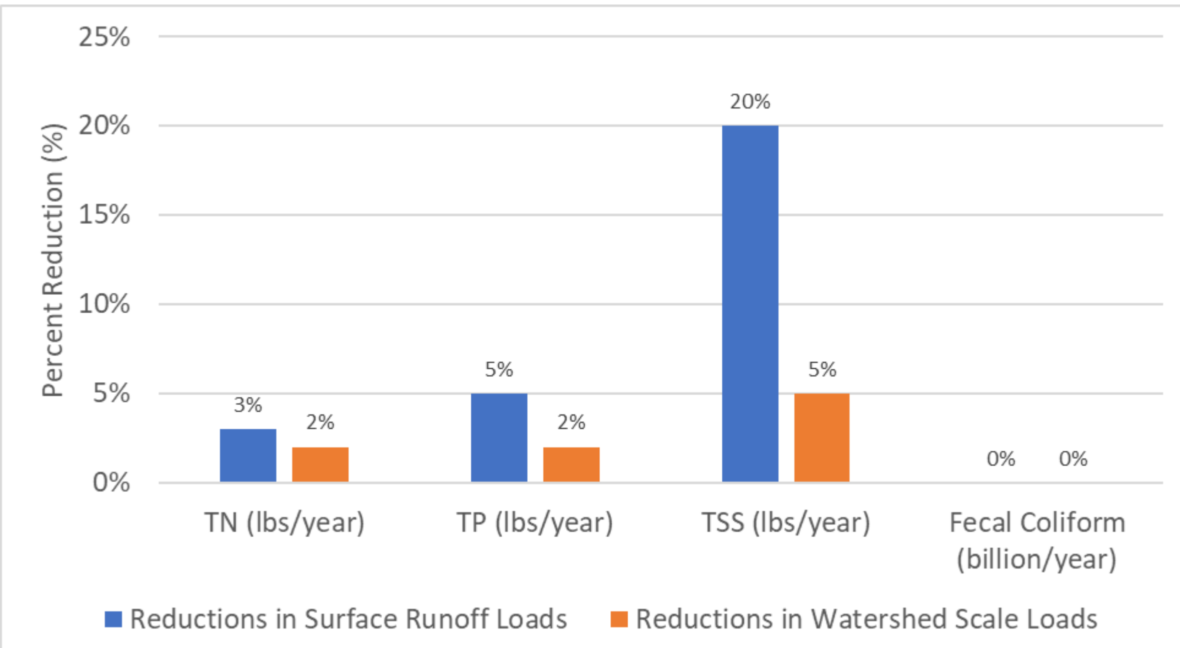


Figure 95. Pollutant load reductions attributable to the Top 10 BMPs for the Surface Runoff category (blue) and for all modeled watershed sources (orange).

3.8.4 Proposed Conditions with Future Development

The hydrologic and water quality benefits of the proposed Top 10 BMPs were then assessed in comparison to the future land cover predictions for the watershed.

3.8.4.1 Hydrologic Modeling Results of Proposed Conditions with Future Development

With the combination of proposed BMPs and forecasted new development in the watershed, peak flow is anticipated to increase between 2030 and 2100 (Figure 96). However, even with the increased impervious cover, the peak flow in 2100 is still predicted to be lower than the existing conditions when the peak flow reductions associated with the Top 10 BMPs are included.

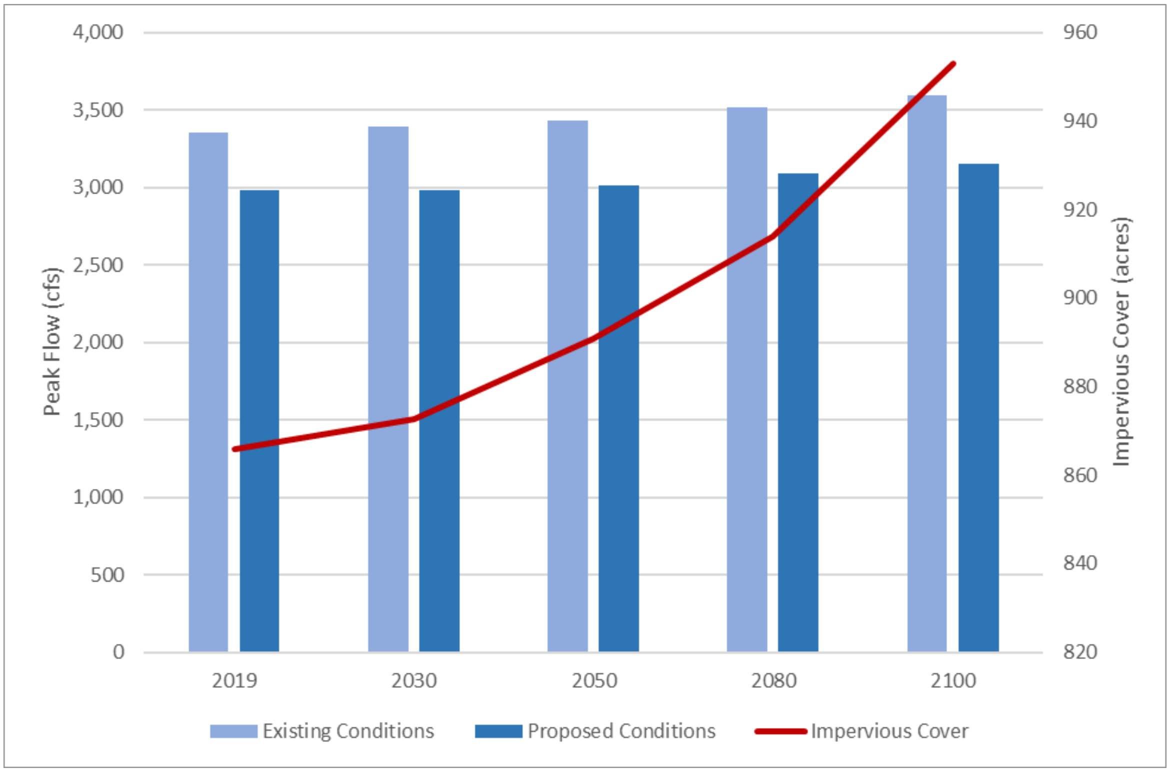


Figure 96. Relationship between watershed peak flow for the existing conditions (light blue) and proposed conditions (dark blue), which includes the implementation of the Top 10 BMPs over time. The predicted impervious cover increase (red) over time is also shown.

3.8.4.2 Water Quality Modeling Results of Proposed Conditions with Future Development

The predicted future development in the watershed results in increased pollutant loads between 2030 and 2100 (Figure 97). The increase in development is well correlated to increased pollutant loads. The pollutant load reductions associated with implementation of the Top 10 BMPs reduces these loads. However, over time and with increased development, the benefits of these BMPs are diminished and, in some cases in the future conditions, pollutant loads exceed existing conditions. This highlights the need for continued efforts to mitigate the impacts of development so that watershed conditions improve over time.

Figure 97. Relationship over time between watershed scale pollutant loading for the existing conditions (lighter colors) and proposed conditions (darker colors), which includes the implementation of the Top 10 BMPs. Loading is shown for TN (yellow), TSS (blue), TP (green), and Fecal Coliform (orange). The predicted impervious cover increase (red line) over time is also shown.

4 Recommendations & Conclusions

4.1 Proposed Management Measures

A variety of proposed management measures and specific actions were identified during the development of this Watershed Management Plan. Some of the measures are proposed at an island scale while others apply to specific watersheds. Recommendations were derived from the watershed specific modeling, field assessments, water quality monitoring, community outreach, review of existing research, and discussions with DPNR, DPW, and WMA. Additionally, the "Eight Tools of Watershed Protection" was used by the project team to evaluate the current state of watershed management in the USVI. This audit tool, developed by CWP, identified programmatic strengths and gaps in watershed protection strategies and helped to inform the following watershed planning recommendations.

The recommendations detailed below are categorized as recommendations for:

1. Stormwater Management and Non-Stormwater Discharges
2. Watershed Planning
3. Land Use Planning and Resource Protection
4. Site Design Guidelines
5. Solid Waste Management
6. Watershed Stewardship
7. Future Research

4.1.1 Stormwater Management and Non-Stormwater Discharges

4.1.1.1 Stormwater Management Standards and Regulations

USVI is not currently regulated by the US EPA under the NPDES Phase II permit for municipal separate storm and sewer systems (MS4 program); however, EPA authorized the USVI TPDES program in 1976. **Organization of the TPDES program around the basic NPDES MS4 six minimum measures for stormwater management** is recommended to incorporate basic elements of a stormwater management program that are missing in USVI, including post-construction, pollution prevention and good housekeeping, and illicit discharge detection and elimination (IDDE).

The USVI does not currently have regulatory criteria for post-construction stormwater management including inspection and maintenance; however, the Horsley Witten Group is in the process of developing a **USVI Stormwater Standards and Design Manual** that should incorporate specific design criteria, maintenance requirements, and typical plan details necessary for best management practices to meet stormwater standards (USVI, 2020). The updated manual should **incorporate green infrastructure (GI) techniques** to reduce stormwater runoff to the maximum extent practicable such that there is little to no discharge from the 1-year, 24-hour storm. It is recommended that this manual be adopted and promoted.

It is also recommended that USVI **develop a post-construction stormwater management program with inspection and maintenance checklists and adopt a post-construction stormwater management ordinance for new and redevelopment**. Specific references to help develop these standards include:

- Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program and the Appendices with Model Post Construction Ordinance
- Maryland Model Stormwater Management Ordinance

4.1.1.2 Erosion & Sediment Control (ESC)

In the USVI, erosion and sediment control (ESC) is required for all sites (12 V.I.C. § 533, Earth Change Plans) "[b]efore any real property is cleared, graded, filled or otherwise disturbed for any purpose or use." An earth change permit is provided upon approval of an earth change plan detailing the erosion and sediment control for a development site. A building permit or other permits will not be received until an earth change permit is obtained. It is recommended that requirements be amended to **require limits of disturbance to be shown on construction plans and physically marked at the site**. Limits of disturbance for existing trees should include the critical root zone also known as the drip line.

