Appendix E, Attachment H – Hydrology & Drainage – Assessment of Alternatives

Environmental Statement

East-West Arterial Extension:

Section 2 (Woodland Drive – Lookout Road)
Section 3 (Lookout Road – Frank Sound Road)

Hydrology and Drainage FINAL

Assessment of Alternatives Grand Cayman East-West Arterial Extension

NRA
NATIONAL ROADS
AUTHORITY

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List of Terms

ac	Acre
Baird	W.F. Baird and Associates Coastal Engineers, LTD
°C	Degree Celsius
cm	Centimetre
CMW	Central Mangrove Wetland
Defra	Department for Environment Food and Rural Affairs
DEH	Department of Environmental Health
DMRB	Design Manual for Road and Bridges
DoE	Department of Environment
EIA	Environmental Impact Assessment
ERP	Environmental Resource Permit
EWA	East West Arterial
°F	Degree Fahrenheit
FDOT	Florida Department of Transportation
ft	Foot
ha	Hectare
hr	Hour
IDF	Intensity-Duration-Frequency
in	Inch
K	Horizontal hydraulic conductivity
km	Kilometre
kph	Kilometres per hour
LiDAR	Light detection and ranging
m	Metre
mi	Mile
mm	Millimetre
mph	Miles per hour
NCA	National Conservation Act
NRA	National Roads Authority
NT	National Trust

Plan	Meagre Bay Pond Management Plan
Pond	Meagre Bay Pond
RVE	Remington & Vernick Engineers
SFWMD	South Florida Water Management District
SuDS	Sustainable Drainage Systems
WebTAG	UK Department for Transport "Transport Analysis Guidance"
WMD	Water Management District
WRA	Whitman, Requardt & Associates, LLP

1 Introduction

The East-West Arterial (EWA) Extension Environmental Impact Assessment (EIA) is proposed to evaluate an alternative east-west travel route on Grand Cayman. The Terms of Reference (ToR) for the proposed EWA Extension EIA was finalized on April 4, 2023. Since then, five Build alternatives (B1, B2, B3, B4, and C1), in addition to the No-Build scenario, were developed and assessed as part of the Longlist Alternatives Evaluation. A separate Longlist Alternatives Evaluation Document has been prepared to document this analysis.

As a result of the Longlist Alternatives Evaluation, four Build alternatives (B1, B2, B3, and B4) and the No-Build scenario were advanced as a shortlist for evaluation. This report focuses on the assessment of hydrology and drainage for these shortlisted alternatives. Information from this report will be incorporated within the Shortlist Alternatives Evaluation Document and Environmental Statement.

2 Shortlist Evaluation

Hydrology and drainage are important processes on Grand Cayman and within the EWA EIA study area (**Figure 1**). These processes support the health and safety of residents and natural resources. Applicable governmental standards were reviewed, and baseline conditions were assessed for the Island's hydrology and drainage processes, including the influences of topography, climate, tropical storms and hurricanes, and storm surge and flood risk. In addition, hydrologic and drainage functions of natural resources, including the Central Mangrove Wetland (CMW) and Mastic Reserve have been considered, as well as the hydrologic interaction of the Meagre Bay Pond.

A field assessment was conducted in July 2023 to observe hydrology and drainage processes on Grand Cayman and the natural resources within the EIA study area. Technical studies and analyses were also requested by the NRA and performed by W. F. Baird & Associates Coastal Engineers, LTD (Baird) and Remington & Vernick Engineers (RVE) in support of this EIA and included rainfall analysis, hydrology and hydraulic analysis, water budget analysis for the CMW, and a coastal risk study. In addition, a groundwater mounding analysis of the freshwater lenses was requested by the National Roads Authority (NRA) and performed by Whitman, Requardt & Associates, LLP (WRA). Potential impacts for each of the shortlist alternatives, including the No-Build scenario and Build alternatives (**Figure 1**), were assessed based on the baseline conditions, field assessment, and the studies performed utilizing the proposed 2074 roadway design for each alternative. Additional evaluation will occur as part of the upcoming Preferred Alternative assessment in order to refine the Preferred Alternative design and conceptually design features such as the stormwater conveyance and treatment systems, bridge openings, and erosion control designs.

The Shortlist of Alternatives includes the No-Build scenario and four Build alternatives (B1, B2, B3, and B4) as shown in **Figure 1.** The four Build alternatives share the same common section beginning at the western terminus, near Woodland Drive, and continuing east to near Lookout Road (**Figure 1**). They also share the same common improvements to the local roadway network referred to as the Will T Connector. Additional details describing the

Shortlist of Alternatives including full descriptions of each alternative along with typical design sections can be found in the Shortlist Evaluation Document.

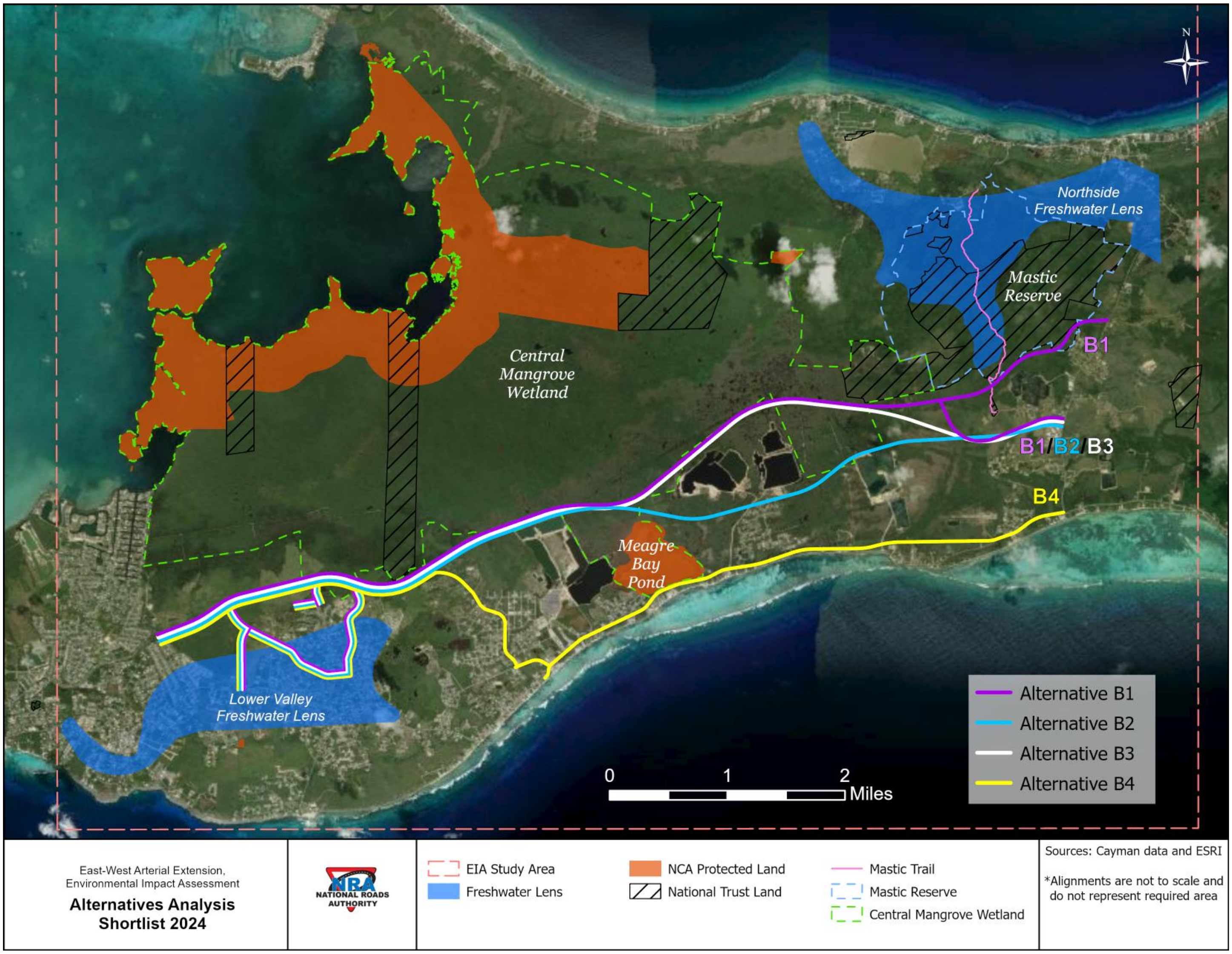

Figure 1: Shortlist of Build Alternatives

3 Data Sources Evaluated

A variety of sources of information were evaluated throughout the study process and applicable standards of various national and international governmental entities were assessed. Technical reports and papers, in addition to data provided by the Cayman Islands government, were used to develop baseline conditions for the overall hydrology and drainage processes and specifically for selected natural resources. The data sources utilized are listed in the References section, including the sources listed below.

There are limitations to the data provided for evaluation. The reports provided by Baird and RVE and listed below detail limitations to their modelling results. These limitations include the absence of the northern spur in the Alternative B1 modelling, the inability to include community-level drainage design and analysis at the scale of the modelling provided, a need for refined ground topography through areas such as the CMW where tree cover affects the accuracy of the ground readings, in addition to other limitations. However, the results of this data are sufficient to complete the comparative analysis required for this stage of the EIA process. Additional study is recommended for more refined design analysis in the future.

The following spreadsheets, files and data were provided by the Cayman Islands Department of Environment (DoE):

- Provided November 2022:
    - Lands protected under the National Conservation Act (NCA) of 2013 (*.shp shapefile)
    - Lands owned by the Cayman Islands National Trust (NT) (*.shp shapefile)
- Provided July 2023:
    - Central Mangrove Wetland (CMW) (*.shp shapefile)
    - Mastic Reserve and Mastic Trail (*.shp shapefile)

The following geospatial datasets were provided by the Cayman Islands government and other sources:

- Provided by the Cayman Islands Land and Survey Department on August 4, 2023:
    - Light detection and ranging (LiDAR) LAS geospatial data
- "Drain Well" shapefile provided by the National Roads Authority (NRA) on August 4, 2023
    - Note: Shapefile is not a comprehensive list of all drain wells in the area and does not include areas within private developments.
- Satellite imagery from Google Earth Pro dated between June 5, 2023 to September 15, 2023

The following reports were provided by Baird and RVE:

- Provided by Baird on April 3, 2024:
    - Cayman East-West Arterial Extension, Flood Modeling and Roadway Drainage Openings – Final Report.
- Provided by RVE in March, 2024:
    - Hydraulic and Hydrologic Studies of Proposed East-West Arterial Roadway Expansion, Hydraulic Modelling – Alternatives Assessment
- Provided by RVE in April, 2024:
    - Hydraulic and Hydrologic Studies of Proposed East-West Arterial Roadway Expansion, Memorandum 3 – Water Budget Analysis
- Provided by RVE on August 11, 2022:
    - Hydraulic and Hydrologic Studies of Proposed East-West Arterial Highway Expansion, Memorandum 1 – Preliminary Rainfall Analysis
- Provided by RVE in March, 2024:
    - Hydraulic and Hydrologic Studies of Proposed East-West Arterial Highway Expansion, Memorandum 2 – Hydrology and Hydraulic (H&H) Analysis

4 Review of Applicable Standards

The Cayman Islands have limited existing regulations that cover a variety of hydrology and drainage topics. However, there are several international standards and regulations that were considered for this evaluation. For the topics that are not included in the Cayman Island regulations, international standards from the UK, Canada, United States of America (US), and global standards were utilized. Specifically, there are no Cayman Island regulations covering environmental water quality for roadway stormwater runoff. Coordination with the Cayman Island DoE, Water Authority (WAC), and Department of Environmental Health (DEH) is suggested as part of the Preferred Alternative assessment to determine the applicable governing standards for environmental water quality.

4.1 Cayman Islands

The Cayman Islands have some existing documents covering hydrology and drainage in general; however, there are no specific regulations handling this subject matter. One such document is the Planning Department's Grand Cayman Stormwater Management Guidelines. This document discusses general requirements for stormwater runoff and suggestions for small scale alternative environmental water quality treatment methods.

The Cayman Islands also enacted the EIA Directive which was issued in accordance with the NCA and contains requirements and directives regarding the development of EIAs.

4.2 International (UK, US, Canada, General International)

Various international standards were researched and considered regarding their application in the Cayman Islands. One such standard is the General Environmental Health and Safety Guidelines endorsed by the International Finance Corporation and World Bank Group. This document covers standards involving ambient environmental water quality and contamination. The document sets forth target levels to achieve reductions in certain contaminates. The document also lists general standards regarding construction activities.

Numerous Canadian standards were also researched and reviewed. The Ontario Stormwater Management Planning and Design Manual covers topics such as environmental water quality and quantity requirements and design recommendations for water treatment and conveyance facilities. British Columbia's Stormwater Planning Guidebook was also reviewed. This document covers methods for developing water protection strategies and provides details related to the design of stormwater treatment features. In addition, the City of Moncton Design Criteria Manual for Municipal Services was also reviewed. This document covers design of stormwater conveyance, management systems, and stormwater treatment requirements for the City of Moncton in New Brunswick, Canada.

UK standards were also researched and reviewed including the Department for Environment Food and Rural Affairs (Defra) River Basin Management Plans. These documents cover regulations for specific water bodies and detail environmental water quality and protection requirements in the basins of interest. The documents also provide discussion related to highway runoff treatment and the use of Sustainable Drainage systems (SuDS). The Defra Non-Statutory Technical Standards for Sustainable Drainage Systems was analysed; it covers design methods and considerations for

SuDS. Another document that was reviewed was the Design Manual for Road and Bridges (DMRB) LA 113 Road Drainage and the Water Environment. This document covers environmental water quality and flood risk requirements for roadways.

US standards considered included several nationwide sources such as the US Department of Agriculture Natural Resources Conservation Service National Engineering Handbook, as well as standards developed by the State of Florida. The standards for the state of Florida were considered because of the geographical proximity to the Cayman Islands as well as the fact that the state standards cover the regulations for the Florida Keys, which have a similar topography and tropical weather conditions to the Cayman Islands. Tropical insular nation standards were reviewed but none of the locations reviewed contained sufficient detail on hydrology and drainage topics. The most similar location standards identified were the local regulations for the Florida Keys.

Regarding environmental water quality, the state of Florida environmental water quality regulations are governed by five Water Management Districts (WMDs) as well as the Florida Department of Environmental Protection. The WMDs developed a two-part Environmental Resource Permit (ERP) Applicants Handbook that details the environmental water quality regulations for the state. All of the WMDs share the same version of Volume 1 of this manual which covers topics such as the legal basis for environmental water quality regulation, special basin criteria, wetland impacts, and operation and maintenance requirements. Volume 2 of the Applicants Handbook is specific to each WMD. For this application, the version developed by the South Florida WMD (SFWMD) was analysed because this is the district that governs environmental water quality in the Florida Keys. Volume 2 of the ERP Applicants Handbook details environmental water quality treatment requirements and states that the treatment requirements are based on the treatment system used. The Handbook also details additional treatment for discharges to environmentally sensitive or compromised water bodies.

Chapter 62-777 of the Florida Administrative Code was also reviewed for applicability. This regulation details contaminants of concern, as well as target levels to achieve cleanup of sites affected by these contaminants. This document is currently used on Grand Cayman for general reference and guidance in environmental water quality matters.

Florida Department of Transportation (FDOT) regulations and guidance documents were also reviewed. The FDOT Drainage Manual sets forth drainage design standards for roadway projects and addresses sea level rise considerations and how they factor into drainage design. This manual also covers design requirements for open channels, storm drains, cross drains, stormwater management systems, and pipe materials among other items. The FDOT also uses the FDOT Drainage Design Guide to provide further clarification and design details for the Drainage Manual. This guide covers the topics mentioned above in the Drainage Manual and provides additional design guidance. FDOT also uses the FDOT Bridge Scour Manual for evaluating and designing for scour at bridges. One other manual that the FDOT employs is the State of Florida Erosion and Sediment Control Manual. This manual discusses design methods for the prevention of erosion associated with construction activities.

Finally, another document reviewed was the US Department of Agriculture Natural Resources Conservation Service National Engineering Handbook. This document covers physical processes and design guidance regarding topics related to erosion control, hydraulic structures, and hydrology among other topics.

4.3 Conclusions

After review of the above listed standards and manuals, there are several standards and manuals that are recommended for application on this project. The Grand Cayman Planning Department's Grand Cayman Stormwater Management Guidelines is recommended for general design of drainage system features. The Defra Non-Statutory Technical Standards for Sustainable Drainage Systems is recommended for guidance in selecting alternative environmental water quality treatment features. FDOT documents, including the Drainage Manual, Drainage Design Guide, Bridge Scour Manual, and State of Florida Erosion and Sediment Control Manual, are recommended for design detail of drainage and erosion control features and scour design at bridge openings. Finally, Volume 2 of the ERP Applicants Handbook for the SFWMD is recommended for detailing environmental water quality treatment requirements, in addition to Chapter 62-777 of the Florida Administrative Code that is currently in use on Grand Cayman.

As mentioned at the beginning of this section, coordination with other government departments is suggested during the Preferred Alternative assessment in order to gain concurrence on utilizing the above listed standards and manuals.

5 Baseline Conditions

5.1 Topography

Grand Cayman is irregularly shaped with an approximate area of 76 mi^2 (197 km^2). It is approximately 22 mi (35 km) long by 9 mi (14 km) wide at its widest point. The island is relatively flat, low-lying, and has limited concentrated drainage patterns generated by topographic relief (e.g. valleys and rolling terrain). A recent estimate of the maximum land surface elevation at Grand Cayman is approximately 56 feet (17 metres) above sea level, from the book "Geology of the Cayman Islands" by Dr. Jones, which was published by Springer in November 2022. The low-lying topography is vulnerable to winds and flooding caused by hurricanes and tropical storms.

5.2 Climate

Grand Cayman has a tropical climate that is typically hot and humid throughout the year, with some cooler temperatures during dry season months. The prevailing wind direction is generally south-easterly from May to October and north-easterly from December to April (Cayman Islands Government, 2013). Since it is located in the northwest Caribbean, Grand Cayman is affected in the dry season by cold fronts. In the wet season, weather conditions are influenced by tropical waves, tropical storms, and hurricanes with very intense rainfall. The dry, relatively cold months are from late November to mid-April. Dry season cold fronts generate cooler temperatures, stronger winds and rough sea swells known locally as 'Nor-westers', which occur suddenly and can be severe, with sustained wind speeds of up to 46 miles per hour (mph) [74 kilometres per hour (kph)] and gusts up to 69 mph (111 kph). The warm, rainy wet season spans from mid-May through October. In July to November, low pressure systems moving west across the Caribbean frequently bring weather conditions ranging from weak tropical waves to hurricanes. A table of Grand Cayman climate variables are shown in **Table 1.**

Table 1: Climate Variables

Variable	Average (min/max)
Average Annual Temperature (2012-2021)[1]	82.7°F (80.6°F/83.5°F), 28.1°C (27.0°C/28.6°C)
Highest Daily Temperature (2012-2021) [1]	92.5°F (91.5°F/93.2°F), 33.6°C (33.1°C/34.0°C)
Lowest Daily Temperature (2012-2021) [1]	67.4°F (64.0°F/70.8°F), 19.7°C (17.8°C/21.6°C)
Average Daily Temperature in Wet Season[2]	84.4°F (88.9°F high daily/77.4°F low daily), 29.1°C (31.6°C high daily/25.2°C low daily)
Average Daily Temperature in Dry Season[2]	80.8°F (84.2°F high daily/73.4°F low daily), 27.1°C (29.0°C high daily/23.0°C low daily)
Average Annual Relative Humidity (2011-2021)[1]	79% (75%/81%)
Average Total Annual Precipitation (1982-2021) [3]	55 in (139 cm)
Average Total Annual Precipitation (2012-2021) [1]	52.91 in (41.92 in/60.78 in), 134.39 cm (106.48 cm/154.38 cm)
Average Monthly Rainfall Total in Wet Season[2]	5.7 in, 14.48 cm
Average Monthly Rainfall Total in Dry Season [2]	2.5 in, 6.35 cm
Number of Days in a Year with at Least 0.01 Inches of Rain (2012-2021)[1]	150 days (119 days/184 days)
24-hour Rainfall Intensitities[3]	0.32 in/hr (0.13 in/hr / 0.81 in/hr)[4], 8.15 mm/hr (3.22 mm/hr / 20.49 mm/hr)[4]

[1] The Economics and Statistics Office, 2022
[2] Wood, 2021
[3] Razzaghmanesh and Gause, 2022
[4] 0.81 in/hr (20.57 mm/hr) is an extreme event that corresponds to Hurricane Ivan in 2004

The overall average temperature between 2012 and 2021 was 82.7°F (28.1 °C) and the average annual relative humidity between 2011 and 2021 was 79% (Economics and Statistics Office, 2022). In 2021, the annual average relative humidity was 75% and ranged from 71% (April) to 79% (May) (**Figure 2**). In 2021, temperatures were cooler in January to March then increased from April to October and were then cooler in November and December (**Figure 3**). Overall, temperatures remain relatively consistent through the year. Between 2012 and 2021, the difference between the highest daily temperature and the lowest daily temperature was 29.2°F (16.2°C) (The Economics and Statistics Office, 2022). The region has increasing higher average and extreme temperature events as average temperatures have increased approximately 3.9°F (2.2°C) over the past 40 years, at a rate of around 0.09°F (0.06 °C) annually (Pinnegar et. Al, 2022). In addition, the Caribbean Sea has warmed by around 2.7°F (1.5°C) over the last 100 years (Cayman Islands Government, 2013).