Construction sites are inspected for compliance with erosion and sediment control requirements by third party inspectors on a weekly basis. The inspectors have national certification – Stormwater Pollution Prevent Plan (SWPPP) Inspector or similar or Professional Engineer (P.E.) or similar. There are erosion and sediment control enforcement mechanisms in place (e.g., fines, stop work orders, etc.). However, several construction sites were observed during field assessments where erosion control measures such as silt fences were not properly installed. This is an issue of concern as these unstable construction areas, even in temporary, can contribute significant sediment loads to surface waters if not properly managed. It should be determined whether these noncompliant sites were either:

- Not inspected,
- Were inspected but no compliance issues were recorded indicating a misunderstanding of ESC standards by inspectors, or
- ESC noncompliance was noted by inspectors and was not fixed on site.
    - If following initial observations of noncompliance, the site was still not meeting ESC standards this could indicate that either the site was not reinspected to ensure compliance or enforcement mechanisms were levied but did not result in ESC compliance.

It is recommended that a **review of noncompliant construction sites be completed** to determine the reasons for ESC violations and determine the appropriate steps that need to be taken to address these violations. This could include formal training for inspectors, training for contractors, increased enforcement of fines or stop work orders, increased frequency of inspection, or other measures as determined by this assessment.

Currently, the 2002 Virgin Islands Environmental Protection Handbook is being updated, and it is recommended that the USVI **finalize and adopt the revised Environmental Protection Handbook**. The Handbook should illustrate proper stormwater practice design, installation, and maintenance procedures, as well as construction phase stormwater practices that reduce runoff volumes and prevent or decrease the discharge of pollutants in stormwater.

4.1.1.3 Demonstration Projects

The **implementation of GI demonstration projects on public properties** is also recommended. Demonstration of GI practices should be promoted during restoration activities that address drainage improvements to existing conditions, including public projects such as road repairs, facility renovations, and other capital improvements. Parks, schools, and other public spaces should also be inventoried and opportunities for GI identified.

One opportunity is to publicly showcase GI stormwater practices installed at the 64 West Center located on UVI's St. Croix campus. The stormwater practices at this facility include permeable pavements, vegetated bio-swales, and underground detention storage (Rain TanksTM) for landscape irrigation and to supplement water supplies for water closets, urinals, and cooling towers.

In addition to the water quality benefits of these practices, **educational materials and signs should be distributed and installed** in conjunction with these demonstration projects. Increasing the public's understanding of the importance of managing land based sources of pollution can encourage support of additional and larger stormwater best management practices (BMPs), some of which could be located on private property with participating private landowners. It can also encourage the adoption and construction of smaller scale residential stormwater BMPs.

4.1.1.4 Implementation of Identified BMPs

One of the outcomes of this plan was the identification of stormwater and flooding BMPs including 10 high priority sites within each watershed. From the 10 high priority sites per watershed, 30% concept design plans were developed for two priority ranked sites. These concept design plans can be found in Appendix B4.

To address the water quality and flooding problems derived from stormwater, the **final design and implementation of the two 30% conceptual designs per watershed should be of high priority**. Also of importance, **further design development and implementation should be pursued for the remaining eight high priority potential BMP sites per watershed**. A map and tabulated summary of the 10 high priority sites per watershed can be found in the watershed-specific appendices and sections of this report. The full list of identified BMPs should also be further investigated in the long term.

4.1.1.5 Illicit Discharge & Wastewater Management

The USVI does not currently have an Illicit Discharge Detection and Elimination (IDDE) program. Dry-weather flows discharging from storm drainage systems can contribute significant pollutant loadings to receiving waters. Illicit dry weather flows originate from many sources. The most important sources typically include sanitary wastewater or industrial and commercial pollutant entries, failing septic tank systems, and vehicle maintenance activities. It is recommended that the **USVI adopt an IDDE ordinance and develop an effective IDDE program**. Technical guidance to assist in the creation of such a program can be found in Illicit Discharge Detection and Elimination: A Guidance Manual for Program Development and Technical Assessments (Brown et al., 2004).

4.1.2 Watershed Planning

Watershed planning involves critically analyzing the degree and location of future development and associated impervious cover to best account for changes in land use and its effect on water resources. Consequently, watershed planning ranks as perhaps the single most important watershed protection tool. One of the goals of watershed planning is to **shift development toward areas that can better support a**

particular type of land use and/or density. The goal of watershed planning is to apply land use planning techniques to **redirect development, preserve sensitive areas, and maintain or reduce the impervious cover** within a given watershed.

4.1.2.1 Comprehensive Water and Land Use Plan

A primary recommendation to is to adopt an updated comprehensive water and land use plan. A proposed comprehensive planning effort for land and water resources was started in 2004 but never adopted. A new Comprehensive Land and Water Use plan was proposed in 2020 and is currently in the RFP process.

Associated with the plan adoption are two additional recommendations. First, **ensure that the proposed Comprehensive Land and Water Use Plan accounts for impacts of future land use on water resources,** including identifying land use planning techniques that promote land development patterns **that reduce overall impervious cover**, and limit the scale of development and land disturbance in the most sensitive or high-quality watersheds. Second, **ensure that current zoning is evaluated and revised to be consistent with overall plan goals**.

4.1.2.2 Planning Tools and Conservation Easements

Another recommendation is to **assess a larger suite of land use planning tools** to see if additional techniques may be appropriate**.** Currently DPNR does permit conservation easements and land acquisition programs as techniques to manage land use and impervious cover, but does not actively facilitate, support, or encourage them. We recommend that DPNR consider **promoting the use of easements** by gathering informational materials together for applicants and providing these materials and training to DPNR review staff on how to inform and facilitate this existing policy opportunity. In addition, there are other tools such as promoting infill/redevelopment, transfer of development rights (TDRs), and overlay zoning that may also provide additional protections.

4.1.2.3 Zoning and Subdivision Code Revisions

Another recommendation is to **revise the Zoning and Subdivision Code**, which currently has an exemption for subdivisions creating less than four lots so that they do not come to DPNR for review. There is also a policy of "family subdivisions" not being required to pave their roads. This means that development can occur with little or no erosion and sediment controls in place, and that the road system can act as both a source of sediment and a conduit for stormwater runoff. A thorough review of the Code may reveal other specific code changes that could ensure that most developments are required to meet minimum standards.

4.1.2.4 Coastal Zone Tier Revisions

The management of major developments in the coastal zone uses a tiered system as was discussed in previously. It has been suggested that a **shift from the two-tier system to a watershed approach** will make plan reviews more thorough and provide more protections to upland sites currently considered Tier 2. While removing the boundary between Tiers 1 and 2 would provide a more comprehensive review process for permit applications for major developments, it would also have a major impact on the review process and require additional permit staff.

Since this change would require revamping the current process and coordination through several departments, a stepped process may work best. Potential steps in the process include:

1. Adopt a comprehensive plan to address water resources.
2. Revise the current Earth Change law to provide to provide additional protections and stringent application conditions to areas near guts and on steep slopes in the Tier 2 zone, similar to the more stringent Tier 1.
3. Increase plan review fees and fines to fund additional staffing and required training.
4. Identify some sample development projects in the Tier 2 zone that can be test subjects for a more extensive review similar to Tier 1 projects. These pilot projects could be selected by some combination of project size and distance from or impact on significant environmental resources.
5. Redefine coastal setback limits in the codes and comprehensive plan.

4.1.3 Land Use Planning and Resource Protection

The green spaces, guts, wetlands, and coastal buffers of St. Thomas provide critical hydrologic functions, offer unique habitats, and support human and environmental health. **Conserving and restoring** these spaces are of the utmost importance when it comes to maintaining and improving the health of the watersheds of St. Thomas.

Land conservation as a watershed protection tool involves **making careful choices about the mix of natural habitats and cultural areas that must be conserved** to sustain the integrity of its aquatic and terrestrial ecosystems while maintaining desired human uses. The land conservation areas to protect can include:

- **Critical habitats** for plant and animal communities,
- **Aquatic corridors** along streams and shorelines,
- **Hydrologic reserve areas** that sustain a stream's hydrologic regime,
- **Water hazards** that pose a risk of potential pollution spills,
- **Cultural and historical areas** that are important to a sense of place.

The USVI currently uses multiple land conservation tools to protect valued resources. These include participating in the National Flood Insurance Program and mapping their floodplains, as well as having code language (29 V.I.C. § 280-288 and 29 V.I.C. § 950 – 964) to preserve cultural or historical areas.

4.1.3.1 Agriculture Preservation

Future food security needs should be protected by **more actively encouraging agriculture preservation**. The Virginia Office of Farmland Preservation has developed tools that provide examples of methods for agricultural preservation, including agricultural and forest districts that protect working farm and forestland, and land use assessment based on current use value of a property and not at its fair market value when determining local property taxes.

4.1.3.2 Develop a Steep Slope Ordinance

Steep slopes are not currently protected in the USVI, but when these areas are disturbed and developed, they can become major sources of land based sources of pollution. These areas are already of interest for DPNR. We recommend the **adoption of steep slope legislation to protect hilltops and prevent erosion**, potentially with varying levels of requirements based on slope percentage. Some communities regulate slopes starting at 15%, which ties in with U.S. Department of Agriculture soil survey slope classifications. Others start at 25%, another soil survey threshold and a clear benchmark for land-use limitations. While the development of this ordinance would require a thorough literature review to determine appropriate standards, specific guidance, and examples to help the USVI with development of steep slope regulations include:

- WeConservePA Steep Slope Guide
- Example steep slope regulations in Appendix B from Town of Boone, North Carolina Unified Development Ordinance that separates slopes based on conditions
- Peoria, Arizona steep slopes zoning overlay district (pg. 5-19)
- Verona, NY Steep Slope Ordinance
- Vancouver, Canada Slope Hazard Development Permit Area

4.1.3.3 Forest Conservation and Tree Removal Fee

Trees are important for soil stabilization, reducing stormwater runoff, reducing climate change, shade, aesthetics, and wildlife habitat. Forest conservation is encouraged (12 V.I.C. § 133) in the Community and Heritage Tree Law of the Virgin Islands. The Virgin Islands Tree Board is charge with a mission to protect, manage, remove, and establish trees on public property within the Virgin Islands. It was noted that several parcels of land that were purchased through federal funds from the Forestry Service program have strict mandates and guidelines for conservation:

- No heritage tree may be pruned, removed, or damaged in any way unless an Urban Forester, a designated arborist, or the Territorial Forester determines that there is an overriding need for public improvements, or a severe hardship exists for reasonable use of a site.
- Any person or entity that violates any provision of this chapter by causing, contributing to, or permitting the injury of, removal, or destruction of a public tree, shrub or a heritage tree is subject to a civil penalty of not less than $100, but not more than $500 for each violation.