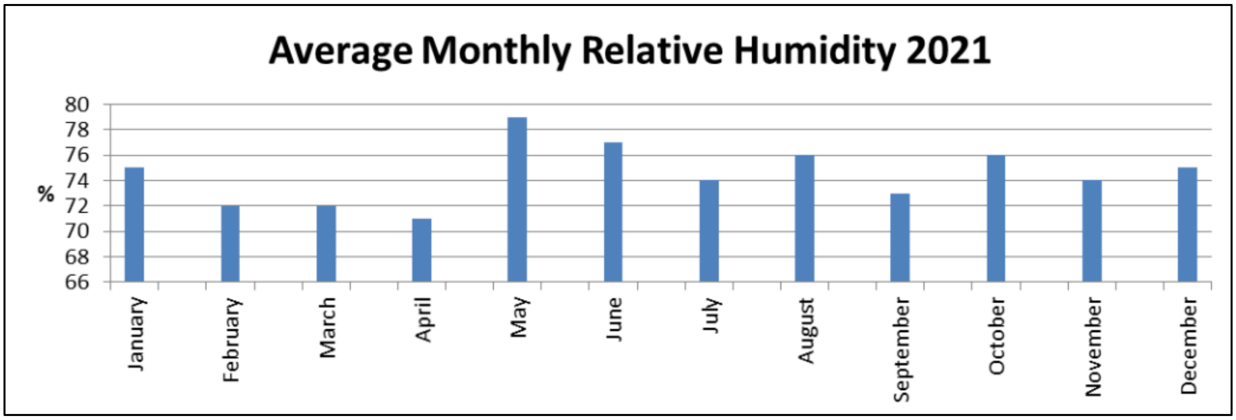

Figure 2: Average Monthly Relative Humidity 2021

Source: Economics and Statistics Office, 2022, and National Weather Service

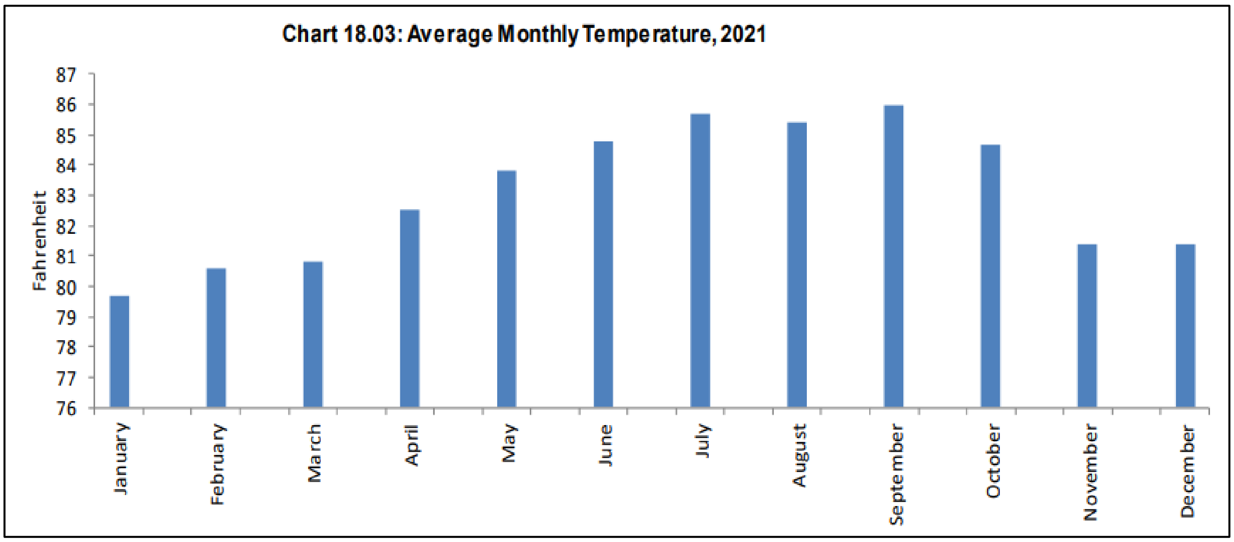

Figure 3: Average Monthly Temperature 2021

Source: Economics and Statistics Office, 2022, and National Weather Service

The wettest months are typically September and October, while March is the driest month (Razzaghmanesh and Gause, 2022). During wet season months, rainfall is typically the result of tropical thunderstorms or localised rain. Some of the rain is generated from the evaporation of water in the CMW. In the dry season months, occasional surges of cooler air from continental North America are the major producers of rainfall although precipitation is of much shorter duration and lesser amount than the wet season. Typically, heavy showers are interspersed by long dry spells during the wet season, which leads to periodic flooding in low-lying areas and depressions as well as a moisture deficiency which is accentuated by shallow soil depth and low water holding capacities.

The average total precipitation from 1982-2021 was 55 in (139 cm) a year (Razzaghmanesh and Gause, 2022), with rainfall amounts increasing from east to west due to the evaporation of water in the CMW that is deposited as rainfall in the western side of Grand Cayman. The calculated 24-

hour rainfall intensities have an average of 0.32 in/hr (8.15 mm/hr) (Razaghmanesh and Gause, 2022). Between 2012 and 2021, the most rain in a 24-hour period was 11.5 in (29.2 cm) on June 5, 2015 (Economics and Statistics Office, 2022). In 2021, George Town had a total of 53.7 in (136 cm) of rain, with August having the highest amount of rainfall (12.6 in or 32 cm) and January having the lowest amount of rainfall (0.3 in or 0.76 cm) (**Figure 4**). Recent precipitation records show that the Cayman Islands also have experienced multiple drought periods over the last 55 years (1958, 1960, 2003 and 2004) which occurred during the regular dry season (Government of the Cayman Islands, 2013).

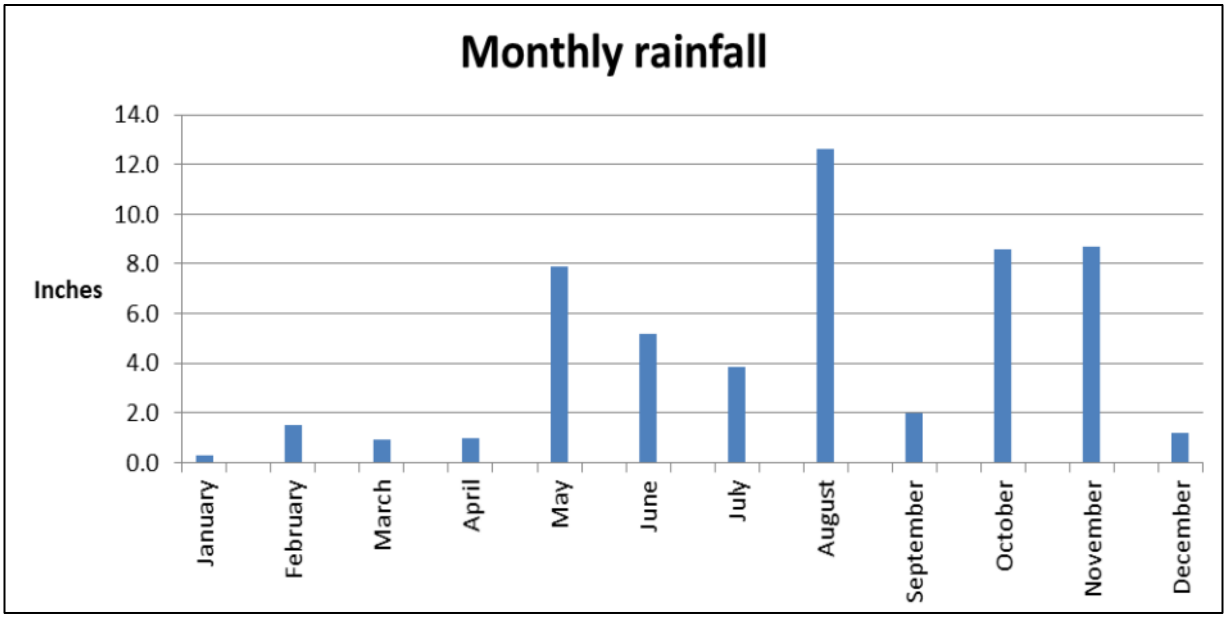

Figure 4: Average Monthly Rainfall in George Town in 2021
Source: Economics and Statistics Office, 2022, and National Weather Service

Climate and land use changes could affect the hydrology and drainage patterns and geo-environmental conditions within the project area in the future. Climate change could affect the amount, intensity, and duration of rainfall, temperature, and evapotranspiration, as well as the occurrence of extreme weather (e.g., hurricanes). Observational trends appear to show a decrease in total precipitation but an increase in rainfall intensity resulting in an increased occurrence of flood and drought events. Fewer but more severe rain events in recent years were observed from rainfall data collected at the Owen Roberts International Airport (Pinnegar et. Al, 2022). In addition, it has been predicted that the Cayman Islands may experience a decrease of between 0.4 and 2 in (10 and 50 mm) in annual rainfall totals between 2011 and 2099 (National Climate Change Committee, 2011). The Intergovernmental Panel on Climate Change predicts that there will likely be a decrease in rainfall during the wet season in the Caribbean and that this drying trend will likely continue in the coming decades (Arias et al., 2021). Between December 2021 and November 2022, the rainfall monthly totals were 4.9% lower than the 30-year average (Cayman Islands National Weather Service, 2022). The change in rainfall patterns, increased evaporation, and extreme weather could impact the hydrology and drainage patterns and the recharging of the island’s freshwater lenses.

5.3 Tropical Storms and Hurricanes

Hurricanes are a major climatic factor because the Cayman Islands are located within the Caribbean hurricane belt, a region of the Atlantic Ocean that extends from the Gulf of Mexico to north of the Lesser Antilles where hurricanes are most likely to form (**Figure 5**). The months of September, October, and November are typically the most active for hurricanes, when storms tend to form in the southern Caribbean and move north. The intense tropical storms and hurricanes are typically accompanied by intense rainfall. Storm surges combined with wave action are responsible for much of the damage typically caused by hurricanes, especially in large, low-lying coastal settlements.

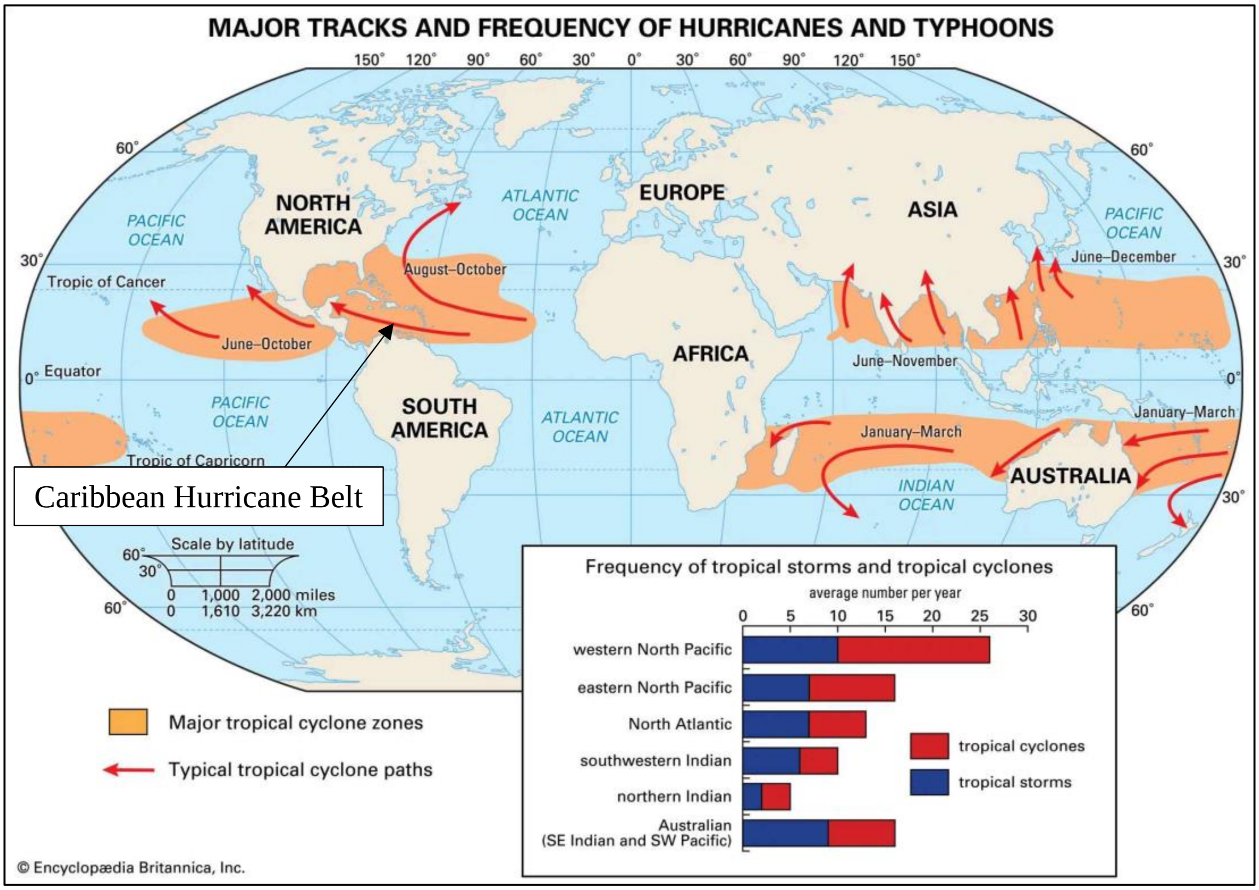

Figure 5: Caribbean Hurricane Belt

Source: Encyclopaedia Britannica, Inc., 2024

The Cayman Islands have experienced 74 tropical storms and hurricanes over 156 years (1852-2008), with nine major storms (Category three or higher). On average, the Cayman Islands are affected by passing hurricanes every 2.23 years and directly hit by hurricanes every 9.06 years. Also on average, the Cayman Islands are affected by Categories 1 and 2 hurricanes every 2.23 years, Category 3 hurricanes every 9.06 years, and Categories 4 and 5 hurricanes every 100 years (Young, 2004).

More recently, hurricanes have increased in intensity and rainfall, which is potentially a result of warming ocean temperatures and more moisture in the air. Hurricanes have been noted to be more active in the North Atlantic Ocean since the 1980s, and on average, the quantity, strength, and number of hurricanes that intensify has increased (Colbert, 2022). Between 1979 and 2017, the global increase in major hurricanes (aka “tropical cyclones”) exceedance probability was approximately 8% per decade (Kossin et al., 2020). There have been significant increases in tropical cyclone intensification rates, specifically in the Atlantic basin (Bhatia et al., 2019). The proportion of very intense tropical cyclones (Category 4 and 5) is anticipated to increase globally with increased warming (IPCC, 2021). There is high confidence that rainfall rates in hurricanes will increase by at least 7% per degree of planet warming (Seneviratne e. al., 2021). The proportion of very intense tropical cyclones (Category 4 and 5) is anticipated to increase globally with increased warming (IPCC, 2021).

Hurricane Ivan was a Category 5 Atlantic hurricane that passed southwest of Grand Cayman on September 12th, 2004, and is considered one of the most impactful hurricanes recorded in the Caribbean region. It sustained winds of 160 mph (257 kph) and gusts of up to 217 mph (349 kph), producing storm surges of 8 to 10 ft (2.4-3.0 m) and wave heights of 20-30 ft (6.1-9.1 m) while in the area of Grand Cayman. The storm wave action flooded large portions of the coastal areas and deposited major amounts of sand over roads, houses, and utilities infrastructure. Most of Grand Cayman’s low-lying areas were under water during and following the storm (**Figure 6**) and widespread property damage resulted. It is estimated that this hurricane caused US $3.4 billion (CI $2.86 billion) in damages across the Cayman Islands, equivalent to over 180% of gross domestic product (Pinnegar et. al, 2022).

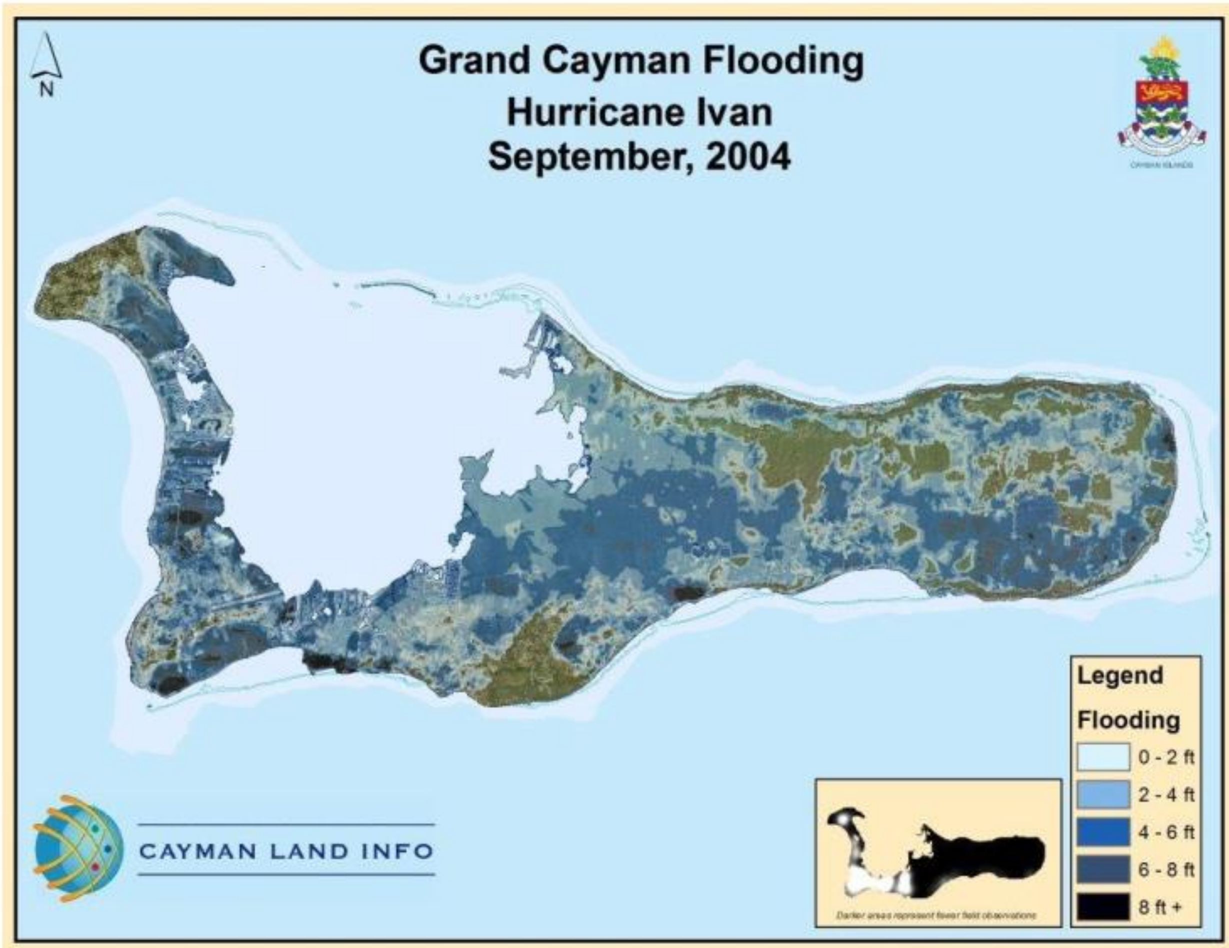

Figure 6: Grand Cayman Rainfall Distribution

Source: Simpson, Robson & Smith, 'Sea Level Rise and its impact on The Cayman Islands', 2009

5.4 Storm Surge and Flood Risk

There are two main categories of flooding that impact Grand Cayman, coastal and surface water. Coastal flooding has caused much damage in the Cayman Islands with both the intensity of tropical storms and their frequency. Coastal flooding occurs because of the combined increase in water level from storm surge and waves on an elevated sea level. Due to the overall low elevation of Grand Cayman, coastal flooding extends to large areas of the island even in less severe storms (Category 3). Storm surges combined with wave action are responsible for much of the damage usually caused by hurricanes, especially in large, low-lying, developed coastal areas.

Surface water flooding typically occurs when a tropical depression settles over the island, depositing extreme amounts of rainfall over several days. Due to the generally low elevation and unconcentrated nature of drainage patterns on the island, there are few surface water flow paths, and surface water flooding is typically widespread and of low velocity. Surface water flooding varies on Grand Cayman, generally depending on the underlying bedrock formation and other physical features, such as topographic depressions, which may isolate surface water over subsurface geologic formations. Specifically, areas with underlying rock formations characterized by high permeability, such as the Cayman Formation and Pedro Castle Formation, typically do not flood unless they occur at the interface with the water table. Rainfall either evaporates, percolates, or accumulates in depressions for shorter durations than areas with more impermeable formations. Areas with underlying Ironshore Formation are much less permeable and are highly prone to surface water flooding. Much of the Ironshore Formation surface, when unbroken, is "case hardened" and only allows water to percolate down sinkholes, which are variable in spacing and distribution across Grand Cayman (Jones, 1994). Sinkholes, like deep wells, cease to function in lower lying areas when the groundwater horizon surges during prolonged and heavy rainfall events. Even with the case-hardened surface broken, the Ironshore rocks are quite clay-like and are not as permeable as the Cayman and Pedro Castle formations. Developed and undeveloped areas with low elevation and/or soil, peat, or cap rock with low permeability are also prone to frequent flooding. Additional information on geology can be found in the Geo-Environmental Assessment of Alternatives report.

No generally accepted, delineated floodplain and watershed mapping exists for the Cayman Islands; however, the EIA study area, like much of Grand Cayman, contains low-lying areas vulnerable to tidal flooding and hurricane/tropical storm-associated activity. Novelo-Casanova and Suarez (2010) delineated flood zones resulting from hurricanes according to hurricane categories on the Saffir-Simpson Scale (**Figure 7**).

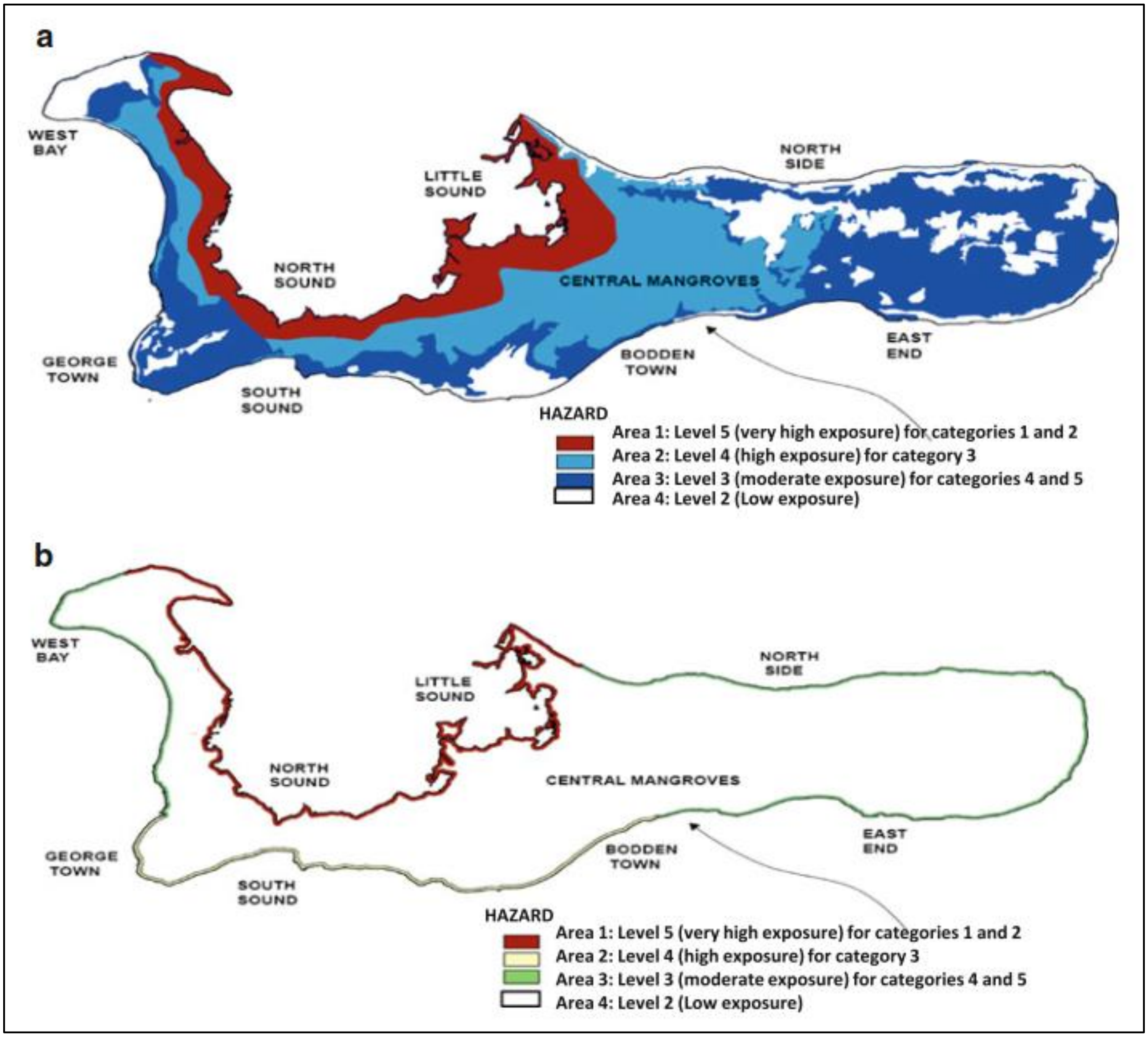

Figure 7: Flood (a) and Storm Surge Areas (b)

Source: Novelo-Casanova and Suarez (2010). Note that the arrow indicates the typical direction hurricane approach.

Another consideration which impacts the effects of storm surge and flooding is the dense vegetation on Grand Cayman which provides flood protection by intercepting and absorbing rainwater before it reaches the ground runoff conditions, holding back water temporarily. The dense vegetation also appears to act as a source of friction against moving water, resulting in a reduction of wave heights and peak flows. In addition, mangrove roots trap sediments and soil cohesion is increased by the mangrove root systems, which reduces sediment load in flood waters (Alongi, 2012; Wood Environment & Infrastructure Solutions UK, 2021; Global Nature Fund, 2007).

In reviewing these considerations, it was determined that the level of exposure to hurricanes and associated flooding and storm surge varies along the proposed alternatives (No-Build, B1, B2, B3, and B4). The location of the proposed Build alternatives in the western area near the CMW are within an area of high exposure and the proposed eastern roadway sections are within an area of moderate exposure, based on the delineations shown in **Figure 7** for a hurricane approaching from the southeast. There is additional discussion regarding storms approaching from different directions and maximum storm surge impacts later on in this report, as well as in the Baird coastal flooding study (Baird and Associates, 2024). Storm surges combined with wave action are responsible for much of the damage usually caused by hurricanes, especially in large, low-lying developed coastal areas where the ability to convey or infiltrate water is affected by the conditions described above.

The coastal storm surge and wave overtopping analysis performed by Baird further demonstrates the impact anticipated from storm surge and wave action (Baird and Associates, 2024). The analysis discusses the effects of a storm surge driving water into the CMW through the North Sound and the widespread flooding and extended drawdown that would ensue. This effect was one of the driving factors in the analysis of the roadway bridge openings in order to effectively convey this surge flow without creating significant increases in the peak or duration of floodwaters. The analysis also discussed the wave overtopping impacts along the southern shore, specifically covering the impacts from Hurricane Ivan in 2004. The analysis referred to aerial imagery from this time showing the massive movement of sand from the beach and up onto the existing Bodden Town Road. This movement of sand and the time required to clear it creates a major concern for the accessibility of coastal roadways following a storm event, as discussed in later sections.

5.5 Central Mangrove Wetland (CMW)

Mangroves are important for both the terrestrial and marine ecology of Grand Cayman as they provide a variety of ecosystem services, such as influencing hydrology and water movement patterns; protection of beaches and coastlines from storm, wave, and flood action; reduction of progressive beach and soil erosion; pollution absorption; providing nursery grounds, food, shelter, and habitat for a wide range of aquatic species; and carbon sequestration.

Studies have shown that mangroves provide a natural protection from strong waves, acting as a natural buffer. It is estimated that an approximate 650-ft (200 m) width buffer of mangroves can reduce the power of a marine surge up to 75% (Global Nature Fund, 2007).

Mangroves also prevent erosion by acting as buffers and catching alluvial materials, thereby stabilizing land elevation by sediment accretion that balances sediment loss. In addition, mangroves functionally act as natural water treatment systems by retaining heavy metals, trapping sediments, and providing chemical buffering and water quality maintenance of both rainfall and tidal inundation.

Figure 8: Mangroves along North Sound (February 2023)

Mangroves are flow-through ecosystems. Runoff flows begin at the terrestrial edge of the inland side from ground water, springs, and stormwater runoff and continue to the sea. Tidally affected areas facilitate the exchange of tidal waters in and out of the mangrove area. Tidal fluctuation brings saltwater into the mangroves against the outflow of freshwater, and transports sediments, nutrients, and clean water into the mangrove habitat, which is important for mangrove distribution. When tidal flow in the mangroves is disturbed, a mangrove may dry out and die over time.

The normal hydrologic patterns that influence the distribution and growth of existing natural mangrove plant communities include depth, duration, and frequency of tidal inundation and tidal flooding because the hydroperiod (flooding frequency, duration, and depth) regulates biogeochemical processes such as gas exchange (oxygen and carbon dioxide) between plants and the environment, metabolic turnover rates, and the accumulation of sulphide in soil. For the CMW, the tidal pattern is mixed, primarily semi-diurnal, and the average tidal range is approximately 14 to 24 in (35 to 60 cm) (Rigby and Roberts, 1976). Brackish water during high tides influences much of the island, and more than 31 mi^2 (80 km^2) of the island's surface was once covered by mangrove swamp, which is still most extensive around North Sound within the CMW (Woodroff, 1981).

Mangroves are also sensitive to many environmental factors. They prefer low wave energy and are very sensitive to soil modifications, mainly due to shifts in substrate elevation relative to water level. The normal hydrologic patterns, including depth, duration, and frequency of tidal inundation and tidal flooding, influence the distribution and growth of existing natural mangrove plant communities. They grow best with low wave energy because high waves limit the accumulation of fine sediments. They have extended buttress roots that slow the tidal flow and promote the deposition of mud and silt. In addition, a change in salinity can result in a change or loss of mangrove species.

The salinity of water is also important for mangroves. Mangroves can grow in freshwater conditions, but normally, the competition with freshwater species is too high; in areas with higher salinity, they can outcompete the freshwater species. In addition, variation of salt concentration influences the distribution of mangrove species in the mangrove forest because different species have varying degrees of success in coping with the excessive salinity levels. A change in salinity can change the vegetation species that can grow in that location.

The CMW is part of a large-scale, water flow system which filters and conditions the surface water and shallow ground water that flows into the North Sound while providing a constant flow of nutrients, which form the base of a complex food chain for both terrestrial and marine wildlife (**Figure 9**). In addition, the CMW has an important role in the evapotranspiration/precipitation cycle of Grand Cayman, including rainfall generation. An estimated 40% of the rainfall in western districts of the island is believed to be due to evapotranspiration in the CMW (Bradley et al, 2004). The evaporation of water from mangrove swamps creates a seaward hydraulic gradient for the regional flow regime (Ng et al., 1992). The evaporative loss for Grand Cayman is estimated to be approximately 75% to 85% (Ng et al., 1992).

Figure 9: Central Mangrove Wetland (July 2023)

The hydrologic and drainage patterns of the CMW change throughout the year. During the wet season months of April through October, the CMW is typically fully inundated with overflows into the North Sound. During the dry season months of November to March, a draw-down of the water surface can occur unless heavy or sustained rainfall or sea water inundation is received. The Lower Valley Freshwater Lens and North Side Freshwater Lens feed into the CMW year-round.

Over time, the plant community has adapted to the changing water and salinity conditions in the CMW.

5.6 Mastic Reserve

The Mastic Reserve, a 1,329-acre (538 ha) ecosystem, contains the largest contiguous area of primary dry forest remaining on Grand Cayman and represents one of the last remaining examples of Caribbean subtropical, semi-deciduous dry forests (National Trust, 2022). In 1992, the Mastic Reserve was founded following the donation of 145 acres (58 ha) of land to the NT for the purpose of protection and conservation of the old-growth forest and has since grown to 845 acres (342 ha). Prior to its establishment, the area was historically used as a passageway to traverse the many wetlands on the Cayman Islands. In 1995, the passageway was re-established as an official trail, the Mastic Trail, allowing users to experience the natural, undisturbed areas of Grand Cayman (National Trust, 2022). A field evaluation of the Mastic Reserve, from the Mastic Trail, was completed in July 2023 and is documented in **Figures 10** and **11** below, as well as **Attachment A**.

The Mastic Reserve serves as primary habitat to a variety of plants, birds, reptiles, and insects. The Mastic Reserve provides habitat for threatened and near-threatened bird species such as the Vitelline Warbler, the White-crowned Pigeon, and the Grand Cayman Parrot. These bird species live in the endemic Silver Thatch Palms, Royal Palms, Mahogany, or Cedars. The Reserve is also home to several endemic species, including four reptile species, five butterfly species, and ten plant species, and has the highest level of endemism in the Cayman Islands (Bradley et al., 2004).

Figure 10: Mastic Trail (July 2023)

The Mastic Reserve is part of a precipitation/runoff catchment area, absorbing rainfall and gradually releasing it, helping to regulate water flow. Pools and seasonal ponds support diverse aquatic life, including fish, turtles, crustaceans, and waterfowl. The Mastic Reserve is also significant for its role in groundwater recharge. Rainfall is absorbed by the soil, replenishing underground aquifers (North Side Freshwater Lens), and maintaining the island's freshwater supply.

Figure 11: Mastic Trail – Boardwalk (July 2023)

5.7 Meagre Bay Pond

Meagre Bay Pond (the "Pond") was designated as an Animal Sanctuary in 1976 to protect seasonally feeding flocks of herons and egrets and other resident and migratory birds and then transitioned to a Protected Area designation under the 2013 NCA. The Pond is surrounded with a 300-ft (91 m) buffer zone along all sides except the side that borders Bodden Town Road. The Pond has recorded over 104 different species of migratory birds that stop and eat fish that are stranded in the Pond. Other species observed include fiddler crabs, mosquito fish, pygmy blue butterfly, and the alien invasive species tilapia (cichlid fish) and green iguanas. The Pond is surrounded by black mangrove (endangered), white mangrove (vulnerable), red mangrove, buttonwood (vulnerable), and the *Blutaparon vermiculare* succulent.

Figure 12: Meagre Bay Pond, facing North from access off Bodden Town Road (July 2023)

The Pond is situated on limestone of the Ironshore Formation, which creates a perched water table and has little or no connection to the underlying groundwater. Through the wide beach ridge, the Pond has a highly damped and attenuated connection to sea water. Therefore, the water level of the Pond fluctuates due to the seasonality of rainfall. From May to November, rainfall exceeds evapotranspiration and so the Pond water elevation is higher. In the most arid months of March and April, Pond water levels are at their minimum and water salinity is at its maximum. Sea spray generated by waves breaking on the fringing reef and carried in by southerly winds deposits salt into the Pond year-round. Salt is flushed out of the Pond when prolonged and heavy rains result in surface sheet flow across the CMW to the North Sound.

The natural and manmade factors that can affect the Pond include climate change, storms/hurricanes, development, and roadway and quarry expansion. The surrounding mangrove forest, which affords protection to the Pond, is currently rebounding from Hurricane Ivan in 2004, which caused extensive damage and mortality to the surrounding mangroves. In addition, storm surges can change the Pond’s sedimentary composition by carrying sand from the south side beach and mixing the sand with the organic peat, which forms from decomposition ofthe mangroves’ foliage. Regarding developmental impacts, a residential subdivision was constructed to the immediate south-west of the Pond within the protected area, which resulted in landfilling and home building. The proximity of the Pond to the existing coastal roadway (Bodden Town Road) provides little space for mangroves to expand and create a wider buffer for the Pond. In addition, the existing mangrove buffer between the Pond and road may be impacted by the ongoing maintenance and utility work.

The adjacent quarries have also impacted the hydrology of the Pond. The quarry to the west of the Pond is not active, but the quarry to the northeast of the Pond is still active. By 2004, the quarry west of the Pond had been excavated below the Pond water level, and in 2008, the expansion of this extended into the 300-ft (91 m) buffer zone of the Pond. The quarry water mixes with brackish groundwater and sea water influenced by marine tides. The interconnection of the quarry water threatens the salinity of the Pond when high tides spill large volumes of brackish quarry water into the Pond. This occurs whenever the water level in the quarry exceeds the elevation of the quarry rim road. This condition potentially inhibits the seasonal dry-down of the Pond and, with repeated inputs of brackish water, may increase salinity during the dry season. In addition, the quarry development around the Pond could disconnect the Pond from the CMW, which could limit the periodic salt flushing during heavy and prolonged rainfall events. Pollutants in the closed, flooded quarry, such as lubricating oil and hydraulic fluid from quarry machinery, can enter the protected area when the water level is high. Non-native tilapia cichlid fish from the closed quarry have also migrated to the Pond, which may adversely impact the Pond's native biodiversity.

Figure 13: Active Quarry located northeast of Meagre Bay Pond (July 2023)

Meagre Bay Pond Management Plan (the "Plan") was developed to restore and maintain key ecological functions and facilitate sustainable public use. The Plan was approved by the Cayman Islands Cabinet in 2022. Its focus is the maintenance of seasonal hydrology and salinity cycles and facilitating sustainable public use. In addition to maintenance of hydrology and salinity, targeted resources include mangrove surface water and forest, as well as seasonal heron and egret feeding aggregations. The DoE plans to establish a long-term water level and salinity monitoring program in the Pond to better characterise the current hydrological regime and assess the success of management.

Specific Goals of the Plan include:

- Separate the protected area waters and the adjacent submerged quarries
- Maintain the ability of the protected areas water levels to overflow and discharge after extreme rain events
- Facilitate natural regeneration of black mangrove forest and wetland communities around the Pond
- Establish protected area zoning
- Provide appropriate public access

Key Strategies identified in the Plan include:

- To work with quarries and landowners to create and maintain hydrological separation between quarry water, the protected area, and Meagre Bay Pond.
- Land acquisition to ensure a hydrological connection is maintained between Meagre Bay Pond and the CMW.
- Installation of culvert connections with weirs and flap gates to restore a hydrological regime equivalent to the pre-quarry state, if ultimately deemed necessary
- Restoration of seasonal pond draw-down to limit survival of tilapia and to restore seasonally concentrated food resources for herons and egrets.
- Demarcate and ensure the integrity of the protected area boundary adjacent to Bodden Town Road.

The Plan proposes continued study of factors controlling Pond hydrology, including water level monitoring, Pond hydrology dynamics modeling, and effects of management policies.

6 Assessments and Studies

6.1 Overview

A field assessment and groundwater mounding analysis has been performed by WRA and various analyses by Baird and RVE were completed to provide additional information on the hydrologic and drainage processes on Grand Cayman in order to evaluate the potential impacts on the shortlisted alternatives. These assessments included: 1) an analysis of rainfall intensity, extreme event identification, and rainfall distribution (Razzaghmanesh and Gause, 2022); and 2) a water budget analysis for the CMW to assess potential hydrologic impacts of the Build alternatives (Gause and Razzaghmanesh, 2024). Two-dimensional hydraulic analyses modelled existing and the proposed conditions for each of the Build alternatives (B1, B2, B3, and B4) to preliminarily identify water surface elevations and flooding conditions resulting from various rainfall storm events (Gause, 2024). In addition, a coastal flooding study was performed to assess storm surge and wave overtopping for each of the Build alternatives (B1, B2, B3, and B4) in existing and proposed conditions for various synthetic and historic (i.e. Hurricane Ivan) hurricane events (Baird and Associates, 2024). **Figure 14** includes the modelled bridge openings along each of the Build alternatives (B1, B2, B3 and B4) used for the hydraulic modelling. The coastal risk study used very similar bridge openings (Baird and Associates, 2024).

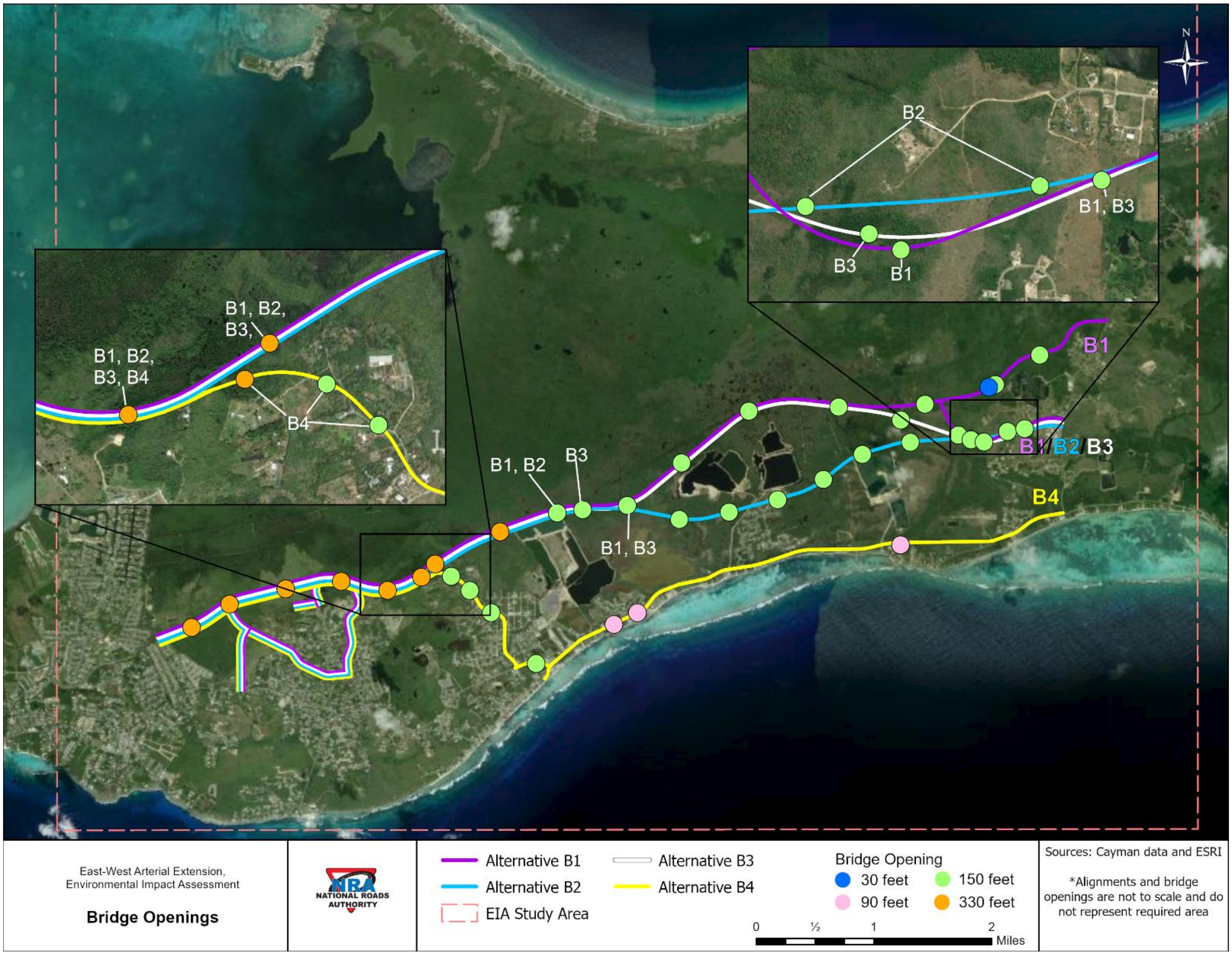

Figure 14: Modelled Bridge Openings

The modelled bridge openings were preliminarily identified as part of the RVE hydrology and hydraulic analysis (Razzaghmanesh and Gause, 2024); the openings were placed based on minor variations in the local topography. The opening locations were then further refined, as modelling progressed, to be located in areas of specific flooding concerns (Baird and Associates, 2024; and Gause, 2024). Overall, the modelling effort performed was at a proof-of-concept level. The opening configuration and model details will require further refinement in the Preferred Alternative and final design analysis (Gause, 2024).