To discourage removal of trees, **a fee for proposed tree removal could be implemented** during the application process for a tree removal permit. This fee could act as a source of funding for the permit review office for additional staffing or as funding for heritage tree conservation. The USVI should also consider **adopting a tree ordinance and permit requirements for private lands**. This ordinance can include measures such as requiring a percentage of a site to be maintained as trees and directing that those trees be located near guts to provide channel protection. This would also help with protecting development from happening near or on top of guts. Example ordinances include:

- City of Charlotte, North Carolina tree ordinance
- Key West, Florida Tree Protection Ordinance
- Gulf Breeze, Florida Tree Protection Ordinance

4.1.3.4 Tree Canopy Goal

The VI Tree Board should also consider **developing a tree canopy goal** using the land cover dataset developed under this WMP and evaluating the current tree canopy extent. The future land cover dataset could be used to determine the estimated tree canopy loss based on previous development patterns. Opportunities can then be analyzed to reduce or limit future tree canopy loss and increase the current canopy level (i.e., plantings in gut buffers, public parks, etc.) to help achieve the tree canopy goal. Tree canopy is also an important part of addressing climate change.

4.1.3.5 Undeveloped Land Protection in Headwaters

It is highly recommended that the USVI implement a program to **preserve the undeveloped land within the gut headwaters** of the St. Thomas watersheds. Using the land cover dataset developed for this WMP, maps displaying developed and undeveloped land cover were developed for each of the study watersheds to guide these protection efforts (Figure 98). Protection measures could include conservation easements, purchase of undeveloped areas along gut headwaters, or zoning restrictions.

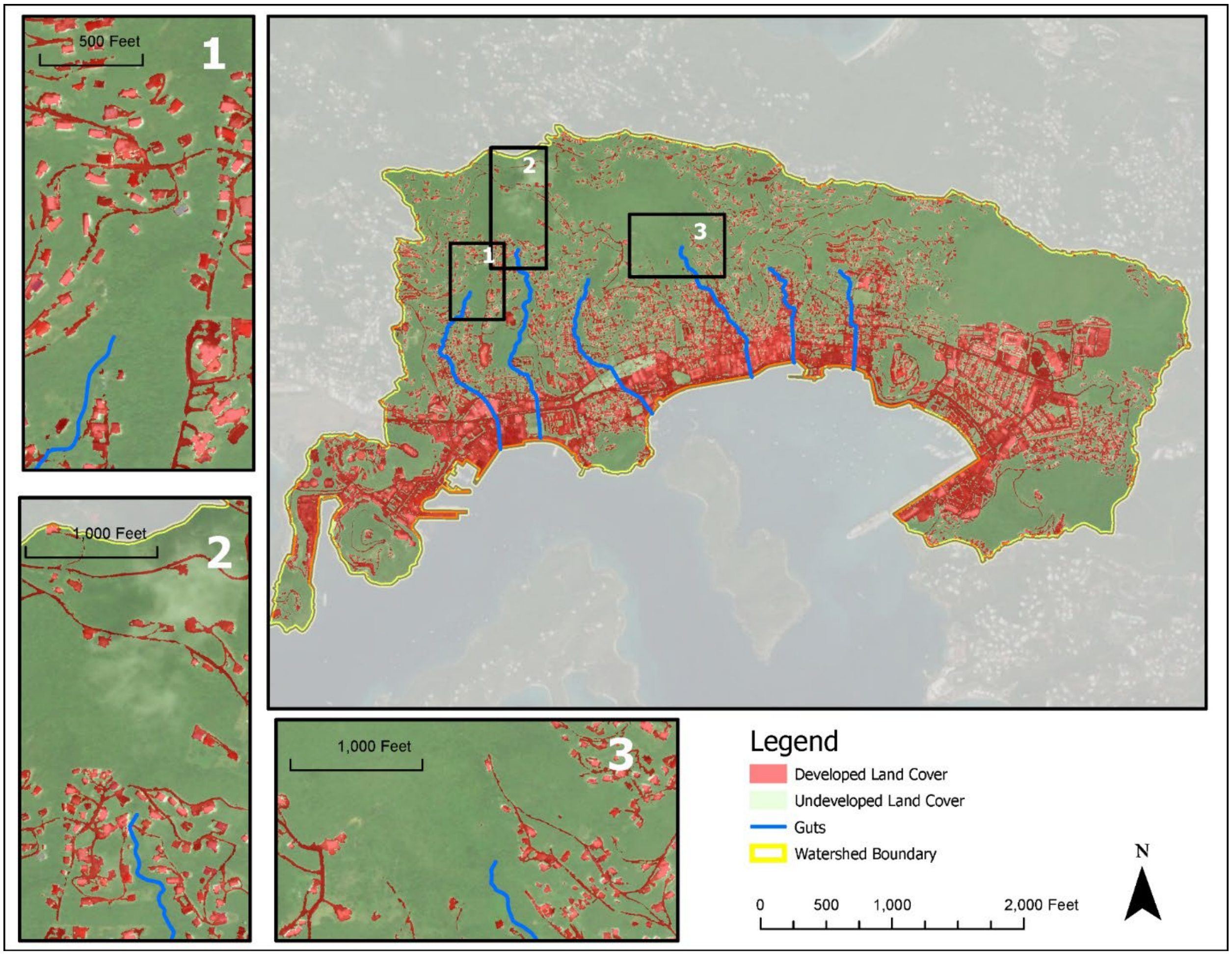


Figure 98. Potential gut headwater protection areas in the St. Thomas Harbor watershed.

4.1.3.6 Gut Channel and Buffer Zone Protection

Guts in the USVI act as the conveyance system for most stormwater runoff and deserve special protection including riparian buffers. There are protections for guts and drainage channels (29 V.I.C. § 226) in the code. However, it is unclear how strictly this is enforced or how often variances are granted to this requirement. Field observations have found that development may be occurring overtop some guts. It is recommended that **gut locations and potential impacts be reviewed during the permit review process** and then during the construction inspection phase to afford the necessary protections to these channels.

A buffer can be placed along a gut, shoreline, or wetland to physically protect a channel from future disturbance or encroachment. For guts, a network of buffers will act as a right-of-way during floods and sustain the integrity of gut ecosystems and habitats. Buffers can also filter pollutants traveling in stormwater or groundwater and provide wildlife habitat and recreation. Current code language does not allow clearing or construction within 25 feet of the edge or 30 feet of the center of natural watercourses (12 V.I.C. § 123). A natural watercourse is defined as any gut with a reasonably well-defined channel and includes guts with a permanent flow and those that result from the accumulation of water after rainfall, and which regularly flow through channels formed by the force of the water. However, this protection should **be expanded to a minimum of 50 feet for all guts, and 100 feet for guts where rare, threatened, or endangered species exist**. Exceptional circumstances will include areas with steep slopes or valued wetlands that require additional protections.

The DPNR should promote a **zoned buffer system** that will allow for some uses while supporting channel protection. One proposal would be a system with 30 feet of “natural vegetation” adjacent to the protected water requirements (as is currently in the codes) with an outer additional 20 feet where a greater range of impacts are allowed. The allowable uses might include septic fields (assuming they are vegetated), pathways with permeable surfaces, or other low impact activities. The publication “Better Site Design” (CWP, 1998) provides an example of a three-zone buffer system and suggested allowable uses in the buffer zones.

The development of a **gut restoration program** should also be a high priority and include riparian buffer assessment and reforestation to ensure buffers are vegetated primarily with high quality native vegetation instead of possible invasive species. The program should identify and prioritize the list of guts for restoration based on the larger overall watershed plans to ensure that the most impacted channels are addressed first.

4.1.4 Site Design Guidelines

4.1.4.1 Better Site Designs

The Better Site Design (BSD) development code review identified street widths, rights-of-way, and parking lot ratios as meeting BSD standards. These are areas of development that together help **reduce the creation of impervious cover**. Within the right of way, placing utilities under the pavement allows for the opportunity for stormwater treatment using bioretention or other green stormwater infrastructure. This area can also be planted with large trees to provide shade, capture rainfall, and generally beautify and improve neighborhoods.

The review identified other opportunities in the development code to minimize impervious cover in requirements for parking lots and driveways. USVI parking ratios meet better site design standards while other aspects of parking need improvement. **Shared parking** is allowed as a practice in the USVI and is a strategy that reduces the number of parking spaces needed by allowing a parking facility to serve multiple users or destinations. This practice should be encouraged by providing a model shared parking agreement and allowing for reduced parking requirements.

To reduce the creation of impervious cover in parking lots consider **allowing a percent of commercial parking spaces for compact cars**. Compact stalls create up to 30% less impervious cover than standard stalls so can be an important strategy for reducing impervious cover in large parking lots (CWP, 2017). Also, consider designating spillover parking areas for larger parking lots and promoting the use of alternative paving materials in these areas. The University of the Virgin Island’s St. Croix campus at the 64 West Center is a local example of the use of **permeable pavements**. In addition, the standard parking space stall width should be reduced to nine feet or less. **Landscaping requirements** should be considered for parking lots that can manage stormwater in best management practices while increasing aesthetics and providing shade. Some options include: bioretention, bio swales, perimeter sand filters, filter strips, and structural soils with trees.

The analysis revealed several opportunities for code revisions regarding driveways. Consider allowing for the use of **alternative driveway surfaces, two-track design, and shared driveways** that connect two or more homes together. A two-track driveway has two strips of paving corresponding to wheel tracks with a vegetated area in between. In addition, the minimum width for a one-lane driveway should be defined in the code. Another recommendation to consider in residential areas is to allow parking lanes to also serve as traffic lanes in higher density developments. Also, in residential areas consider allowing the use of **alternate pedestrian networks** (e.g., paved trails through common areas, walkways and bike trails connecting streets) to be substituted for sidewalks.

The USVI allows for the creation of open space developments and does not require extra steps for development review. Consider allowing for **flexible site design criteria for development that utilize open space or cluster design options**. This will allow for a more unified open space rather than leftover bits of unusable property. One of the goals of open space development is to protect natural lands. Regulatory changes to consider meeting this goal include **requiring a percentage of open space to be left in its natural condition, consolidating into larger units, and defining allowable and unallowable uses** in the open space.

4.1.5 Solid Waste Management

Illegal dumping and trash were identified as a major environmental concern. Trash and debris are abundant alongside roadways and dumpster sites, most often caused by improper household waste disposal. Although bins are provided for waste disposal, they are sometimes located in areas where runoff from leaky dumpsters drains to the guts and sensitive mangrove areas.