Another significant consideration for the bridge opening configuration is arranging the configuration to ensure that natural water flows are maintained, and no negative environmental impacts ensue, such as hydrologic disconnection of wetlands or isolation of Meagre Bay Pond. These concerns were considered when placing the current configuration of structure locations to ensure the larger conveyances are maintained, such as locating an opening along the historic northern flow path from Meagre Bay Pond to the CMW.

Locations of hydrologic isolation of wetlands and other areas will need to be identified as part of the Preferred Alternative and final design analysis; however, these smaller magnitude flows could be accommodated with smaller, piped culvert crossings that could be placed in later stages of design.

The analysis provided was deemed sufficient to capture the appropriate, large scale hydraulic and hydrological components of the roadway alternatives in order to aid in the selection of the Preferred Alternative.

6.2 Field Assessment

A field assessment was conducted to observe hydrology and drainage processes on Grand Cayman along with the natural ecological resources within the EIA study area. Hydrology and drainage field investigation efforts included observation and collection of information regarding existing drainage conveyance structures (pipes, inlets, manholes, etc.) along the No-Build and Build alternatives (B1, B2, B3, and B4), observations of the only existing on-island bridge in the Seven Mile Beach Area, field views of the natural ecological resources (CMW, Meagre Bay Pond, Mastic Reserve/Mastic Trail) and mosquito canals, and a field observation of one of the active quarry operations. The existing roadways and areas along the proposed Build alternatives were viewed to assess existing conditions and observe drainage patterns. The existing inlets and drainage systems were measured, mapped, and photographed. A rainfall event was also observed and photographed. Observations of the rainfall event included localized temporary flooding along Bodden Town Road. Flow patterns along the Savannah Gully were also assessed. The archaic mosquito canals were walked and periodically measured. Exposed bedrock was also mapped and photographed. Details regarding the findings of the field assessment are included in **Attachment A**.

6.3 Rainfall Analysis

A rainfall analysis, including intensity analysis, extreme event identification, and rainfall distribution analysis was completed for the EWA EIA study area by RVE (Razzaghmanesh and Gause, 2022). A summary is provided as follows.

Daily (24-hour) rainfall data collected by sixteen WAC rain gauges between 1982 and 2021 was used to determine the maximum daily (average 24-hour) rainfall intensity and identify extreme events. Hourly data from four weather stations was used to create events for the rainfall distribution analysis (**Figure 15**) to develop Intensity-Duration-Frequency (IDF) curves (**Figure 16**). The associated rainfall intensities and return periods were calculated for the generated time series durations, including 5 minutes, 10 minutes, 15 minutes, 30 minutes, 1 hour, 6 hours, 12 hours, and 24 hours and used to develop the IDF curves.

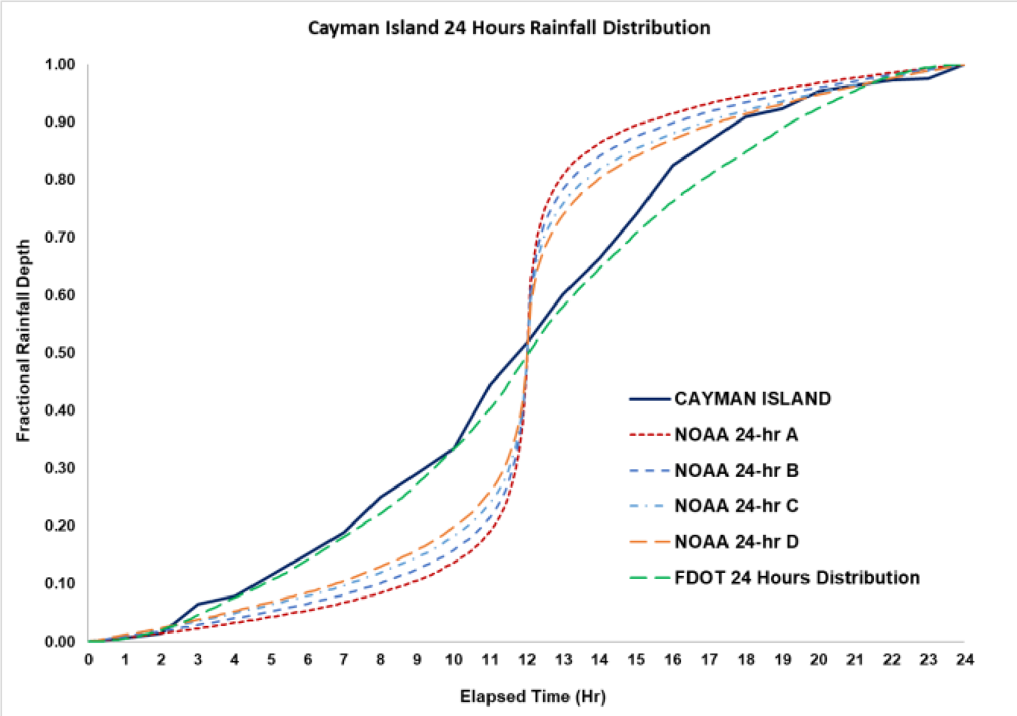

Figure 15: Grand Cayman Rainfall Distribution

Source: Razzaghmanesh and Gause, 2022

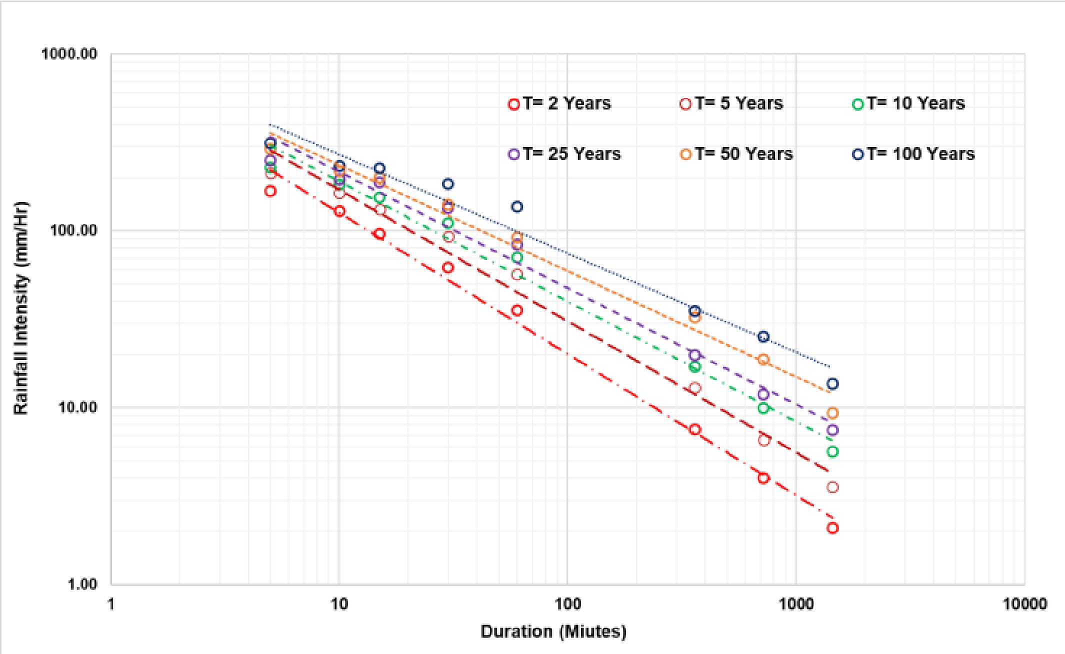

Figure 16: Intensity-Duration-Frequency (IDF) Curves

Source: Razzaghmanesh and Gause, 2022

6.4 Rainfall Hydrology and Hydraulic Analysis

A hydrology and hydraulic analysis was completed for the shortlist of Build alternatives (B1, B2, B3, and B4) by RVE (Razzaghmanesh and Gause, 2024; and Gause, 2024). A summary is provided as follows.

Analysis of the No-Build scenario is associated with the existing baseline conditions. All analyses used the results of the rainfall analysis described above, land use data and terrain modelling to develop a two-dimensional hydraulic model and prepare inundation flood maps for various rainfall events. The Hydrologic Engineering Center River Analysis Program (HEC-RAS 2D) was used to develop two-dimensional flood maps using the diffusion wave equation and various inputs, including delineated drainage area, hydrographs, land use, infiltration, and Manning's coefficients. Rainfall scenarios included 2-year, 10-year, 25- year, 50-year, and 100-year for a 24-hour event and the 2004 Hurricane Ivan. Existing conditions and the proposed conditions for each shortlist alternative were modelled.

The results of this effort are generally referred to rainfall flooding and show similar results for all of the Build alternatives (B1, B2, B3 and B4) on the western end of the project corridor and similar results for Alternatives B1 through B3 on the eastern end of the corridor. The results show minor differential rainfall flooding or what is described as roadway embankment impounding for the smaller storms, such as the 2-year storm and impoundment differentials of 1 to 2 feet (0.3 to 0.6 m) for larger storms, such as the 50-year and 100-year storms. The largest areas of potential floodwater impoundment occur on the western end of the alternatives where topography channelized rainfall would runoff towards the proposed new road with only the opening under the road as an outlet location. This impoundment situation can potentially be mitigated by the location(s) and size(s) of the roadway openings in this area of the proposed new roadway. The portion of Alternative B4 that runs along the existing roadway corridor of Bodden Town Road located along the southern coast is mostly located on a ridge and does not experience appreciable rainfall runoff impoundment. However, this area that contains the proposed new road for Alternative B4 is subject to other factors, such as wave overtopping, that are discussed in later sections.

6.5 Water Budget Analysis for Central Mangrove Wetland (CMW)

A water budget analysis was completed for the CMW in the vicinity of the EWA alignment alternatives by RVE (Gause and Razzaghmanesh, 2024). A summary is provided as follows.

The assessment included runoff, pooled water, and soil moisture fluctuations for shorter precipitation time frames. Monthly time intervals and total rainfall per month were used to analyse CMW pool water fluctuations over a 10-year time frame to identify potential impacts of the Build alternatives (B1, B2, B3 and B4) on the CMW. Extreme rainfall and flood events were not included in the analysis but are addressed in the Rainfall Hydrology and Hydraulic Analysis section previously provided.

The study found that the wetland pool occasionally draws down when the monthly precipitation is lower than normal, particularly in the dry season. The pool likely shrinks from the higher ground towards the deeper areas along the North Sound. In the past, drought periods have caused extensive drawdowns in the CMW. In addition, large storm events have resulted in saltwater flooding and waves along with high winds. The wetland habitat and species have evolved during these periods of dryness and disturbance wherein the CMW sustains damages and then recovers.

Under existing conditions, the study notes that most rainfall within the CMW study drainage area is consumed by evapotranspiration. Of the 33.9 inches (86.1 cm) of average annual rainfall, 11.4 inches (28.9 cm) becomes runoff, 0 inches (0 cm) is infiltrated from the Lower Valley Lens into the CMW, and 71.4 inches (181.4 cm) is utilized by evapotranspiration in the study drainage area of the CMW.

The proposed conditions were modelled by estimating the proposed build-out roadway cross section area and corresponding runoff curve number for the roadway through the CMW. It was determined that the CMW pool and water level would not be significantly impacted by the proposed new roadway despite the small increase in the total runoff curve number for the drainage area analysed. The overall size of the watershed is so great that the increase in runoff from the Build alternatives is not reflected within the accuracy of the analysis. Accordingly, proposed conditions are anticipated to be identical to existing conditions wherein of the 33.9 inches (86.1 cm) of average annual rainfall, with 11.4 inches (28.9 cm) becoming runoff, 0 inches (0 cm) is infiltrated, and 71.4 inches is (181.4 cm) consumed by evapotranspiration in the CMW study drainage area in proposed conditions.

6.6 Coastal Storm Surge and Wave Overtopping Analyses

A Coastal Risk Study was completed for the shortlist of Build alternatives, including Alternatives B1, B2, B3 and B4 by Baird (Baird and Associates, 2024). This study includes the results of storm surge (originating in the North Sound) and the wave overtopping (along the southern shoreline) analyses. The No-Build scenario is associated with the existing conditions presented within the surge analysis. Extreme flooding due to tropical storms and hurricanes, including the effects of tide, storm surge, waves, and rainfall, were numerically modelled. Baird did not model sea level rise for this study but recommended that sea level rise be considered during the final design of the road. A summary of the surge analysis is provided as follows.

The proposed new roadway conditions were modelled using the proposed new roadway alternative designs in addition to the existing roadway conditions which were modelled with the current island topo bathymetry without the proposed roadway corridors in place. For each scenario, the surge analysis simulated a suite of seven synthetic tropical storms and hurricanes that represent the results of 484 synthetic storms that were simulated. The simulations were completed using the Telemac model with wind fields developed using a modified version of the Holland et al. (2010) wind profile and rainfall developed using Bader’s 2019 framework. The selected synthetic storms were modelled to pass north of Grand Cayman to create a surge in North Sound since north-passing storms have resulted in a larger surge response near the proposed Build alternatives via the CMW than the south-passing storms. Flood level return periods modelled include 20-year, 25-year, 30-year, 40-year, 50-year, 75-year, and 100-year. Maximum flood level and flood duration comparison tables and water surface profiles were developed to display the spatial extent and severity of flooding for selected return periods and synthetic storms. The study also analysed floodwater reduction and impoundment.

Model results indicate that Build alternatives B1, B2 and B3 would be affected in a similar manner; mostly by storm surge coming from the North Sound. The model results indicate that the roadway alternative profiles, with a modelled low-profile elevation close to 6 ft (1.8 m) above mean sea level, would not be overtopped by a moderate storm event (25-year) but would be overtopped by larger events (100-year). The model also demonstrates that the floodwaters would behave similarly to the existing conditions model run with a slight reduction in peak flood elevations in some locations and a slight increase in the length of time required to drain the floodwater in some locations. Alternative B4 is shown to receive some effects from the storm surge coming from the North Sound but considered to be most affected by extreme weather in the form of wave overtopping of the existing ridge along the existing southern shoreline, as discussed in later sections. The results also indicate that the western portion of the proposed new roadway that is shared by all of the Build alternatives, stretching from existing Woodland Drive to Lookout Road and referred to as Section 2, contains more topographical relief than the rest of the project area and is subject to a higher water level on the south side of the road due to the impoundment of rainfall. This water impoundment may require a number of openings along the proposed new roadway in this area to reduce flooding impacts compared to the existing conditions.

Wave overtopping was also analysed for the Alternative B4 alignment along the southern coast of the island using adjusted results from the CSHORE numerical model. The other Build alternatives B1, B2 and B3 are located further inland and were determined to not have significant effects from wave overtopping. The model results were also compared to existing imagery and data for the overtopping that occurred at this location due to Hurricane Ivan. The model results allowed wave overtopping elevations to be correlated to return periods and demonstrated that the Hurricane Ivan results were likely more than the 100-year event. The study further detailed that wave overtopping of the area containing Build alternative B4 would not only require road closure due to standing water on the road but would also involve sediment deposition on the road that would require a much longer time to clear off to re-open the road. The study recommended designing the Build alternative B4 vertical profile to a higher level than anticipated for storm surge road closure to account for the greater length of time required to clear the road after a wave overtopping event.

6.7 Groundwater Mounding Analysis

An assessment was performed to identify the impact of the stormwater modelling runoff on the upper surface of the freshwater lenses, including the Lower Valley Freshwater Lens and the North Side Freshwater Lens. Groundwater mounding is the localized rise in the groundwater table that occurs when the recharge rate is higher than the capacity of the aquifer or soil to convey the water out of the recharge zone. Detailed information regarding the Freshwater Lenses can be found in the separate Geo-Environmental Assessment of Alternatives report.

Based on the Baird modelling results, a rise in water level of 0.2 feet (0.06 metres) over a duration of 10 hours was associated with the runoff for both mounding assessments. Mounding was estimated using the method in U.S. Geological Survey Scientific Investigations Report 2010–5102 titled "Simulation of Groundwater Mounding Beneath Hypothetical Stormwater Infiltration Basins" (Carleton, 2010). This desktop method necessarily uses simplifying hydraulic assumptions about the unconfined aquifer, and it uses values from available hydrogeologic sources. The predicted mounds represent an order-of-magnitude estimate.

Lower Valley Freshwater Lens

The input values in the mounding assessment for the Lower Valley Freshwater Lens were as follows:

- Recharge rate = 0.5 feet/day (0.15 metres/day)
- Specific yield = 0.25
- Horizontal hydraulic conductivity (K) = 356 feet/day (109 metres/day)
- Half-length of basin in both directions = 391 feet (119 metres)
- Duration of infiltration = 0.42 day
- Initial saturated thickness = 83 feet (25 metres)

The input recharge rate of 0.5 feet/day (0.15 metres/day) was 0.2 feet (0.06 metres) divided by a duration of infiltration of 10 hours multiplied by 24 hr/day.

The input specific yield of 0.25 of the aquifer was estimated based on Figure 4.30 in "Geology of the Cayman Islands: Evolution of Complex Carbonate Successions on Isolated Oceanic Islands" (Jones, 2022). The value of 0.25 is approximately in the middle of the range of reported porosities.

The input K was an average of four values in the low thousands of gallons per day per square foot (gpd/sq.ft.), from map number 5 in the report "Lower Valley Groundwater Lens Exploration" (Hukka, 1982). The values are at the high end of the range reported and are considered to be reasonably representative of the high-K karst aquifer. The averaged K data were 2,286 gpd/sq.ft., 3,744 gpd/sq.ft., 2,455 gpd/sq.ft., and 2,170 gpd/sq.ft. The average of 2,664 gpd/sq.ft. was converted to 356 feet/day (109 metres/day) by multiplying it by 1 cubic foot/7.48 gallons.

The input half-length of the receiving basin was estimated using the assumption that the impermeable surface area on the Lower Valley Lens, associated with development of the "Will T" roadway section, is a square. The square root of the impervious area of 611,638 square feet (56,823 square metres) was 782 feet (238 metres), and the half-length was 391 feet (119 metres). The assumption of a square is conservative because it tends to overestimate the height of the groundwater mound. The input initial saturated thickness of the unconfined aquifer (83 feet, approximately equal to 25 meters) was estimated based on Figure 4.31 in the aforementioned Jones book (Jones, 2022). It shows the Lower Valley Lens existing within the Ironshore Formation and the Pedro Castle Formation, which rest on low-K cap rock at a depth of 25 meters (82 feet). The analysis results in a theoretical mound of 0.7 foot (0.21 metre) at the centre of the basin for the Lower Valley Freshwater Lens.

North Side Freshwater Lens

The input values in the mounding assessment for the North Side Freshwater Lens were as follows:

- Recharge rate = 0.5 foot/day (0.15 metres/day)
- Specific yield = 0.25

- K = 359 feet/day (109 metres/day)
- Half-length of basin in both directions = 391 feet (119 metres)
- Duration of infiltration = 0.42 day
- Initial saturated thickness = 50 feet (15 metres)

The input recharge rate, specific yield, and duration of infiltration were the same as the values used for the Lower Valley Freshwater Lens mounding assessment.

The input K was the mean permeability reported for the North Side lens (2,683 gallons per day per square foot) converted to 359 feet/day (109 metres/day). The mean value was from "Further Report on the Groundwater Resources of Grand Cayman" (Richards and Dumbleton International, 1980).

To be conservative, the input half-length of the receiving basin was the same as the value used in the Lower Valley Freshwater Lens mounding assessment, although the edge of the lens is approximately 0.1 mile (0.16 kilometre) away from the closest highway alignment.

The input initial saturated thickness of the unconfined aquifer of 50 feet (15 metres) was based on the geologic section of the North Side Freshwater Lens, in figure G7 of the report by Richards and Dumbleton International (Richards and Dumbleton International, 1980).

The predicted theoretical mound for the North Side Freshwater Lens was 0.8 foot (0.24 metre) at the centre of the basin. The mound at the freshwater lens would actually be smaller than 0.8 foot (0.24 metre), because the theoretical mound is highest at the basin centre, and the edge of the lens is approximately 0.1 mile (0.16 kilometre) from the closest highway alignment.

Analysis Results

As demonstrated in the above mounding assessments, the theoretical mounds (rise in the water table) at the lenses are 0.7 foot (0.21 metre) at the centre of the basin for the Lower Valley Freshwater Lens and 0.8 foot (0.24 metre) at the centre of the basin for the North Side Freshwater Lens. Both results are less than 1 foot (0.3 metres), which is a relatively small temporary change.

7 Quantitative Impact Assessment

Potential impacts from the proposed Build alternatives B1, B2, B3 and B4 on various resources may include a change of water circulation patterns, increase of stormwater runoff volume and velocity, pollution from stormwater runoff, and impact on the ecology of natural resources. The identified resources included in the shortlist of alternatives assessment include:

- Central Mangrove Wetland
- Mastic Reserve
- Meagre Bay Pond
- Freshwater Lenses
- Developed Areas
- Drainage Wells

Based on the storm surge model prepared by Baird and the rainfall runoff model prepared by RVE, the openings provided by the proposed structures are anticipated to prevent the roadway from impounding water at any significant depth or for any significant duration, thereby allowing the corridor to function without the negative impacts associated with "damming" storm surges or runoff. The final design and construction of the roadway should be developed such that storms larger than those modelled are anticipated to overtop the roadway before complete inundation of the structure openings. The final design should also address the placement of openings under the road to avoid hydrologic disconnection of wetlands and other such impacts.

Based on the modelling results prepared by Baird and RVE and the impact evaluation analysis presented below, it was determined that hydrology is not a key differentiator between Alternatives B1, B2, and B3. However, Alternative B4 presents significant hydrological concerns, specifically in relation to the wave overtopping analysis, as discussed below.

Regarding stormwater management design and the construction of measures deemed necessary to manage roadway runoff, the following classification is offered. Due to the direct proximity of tidal waters, the management of peak runoff discharge rates (aka "stormwater quantity control") is not recommended for the project. Instead, in areas directly adjacent to developed areas, conveyance of storm flows will be designed using closed conduit (i.e. "pipe and inlet") systems to convey runoff to stable outfalls away from private properties or adjacent, habitable structures. In naturalized areas (i.e. the open-section, ditched roadway through the CMW), stormwater management is proposed to be provided in the form of linear treatment systems such as vegetated, pretreatment storage strips or other linear means, to filter roadway runoff and mitigate for the lack of the infiltration wells traditionally used on Grand Cayman.

Since the potential change of surface water flows/drainage patterns/flood risk and pollution impacts various resources, an overview is provided for these two general impacts and then resource-specific impacts are provide under each resource impact section. Resiliency to rainwater runoff, coastal surge and wave overtopping is discussed in later parts of this section.

7.1 Change of Surface Water Flows and Drainage Patterns/ Flood Risk Overview

The proposed Build alternatives B1, B2, B3 and B4 may change surface water flows and drainage patterns and locally increase flood risk on the CMW, Mastic Reserve, Meagre Bay Pond, Freshwater Lenses, and developed areas. Impacts may occur temporarily during construction by elements such as temporary storage and stockpiling of materials and during long-term operation by elements such as an increase of stormwater runoff volume and velocity from impervious surfaces (pavement). Best Management Practices can be utilized during construction to minimize these potential impacts. In addition, a potential damming or impoundment effect caused by the construction of the proposed roadway could change the existing water circulation patterns. The hydrology could be restricted to the CMW north of the proposed roadway and cause inundation of the mangroves and adjacent developed areas south of the proposed roadway. Openings in the roadway, such as bridges and culverts, could reduce the damming and impoundment effect.

Distance, increase of impervious area and storm modelling results were used to assess potential hydrologic and hydraulic impacts for each of the Build alternatives upon the applicable resource. The distance from each Build alternative to each resource was measured. This metric was used because runoff from a Build alternative is anticipated to contain more pollutants and have a greater hydrologic impact on a resource that is closer to the Build alternative than one that is farther away. In addition, since impervious surfaces can increase stormwater runoff volume and velocity, the increase of impervious surface area was compared for each of the Build alternatives for each applicable resource. Hydrologic and hydraulic modelling described in Section 6 has been used to assess the impoundment effect of the Build alternatives.

Assessment of individual alternative impacts upon the applicable resources with respect to the components previously described are provided in subsequent sections; however, the overall increase of impervious area for each roadway alternative is summarized in **Table 2**. Of the Build alternatives, Alternative B1 has the greatest increase in impervious area and Alternative B4 has the least increase of impervious area. The No-Build scenario assumes no increase in impervious area.

Table 2: Increase in Impervious Area

Alternative	Increase of Impervious Area (Acre)	Increase of Impervious Area (Hectare)
No-Build	0	0
B1	161	65
B2	132	53
B3	135	55
B4	98	40

7.2 Pollution Overview

The operations from the Build alternatives B1, B2, B3 and B4 have the potential to release contaminants that may potentially pollute sensitive habitats and the underlying aquifers. Contaminants may consist of toxic metals, suspended solids, and hydrocarbons and can be deposited onto the roads from vehicle leaks, such as crankcase oil, transmission, hydraulic, and brake fluid, antifreeze, and gasoline. Contaminants can be released directly (e.g., spillages) or indirectly (via surface water runoff).

For this analysis the future year 2074 roadway surface was used to analyse the potential for contamination and to compare potential for pollution impacts for each of the Build alternatives for each resource. The proposed year 2074 typical roadway sections showing the dimensions of the impervious areas are included in the Shortlist Evaluation document.

The results of the hydrology and hydraulic analysis were utilized to determine the potential impact of the Build alternatives on each resource by using the movement of stormwater runoff from a rainfall event. Within the study area, stormwater runoff generally flows (1) from the west to the east and then north and (2) from the east to the west and then north. The distance from the resource and the alternatives was measured for comparison purposes. In addition, the increase of impervious area was compared to the total estimated drainage area of the resource based on the subwatershed areas developed during the hydrology and hydraulic analysis (see Section 6 and **Figure 17**). The potential pollution impact on the CMW, Mastic Reserve, Meagre Bay Pond, Freshwater Lenses, and developed areas is included in their respective section.

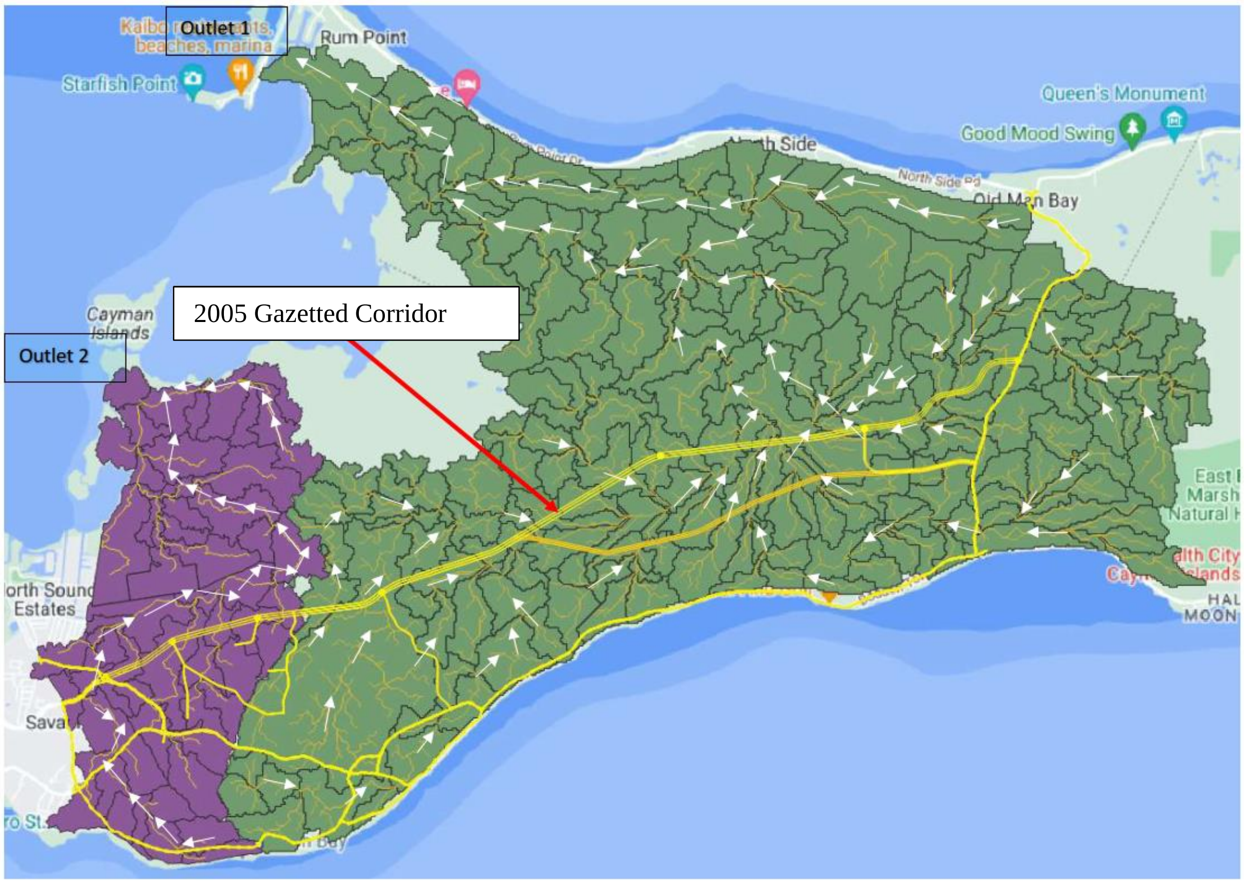

Figure 17: Subwatershed Areas Map

Source: Razzaghmanesh and Gause, 2024

7.3 Central Mangrove Wetland (CMW)

The hydraulic functions of the CMW may be impacted by each of the proposed Build alternatives. The potential impoundment effect of the proposed roadway within the CMW could change the existing water circulation patterns. The hydrology could be restricted to the CMW north of the proposed roadway and cause inundation of the mangroves and also to adjacent developed areas south of the proposed roadway. This could result in alterations of hydrology, water flow, water levels, surface drainage, salinity levels, nutrient balance, oxygen concentration or temperature that may be harmful to mangrove trees and wildlife, the ecological or aesthetic value of the area, and may exacerbate erosion. In addition, the Build alternatives have the potential to release contaminants that may potentially pollute the CMW as previously described.

The loss of mangroves reduces transpiration, may increase runoff, and could reduce floodplain roughness, which in turn could increase run-off velocity and reduce protection from tropical storms and hurricanes. In addition, the removal of or drowning of mangroves may decrease precipitation on the western end of the island. Additional impacts to the CMW are discussed in the Terrestrial Ecology Assessment of Alternatives report.

7.3.1 Hydrology, Hydraulics and Drainage Impact Assessment

The potential hydrologic and hydraulic impacts and potential for pollution impacts were assessed for the CMW. The potential hydrologic and hydraulic impacts on the CMW were assessed using the following methods:

- Removal of CMW area
- Length of proposed roadway through CMW
- Water budget
- Rainfall runoff modelling
- Surge modelling

It is assumed that the larger the removal of the CMW, the larger the potential for hydraulic function impacts. Therefore, the extent of hydraulic impact to the CMW was determined by the area of CMW that would be removed. The CMW areas that are anticipated to be removed for each of the Build alternatives are summarized in **Table 3** and, of the Build alternatives, Alternatives B1 and B3 remove the highest amount of area of the CMW and Alternative B4 removes the lowest amount of area of the CMW. To determine the % of CMW removed for each of the Build alternatives, the CMW removed area was divided by the total area of the CMW (8,655 acres/ 3,502 ha). Overall, all of the Build alternatives would result in less than 1% CMW removal.

Table 3: Removed CMW Area

Alternative	Area of Removed CMW (Ac)	Area of Removed CMW (HA)	Total Area of CMW (Ac)	Total Area of CMW (HA)	Decrease of CMW (%)
No-Build	0	0	8,655	3,502	0%
B1	76	31	8,655	3,502	0.9%
B2	57	23	8,655	3,502	0.7%
B3	76	31	8,655	3,502	0.9%
B4	10	4	8,655	3,502	0.1%

The length of each Build alternative through the CMW was measured. This metric was used because, as the Baird and RVE modelling demonstrates, the Build alternatives cause some level of hydrologic impacts in the CMW and, therefore, a greater span across the CMW would result in overall greater level of impacts. The length of roadway through the CMW for each of the Build alternatives is summarized in **Table 4**. Of the Build alternatives, Alternatives B1 and B3 have the longest length within the CMW and Alternative B4 has the shortest length within the CMW.

Table 4: Length of Roadway Through Central Mangrove Wetland

Alternative	Length of Roadway (mile)	Length of Roadway (kilometre)
No-Build	0	0
B1	2.8	4.5
B2	2.1	3.4
B3	2.8	4.5
B4	0.7	1.1

A water budget analysis was completed for the CMW for existing and proposed conditions. The results indicate that the CMW pool and water level would not be affected by the proposed Build alternatives. See **Figure 18** and **19** for the existing and proposed water budget respectively. These figures demonstrate the negligible effects of the Build alternatives on the water budget of the CMW.

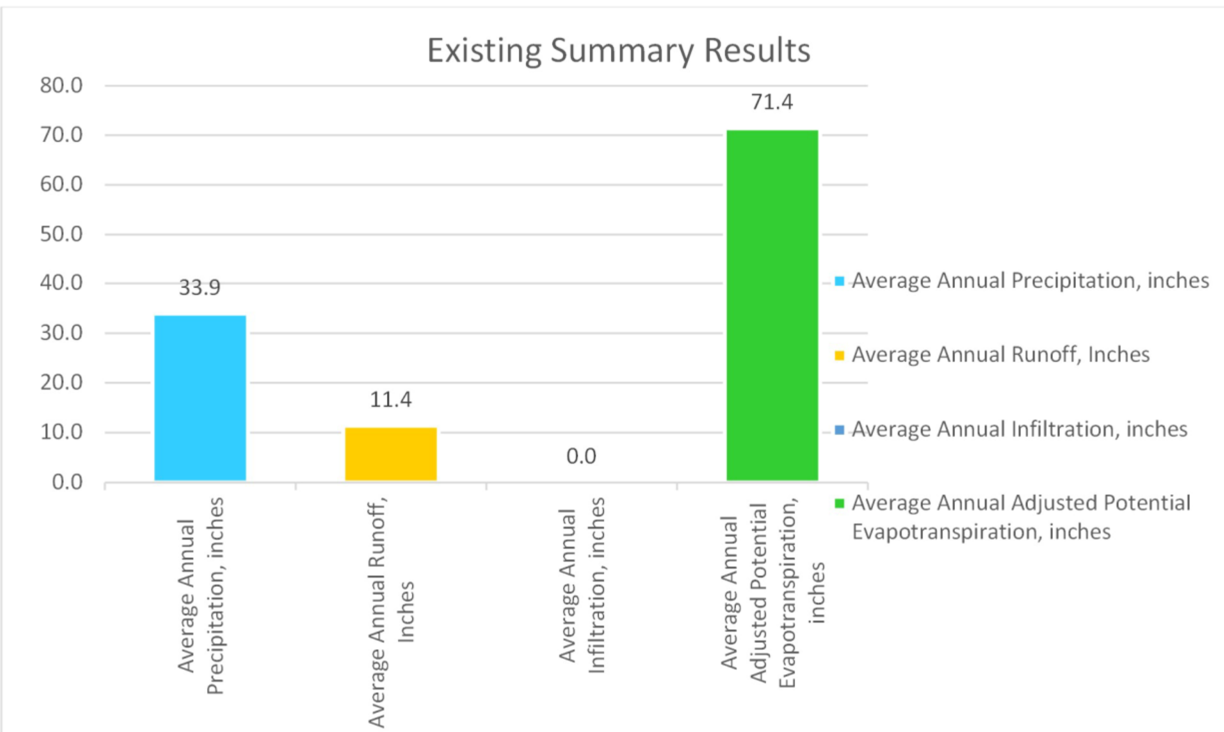

Figure 18: Existing Water Budget Summary Results

Source: Gause and Razzaghmanesh, 2024

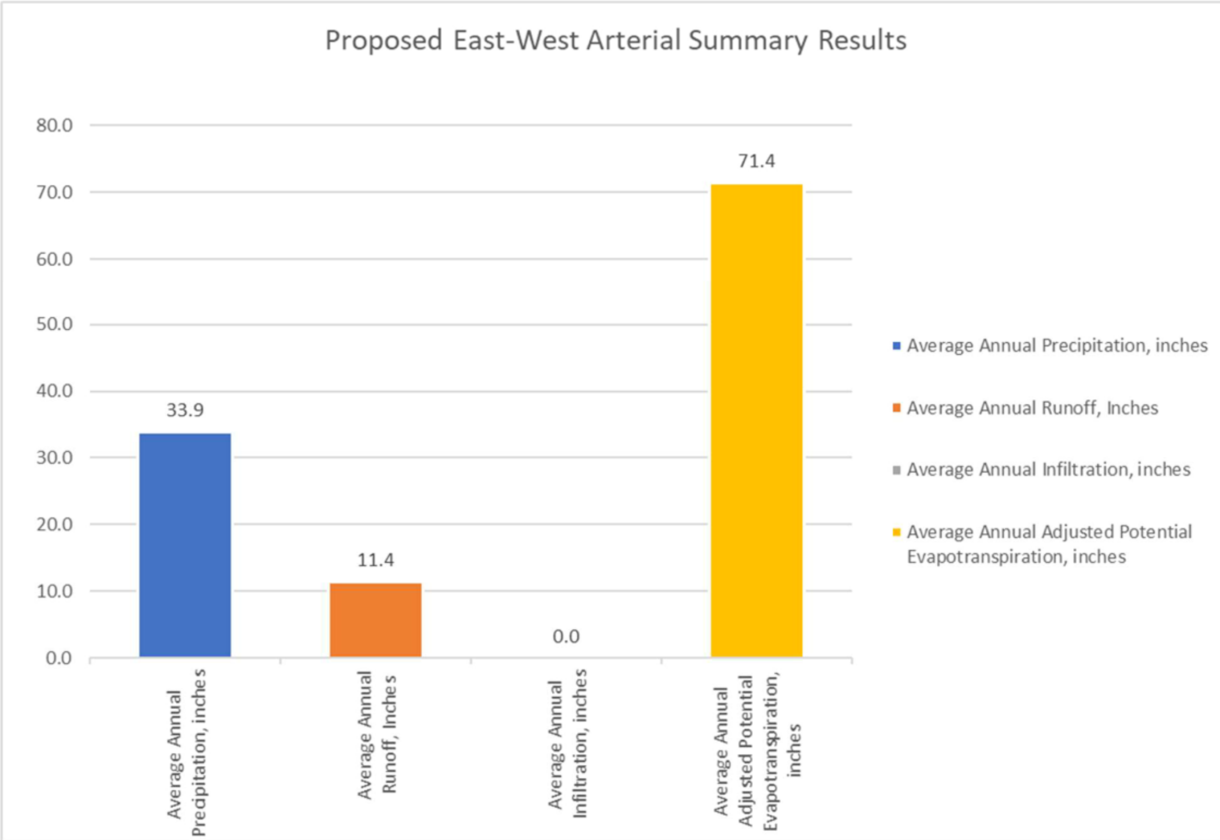

Figure 19: Proposed Water Budget Summary Results

Source: Gause and Razzaghmanesh, 2024

Rainfall modelling and surge modelling was completed by RVE and Baird respectively to assess the potential drainage impact of the Build alternatives on the CMW. This modelling included the effects of the preliminary bridge opening configurations for the different alternatives. Generally, the results for Alternatives B1, B2, and B3 showed a slight increase in flood levels in the CMW as compared to the existing condition, presumably due to the road embankment slightly limiting the floodwater’s inland movement. The study also indicates that the water level in the CMW exceeded the existing condition water level for a certain length of time for these alternatives.

The hydrologic/hydraulic and storm surge/wave overtopping studies completed by RVE and Baird respectively concluded that impoundment for the portion of Alternative B4 beyond Section 2 (Woodland Drive to Lookout Road) was not included in the impoundment analysis because the portion along the coast is on a ridge and does not induce significant impoundment and the portion from Section 2 to the coast was also not anticipated to induce significant impoundment. The magnitude of impact discussion in Section 7.3 of this assessment discusses these impacts for the locations along Section 2.

The formation of an impoundment was assessed using two factors. The first factor is the difference in peak flood level between existing and proposed conditions. The second factor is the length of time that the flood level with the proposed Build alternative roadway is greater than the existing flood level by at least 0.3 ft (0.1 metres). The values reported are averages of the results from the seven synthetic storms that were run in the model. The results of this analysis are summarized in **Table 5**.

Table 5: Floodwater (Including Surge and Rainfall) Impoundment Impacts on the Central Mangrove Wetland

Alternative	Average Duration of Impoundment in Proposed Conditions (hours)	Average Difference of Maximum Impoundment (ft/m)
No-Build	0	0
B1	2	0.2/0.07
B2	1	0.2/0.05
B3	2	0.2/0.07
B4	*	*

**Impoundment impacts for the portion of Alternative B4 within Section 2 are considered negligible due to the fact that Section 2 does not traverse a significant portion of the CMW.*

The results show slight increases in the maximum floodwater levels and duration of flooding. Based on discussions with Baird and RVE, the slight differences in floodwaters shown for the CMW and for the other resources discussed in later sections are within acceptable tolerances for the scale of storms being considered.