4.1.5.1 Reduce Waste and Encourage Reuse

The most important and impactful strategy to reduce the negative impacts of solid waste is to have residents and visitors complete a lifestyle change where a **focus on reducing waste and reusing items** is the new normal. A territory wide campaign to emphasize reuse and source reduction to reduce reliance on disposal infrastructure for solid waste is critical. Options for reuse and composting are not readily available in USVI, forcing residents to put these items into the waste stream. Strategies for reducing waste include:

- **Develop an incentive program and/ or an ordinance to prevent the use of Styrofoam and plastic single use food and beverage packaging for "to go" items,**
- **Encourage residents to select products with minimal packaging, utilize reusable bags, decline plastic straws, and use refillable water bottles,**
- **Install public water refill stations in public areas,**
- **Encourage and provide educational materials on how to compost food scraps at a residential scale,**
- **Explore the feasibility of encouraging and / or incentivizing a commercial or other large scale composting facility where food scraps could be collected and processed,**
- **Sponsor or encourage repair and repurposing of items that would otherwise enter the waste stream, and**

- **Publicize the Caribbean Green Technology Center's Trash to Treasure Guide and other similar reuse guides.**

4.1.5.2 Expand Recycling Program

Another option for removing items from the waste stream involves **expanding the recycling program.** In the USVI, approximately 35% of waste is organic, 21% is paper, 13% is plastic, 11% is classified as "other" (contaminants and hazardous waste), 11% is textiles, 4% is glass, 4% is metals, and 1% is electronics.

There are funds to **begin a sustainable waste diversion and materials management program** to help reduce waste and divert waste from the Bovoni Landfill on St. Thomas and Anguilla Landfill on St. Croix to the Susannaberg Transfer Station. Through the Department of Planning and Natural Resources, VIWMA has been awarded a Solid Waste Supplemental Grant. Waste types to be diverted include green waste, scrap metal, tires and construction and demolition debris. It will also provide the much-needed equipment to divert the waste stream from the landfill (VIWMA, 2021).

4.1.5.3 Improve Waste Bin Sites

It is recommended **that waste bin sites be evaluated for waste and stormwater runoff management**. The waste bin sites are operated by the Virgin Islands Waste Management Authority (VIWMA). Each waste bin site should be evaluated for site specific issues. Additionally, designs for covered bin areas should be explored as stormwater flowing through the full waste bins and draining to surface waters can contain a number of pollutants. If used motor and cooking oil are to be accepted at a bin site, a leak proof and approved container should be supplied.

4.1.5.4 Increase Enforcement of Illegal Dumping

Per Title 19: Health, Chapter 56 § 1563, illegal dumping is subject to a fine of $1,000 and/or imprisonment. The items that are not accepted at bin sites should be brought to the most conveniently located landfill where they can be disposed of, often without a fee (depending on the item). However, illegal dumping, particularly at bin sites and along roadways, is widespread. This illegal dumping introduces hazardous and often toxic materials and other pollutants into the environment, decreases aesthetic value, and encourages additional illegal dumping. It is recommended **that enforcement of penalties for illegal dumping be enforced whenever possible. Monitoring of bin locations is also recommended via video surveillance.**

4.1.5.5 Increase Education about Proper Disposal

Accessing up to date information regarding proper disposal of items outside of normal household trash can be challenging. It is recommended that **a simple web page be developed** instructing residents how and where to dispose of items such as tires, batteries, used motor oil, used cooking oil, junk vehicles, appliances, and other waste. The site should be prominent, easy to locate, and easy to navigate. Hours of operation and fees should be clearly stated in these materials. Currently, the VIWMA website has outdated and incomplete information. Pertinent details can be difficult to locate and those that are available online often contradict. This information should also be **publicized on social media and via community groups and other community platforms**. This recommendation may also help reduce illegal dumping.

4.1.5.6 Mitigate Known Solid Waste and Hazardous Sites

As discussed in the watershed-specific sections of the plan, a number of solid waste management and hazardous waste management sites for future mitigation were documented for each of the watersheds.

Seven sites within the St. Thomas Harbor watershed were identified (Figure 99). It should be noted that the provided list of sites is not exhaustive and were collected only if observed during the course of other targeted field investigations.

Figure 99. St. Thomas Harbor watershed hazardous waste management sites identified for mitigation.

4.1.6 Research Topics

4.1.6.1 Recycling Market Study

The Green Technology Center conducted a market analysis of the waste, and it is estimated that the possible revenue stream from recycling is $6 million, with aluminum cans, plastic bottles, and cardboard being the most potentially profitable waste (Penn, 2021). A **study should be completed to assess recycling markets, existing recycling options, and determine the most feasible expansions to the recycling program** for the USVI.

4.1.6.2 Coastline Recession Mapping

Multidate high resolution aerial imagery including UAS-collected data and historic imagery could be utilized along the coastline to **accurately map areas of coastal erosion**. These areas could then be targeted for stabilization efforts including the identification of additional stormwater BMPs, the prioritization of currently proposed stormwater BMPs, the planting of coastal vegetation, or the stabilization of eroding slopes.

4.1.6.3 Sargassum Mitigation

Influxes of sargassum seaweed has been a recent ongoing issue negatively impacting coastal ecosystems, air quality, and the tourism industry. Removal by heavy equipment can cause compaction, remove coastal sand, exacerbate erosion, and impact native wildlife such as disturbing turtle nesting areas. The problem continues after the sargassum has been removed because it must be safely disposed of to prevent contamination from leachate.

Unfortunately, solutions to reduce sargassum accumulation, remove the seaweed without damaging beaches and harming wildlife, and process the collected materials are not well understood. As these unprecedented influxes likely stem from increased temperatures related to climate change and increased nutrient loads from the Amazon River as land is cleared for agricultural purposes (Wang et al., 2019), wholistic solutions to reduce the sargassum influx would require global cooperation. It is recommended that the USVI **participate in these global actions** to the extent possible and continue to **participate in and review research** related to sargassum management and take science-based actions to manage the influx while protecting wildlife. Additionally, **research related to safely disposing of sargassum** and the **potential use of the seaweed** for biofuel, fertilizer, building materials, or for other applications should be continued.

4.1.7 Watershed Stewardship Programs

4.1.7.1 Expand Targeted Residential and Commercial Campaigns

Several education and outreach programs are currently targeted to residents and the commercial and industrial sectors. However, **additional education and outreach could be expanded in terms of the scope of messages, frequency of publications, and media type** (i.e., social media posts, Story Maps, signs, workshops, handouts including the Visioning Document developed in concert with this WMP, and others). Topics of importance include but are not limited to:

- Recycling
- Reuse
- Waste reduction including reusable items like straws, water bottles, shopping bags, and others
- Proper waste disposal including hazardous materials, appliances, vehicles, tires, and others
- Stabilize exposed soils and install homeowner and small business owner scale stormwater BMPs

- Vegetation protection
- Gut importance and protection

Many of these recommendations are detailed in the **Visioning Document and Story Map** as well as the **short educational videos** that were produced to accompany this project. These materials should be used to **advance and inform these campaigns**.

4.1.7.2 Develop Targeted Educational Campaigns

In additional to residential and commercial outreach, **targeted campaigns should also be conducted to inform and educate the judiciary and other key decision makers to build awareness for the need to enforce existing regulations and promulgate new ones**. In addition, the **tourism industry should be engaged to increase stewardship of coastal areas where hotels, marinas, and restaurants are located**.

4.1.7.3 Develop Stewardship Programs

A lack of gut stewardship programs and pet waste management were concerns identified from the surveys distributed to DPNR staff. It is recommended that **water stewardship programs be developed in coordination with existing community groups** such as the Coral Bay Community Council, St. Croix Environmental Association, and Virgin Islands Conservation Society. Another resource could be the University of Vermont Volunteer Water Monitoring Network, which developed a guide for developing volunteer water monitoring programs. The Anne Arundel Watershed Stewards Academy builds capacity in Anne Arundel County, Maryland by training Master Watershed Stewards to help neighbors reduce pollution in our local creeks and rivers. These and other resources can help direct the development of similar programs in the USVI.

4.1.7.4 Develop Homeowner's Guide to Stormwater Management

In order to encourage adoption of best practices at a residential scale, it is recommended that **a homeowner and small business owner focused manual is developed to guide design and implementation of these stormwater management practices**. This guide can serve as a companion to revisions of the Environmental Protection Handbook currently underway. Examples include Vegetation for Erosion Control – A Manual for Residents published by the Coral Bay Community Council, the Homeowner Guide for a More Bay-Friendly Property from the Chesapeake Stormwater Network, and the Vermont Guide to Stormwater Management for Homeowners and Small Businesses published by the Vermont Department of Environmental Conservation.

4.1.7.5 Provide Technical and Financial Assistance to Homeowners

A **homeowner BMP cost-share program could be implemented to provide property owners financial and technical assistance in implementing stormwater BMPs** for improving water quality and reducing the amount of stormwater runoff. If for example, a stormwater utility fee program is developed (see funding mechanisms below), the BMPs developed from the cost-share program could help property owners receive a credit or reduction of their stormwater fee.

4.2 Financial and Technical Assistance Needs, Timeline, and Costs

The tables below summarize the recommendations outlined in the previous section and identify potential technical assistance and financial needs for each recommendation. The tables also include a column for the potential lead agency in implementing the recommendation from five DPNR operating divisions and three departments that have responsibilities relevant to watershed management. These include:

- Division of Coastal Zone Management (CZM)
- Division of Comprehensive and Coastal Zone Planning (CCZP)
- Division of Environmental Protection (DEP)
- Division of Fish and Wildlife (DFW)
- Division of Building Permits (DBP)
- Department of Public Works (DPW)
- Department of Agriculture (DA)
- Waste Management Authority (WMA)

An implementation timeline by year is included. It is assumed that many of these actions will be ongoing over time and thus span the entire five-year timeline and may continue into the future.

A relative cost (low = $, medium = $$, and high = $$$) was assigned for each action. These costs are based on prior projects and general knowledge as true costs are not obtainable due to the ongoing and preliminary planning level stage of these tasks.

4.2.1 Stormwater Management and Non-Stormwater Discharges

Table 34. Stormwater Management and Non-Stormwater Discharges: Technical Assistance and Financial Needs summary table.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Solution 1: Internal Operations Changes								
Complete the USVI Stormwater Standards and Design Manual and incorporate green infrastructure techniques.	DPNR DEP						$$	Staff will be required to develop and review the final product.
								Example designs for stormwater BMPs will need to be developed and reviewed by a professional engineer.
								Training will be necessary for contractors who install stormwater practices to ensure they understand the new standards and design procedures.
Finalize and adopt a revised Environmental Handbook.	DPNR DEP						$$	Staff will be required to develop and review the final product.
								The Handbook will need to be distributed to contractors and a final determination on adopting the handbook as a required guidance document will be needed.
Adopt an IDDE ordinance and develop an effective IDDE program.	DPNR DEP						$$$	A legal expert may be necessary to draft the language of the ordinance and ensure the regulatory authority necessary.
								Consultant to develop a guide or SOP for conducting IDDE in USVI.
								Training for multiple staff will be required to learn IDDE field testing procedures and remediation measures.
								Staff will need to complete a baseline survey of existing sewer infrastructure to identify any CSO/SSO problem areas and illegal discharges.
								A staff member or consultant would be required to develop and maintain a database to track discharges and enforcement decisions to ensure compliance.
								Test kits and other equipment will need to be purchased for field evaluations.
Solution 2: Policy/Program Changes								
Organize the TPDES program around the basic NPDES MS4 six minimum measures.	DPNR DEP						$$	A qualified consultant would be required to develop the organizational structure.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
								Reassignment and training of staff will be necessary to realign programs with minimum measures.
Require limits of disturbance to be shown on construction plans and physically marked at the site.	DPNR CCZP						$	A qualified DPNR staff member will need to review site plans to ensure compliance.
								An alteration of the Earth Change code will need to be enacted to make this a regulation.
Implement green infrastructure demonstration projects.	DPW						$$$	Staff would be required to catalog the type of practice, maintenance schedule, and what equipment is required to maintain the practice (i.e., hand tools or heavy equipment).
								Staff would be required to write grant applications or reallocate DPNR's existing funding.
								Staff time for outreach and education task to target the public and contractors who would be putting the practices.
Solution 3: Structural Improvements								
Final design and implementation of six highest priority BMPs (two per watershed).	DPNR						$$$	Staff will be required to manage the development of the final 100% design documents for the construction of project.
								Contractors with the required equipment, materials, and training to design and install the priority BMPs as needed.
Further design development and implementation of the remaining 24 high priority BMPs (eight per watershed).	DPNR						$$$	Staff will be required to develop or commission the preliminary 30% design documents for the construction of project
								Staff will be required to develop or commission the final 100% design documents for the construction of project
								Contractors with the required equipment, materials, and training to design and install the priority BMPs as needed.

4.2.2 Watershed Planning

Table 35. Watershed Planning: Technical Assistance and Financial Needs summary table.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Solution 1: Internal Operations Changes								
Shift from the two-tier management system in the coastal zone to a watershed approach.	DPNR CCM						$$$	Hire additional permit staff for potential increase in workload. Development of a guidance document for staff detailing the watershed approach and the changes to current procedures Training for staff on how the watershed approach differs from the tier system and how to address properties that may straddle watershed boundaries.
Adopt an updated Comprehensive Land and Water Use Plan and ensure that it accounts for impacts of future land use on water resources.	DPNR DEP						$$$	Staff will be required to develop and review the final product. Staff will need to guide the plan through the legislative adoption process. Legal expertise will be needed to address any possible conflicts with other codes or policies.
Confirm that current zoning is evaluated and revised to be consistent with the overall Comprehensive Land and Water Use Plan goals.	DPNR CCZP						$	Internal staff review time will be needed to compare current zoning to any proposed changes. Staff time may be required for public hearings as needed to make changes to zoning categories. Legal expertise will be needed to address any possible conflicts with other codes or policies.
Solution 2: Policy/Program Changes								
Review a larger suite of land use planning tools to see if additional techniques may be appropriate.	DPNR CCZP						$$	Internal staff review time will be needed to identify potential land use tools. Legal expertise will be needed to address any possible conflicts with other codes or policies.
Promote the use of conservation easements.	DPNR CCZP						$$	Gather informational materials together for applicants and provide these materials. Train DPNR review staff on how to inform and facilitate easements.
Revise the Zoning and Subdivision Code regarding small subdivisions	DPNR CCZP						$$$	Legal expertise will be needed to address any possible conflicts with other codes or policies.

4.2.3 Land Use Planning and Resource Protection

Table 36. Land Use Planning and Resource Protection: Technical Assistance and Financial Needs summary table.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Solution 1: Internal Operations Changes								
Adopt steep slope legislation to protect hilltops and prevent sediment erosion.	DPNR CCZP						$$$	Staff will need to review example steep slope legislation and draft ordinance language. The proposed legislation will need to be reviewed to address any possible legal conflicts with other codes or policies.
Adopt a tree ordinance and permit requirements for private lands.	DPNR DBP						$$	The proposed legislation will need to be reviewed to address any possible legal conflicts with other codes or policies. Staff will need to review examples of ordinance language and draft final ordinance language. Training will be required for staff and materials distributed to the public about the new legislation.
Implement a fee for proposed tree removal.	DPNR CCZP						$$	A fee schedule and tracking system for tree removal permit applications will need to be developed. Potential waivers/exemptions will need to be established by staff. Staff would be needed to implement the fee after tree ordinance is adopted.
Develop a tree canopy goal.	DPNR CCZP						$	Staff will need to review existing and projected future canopy coverage. Planting plans will need to be developed to increase tree canopy in areas where it is lacking.
Review gut locations and impacts during the permit review process and then during the construction inspection phase to afford the necessary protections to these channels.	DPNR DEP						$	Training for staff on review process and necessary protections for guts. Accurate mapping of gut locations and existing development will be needed.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Solution 2: Policy/Program Changes								
Expand buffer requirements to a minimum of 50 feet for all guts and 100 feet for guts where rare, threatened, or endangered species exist.	DPNR DEP						$	Staff time to review information to identify areas with RTE species. A decision will need to be made about existing locations that do not meet new requirements and how to deal with those situations. Legal expertise may be required if a challenge to increases in required buffer widths is expected.
Promote a zoned buffer system.	DPNR DEP						$	There will be a staff time cost for any code change work. Educational materials will be necessary, highlighting the change and allowed uses of the buffer system.
Create a gut restoration program.	DPNR DEP						$$	Staff or consultant for gut corridor assessments and development of appropriate restoration strategies. Equipment needs will include machinery for gut modification, materials for stream restoration structures, invasive species removal and stock of native species for buffer planting. Staff time and funding for education of contractors who would conduct gut restoration projects. Staff time to update the Stormwater Standards and Design Manual?
Create a program to preserve the undeveloped land within the gut headwaters.	DPNR DEP						$$	Staff time will be required to identify areas, contact landowners, and identify applicable properties where conservation easements could be applied. For some parcels, funding and legal guidance will be needed for the purchase of undeveloped areas along gut headwaters so they can be preserved. Staff time would be needed to monitor and administer program.
Actively encourage agriculture preservation.	DA						$	Gather informational materials on preservation options for applicants and provide these materials. Staff time to provide support for those interested in preserving their agricultural properties.

4.2.4 Site Design Guidelines

Table 37. Site Design Guidelines: Technical Assistance and Financial Needs summary table.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Solution 1: Internal Operations Changes								
Provide a model shared parking agreement.	DPNR CCZP						$	Staff will need time and funding to review examples of shared parking agreements and prepare and print handouts to further educate participants.
Allow for reduced parking requirements.	DPNR CCZP						$$	Staff will need time for code review of current parking requirements and analysis of impact of reduced parking requirements. Time for staff with legal expertise for necessary legal changes to update codes.
Allow a percent of commercial parking spaces for compact cars.	DPNR CCZP						$$	Staff time and funding for code change related costs.
Designate spillover parking areas for larger parking lots.	DPNR CCZP						$$	Staff time and funding for code change related costs. Time to conduct and analysis of possible spillover parking areas.
Develop landscaping requirements for parking lots.	DPNR CCZP						$	Staff time and funding for code change related costs. Development of landscaping standards for parking lots.
Enact code revisions regarding driveways allowing for the use of alternative driveway surfaces, two-track design, and shared driveways.	DPNR CCZP						$	Staff will need time for code review, training on alternative driveway options, and code revisions.
Promote the use of alternative paving materials.	DPNR CCZP						$	Contractors with the required equipment, materials, and training to install alternative paving materials are needed. Development of outreach and education materials including locations for demonstration sites.
Solution 2: Policy/Program Changes								
Place utilities under the roadways.	DPW						$	Staff time to train contractors. Funding for changes to codes and design manual. Need to make decision on how to retroactively address any exiting utilities and track so that when improvements are made to roadway the utilities are placed correctly.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Plant ROW with large trees.	DPW						$	Staff time to conduct assessment to identify potential tree planting areas. Staff time or funding for contractors for tree planting and maintenance.
Reduce the standard parking space stall width to nine feet or less.	DPNR CCZP						$	Staff time and funding for code change related costs.
Allow parking lanes to also serve as traffic lanes in higher density developments.	DPNR CCZP						$	Staff time and funding for code change related costs. Conduct traffic analysis to identify any potential impacts in any areas where conflicts may arise. Staff time for changing the lane structure. Education/outreach to the public on the changes.
Allow the use of alternate pedestrian networks in residential areas.	DPNR CCZP						$	Staff time and funding for code change related costs.
Approve flexible site design criteria for developments that utilize open space or cluster design options.	DPNR CCZP						$	Staff time and funding for code change related costs.

4.2.5 Solid Waste Management

Table 38. Solid Waste Management: Technical Assistance and Financial Needs summary table.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Solution 1: Policy/Program Changes								
Develop an incentive program and/ or an ordinance to prevent the use of Styrofoam and plastic single use food and beverage packaging for "to go" items.	WMA						$	Staff time and funding for code change related costs. Staff time for education/outreach to the public on the changes.
Expand the recycling program. Encourage residents to select products with minimal packaging, utilize reusable bags, decline plastic straws, and use refillable water bottles.	WMA						$	Staff time and funding for program development related costs including using the results of the recommended research on recycling markets and options. Staff time for education/outreach to the public on the recommendations.
Install public water refill stations in public areas.	DPW						$	Staff time and funding for implementation and to interface with private commercial business owners to install water stations on their properties.
Encourage and provide educational materials on how to compost food scraps at a residential scale.	WMA						$	Staff time to develop and distribute education and outreach to the public on the recommendations.
Explore the feasibility of encouraging and / or incentivizing a commercial or other large scale composting facility where food scraps could be collected and processed.	WMA						$	Staff will need time and funding to host workshops, find a meeting location, prepare a presentation, and prepare and print handouts to further educate participants. Funding for compost bins may be required if the program elects to distribute bins to workshop attendees.
Sponsor or encourage repair and repurposing of items that would otherwise enter the waste stream.	WMA						$	Education/outreach to the public on how to repair and repurpose items. Funding for repair or provide location for a community repair recurring event so community member can meet and fix items.
Publicize the Caribbean Green Technology Center's Trash to Treasure Guide and other similar reuse guides.	WMA						$	Staff time will be need for education and outreach to the public on reuse guides as they are released.
Evaluate waste bin locations and runoff management.	WMA						$	This process would require staff time to complete a survey or study of current locations and alternative dumpster sites. Educational materials would need to be developed such as signage to indicate any new dumpster locations. In cases where relocation is not possible, design and installation of stormwater BMPs may be necessary to prevent pollution from runoff.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Increase enforcement of illegal dumping and install monitoring network.	DPNR						$$	Additional staff time will be required to pursue enforcement of illegal dumping.
								Staff time to install and monitor monitoring equipment and funding to purchase and maintain equipment.
Mitigate known solid waste and hazardous sites.	WMA						$$	Inspection and evaluation of identified hazardous waste sites.
								Develop plans and strategies to remediate known hazardous sites.