7.3.2 Pollution Impact Assessment

Potential for pollution from the roadway was assessed based on the increase of impervious area compared to the CMW drainage area. Most of the stormwater runoff from each of the Build alternatives eventually travels to and though the CMW. Therefore, the entire increase in impervious area was calculated for each Build alternative (B1, B2, B3 and B4). In addition, the increase in impervious area directly adjacent to the CMW was calculated by using the length of proposed roadway through the CMW and multiplying by the width of the paved roadway.

The impervious area increase for each alternative is summarized in **Table 6**. Of the Build alternatives, Alternative B1 has the greatest increase of impervious area and the most directly adjacent impervious area. Alternative B4 has the lowest increase in impervious area and the least directly adjacent impervious area. The total increase of impervious area divided by the total drainage area of the CMW ranges from 1.4% for Alternative B1 to 0.9% for Alternative B4.

Table 6: Impervious Area Increase Assessment for the CMW

Alternative	Total Increase of Impervious Area (Ac/HA)	Increase of Impervious Area Direct Discharge to CMW (Ac/HA)	Total Drainage Area to CMW (Ac/HA)	Total Increase Impervious Area/Total Drainage Area (%)
No-Build	0/0	0/0	11,172/4,521	0.0%
B1	161/65	42/17	11,172/4,521	1.4%
B2	132/53	32/13	11,172/4,521	1.2%
B3	135/55	42/17	11,172/4,521	1.2%
B4	98/40	10/4	11,172/4,521	0.9%

7.4 Mastic Reserve

The Mastic Reserve, encompasses much of the area of the Mastic Trail, is part of a catchment area and is also valued for its role in groundwater recharge. The hydrology and water quality of the Mastic Reserve could be potentially affected by the Build alternatives by converting pervious groundwater recharge areas to impervious roadway surface. A portion of Alternative B1 is located within the Mastic Reserve while Alternatives B2, B3, and B4 are not located within the Mastic Reserve. Additional information on the Mastic Reserve is included in the Terrestrial Ecology and Cultural and Natural Heritage Assessment of Alternatives reports.

7.4.1 Hydrology, Hydraulics and Drainage Impact Assessment

The potential hydrologic and hydraulic impacts and potential for pollution impacts were assessed for the Mastic Reserve. The potential hydrologic and hydraulic impacts were assessed using the following methods:

- Distance from Mastic Reserve
- Rainfall runoff modelling
- Surge modelling

The centreline distance from each Build alternative to the Mastic Reserve is summarized in **Table 7**. Of the Build alternatives, Alternative B1 is the closest (0 ft/0 m) as it crosses through the Mastic Reserve and Alternative B4 is the furthest (6,399 ft/1,950 m). Of all the Build alternatives, Alternative B1 is the only alternative that directly impacts the Mastic Reserve with a total area of impact of 8 acres (3 ha).

Table 7: Distance Between the Alternatives and the Mastic Reserve

Alternative	Distance (ft)	Distance (metre)
No-Build	6,430	1,960
B1	0	0
B2	2,058	627
B3	1,574	480
B4	6,399	1,950

Rainfall runoff modelling and storm surge modelling were completed to assess the potential drainage impacts of each of the Build alternatives (B1, B2, B3 and B4) on the Mastic Reserve. Generally, the results showed a slight decrease in the peak water level for Alternatives B1, B2, and B3; however, the study also showed that, on average, the water in the Mastic Reserve is impounded for longer than existing conditions. These conditions suggest that, while the roadway alternatives are generally not impactful when considering peak water surface elevations, the inclusion of the roadway, which would also include associated openings, would result in longer drain times for the water that is impounded. Based on discussions with Baird and RVE, the slight differences in floodwaters shown for the Mastic Reserve are within acceptable tolerances for the scale of storms being considered. Impoundment in the Mastic Reserve is measured using the same variables as were used for the CMW. The results of this analysis are summarized in **Table 8**.

Table 8: Floodwater (Including Surge and Rainfall) Impoundment Impacts on the Mastic Reserve

Alternative	Average Duration of Increased Impoundment (hours)	Average Difference of Maximum Impoundment (ft/m)
No-Build	0	0
B1	1	-0.1/-0.04
B2	1	-0.1/-0.02
B3	1	-0.1/-0.04
B4	*	*

**Impoundment impacts for Alternative B4 are considered negligible due to the fact that Alternative B4 does not traverse the Mastic Reserve nor is in relatively close proximity to this feature.*

The floodwater impoundment differences shown in the modelling results above are expected to affect a majority of the Mastic Reserve area. Generally, impacts on a region such as the Mastic Reserve would be similar over much of the area, although slightly greater impacts could occur close to the road or close to any large openings under the road.

7.4.2 Pollution Impact Assessment

The potential for pollution from the roadway was assessed based on the increase of impervious area with direct drainage to the Mastic Reserve and the distance from centreline of each of the Build alternatives to the Mastic Reserve. The Mastic Reserve is relatively higher in elevation than the surrounding area and thus is less likely to be polluted from roadways. The increase of impervious area with direct drainage to the Mastic Reserve was calculated for each alternative and is summarized in **Table 9**. Alternative B1 is the only alternative that has direct drainage to the Mastic Reserve (17 acres/7 ha). The section of Alternative B1 which would have direct drainage to the Mastic Reserve was assumed to be from the Mastic Trail east to Frank Sound Road.

Table 9: Impervious Area Increase Assessment for the Mastic Reserve

Alternative	Increase of Impervious Area with Direct Drainage (Ac/ha)	Distance from Alignment to Resource (ft/m)
No-Build	0	6,430/1,960
B1	17/7	0/0
B2	0	1,914/583
B3	0	1,455/444
B4	0	5,690/1,734

7.5 Meagre Bay Pond

The hydrology and water quality of the Meagre Bay Pond (Pond) may be potentially affected by each of the proposed Build alternatives. Alternatives B1, B2, and B3 are located between the Pond and the CMW and could potentially disconnect (hydrologically) the Pond from the CMW, which could limit the periodic salt flushing during heavy and prolonged rainfall events. In addition, due to the location of the new roadway in relation to the Pond pollutants from the roadway could be deposited in the Pond during smaller storm events with Alternative B4 and from larger storms for Alternatives B1, B2, and B3. Additional information on the Meagre Bay Pond is included in the Terrestrial Ecology and Cultural and Natural Heritage Assessment of Alternatives Report.

7.5.1 Hydrology, Hydraulics and Drainage Impact Assessment

The potential hydrologic and hydraulic impacts and potential for pollution impacts were assessed for the Meagre Bay Pond. The potential hydrologic and hydraulic impacts were assessed using the following methods:

- Distance from Meagre Bay Pond
- Rainfall modelling
- Surge modelling

The centreline distance from each Build alternative and the Meagre Bay Pond is included in **Table 10**. Of the Build alternatives, Alternative B4 is the closest (148 ft/45 m) and Alternatives B1 and B3 are the furthest (1,291 ft/394 m) from the Pond.

Table 10: Distance Between the Alternatives and the Meagre Bay Pond

Alternative	Distance (ft)	Distance (metre)
No-Build	74	22
B1	1,291	394
B2	968	295
B3	1,291	394
B4	148	45

Rainfall runoff and surge modelling were completed to assess the potential drainage impact of the Build alternatives on the Meagre Bay Pond. Overall, the results showed a slight decrease in the peak water level for Alternatives B1, B2, and B3. The study also showed that the water level in Meagre Bay Pond exceeded the existing condition water level for a length of time for these alternatives. Based on discussions with Baird and RVE, the slight differences in floodwaters shown for Meagre Bay Pond are within acceptable tolerances for the scale of storms being considered.

Wave overtopping was not included in the impoundment analysis. Wave overtopping was modelled as part of the Alternative B4 study and did not extend to impacts from wave overtopping on Meagre Bay Pond.

Impoundment in Meagre Bay Pond is measured using the same variables as were used for the CMW. The results of this analysis are summarized in **Table 11**.

Table 11: Floodwater (Including Surge and Rainfall) Impoundment Impacts to the Meagre Bay Pond

Alternative	Average Duration of Increased Impoundment (hours)	Average Difference of Maximum Impoundment (ft/m)
No-Build	0	0
B1	8	-0.4/-0.11
B2	3	-0.3/-0.11
B3	8	-0.4/-0.11
B4	*	*

** Impoundment impacts for Alternative B4 are considered negligible due to the fact that Alternative B4 is adjacent to the existing beach ridge line in the vicinity of Meagre Bay Pond and does not significantly change the existing drainage patterns in this location.*

7.5.2 Pollution Impact Assessment

The potential pollution impacts were assessed using the increase of impervious area with direct discharge to the Meagre Bay Pond drainage area and the distance from the centreline of each of the Build alternative (B1, B2, B3 and B4) to the Meagre Bay Pond. The results of this analysis are summarized in **Table 12**. Based on this analysis only Alternative B4 would have a potential to pollute from stormwater runoff since it is located just south and adjacent to the area of the Meagre Bay Pond.

Table 12: Increase of Impervious Area Assessment for the Meagre Bay Pond

Alternative	Increase of Impervious Area with Direct Discharge (Ac/ha)	Distance from Alignment to Resource (ft/m)
No-Build	0	74/22
B1	0	855/261
B2	0	524/160
B3	0	855/261
B4	3/1	11/3

7.6 Freshwater Lenses

As demonstrated and stated in Section 6.7: Groundwater Mounding Analysis, the impact of the Build alternatives on the Freshwater Lenses is similar across all of the Build alternatives and is anticipated to produce a negligible effect on these resources. Detailed information regarding the Freshwater Lenses can be found in the separate Geo-Environmental Assessment of Alternatives report.

7.7 Developed Areas

The developed areas within the study area include existing residential, business, and commercial areas of Northward, Lower Valley, Bodden Town, and the Northwest Areas, Southeast Northward, Belfour Estates, Midland Acres, Rossini Drive, Savannah Gully, and the residential developments west of Meagre Bay Pond, and along Frank Sound (**Figure 21)**. There are also numerous additional developed areas along the existing Bodden Town Road corridor throughout the study area. The potential hydrology, hydraulics and drainage and pollution impacts on these developed areas were assessed for each alternative.

7.7.1 Hydrology, Hydraulics and Drainage Impact Assessment

For this analysis it was assumed that the longer the roadway distance through the developed areas, the more potential of the roadway to cause the impoundment of floodwaters through these areas. The impact of the Build alternatives on these developed areas has been assessed by the length of roadway within the developed areas. The results of this analysis are summarized in **Table 13**. Of the Build alternatives, Alternatives B1, B2, and B3 have the shortest length (1.9 miles/3 km) of roadway within the Developed Areas and Alternative B4 has the longest length (14.5 miles/23.3 km) of roadway within the developed areas.

Table 13: Length of Additional Roadway Through Developed Areas

Alternative	Additional Length of Roadway (mile)	Additional Length of Roadway (kilometre)
No-Build	0	0
B1	1.9	3
B2	1.9	3
B3	1.9	3
B4	14.5	23.3

Rainfall runoff and storm surge modelling was also completed to assess the potential drainage impact of the Build alternatives on the developed areas based on the same parameters as was used for Meagre Bay Pond above. Overall, the results showed a slight decrease in the peak water level for Build alternatives B1, B2, and B3. The study also showed that the water level in the developed areas exceeded the existing condition water level for a length of time for these alternatives. The results showed longer flood durations at NW Area, Will T and Rossini Drive, but these are attributed to slight local differences in shallow drainage, rather than any broad impoundment of water in the area for Alternatives B1 and B3. An example of this local shallow drainage effect for a specific location along the B2 Build alternative is shown in **Figure 20**.

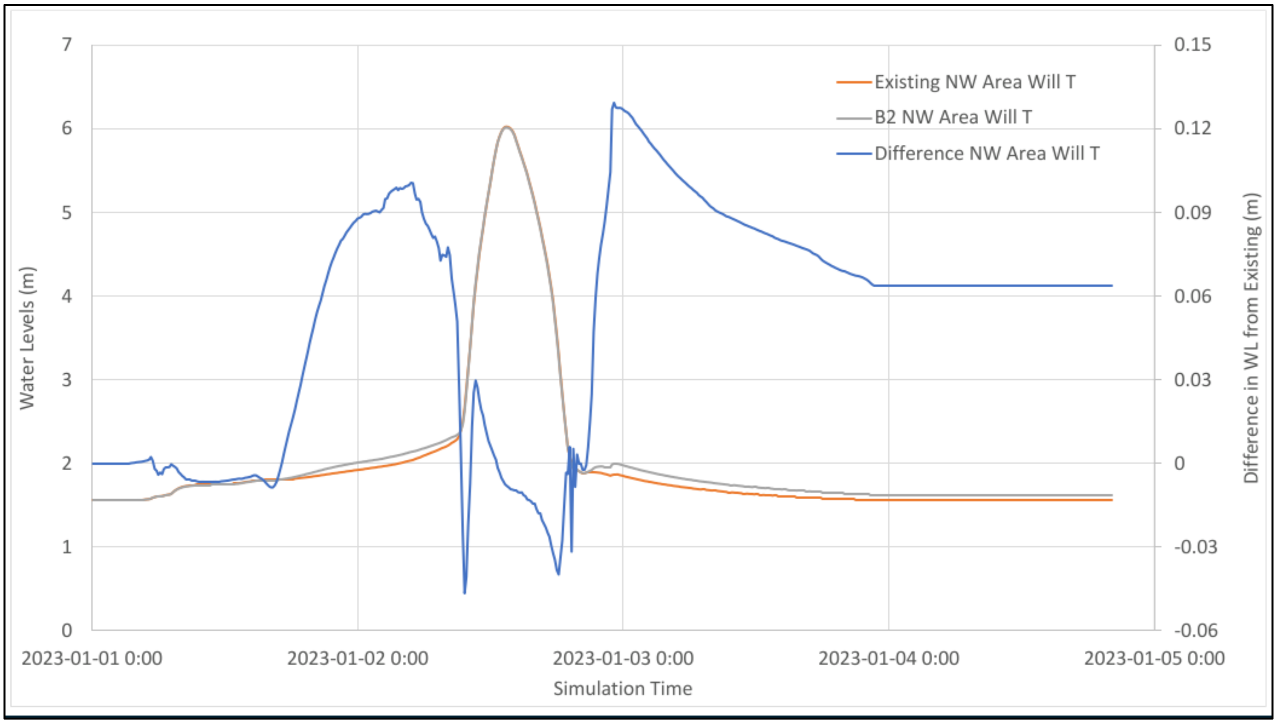

Figure 20: Example of Ponding Issue in Shallow Regions

Source: Baird and Associates, 2024

This figure shows the existing modelling results versus the proposed results for a specific location along the B2 Build alternative. The results show the water levels in the proposed condition flattening out at an elevation higher than the existing results due to localized puddling effects in the modelling (Baird and Associates, 2024).

The results also showed slightly higher values along Alternative B2. One area where this occurred was at Midland Acres. This location is approximately 0.6 miles (1.0 km) away from the nearest potential drainage opening through the Alternative B2 roadway and is shown in **Figure 21** along with some of the other locations of interest.

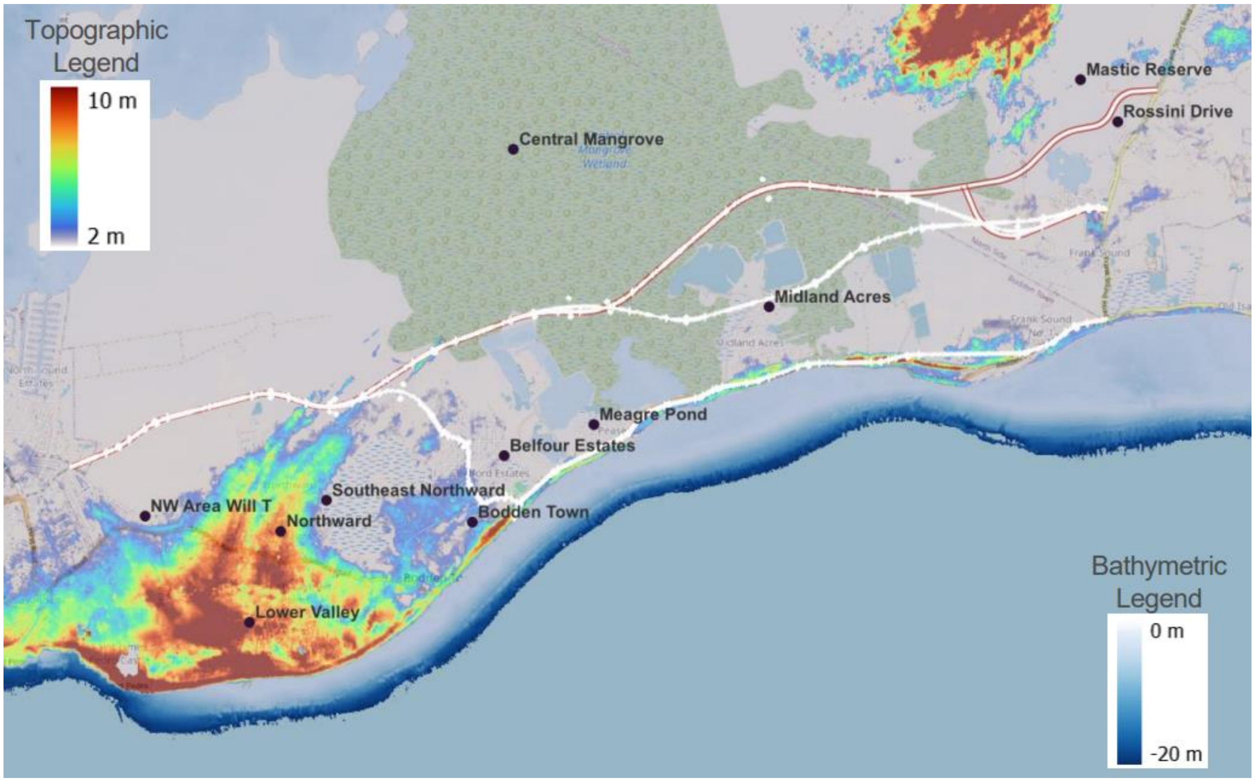

Figure 21: Developed Area Locations
Source: Baird and Associates, 2024

This distance from the drainage opening creates a longer drainage path that possibly could be mitigated by adding an opening through this section of the roadway closer to this location. As previously described for other resources areas, the results of this analysis show that there would be a slight decrease in the peak water level for Alternatives B1, B2, and B3; however, the study also showed that, on average, the water in the identified developed areas is impounded for longer than existing conditions. These conditions suggest that, while the Build alternatives are generally not impactful when considering peak water surface elevations, the configuration of the roadway and the associated openings would result in longer drain times for the water that is impounded. Based on discussions with Baird and RVE, the slight differences in floodwaters shown for the developed areas are within acceptable tolerances for the scale of storms being considered.

The amount of potential impoundment in the developed areas was measured using the same variables that were used for the CMW analysis. The results of this analysis are reported for the individual areas covered by this study. The values were averaged, and the results are summarized in **Table 14**. These averaged values were used for comparative analysis of each of the alternatives.

Table 14: Floodwater (Including Surge and Rainfall) Impoundment Impacts to Developed Areas

Alternative	Average Duration of Increased Impoundment (hours)	Average Difference of Maximum Impoundment (ft/m)
No-Build	0	0
B1	2	-0.1/-0.03
B2	2	-0.1/-0.02
B3	2	-0.1/-0.03
B4	*	*

**Impoundment impacts for Alternative B4 may generally result in a slight reduction of the peak on the SW side of the road with possible slight delays in the drainage of water following a storm (Baird and Associates 2024); however, impacts are not expected at the other locations of interest.*

7.7.2 Pollution Impact Assessment

To assess potential pollution impacts for the developed areas, the increase of impervious area along the Will T Connector was used for all Build alternatives. Due to the lack of development along the remainder of the Alternatives B1, B2, and B3, these surface areas were not included in this analysis. Numerous developed areas are located adjacent to Alternative B4 and the total impervious area along Alternative B4 was calculated and used in this comparison. The summary of the pollution potential assessment is included in **Table 15**.

Table 15: Increase of Impervious Area Assessment for Developed Areas

Alternative	Increase of Impervious Area (Ac/ha)	Distance from Alignment to Developed Areas (mile/km)
No-Build	0	0/0
B1	29/12	0/0
B2	29/12	0/0
B3	29/12	0/0
B4	80/33	0/0

7.8 Damage to Existing Drainage Infrastructure

The construction of any of the Build alternatives (B1, B2, B3 and B4) may potentially inadvertently cause damage to existing drainage infrastructure and result in subsequent flooding of neighbouring properties or infrastructure. A map of the existing drain wells was developed using data provided by the NRA and is shown in **Figure 22.**

Drain wells are one of the main drainage features used on Grand Cayman; therefore, the number of drainage wells that may be impacted was determined for each of the Build alternatives. There is one drainage well along Alternatives B1, B2, and B3 and eighteen drainage wells along Alternative B4 which potentially can be affected by construction activities. No drainage wells are anticipated to be impacted by the No-Build scenario. A summary of the number of potentially affected drainage wells for each alternative is shown in **Table 16**.