4.2.6 Research Topics

Table 39. Research Topics: Technical Assistance and Financial Needs summary table.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Conduct a recycling market study.	DPNR						$$	Create collaboration with researchers, most likely those with UVI to initiate and complete study. Determine funding sources for study, potentially NSF grants.
Conduct a coastline recession mapping study.	DPNR						$$	Create collaboration with researchers, most likely those with UVI to initiate and complete study. Determine funding sources for study, potentially NSF grants. Budget for equipment and assessment costs.
Conduct a sargassum mitigation study	DPNR						$$	Create collaboration with researchers, most likely those with UVI to initiate and complete study. Determine funding sources for study, potentially NSF grants. Budget for equipment and assessment costs.

4.2.7 Watershed Stewardship Programs

Table 40. Watershed Stewardship Programs: Technical Assistance and Financial Needs summary table.

Action	Lead	Implementation Year					Relative Cost	Technical Assistance
		Year 1	Year 2	Year 3	Year 4	Year 5		
Solution 1: Internal Operations Changes								
Inform and educate the judiciary and other key decision makers to build awareness for the need to enforce existing regulations and promulgate new ones.	DPNR DEP						$$	Staff will need time and funding to schedule visits or find a meeting location, prepare a presentation, and prepare and print handouts to further educate participants.
Engage the tourism industry in watershed protection education.	DPNR DEP						$$	Staff will need time and funding to schedule visits or find a meeting location, prepare a presentation, and prepare and print handouts to further educate participants.
Develop stream stewardship and pet waste management programs.	DPNR DEP						$$	Potential to reduce cost for program management by partnering with an existing nonprofit organization to promote the program(s). Funding will be necessary to install dog waste stations at public parks and gathering areas. Staff time will be necessary to maintain waste stations, staff stream cleanup events, and answer questions from the community.
Solution 2: Policy/Program Changes								
Develop a stormwater guide for homeowners.	DPNR DEP						$$	DPNR staff or consultant will need to modify an existing example guide and then reproduce and distribute guide. Staff time will be required for education and outreach events for the public.
Create a homeowner BMP cost-share program.	DPNR DEP						$$	Funding will need to be identified to assist in cost share. Equipment may need to be purchased based on the BMP proposed. Staff time for education and answering homeowner questions or hiring of a consultant. Staff for tracking implementation and management of program
Distribute the Vegetation for Erosion Control – A Manual for Residents.	DPNR DEP						$	DPNR will need funding to update (as necessary), reproduce, and distribute the existing manual from Coral Bay Community Council. Staff time for education and outreach events for the public.

4.3 Implementation Strategy

4.3.1 Funding Mechanisms

Funding is a major factor in the implementation of the identified regulatory recommendations and capacity building. Local governments typically fund the departments and activities such as stormwater programs through a combination of general funds, federal grants and loans, fees/fines/penalties, or a dedicated funding source (user fees). The expectation is that the private sector will help to pay for environmental protection efforts including the proper management of stormwater generated by development and redevelopment activities or provide money to mitigate impacts by supporting offsite stormwater management activities and restoration efforts.

4.3.1.1 USVI Ordinances

There are a number of potential funding sources for watershed restoration efforts already in the current USVI codes. While some are already being used to fund programs, it appears that the language in the code provides enough latitude that funds could be used for watershed planning and protection measures with some creative thinking. Table 10 identifies funds currently authorized in the codes that could provide funding for implementation.

Table 41 highlights places in the Code that employ enforcement measures in the form of fines that could also potentially be used for watershed implementation. The fines (Table 42) can help to ensure compliance with the code and discourage violation of enacted policies.

One thing that was noted by staff is that some of the fines and fees associated with certain programs may be outdated and undervalued. It would be wise to **review the current fee structure and make adjustments** to better reflect the actual cost for conducting plan reviews and other programs to determine if additional funds can be created to assist in staffing and equipment issues. Another note is that some of the funds have maximum caps that require additional funds be moved to the general fund once the threshold has been reached. A review of those thresholds to increase them and provide more funding to programs that support the goals the fund was originally created to accomplish is recommended.

Table 41. Current Funding Mechanisms Related to Watershed Planning.	
Code	**Funding Description**
12 V.I.C.§ 81a. Fish and Game Fund Chapter 1 Wildlife. Subchapter VI Wildlife Restoration	The proceeds from all firearms licenses, all excise taxes on firearms, parts and ammunition, all fines imposed by the courts for violation of the fish, game or conservation laws, and all monies obtained as described in Chapter 9A, Section 314 of this title, shall be covered into a special fund in the Treasury of the United States Virgin Islands to be designated as the "Fish and Game Fund". However, if the balance in the Fish and Game Fund equals $250,000, all monies which would otherwise be covered into such Fund shall be deposited in the General Fund.
12 V.I.C § 81d. Fish and Wildlife Restoration Trust Fund Chapter 1 Wildlife. Subchapter VI Wildlife Restoration	(1) The funds in the Trust under this section may be used exclusively for fish restoration and management projects pursuant to 12 V.I.C. § 81c.
12 V.I.C. § 711. Virgin Islands Coastal Protection Fund	(1) The Virgin Islands Coastal Protection Fund is established to be used by the Department as a revolving fund for carrying out the purposes of this chapter. The fund shall be limited to the sum of one million ($1,000,000) dollars. To this fund shall be credited all license fees, penalties and other fees and charges related to this chapter, including administrative expenses, and costs of removal of discharges of pollution.
33 V.I.C. § 33. Acquisition of certain lands, expenditures Chapter 2A. Territorial Park Trust Fund	The Board may authorize expenditures from the Fund for the following purposes: (1) to acquire lands that represent the ecological diversity of the Virgin Islands, including natural features such as rivers, coastal, and geologic systems and other natural areas; (2) to provide for the preservation and conservation of land for recreational, scientific, educational, cultural, and aesthetic purposes; and (3) to acquire additional lands for parks, trails, aesthetic forests, fish and wildlife management areas, scenic rivers, and natural areas for the use and enjoyment of the public.
33 V.I.C. § 3004. Land Bank Fund Subtitle 3 Finance > Chapter 111. Government Fund	Monies pertaining to the Land Bank Fund shall be available for purchases, authorized by law, of real property (including improvements thereon) for purposes of public housing, outdoor recreation, conservation, or any other public uses or purposes.

Table 42. Current Fines in USVI Code that Could Fund Watershed Planning.

Code	Fine Description
12 V.I.C.§ 107. Penalties Chapter 2. Protection of Indigenous, Endangered and Threatened Fish, Wildlife and Plants	Any person violating any provision of this chapter shall, upon conviction thereof, be subject to a fine of not less than $100, and not more than $10,000.
12 V.I.C.§ 125. Penalties for violation Chapter 3. Trees and Vegetation Adjacent to Watercourses	Whoever violates any provision of this chapter shall be fined not more than $100 or imprisoned not more than 180 days, or both.
12 V.I.C.§ 145. Penalties Chapter 3A. Community and Heritage Tree Law	(a) Any person or entity that violates any provision of this chapter by causing, contributing to, or permitting the injury of, removal, or destruction of a public tree, shrub or a heritage tree is subject to a civil penalty of not less than $100, but not more than $500 for each violation.
12 V.I.C.§ 164. Penalties Chapter 5. Water Resources Conservation	(a) Any person who willfully violates any of the provisions of this chapter or of the rules and regulations promulgated pursuant thereto shall be fined not more than $500 or imprisoned for not more than 6 months, or both.
12 V.I.C § 536. Inspections and enforcement Chapter 13. Environmental Protection	(b) Any person who fails to secure an Earth Change Permit under section 534 of this title, fails to pay the Earth Change Permit fee, or violates any provision of an Earth Change Permit shall be subject to a civil penalty of $200 per day per violation.
12 V.I.C.§ 538. Violations Chapter 13. Environmental Protection	(a) Any violation of this chapter shall be deemed a misdemeanor, and the person, partnership, or corporation who is found guilty of such violation shall be subject to a fine not exceeding $5,000- or one-year's imprisonment for each and every violation.
12 V.I.C § 913. Enforcement, penalties, and judicial review Chapter 21. Virgin Islands Coastal Zone Management	(3) In addition to any other penalties provided by law, any person who intentionally and knowingly performs any development in violation of this chapter shall be subject to a civil fine of not less than one thousand dollars nor more than ten thousand dollars per day for each day during which such violation occurs.
29 V.I.C. § 296. Fees and fines for building permits Chapter 5 Building Code Subchapter II. Permits, Appeals, and Fees	(b) Fees are payable at the Department of Planning and Natural Resources as follows: (1) A nonrefundable deposit of $40/commercial and $20/residential at the time of filing the application for all permits. (d) The fee for a permit authorizing the demolition of any building or structure or appurtenances connected or attached to such building or structure shall be $50/residential and $100/commercial or two cents per square foot for residential properties and five cents per square foot for commercial properties, whichever is greater. If, however, the demolition of the structure is included as part of the permitted construction phase, then the fee shall be calculated per square-footage cost and added to the building permit fee. (e) The fee for a Certificate of Use and Occupancy shall be $50 for residential premises and $100 for commercial premises. (f) The fee for a permit authorizing the placing, erecting, construction, or affixing of any sign to any post, fence, building, or structure for out-of-doors advertising shall be $50. (g) Any person who fails to secure a permit or certificate under this chapter or regulation, fails to pay the permit or certificate fee, or violates any provision of any permit or certificate issued under this chapter or regulation shall be subject to a civil penalty of $1500 per day per violation

Table 42. Current Fines in USVI Code that Could Fund Watershed Planning.	
Code	**Fine Description**
12 V.I.C § 913. Enforcement, penalties and judicial review Chapter 21. Virgin Islands Coastal Zone Management	1) Any person who violates any provision of this chapter, or any regulation or order issued hereunder, shall be subject to a civil fine of not to exceed ten thousand ($10,000) dollars.

4.3.1.2 Grant Funding Sources

Federal grants provide additional funding sources. Table 43 below provides a summary of grant funding opportunities.

Table 43. Grant program funding sources.	
Program	**Description**
Coastal Zone Management Act Section 309 Grants	Improvements to state and territory coastal management programs are encouraged through this program. The focus is on nine enhancement areas: wetlands, coastal hazards, public access, marine debris, cumulative and secondary impacts, special area management plans, ocean and Great Lakes resources, energy and government facility siting, and aquaculture. The program was established in 1990 under Section 309 of the Coastal Zone Management Act. Every five years, states and territories review their programs to identify priority needs and opportunities for improvement. The programs then work with NOAA to develop multi-year improvement strategies that focus on one or more of the priority enhancement goals. https://coast.noaa.gov/czm/enhancement/
NFWF Coastal Resilience Fund	The NFWF National Coastal Resilience Fund restores, increases and strengthens natural infrastructure — the landscapes that help absorb the impacts of storms and floods — to protect coastal communities while also enhancing habitats for fish and wildlife. In partnership with NOAA. Shell Oil Company, TransRe, and beginning in 2020, the U.S. Environmental Protection Agency and AT&T, NFWF invests in projects that plan for, design, build, and monitor the restoration or expansion of natural features such as coastal marshes and wetlands, dune and beach systems, oyster and coral reefs, forests, coastal rivers, and barrier islands that minimize the impacts of storms and other naturally occurring events on nearby communities. https://www.nfwf.org/programs/national-coastal-resilience-fund?activeTab=tab-3
US Housing and Urban Development	Community Development Block Grant (CDBG). This funding can be used for projects under the Infrastructure Repair and Resiliency Program to address issues with solid waste.

4.3.1.3 Additional Potential Funding Mechanisms

Additional potential funding mechanisms that could be considered for implementation in the USVI are provided in Table 44 below.

Table 44. Additional potential funding mechanisms.

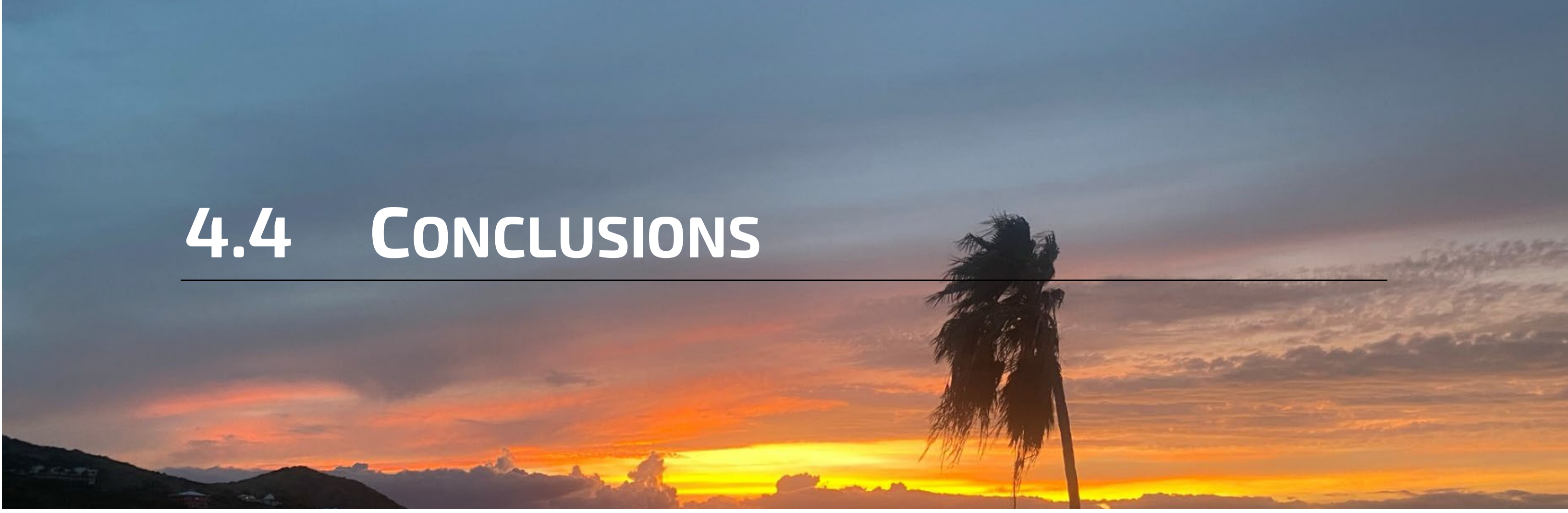
Funding Mechanism	Description
Public Works Hazard Mitigation and Infrastructure Improvement Funds	Ability to incorporate stormwater infrastructure upgrade projects. Can interview Peter from public works to discuss specifics of the program.
Fee-in-lieu Programs	For sites where stormwater management or impervious cover waivers are proposed, a fee-in-lieu program could be used to fund environmental protection efforts.
Stormwater Utility Fee	Similar to a water or sewer fee, a stormwater fee is a recurring user fee charged to property owners by a stormwater utility for the service of managing the stormwater runoff and associated pollutants coming from their property. The fee is calculated based on the demands a property places on the drainage system and is administered separately from general tax fund, ensuring sustainable and adequate funding for these public services.
Tourism Revenue Sources	Work with the Department of Tourism to identify tourism related revenues to conserve and enhance the natural resources that are the foundation of a long-term, robust, and resilient tourism and recreation economy for the Virgin Islands. https://coast.noaa.gov/data/czm/media/usvi-cmp.pdf

4.3.2 Monitoring Program

During the development of this WMP, extensive gut monitoring was carried out in the priority guts within the study watersheds. Several important conclusions were drawn from this initial monitoring. These include:

- Monitoring ephemeral guts is challenging given the variable rainfall patterns and recent history of drought and low antecedent moisture conditions.
- Rain gauges often did not record the storm events being sampled due to the conditions noted in the first conclusion.
- The majority of flowing guts had significant indicators of water quality impairment.

As a next step in this baseline data collection, it is recommended that **monitoring be completed at other key locations in the watersheds of concern**. Monitoring should be carried out over a longer time span with a focus on the rainy season. For guts that have already been monitored, it is recommended that **bracket sampling be completed to isolate potential sources of pollutants** that are likely from point source locations such as heavy metals. Sources should then be addressed as appropriate for the site-specific conditions. All monitored guts with flow during the study period had exceedingly high sediment and nutrient loads. Similar bracket sampling paired with an assessment of the contributing drainage area for likely significant sources of this land-based pollution is recommended for these sites to identify the largest source of these pollutants. Erosion control and stormwater BMPs are recommended as a priority for these locations.



4.4 CONCLUSIONS

This Watershed Management Plan is a comprehensive document meant to document watershed-specific conditions related to water quality, flood risk, and resiliency. A monitoring and modeling component helped to understand the importance of land based sources of pollution within the watershed. A review of current policies and procedures provided insight into the current mechanisms for addressing these pollutants and enforcing the aforementioned policies. This allowed the project team to develop a list of actionable, achievable, and informed recommendations to improve water quality, reduce flooding, and increase resiliency in our changing climate.

Each watershed is an interconnected, complex, and unique area. One of the most important conclusions from this watershed management planning approach is that the entire watershed, from ridge to reef, needs to be considered. However, as conditions change over time and many of the provided recommendations are implemented, new challenges and opportunities will become more prominent. Additionally, many of these recommendations are complex and expensive and will take many years to properly implement. As such, **this Watershed Management Plan should be reassessed and updated on a five-year timeline**.

5 References

Alderson, D. L., Bunn, B. B., Eisenberg, D. A., Howard, A. R., Nussbaum, D. A., & Templeton, J. (2018). Interdependent infrastructure resilience in the US Virgin Islands: Preliminary assessment. Naval Postgraduate School Technical Report NPS-OR-18-005.

Bonnin, G., Martin, D., Lin, B., Parzybok, T., Yekta, M., & Riley, D. (2006). Precipitation-Frequency Atlas of the United States. Volume 3 Version 4.0. Puerto Rico and the US Virgin Islands.

Bowden, J. H., Terando, A. J., Misra, V., Wootten, A., Bhardwaj, A., Boyles, R., Gould, W., Collazo, J. A., & Spero, T. L. (2021). High-resolution dynamically downscaled rainfall and temperature projections for ecological life zones within Puerto Rico and for the US Virgin Islands. International Journal of Climatology, 41(2), 1305–1327.

Bowman, G. T., & Delfino, J. J. (1982). Determination of total Kjeldahl nitrogen and total phosphorus in surface waters and wastewaters. Journal (Water Pollution Control Federation), 1324-1330.

Brander, L. M., & Van Beukering, P. (2013). The Total Economic Value of U.S. Coral Reefs: A Review of the Literature. NOAA Coral Reef Conservation Program, Silver Spring, MD. 32 p.

Brown, E., Caraco, D., & Pitt, R. (2004). Illicit discharge detection and elimination: A guidance manual for program development and technical assessments. Center for Watershed Protection, Ellicott City, MD & University of Alabama, Tuscaloosa, AL.
https://www3.epa.gov/npdes/pubs/idde_manualwithappendices.pdf

Buchanan, D. (2020). Frederiksted Celebrates the Coming of Clean Water. The St. Thomas Source. https://stthomassource.com/content/2020/01/13/frederiksted-celebrates-the-coming-of-clean-water/

The Cadmus Group, Inc. (2011). Watershed Characterization and Planning for Pathogen Source Reduction in the U.S. Virgin Islands. U. S. Environmental Protection Agency Region 2.

Center for Disease Control (CDC). n.d. A Guide to Drinking Water Treatment Technologies for Household Use. Retrieved from: https://www.cdc.gov/healthywater/drinking/home-water-treatment/household_water_treatment.html.

Center for Watershed Protection (CWP). (1998). Better Site Design A Handbook for Changing Development Rules in Your Community (Part 2). Center for Watershed Protection, Ellicott City, MD. https://owl.cwp.org/mdocs-posts/better-site-design-part-2/

Center for Watershed Protection (CWP). (2017). The Codes and Ordinances Worksheet. A Tool for Evaluating the Development Rules in your Community. Center for Watershed Protection, Ellicott City, MD.