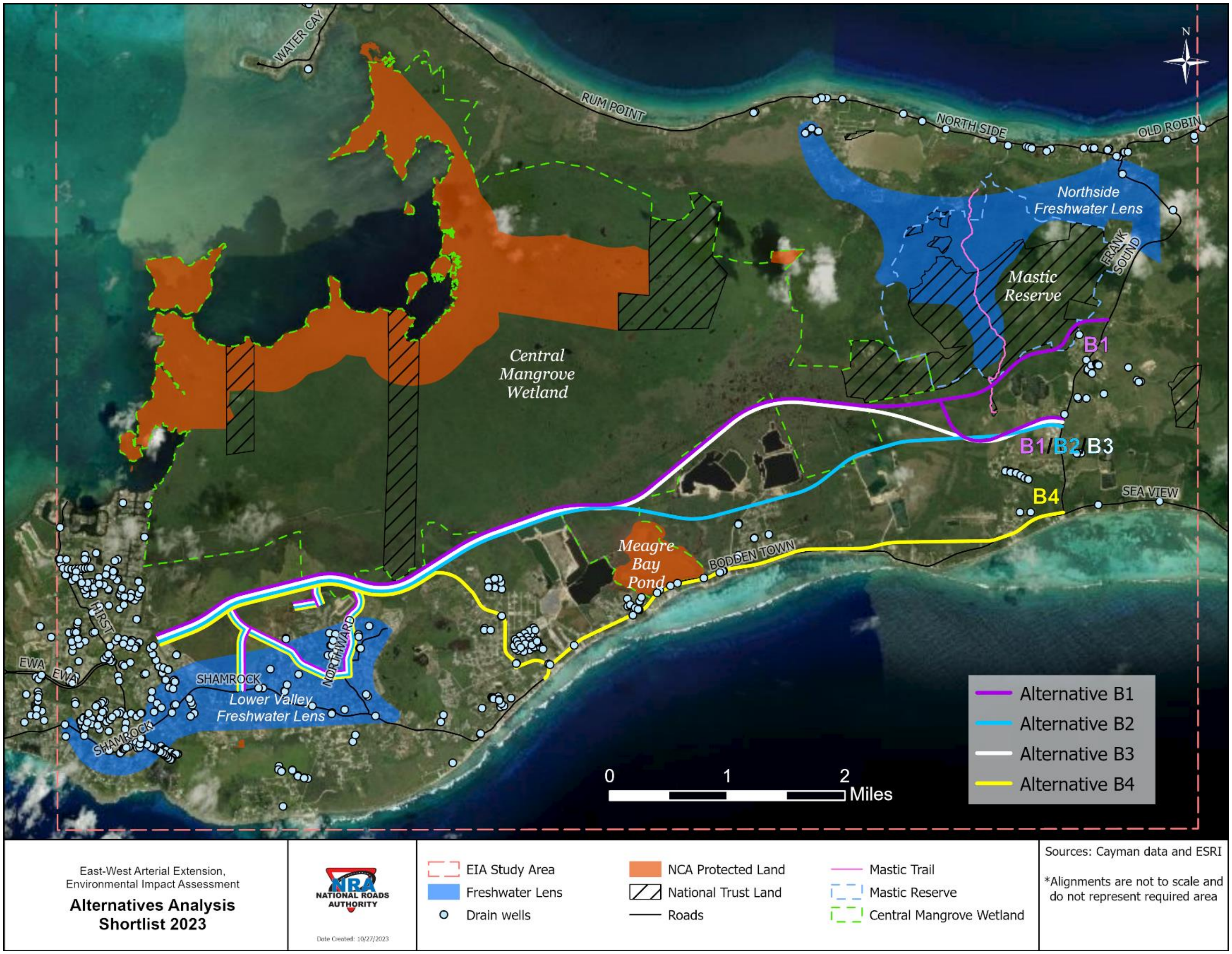

Figure 22: Drain Well Map

Table 16: Potentially Affected Drainage Wells

Alternative	Potentially Affected Drainage Wells (Each)
No-Build	0
B1	1
B2	1
B3	1
B4	18

8 Qualitative Impact Assessment

8.1 Assessment Methodology

The qualitative assessment for Hydrology and Drainage is based upon the UK Department for Transport's "Transport Analysis Guidance Unit A3: Environmental Impact Appraisal" (WebTAG). The most applicable category for Hydrology and Drainage impacts is "Impacts on the Water Environment." The completed qualitative assessment incorporates WebTAG Section 10 of Unit A3: Environmental Impact Appraisal as appropriate. The qualitative assessment also incorporates the March 2020 Design Manual for Roads and Bridges LA 113 as appropriate.

A variation from WebTAG Unit A3 is that this assessment did not include the "Very Large Adverse Impact" category since it is inconsistent with the 7-point qualitative scale assigned in the Appraisal Summary Table.

The **first step** of the qualitative assessment is to determine the importance (or value) of features based on the guidance table below:

Table 17: Estimating the Importance of Water Environment Features

Importance	Criteria	Examples
Very high	• Feature with a high quality and rarity, regional or national scale and limited potential for substitution	• Aquifer providing potable water to a large population (groundwater) • Important fish population (surface water) • Floodplain or defence protecting more than 100 residential properties (flood risk)
High	• Feature with a high quality and rarity, local scale and limited potential for substitution • Feature with a medium quality and rarity, regional or national scale and limited potential for substitution	• High status water body (surface water) • Aquifer providing potable water to a small population (groundwater) • Notable fish population (surface water) • Floodplain or defence protecting up to 100 residential properties or industrial premises (flood risk)
Medium	• Feature with a medium quality and rarity, local scale and limited potential for substitution • Feature with a low quality and rarity, regional or national scale and limited potential for substitution	• Good status water body (surface water) • Aquifer providing abstraction water for agricultural or industrial use (groundwater) • Floodplain or defence protecting up to 10 industrial premises (flood risk)

Importance	Criteria	Examples
Low	• Feature with a low quality and rarity, local scale and limited potential for substitution	• Less than good status (surface water) • Unproductive strata (groundwater) • Floodplain with limited existing development (flood risk)

Source: WebTAG Unit A3, Environmental Impact Appraisal, Table 13, November 2023

The **second step** of the qualitative assessment is to determine the magnitude of impact (positive or negative). This is based on Table 14 from WebTAG Unit A3 as depicted in **Table 18.** The ranking system and criteria from WebTAG were followed; however, some of the terminology within the magnitude of impact section was modified to ease document consistency and reader understanding. Because the subsequent step (the **third step**) in the evaluation uses the terms "Adverse" and "Beneficial," those terms in **Table 18** were changed to "Negative" and "Positive." This change in terminology is consistent with other sections of WebTAG Unit A3.

Table 18: Estimating the Magnitude of Impact

Magnitude	Criteria	Example
Major Negative	• Results in loss of feature	• Loss of important fishery • Change in water quality status • Compromise employment source • Loss of flood storage/increased flood risk • Pollution of potable source of abstraction
Moderate Negative	• Results in adverse impact on integrity of feature or loss of part of feature	• Loss in productivity of a fishery • Contribution of a significant proportion of the effluent in the receiving water body • Reduction in the economic value of the feature
Minor Negative	• Results in minor adverse impact on feature	• Measurable changes in feature, but of limited size and/or proportion
Negligible	• Results in an impact on feature but of insufficient magnitude to affect the use/integrity	• Discharges to watercourse but no significant loss in quality, fishery productivity or biodiversity • No significant impact on the economic value of the feature • No increase in flood risk
Minor Positive	• Results in minor beneficial impact on feature or a reduced risk of adverse effect occurring.	• Measurable changes in feature, but of limited size and/or proportion
Moderate Positive	• Results in moderate improvement of feature	• Enhanced productivity of a fishery • Reduction in a significant proportion of the effluent in a receiving water body • Moderate reduction in flood risk
Major Positive	• Results in major improvement of feature	• Removal of major existing polluting discharge to a watercourse • Major reduction in flood risk

Source: WebTAG Unit A3, Environmental Impact Appraisal, Table 14, November 2023

The **third step** of the qualitative assessment is to determine the overall assessment score based on the results of Step 1 and Step 2. As shown in **Table 19** the assessment scores are based on the magnitude of impact and the importance of the water environment feature. **Table 19** shows the evaluation criteria description matrix that was used to define the scores of the selected features which are presented in **Table 22**.

This step is a streamlined version of determining the Overall Assessment Score of the water resource per WebTAG Unit A3 (see paragraph 10.2.15). In addition, the terminology in **Table 19** was updated to match the terms used in Unit A3's Table 16. However, the process for using the matrix was not changed. This methodology allows for an assessment score per *resource* to be determined.

Table 19: Assessment Score by Resource

Magnitude of Impact*	Importance of Water Environment Features			
	Very High	High	Medium	Low
Major Negative	Large adverse**	Large adverse	Moderate adverse	Slight adverse
Moderate Negative	Large adverse	Moderate adverse	Slight adverse	Neutral
Minor Negative	Moderate adverse	Slight adverse	Neutral	Neutral
Negligible	Slight adverse	Neutral	Neutral	Neutral

**All identified impacts were adverse, therefore beneficial impacts are not shown within the table*
***Very Large and Large Adverse were merged to be consistent with the 7-point qualitative scale for the Appraisal Summary Table*

Source: WebTAG Unit A3, Environmental Impact Appraisal, Table 15, November 2023

An Overall Assessment Score of each alternative, that takes into account the individual assessment score for each resource, was then determined (**Table 20**). WebTAG guides project teams to also consider the number of key water resources affected by a scheme when determining the Overall Assessment Score. Therefore, both the assessment score by resource as well as the number of impacted resources were taken into account when determining the Overall Assessment Score per alternative.

Table 20: Definitions of Overall Assessment Score

Score	Comment
Large Beneficial Impact	It is extremely unlikely that any scheme incorporating the construction of a new transport route (road or rail) would fit into this category. However, a scheme could have a large positive impact if it is predicted that it will result in a 'very' or 'highly' significant improvement to a water feature(s), with insignificant adverse impacts on other water features.
Moderate Beneficial Impact	Where the scheme provides an opportunity to enhance the water environment, because it results in predicted: • Significant improvements for at least one water feature, with insignificant adverse impacts on other features; • Very or highly significant improvements, but with some adverse impacts of a much lower significance. • The predicted improvements achieved by the scheme should greatly outweigh any potential negative impacts.
Slight Beneficial Impact	Where the scheme provides an opportunity to enhance the water environment, because it provides improvements in water features which are of greater significance than the adverse effects
Neutral	Where the net impact of the scheme is neutral, because: • it has no appreciable effect, either positive or negative, on the identified features; • the scheme would result in a combination of effects, some positive and some negative, which balance to give an overall neutral impact. In most cases these will be slight or moderate positive and negative impacts. It may be possible to balance impacts of greater significance. However, in these cases great care will be required to ensure that the impacts are comparable in terms of their potential environmental impacts and the perception of these impacts.
Slight Adverse Impacts	Where the scheme may result in a degradation of the water environment, because the predicted adverse impacts are of greater significance than the predicted improvements.
Moderate Adverse Impacts	Where the scheme may result in a degradation of the water environment, because it results in predicted: • significant adverse impacts on at least one feature, with insignificant predicted improvements to other features; • very or highly significant adverse impacts, but with some improvements which are of a much lower significance and are insufficient positive impacts to offset the negative impacts of the scheme.
Large Adverse Impact	Where the scheme may result in a degradation of the water environment, because it results in predicted: • highly significant adverse impacts on a water feature; • significant adverse impacts on several water features
**Very Large Adverse Impact was eliminated from this table for consistency with the 7-point qualitative scale for the Appraisal Summary Table*	

8.2 Importance of Water Environment Features

8.2.1 Central Mangrove Wetland

As the only large mangrove forest on Grand Cayman, the CMW is a unique national site with significant complexity and limited potential for substitution. Therefore, it receives a **"Very High"** rating on the Importance of Water Environment Features scale.

8.2.2 Mastic Reserve

The Mastic Reserve is a unique national site with significant complexity and limited potential for substitution. Therefore, it receives a **"Very High"** rating on the Importance of Water Environment Features scale.

8.2.3 Meagre Bay Pond

The Meager Bay Pond is a unique national site with significant complexity and limited potential for substitution. Therefore, it receives a **"Very High"** rating on the Importance of Water Environment Features scale.

8.2.4 Freshwater Lenses

The Freshwater Lenses are unique national sites with significant complexity and limited potential for substitution. Therefore, they receive a **"Very High"** rating on the Importance of Water Environment Features scale. Detailed information regarding the Freshwater Lenses can be found in the separate Geo-Environmental Assessment of Alternatives report.

8.2.5 Developed Areas

Although not specifically a water environment feature, developed areas may potentially be hydraulically impacted by the proposed roadway and therefore, they were also included in this analysis. Bodden Town is an important residential and commercial center on Grand Cayman, along with the rest of the developed areas listed in Section 7.6. Therefore, developed areas receive a **"Very High"** rating on the Importance of Water Environment Features scale.

8.2.6 Existing Drainage Infrastructure

Existing man-made drainage infrastructure is an important feature to convey stormwater and to minimize flooding. Since this is a man-made feature it is anticipated that any drainage infrastructure affected by the construction would be replaced; therefore, it receives a **"Low"** rating on the Importance of Water Environment Features scale.

8.3 Magnitude of Impact

8.3.1 Alternative B1

<u>Central Mangrove Wetland</u>: Alternative B1 is anticipated to directly impact 76 acres (31 ha) of the CMW, which is less than 1% of the total CMW area (8,655 acres). Although approximately 2.8 miles (4.5 km) of Alternative B1 travel through the CMW, rainfall and surge modeling results show minimal impact to the CMW drainage patterns, flooding and impoundment durations. The water budget modeling of the CMW showed that the CMW pool and water level would not be affected by the proposed roadway. In addition, pollution from Alternative B1 is anticipated to be limited based on the relatively small percentage increase of impervious area compared to the total drainage area of the CMW (0.9%). While there is anticipated to be a measurable change to this

feature, it would be of limited size and/or proportion and therefore, Alternative B1 received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Mastic Reserve: Alternative B1 is anticipated to directly impact 17 acres (7 ha) of the Mastic Reserve drainage area. Based on the rainfall and surge modeling, it is anticipated that Alternative B1 would minimally impact the drainage patterns, flooding and impoundment durations of the Mastic Reserve. In addition, pollution from Alternative B1 could possibly occur based on the stormwater runoff flow pattern and the close distance of Alternative B1 to the Mastic Reserve. Based on the rainfall and surge modeling, the existing drainage patterns, and distance between the roadway and Mastic Reserve it is anticipated that Alternative B1 would have a moderate impact on the Mastic Reserve and therefore, Alternative B1 received a **"Moderate Negative"** rating on the Magnitude of Potential Impacts scale.

Meagre Bay Pond: Based on the rainfall and surge modeling, it is anticipated that Alternative B1 would minimally impact the drainage patterns, flooding and impoundment durations of the Meagre Bay Pond. In addition, pollution from Alternative B1 is anticipated to be limited based on the stormwater run-off flow pattern and the distance of Alternative B1 from the Meagre Bay Pond (1,291 ft/ 394 m). Based on the rainfall and surge modeling, the existing drainage patterns, and distance between the roadway and Meagre Bay Pond it is anticipated that Alternative B1 would have minimal impact on Meagre Bay Pond and therefore, Alternative B1 received a **"Negligible"** rating on the Magnitude of Potential Impacts scale.

Freshwater Lenses: As demonstrated in the above mounding assessments, the theoretical mounds (rise in the water table) at the lenses are less than 1 foot (0.3 metre) at the centre of the basin for the Lower Valley Freshwater Lens and North Side Freshwater Lens. These impacts are anticipated to be temporary in nature and minimally impact the upper surface of the Freshwater Lenses. Therefore, Alternative B1 received a **"Negligible"** rating on the Magnitude of Potential Impacts scale.

Developed Areas: Although Alternative B1 travels 1.9 miles (3.0 km) through the developed areas, based on the rainfall and surge modeling, it is anticipated that Alternative B1 would minimally impact the drainage patterns and flooding of the developed areas. In addition, pollution from Alternative B1 could possibly occur based on the stormwater runoff flow pattern and the increase of impervious area directly adjacent to the developed area (14 acres/ 6 Ha). Based on the rainfall and surge modeling, the existing drainage patterns, and impervious area increase, it is anticipated that Alternative B1 would have minimal impact on developed areas and therefore, Alternative B1 received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Existing Drainage Infrastructure: Alternative B1 is anticipated to directly impact one drainage well. Based on the wide distribution of this resource and insufficient magnitude of impact, it received a **"Negligible"** rating on the Importance of Water Environment Features scale.

8.3.2 Alternative B2

Central Mangrove Wetland: Alternative B2 is anticipated to directly impact 57 acres (23 ha) of the CMW, which is less than 1% of the total CMW area (8,655 acres). Although approximately 2.1 miles (3.4 km) of Alternative B2 travel through the CMW, rainfall and surge modeling results show minimal impact to the CMW drainage patterns, flooding and impoundment durations. The water budget modeling of the CMW showed that the CMW pool and water level would not be affected by the proposed roadway. In addition, pollution from Alternative B2 is anticipated to be limited based on the relatively small percentage increase of impervious area compared to the total drainage area of the CMW (approximately 1%). While there is anticipated to be a measurable change in the feature, it would be of limited size and/or proportion and therefore, Alternative B2 received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Mastic Reserve: Based on the rainfall and surge modeling, it is anticipated that Alternative B2 would minimally impact the drainage patterns of the Mastic Reserve. In addition, pollution from Alternative B2 is anticipated to be limited based on the stormwater runoff flow pattern, higher ground elevation, and the distance of Alternative B2 from the Mastic Reserve (2,058 ft/ 627 m). Based on the rainfall and surge modeling, the existing drainage patterns, and distance between the roadway and Mastic Reserve it is anticipated that Alternative B2 would have a minimal impact on the Mastic Reserve and therefore, Alternative B2 received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Meagre Bay Pond: Based on the rainfall and surge modeling, it is anticipated that Alternative B2 would minimally impact the drainage patterns, flooding and impoundment durations of the Meagre Bay Pond. In addition, pollution from Alternative B2 is anticipated to be limited based on the stormwater runoff flow pattern and the distance of Alternative B2 from the Meagre Bay Pond (968 ft/ 295 m). Based on the rainfall and surge modeling, the existing drainage patterns, and distance between the roadway and Meagre Bay Pond it is anticipated that Alternative B2 would have minimal impact on Meagre Bay Pond and therefore, Alternative B2 received a **"Negligible"** rating on the Magnitude of Potential Impacts scale.

Freshwater Lenses: As demonstrated in the above mounding assessments, the theoretical mounds (rise in the water table) at the lenses are less than 1 foot (0.3 metre) at the centre of the basin for the Lower Valley Freshwater Lens and North Side Freshwater Lens. These impacts are anticipated to be temporary in nature and minimally impact the upper surface of the Freshwater Lenses. Therefore, Alternative B2 received a **"Negligible"** rating on the Magnitude of Potential Impacts scale.

Developed Areas: Although Alternative B2 travels 1.9 miles (3.0 km) through the developed areas, based on the rainfall and surge modeling, it is anticipated that Alternative B2 would minimally impact the drainage patterns, flooding and impoundment durations in developed areas. In addition, pollution from Alternative B2 is anticipated to occur based on the stormwater runoff flow pattern and the increase of impervious area directly adjacent to the developed area (14 acres / 6 ha). Based on the rainfall and surge modeling, the existing drainage patterns, and impervious area increase, it is anticipated that Alternative B2 would have minimal impact on developed areas and therefore, Alternative B2 received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Existing Drainage Infrastructure: Alternative B2 is anticipated to directly impact one drainage well. Based on the wide distribution of this resource and insufficient magnitude of impact, it received a **"Negligible"** rating on the Importance of Water Environment Features scale.

8.3.3 Alternative B3

Central Mangrove Wetland: Alternative B3 is anticipated to directly impact 76 acres (31 ha) of the CMW, which is less than 1% of the total CMW area (8,655 acres). Although approximately 2.8 miles (4.5 km) of Alternative B3 travel through the CMW, rainfall and surge modeling results show minimal impact to the CMW drainage patterns, flooding and impoundment durations. The water budget modeling of the CMW showed that the CMW pool and water level would not be affected by the proposed roadway. In addition, pollution from Alternative B3 is anticipated to be limited based on the relatively small percentage increase of impervious area compared to the total drainage area of the CMW (approximately 1%). While there is anticipated to be a measurable change in the feature, it would be of limited size and/or proportion and therefore, Alternative B3 received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Mastic Reserve: Based on the rainfall and surge modeling, it is anticipated that Alternative B3 would minimally impact the drainage patterns of the Mastic Reserve. In addition, pollution from Alternative B3 is anticipated to be limited based on the stormwater run-off flow pattern, higher ground elevation, and the distance of Alternative B3 from the Mastic Reserve (1,574 ft/ 480 m). Based on the rainfall and surge modeling, the existing drainage patterns, and distance between the roadway and Mastic Reserve it is anticipated that Alternative B3 would have a minimal impact on the Mastic Reserve and therefore, Alternative B3 received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Meagre Bay Pond: Based on the rainfall and surge modeling, it is anticipated that Alternative B3 would minimally impact the drainage patterns of the Meagre Bay Pond. In addition, pollution from Alternative B3 is anticipated to be limited based on the stormwater run-off flow pattern and the distance of Alternative B3 from the Meagre Bay Pond (1,291 ft/ 394 m). Based on the rainfall and surge modeling, the existing drainage patterns, and distance between the roadway and Meagre Bay Pond it is anticipated that Alternative B3 would have minimal impact on Meagre Bay Pond and therefore, Alternative B3 received a **"Negligible"** rating on the Magnitude of Potential Impacts scale.