ClimaTemps. n.d. Rainfall/Precipitation in Christiansted, St. Croix, U.S. Virgin Islands. Retrieved from: http://www.us-virgin-islands.climatemps.com/precipitation.php (Retrieved May 2021).

Cox, D., Arikawa, T., Barbosa, A., Guannel, G., Inazu, D., Kennedy, A., Li, Y., Mori, N., Perry, K., Prevatt, D., Roueche, D., Shimozono, T., Simpson, C., Shimakawa, E., Shimura, T., & Slocum, R. (2019). Hurricanes Irma and Maria post-event survey in US Virgin Islands. Coastal Engineering Journal, 61(2), 121–134. https://doi.org/10.1080/21664250.2018.1558920

Culbertson, S., Nunez-Neto, B., Acosta, J. D., Cook, C. R., Lauland, A., Leuschner, K. J., Nataraj, S., Preston, B. L., Resetar, S. A., Resnick, A. C., Roberts, P. S., & Shatz, H. J. (2020). Recovery in the U.S. Virgin Islands: Progress, Challenges, and Options for the Future. RAND Corporation. https://doi.org/10.7249/RRA282-1

Gardner, L., Henry, S., & Thomas, T. (2008). Watercourses as landscapes in the U.S. Virgin Islands: State of knowledge (noaa:924). https://repository.library.noaa.gov/view/noaa/924

GreenInfo Network and the Great Basin Cooperative Ecosystem Studies Unit at Boise State University. (2016). Completing America's Inventory of Public Parks and Protected Areas. Retrieved from: http://www.protectedlands.net/wp-content/uploads/2014/09/ParksOpenSpace_PolicyPaperNov2016Final.pdf

Heartsill-Scalley, T., & Crowl, T. A. (2021). Tropical forest understorey riparian and upland composition, structure, and function in areas with different past land use. Applied Vegetation Science, 24(3).

Hernández, W. J., Ortiz-Rosa, S., Armstrong, R. A., Geiger, E. F., Eakin, C. M., & Warner, R. A. (2020). Quantifying the effects of Hurricanes Irma and María on coastal water quality in Puerto Rico using moderate resolution satellite sensors. Remote Sensing, 12(6), 964.

Hirshman, D., & Kosco, J. (2008). Managing Stormwater in Your Community: A Guide for Building an Effective Post-Construction Program. EPA Publication No: 833-R-08-001. Center for Watershed Protection, Ellicott City, MD.

Kapustka, L.A., W.H. Clements, L. Ziccardi, P.R. Paquin, M. Sprenger and D. Wall, (2004). Issue Paper on the Ecological Effects of Metals. Submitted by ERG to U.S. Environmental Protection Agency, Risk Assessment Forum, Washington, DC.

Kendall, M.S., L.T. Takata, O. Jensen, Z. Hillis-Starr, and M.E. Monaco. (2005). An Ecological Characterization of Salt River Bay National Historical Park and Ecological Preserve, U.S. Virgin Islands. NOAA Technical Memorandum NOS NCCOS 14, 116 pp.

Mallin, M. A., Turner, M. I., McIver, M. R., Toothman, B. R., & Freeman, H. C. (2016). Significant reduction of fecal bacteria and suspended solids loading by coastal best management practices. Journal of Coastal Research, 32(4), 923–931.

Moolenaar, R., & Paiewonsky, M. (2005). Legacies of Upstreet: The Transformation of a Virgin Islands Neighborhood. We From Upstreet. https://books.google.com/books?id=eLfOAAAACAAJ

NOAA. (2018). Final Evaluation Findings U.S. Virgin Islands Coastal Management Program December 2007 to August 2017. Office for Coastal Management, NOAA, US Dept. of Commerce. https://coast.noaa.gov/data/czm/media/usvi-cmp.pdf

Platenberg, R. J. and J. M. Valiulis. (2018). United States Virgin Islands Wildlife Action Plan, Vol. 1: Management Framework. Final report to the USVI Department of Planning and Natural Resources Division of Fish and Wildlife. University of the Virgin Islands and St. Croix Environmental Association, US Virgin Islands.

Platenberg, R. J. (2006). Wetlands conservation plan for St. Thomas and St. John, US Virgin Islands. Division of Fish and Wildlife.

RMSI Private Limited. (2021). Natural Hazard Risk Analysis for the U.S. Virgin Islands Flood Analysis and Exposure Report. University of the Virgin Islands.

Rothenberger, J. P., & Henderson, L. M. (2019). United States Virgin Islands' Coral Reef Management Priorities 2020-2025. V.I. Department of Planning and Natural Resources Division of Coastal Zone Management.

Schueler, T. R. (1987). Controlling urban runoff: A practical manual for planning and designing urban BMPs. Metropolitan Washington Council of Governments Washington, DC.

Schueler, T.R., Fraley-McNeal, L., and Cappiella, K. (2009). Is Impervious Cover Still Important? Review of Recent Research. Journal of Hydrologic Engineering. American Society of Civil Engineers. P. 309-315.

Shirley, R., Jones, C., & Kammen, D. (2012). A household carbon footprint calculator for islands: Case study of the United States Virgin Islands. Ecological Economics, 80, 8-14.

Source Staff. (2019a). Island Administrators Tagging Abandoned Vehicles for Removal. The St. Thomas Source. https://stthomassource.com/content/2019/07/16/island-administrators-tagging-abandoned-vehicles-for-removal/

Source Staff. (2019b). Island Administrators Have Over 200 Abandoned Vehicles Removed. The St. Thomas Source. https://stthomassource.com/content/2019/05/28/island-administrators-have-over-200-abandoned-vehicles-removed/

Storlazzi, C.D., Reguero, B.G., Cole, A.D., Lowe, E., Shope, J.B., Gibbs, A.E., Nickel, B.A., McCall, R.T., van Dongeren, A.R., and Beck, M.W., (2019), Rigorously valuing the role of U.S. coral reefs in coastal hazard risk reduction: U.S. Geological Survey Open-File Report 2019–1027, 42 p., https://doi.org/10.3133/ofr20191027.

Sweet, W.V., B.D. Hamlington, R.E. Kopp, C.P. Weaver, P.L. Barnard, D. Bekaert, W. Brooks, M. Craghan, G. Dusek, T. Frederikse, G. Garner, A.S. Genz, J.P. Krasting, E. Larour, D. Marcy, J.J. Marra, J. Obeysekera, M. Osler, M. Pendleton, D. Roman, L. Schmied, W. Veatch, K.D. White, and C. Zuzak, (2022): Global and Regional Sea Level Rise Scenarios for the United States: Updated Mean Projections and Extreme Water Level Probabilities Along U.S. Coastlines. NOAA Technical Report NOS 01. National Oceanic and Atmospheric Administration, National Ocean Service, Silver Spring, MD, 111 pp. https://oceanservice.noaa.gov/hazards/sealevelrise/noaa-nostechrpt01-global-regional-SLR-scenarios-US.pdf

Tobias, W. J. (1996). The determination of mangrove habitat for nursery grounds of recreational fisheries in Salt River and Altona Lagoon, St. Croix, US Virgin Islands. Final Report F-7, Division of Fish and Wildlife, St. Croix, US Virgin Islands.

U.S. EPA. (2008). Handbook for developing watershed plans to restore and protect our waters. U.S. Environmental Protection Agency, Office of Water, Nonpoint Source Control Branch, Washington, DC.

U.S. EPA. (1993). Guidance for Specifying Management Measures for Sources of Nonpoint Pollution in Coastal Waters. U.S. Environmental Protection Agency, Office of Oceans, Wetlands and Watersheds, Washington, DC.

USGS. (2013). Mineral commodity summaries 2013. U.S. Department of the Interior. U.S. Geological Survey. Reston, VA, 198 pp.

USVI DPNR. (2020). 2020 USVI Integrated Water Quality Monitoring & Assessment Report. V.I. Department of Planning and Natural Resources, Division of Environmental Protection. http://dnpr.vi.gov

USVI DPNR. (2019). Amended Virgin Islands Water Quality Management Program Water Quality Standards Rules and Regulations. USVI Code (12 V.I.C § 186). https://www.epa.gov/sites/production/files/2014-12/documents/viwqs.pdf

USVI DPNR. (2018). 2018 USVI Integrated Water Quality Monitoring & Assessment Report. V.I. Department of Planning and Natural Resources, Division of Environmental Protection. http://dnpr.vi.gov

USVI Hurricane Recovery and Resilience Task Force. (2018). USVI Hurricane Recovery and Resilience Task Force: Report 2018 (p. 280). Federal Emergency Management Agency. https://reliefweb.int/sites/reliefweb.int/files/resources/USVI%20Task%20Force%20Initial%20Report.pdf

UVI. (2009). Waves of Change: A Resource for Environmental Issues in the U.S. Virgin Islands.

VanBriesen, J. M. (2014). Potential drinking water effects of bromide discharges from coal-fired electric power plants. EPA NPDES Comments, 1-38.

VIWMA. (2021). Testimony on Updates Relative to VIWMA Initiatives, Programs, Projects, and Processes Related to the Territory's Infrastructure. Retrieved from: https://www.legvi.org/committeemeetings/Committee%20on%20Disaster%20Recovery%20and%20Infrastructure/Thursday,%20April%2029,%202021/Testimony%20VIWMA%204.29.21.pdf.

VIWMA. (n.d). Wastewater. Retrieved from: http://www.viwma.org/index.php/post-formats/wastewater (May 2021).

M. Wang, C. Hu, B.B. Barnes, G. Mitchum, B. Lapointe, J.P. Montoya. (2019). The great Atlantic Sargassum belt. Science. Volume 365, No. 6448. science.org/doi/pdf/10.1126/science.aaw7912

Science, 365 (2019), pp. 83-87, 10.1126/science.aaw7912Wayland, K. G., Long, D. T., Hyndman, D. W., Pijanowski, B. C., Woodhams, S. M., & Haack, S. K. (2003). Identifying relationships between baseflow geochemistry and land use with synoptic sampling and R-mode factor analysis. Journal of Environmental Quality, 32(1), 180–190.

Zak, D., Hupfer, M., Cabezas, A., Jurasinski, G., Audet, J., Kleeberg, A., McInnes, R., Kristiansen, S.M., Petersen, R.J., Liu, H., Goldhammer, T. (January 2021). Sulphate in freshwater ecosystems: A review of sources, biogeochemical cycles, ecotoxicological effects and bioremediation. Earth-Science Reviews, 212. https://doi.org/10.1016/j.earscirev.2020.103446.