Freshwater Lenses: As demonstrated in the above mounding assessments, the theoretical mounds (rise in the water table) at the lenses are less than 1 foot (0.3 metre) at the centre of the basin for the Lower Valley Freshwater Lens and North Side Freshwater Lens. These impacts are anticipated to be temporary in nature and minimally impact the upper surface of the Freshwater Lenses. Therefore, Alternative B3 received a **"Negligible"** rating on the Magnitude of Potential Impacts scale.

Developed Areas: Although Alternative B3 travels 1.9 miles (3.0 km) through the developed areas, based on the rainfall and surge modeling, it is anticipated that Alternative B3 would minimally impact the drainage patterns and flooding of the developed areas. In addition, pollution from Alternative B3 is anticipated to occur based on the stormwater run-off flow pattern and the increase of impervious area directly adjacent to the developed area (14 acres/ 6 ha). Based on the rainfall and surge modeling, the existing drainage patterns, and impervious area increase, it is anticipated that Alternative B3 would have minimal impact on developed areas and therefore, it received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Existing Drainage Infrastructure: Alternative B3 is anticipated to directly impact one drainage well. Based on the wide distribution of this resource and insufficient magnitude of impact, it received a **"Negligible"** rating on the Importance of Water Environment Features scale.

8.3.4 Alternative B4

Central Mangrove Wetland: Alternative B4 is anticipated to directly impact 10 acres (4 ha) of the Central Mangrove Wetland, which is less than 1% of the total CMW area (8,655 acres). Approximately 0.7 miles (1.1 km) of Alternative B4 travel through the CMW. Rainfall and surge modeling results show minimal impact to the CMW drainage patterns, flooding and impoundment durations for the portion of alternative B4 within Section 2. The water budget modeling of the CMW showed that the CMW pool and water level would not be affected by the proposed roadway. In addition, pollution from Alternative B4 is anticipated to be limited based on the relatively small percentage increase of impervious area compared to the total drainage area of the CMW (approximately 1%). While there is anticipated to be a measurable change in the feature, it would be of limited size and/or proportion and therefore, Alternative B4 received a **"Minor Negative"** rating on the Magnitude of Potential Impacts scale.

Mastic Reserve: Based on the rainfall and wave overtopping modeling, it is anticipated that Alternative B4 would not impact the drainage patterns of the Mastic Reserve. In addition, pollution from Alternative B4 is anticipated to be limited based on the stormwater run-off flow pattern, higher ground elevation, and the distance of Alternative B4 from the Mastic Reserve (6,399 ft/ 1,950 m). Based on the rainfall and surge modeling, the existing drainage patterns, and distance between the roadway and Mastic Reserve it is anticipated that Alternative B4 would have no impact on the Mastic Reserve and therefore, Alternative B4 received a **"Negligible"** rating on the Magnitude of Potential Impacts scale.

Meagre Bay Pond: Based on the rainfall and wave overtopping modeling and discussions in earlier sections of this assessment, it is anticipated that Alternative B4 would not impact the drainage patterns of the Meagre Bay Pond. In addition, pollution from Alternative B4 is anticipated to occur based on the stormwater run-off flow pattern and the close distance of Alternative B4 from the Meagre Bay Pond (148 ft/ 45 m). Based on the rainfall and surge modeling, the existing drainage patterns, and distance between the roadway and Meagre Bay Pond it is anticipated that Alternative B4 would have significant impact on Meagre Bay Pond and therefore, Alternative B4 received a **"Major Negative"** rating on the Magnitude of Potential Impacts scale.

Freshwater Lenses: As demonstrated in the above mounding assessments, the theoretical mounds (rise in the water table) at the lenses are less than 1 foot (0.3 metre) at the centre of the basin for the Lower Valley Freshwater Lens and North Side Freshwater Lens. These impacts are anticipated to be temporary in nature and minimally impact the upper surface of the Freshwater Lenses. Therefore, Alternative B4 received a **"Negligible"** rating on the Magnitude of Potential Impacts scale.

Developed Areas: Alternative B4 travels 18.1 miles (29.1 km) through the developed areas. Based on the rainfall and surge modeling, it is anticipated that Alternative B4 would minimally impact the drainage patterns and flooding of the developed areas for the portion of Alternative B4 within Section 2.Within Section 3, the wave overtopping analysis recommended some form of protective structure or raising of the road up to 22 ft (6.7 m) above mean sea level along the south coast in order to prevent significant wave overtopping from occurring and to meet the resiliency performance critical success factor identified for this project. This addition of a protective structure or change in roadway elevation would result in numerous impacts to the many developed areas along this area. In addition, pollution from Alternative B4 is anticipated to occur based on the stormwater run-off flow pattern and the large increase of impervious area directly adjacent to the developed area (98 acres/ 40 Ha). Based on the rainfall and surge modeling, wave overtopping, existing drainage patterns, and impervious area increase, it is anticipated that Alternative B4 would have significant impact on developed areas and therefore, Alternative B4 received a **"Major Negative"** rating on the Magnitude of Potential Impacts scale.

Existing Drainage Infrastructure: Alternative B4 is anticipated to directly impact 18 drainage wells, which is 3% of the total number of drainage wells within the EIA study area (604 drainage wells). Based on the magnitude of this impact, Alternative B4 received a **"Moderate Negative"** rating on the Importance of Water Environment Features scale.

8.4 Overall Assessment Score

A summary of the anticipated magnitude of impact per alternative, along with the importance of each identified feature, is shown in **Table 21**.

Table 21: Summary Table of Importance of Water Environment Features and Magnitude of Impact

Feature	Importance of Water Environment Features	Anticipated Magnitude of Impact by Alternative				
		No-Build	B1	B2	B3	B4
CMW	Very High	Negligible	Minor Negative	Minor Negative	Minor Negative	Minor Negative
Mastic Reserve	Very High	Negligible	Moderate Negative	Minor Negative	Minor Negative	Negligible
Meagre Bay Pond	Very High	Negligible	Negligible	Negligible	Negligible	Major Negative
Freshwater Lenses	Very High	Negligible	Negligible	Negligible	Negligible	Negligible
Developed Areas	Very High	Negligible	Minor Negative	Minor Negative	Minor Negative	Major Negative
Existing Drainage Infrastructure	Low	Negligible	Negligible	Negligible	Negligible	Moderate Negative

9 Monetary Impact Assessment

A Monetary Impact Assessment for water and environment features analysed for hydrology and drainage is not applicable per the WebTAG.

10 Shortlist Evaluation Summary

The importance of each water environment feature and the anticipated magnitude of impact by alternative were assessed, and the qualitative impact ratings are presented in **Table 22**. The qualitative impact rating per water environment feature is then summarized into an Overall Qualitative Rating for the No-Build scenario and each Build alternative.

Table 22: Overall Assessment Score per Alternative

Water Environment Feature	No-Build	B1	B2	B3	B4
Central Mangrove Wetland	Slight Adverse	Moderate Adverse	Moderate Adverse	Moderate Adverse	Moderate Adverse
Mastic Reserve	Slight Adverse	Large Adverse	Moderate Adverse	Moderate Adverse	Slight Adverse
Meagre Bay Pond	Slight Adverse	Slight Adverse	Slight Adverse	Slight Adverse	Large Adverse
Freshwater Lenses	Slight Adverse	Slight Adverse	Slight Adverse	Slight Adverse	Slight Adverse
Developed Areas	Slight Adverse	Moderate Adverse	Moderate Adverse	Moderate Adverse	Large Adverse
Existing Drainage Infrastructure	Neutral	Neutral	Neutral	Neutral	Neutral
Overall Qualitative Rating	**Slight Adverse**	**Large Adverse**	**Moderate Adverse**	**Moderate Adverse**	**Large Adverse**

- *No-Build* – The No-Build scenario is anticipated to have a “Slight Adverse” impact to five of the six water environment features discussed in this technical report resulting in an overall **Slight Adverse** rating.

- *Alternative B2* – Alternative B2 is anticipated to be the least impactful of the four Build alternatives on water environment features. Alternatives B2 and B3 have the same overall qualitative rating (**Moderate Adverse**) and each was assessed to have a “Moderate Adverse” impact on three water environment features (CMW, Mastic Reserve and Developed Areas.) Because Alternative B2 is anticipated to impact 57 acres (23 ha) of CMW and Alternative B3 is anticipated to impact 76 acres (31 ha) of CMW, Alternative B2 is anticipated to be slightly less impactful than Alternative B3.

- *Alternative B3* – Alternative B3 is anticipated to be the second least impactful of the four Build alternatives. As described for Alternative B2, Alternative B3 would have a slightly larger impact on the CMW by area (still less than 1% of the total area) than Alternative B2.

- *Alternative B1* – Alternative B1 is anticipated to be the third least impactful of the four Build alternatives. Alternatives B1 and B4 have the same overall qualitative rating **Large Adverse.** However, Alternative B1 has overall lower qualitative ratings for the individual resources (one Large Adverse, two Moderate Adverse, two Slight Adverse, and one Neutral versus two Large Adverse, one Moderate Adverse, two Slight Adverse, and one Neutral).

- *Alternative B4* – Alternative B4 would be the most impactful of the four Build alternatives and has the overall qualitative rating **Large Adverse**. Alternative B4 is anticipated to be more impactful than Alternative B1 due to its two "Large Adverse" impacts on Meagre Bay Pond and the Developed Areas as described in the Alternative B1 section above.

This Hydrology and Drainage Assessment is one in a series of Technical Reports that have been prepared for the Shortlist Evaluation. The level of impacts and the identification of the least impactful or most beneficial alternative will differ based on the resource/feature evaluated in each of the Technical Reports. Therefore, the most beneficial alternative described in this evaluation summary and in each technical document **does not** move an alternative forward to the Preferred Evaluation nor does it constitute any special weighting or extra consideration in the Shortlist Evaluation Document. The comprehensive analysis of all the resources/features evaluated along with the rationale for the identification of the Preferred Alternative are presented in the Shortlist Evaluation Document.

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Attachment A

Hydrology and Drainage Field Effort Summary

1 Field Effort Method

Hydrology and drainage field investigation efforts in July 2023 included observation and collection of information regarding existing drainage conveyance structures (pipes, inlets, manholes, etc.) along the No-Build and Build Alternative alignments (B1, B2, B3, and B4), observations of the existing on-island bridge, field views of the natural resources and mosquito canals, and a visit to an active quarry. The existing roadways and the proposed alternatives, when possible, were viewed to assess existing conditions and observe drainage patterns. The existing inlets and drainage systems were measured, mapped, and photographed. A rainfall event was observed and photographed. Observations of the event including localized temporary flooding along Bodden Town Road. An existing bridge in the Seven Mile Beach area was also observed. Flow patterns along the Savannah Gully were also assessed. Field views of natural resources, including the Central Mangrove Wetland, Meagre Bay Pond, and Mastic Trail were conducted. The archaic mosquito canals were walked and periodically measured. Drainage pipes and structures were mapped, characterized, and photographed. Exposed bedrock was mapped and photographed.

2 Existing Roadways, Inlets, and Bridges

During the field walk, several existing roadways were traversed including Lookout Road, Bodden Town Road, Shamrock Road, and Hirst Road. Pictures were taken to document the existing conditions of the roads. Generally, the existing roads were two lane roads with housing developments, businesses, and government buildings in close proximity to the road. There were some locations, particularly along Shamrock and Bodden Town Roads, with small (approximately 3 to 4 ft (0.9 to 1.2 m) tall) decorative walls that were only a few feet from the edge of the roadway on either side of the road (**Photo 1**). Bodden Town Road was at times close to the ocean (**Photo 2**). Bodden Town Road is also in close proximity to Meagre Bay Pond. The roads follow the existing topography with Hirst and Shamrock Roads rising along the ridge located in the Bodden Town Area and Bodden Town Road following the coastline. Bodden Town Road is located several feet above sea level for a majority of the EIA study area with only a few locations, particularly at Meagre Bay Pond, dropping closer to sea level.

Photo 1: Two-lane road in residential area with relatively short decorative walls (July 2023)

Photo 2: Bodden Town Road in close proximity to the ocean (July 2023)

The existing inlets and drainage systems in the roadways were also observed during the field view. The observed drainage systems consisted of shallow inlets located on the roadside in between the edge of the roadway and the adjacent properties (**Photo 3**). Several locations contained multiple inlets that were connected with small pipes (approximately 15-inches in diameter, maximum) (**Photo 4**). There were also several locations of kerb and gutter that contained combination kerb opening/grate inlets with grates that indicated they were manufactured in the USA (**Photo 5**). All the inlets either drained to or contained a drainage well standpipe (**Photo 6**). Most of the well standpipes were observed to be approximately 8-inches in diameter and were fabricated from Polyvinyl Chloride (PVC) pipe. The ends of the PVC standpipes were generally oriented upward with no trash racks or other screening devices. Several of the wells observed contained perforations along the raised portion of the standpipe. Water was visible within most drainage/well standpipe inlets with a few of the standpipes appearing clogged with debris (**Photo 7**). Conversation with NRA field personnel in July 2023 verified that the water table is close to the surface in most locations and that the well standpipes are cleaned out periodically to ensure they will function properly during the hurricane season.

Photo 3: Typical inlet location (July 2023)

Photo 4: Inlet on shoulder drains to inlet in centre of roadway (July 2023)

Photo 5: Made in USA inlet (July 2023)

Photo 6: Typical well- 8inch diameter PVC standpipe (July 2023)

Photo 7: Inlet clogged with sediment (left) and debris (right) (July 2023)

A rainfall event was observed during the field view. During the rainfall event, the water drained from the roadway to the roadside and ponded above the inlets. The water ponded on to the roadway surface in several locations with the worst of these locations having the water almost reach the centerline of the road (**Photos 8 and 9**). These locations were also observed approximately 1.5 hours after the rainfall stopped and the drainage wells in the inlets had drained runoff from the roadside.

Photo 8: Flooding on Bodden Town Road during rainfall event (July 2023)

Photo 9: Flooding on Bodden Town Road after rainfall event (July 2023)

Research prior to the field review identified the location of only one existing bridge on Grand Cayman in the Seven Mile Beach area. Observations during the field review indicate that the bridge was raised with a 17-foot (5-meter) clearance under the bridge. The bridge appeared to be constructed of concrete girders with embankment and retaining walls used to raise roadway approaches to the elevation of the bridge deck (**Photo 10**). No areas of erosion or stream instability were noted on the watercourse spanned by the bridge.

Photo 10: Existing Bridge in the Seven Mile Beach area (July 2023)

3 Savannah Gully

The Savannah Gully is an area of geographic relief along the south shore of Grand Cayman in the Savannah area that has been documented as a historical area of storm surge inundation and conveyance. In 2006, the Savannah Gully was flooded and a wall was designed to prevent subsequent surges from being conveyed over the gully and to the north; however, the wall was not constructed. The Savanah Gully has not been reported to have flooded since the 2006 storm event. Several photos were taken along Sandy Ground Drive in the vicinity of the gully to document the existing conditions. The relief area is easily observable along the shoreline and appears to run back along Sandy Ground Drive into the vicinity of Shamrock Road. There was an obvious increase in dense vegetation in the vicinity of the gully as well as an accumulation of plant and trash debris. **Photos 11 to 14** show the general direction of flow with red arrows.

Photo 11: Savannah Gully, facing south from Sandy Ground Drive toward ocean (July 2023)

Photo 12: Savannah Gully, facing east along Sandy Ground Drive (July 2023)

Photo 13: Savannah Gully, facing north from Sandy Ground Drive (July 2023)

Photo 14: Savannah Gully, facing west from Sandy Ground Dr. Downslope extent (July 2023)

4 Central Mangrove Wetland

The Central Mangrove Wetland is densely vegetated and was only accessible during the field review via the roads along the archaic mosquito canals, or ditches, on the west side of the wetland located off the Windward Road near Nadine Street, just south of the North Sound (**Photo 15**). The ditches along the side of the road contained two observable reinforced concrete pipes (RCP) connecting the ditches underneath the roadway; however, there did not appear to be any flow in the ditches (**Photo 16**). The RCP were round with a 42-inch (1.1 m) diameter and a 2-inch (5.1 cm) wall thickness. At the western RCP, the observed water depth was 2.5-feet (0.8 m) from the pipe crown and 1.5-feet (0.5 m) from the ditch bottom. At the eastern RCP, water depth was 2.75-feet (0.84 m) from the pipe crown and 1.75-feet (0.53 m) from the ditch bottom.

The ditches were, on average, approximately 10 feet to 15 feet (3 to 4.6 m) wide with 1.5 to 2 feet (0.5 to 0.6 m) water depth (**Photo 17**). The density and species of mangrove trees appeared to vary with proximity to the centre of the wetland. The amount of water inundating the wetland also appeared to increase towards the centre of the wetland with obvious signs of water level fluctuation visible on the vegetation. There were also multiple locations of exposed rock surface located throughout the wetland (**Photo 18**).

Photo 15: Access road with adjacent mosquito ditches (July 2023)

Photo 16: RCP drainage pipe (July 2023)

Photo 17: Drainage Canal (July 2023)

Photo 18: Bedrock outcrop in the Central Mangrove Wetland (July 2023)

5 Meagre Bay Pond

Meagre Bay Pond was accessed by a short trail off Bodden Town Road (**Photo 19**). The distance between the edge of the pond water and the edge of the roadway stripe was roughly measured to be 90 feet (27 meters). Quarry equipment was observed on the far side of the pond. The pond bottom as viewed from the bank consists mainly of sand with scattered rock outcrops and woody debris (**Photos 20 to 22**).

Photo 19: Access Trail to Meagre Bay Pond from Bodden Town Road (July 2023)

Photo 20: Meagre Bay Pond, facing Northwest. Bird in water. (July 2023)

Photo 21: Meagre Bay Pond, facing North. Sandy substrate and rock outcrops (July 2023)

Photo 22: Meagre Bay Pond, facing Northeast. Woody debris (July 2023)

6 Mastic Trail

The Mastic Trail is located on the eastern side of the island and 2.3-mile (3.7 kilometre) trail was traversed from the southern trailhead to the northern trailhead. The trail width varied with an approximate average width of 5 feet (1.5 m). Dense vegetation was noted immediately adjacent to either side of the trail. The trail transitioned from a dirt path in the south to a rocky path in the north with several wooden boardwalks located in between. The area was mostly dry with a few puddles located adjacent to the boardwalk and in the bottom of pits in the rock surface. The vegetation varied along the trail but remained dense along the length of the trail. The elevation of the trail also varied, particularly along the rock formations encountered towards the north end of the trail, with some locations climbing over approximately 6-foot-high (1.5 meter) rock outcroppings.

The two elevated boardwalks and the trail in vicinity of the Alternative B1 were measured. The southern boardwalk was 3 feet (0.9 m) wide, consisted of 2 inches by 6 inches (5 cm by 15 cm) wooden planks and was elevated up to 2 feet (0.6 m) above existing grade (**Photo 23**). The depth of existing standing water adjacent to the bridge was approximately 1.5 feet (0.5 m) in the deepest spot (**Photo 24**). The northern boardwalk was 4-feet wide, consisted of 2 inches by 6 inches (5 cm by 15 cm) wooden planks, and was elevated up to 29 inches (74 centimetres) above existing grade by PVC pipe posts (**Photo 25**). There was no standing water under or adjacent to the bridge. It appears that the existing bridge had replaced an earlier bridge. The trail in the vicinity of Alternative B1 was approximately 5 feet wide and had bedrock outcroppings (**Photo 26**).

Photo 23: Southern Boardwalk (July 2023)

Photo 24:Standing water adjacent to southern boardwalk. (July 2023)

Photo 25: Northern Boardwalk, no standing water (July 2023)

Photo 26: Trail in the vicinity of the Alternative B1 crossing. (July 2023)

7 Bedrock and Peat

Exposed bedrock formations and peat were assessed during the field effort. Bedrock formations were found in the Central Mangrove Wetland area (**Photo 27**), near the existing EWA (**Photo 28**), Savannah Gully, Alternative B4, and Mastic Trail (**Photos 29 to 32**). Access was provided by the NRA to the quarry just east of the Meagre Bay Pond. Observations were made around the perimeter of the quarry up to the northern most point of the quarry where it borders the Central Mangrove Wetland. The quarry contained large excavators that were actively being used for excavation in the quarries (**Photo 33**). The NRA personnel also indicated that blasting was being used in the excavation process. Limestone is being excavated from the quarry (**Photo 34**). The excavation areas were filled with groundwater almost up to the existing ground level. The NRA personnel mentioned that the quarries are approaching 60-feet (18.3 m) in depth. Excess material was observed piled up around the perimeter of the quarry including piles of an unknown dark material on the north end of the quarry. The portion of the Central Mangrove Wetland that could be observed from the north end of the quarry was mostly covered with pools of water at the surface level and was populated with mangrove trees, similar to the portion of the wetland along the mosquito ditches. Peat was found in conjunction with the mangroves (**Photo 35**).

Photo 27: Bedrock outcrop in the Central Mangrove Wetland area (July 2023)

Photo 28: Bedrock outcrop near the existing EWA (July 2023)

Photo 29: Limestone Pit along the Mastic Trail (July 2023)

Photo 30: Exposed bedrock along Mastic Trail (July 2023)

Photo 31: Large bedrock outcrop along the Mastic Trail (July 2023)

Photo 32: Crevice in the bedrock along the Mastic Trail (July 2023)

Photo 33: Active Quarry (July 2023)

Photo 34: Quarried rock (July 2023)

Photo 35: Peat in mangroves north of quarry (July 2023)