JNCC – UK Overseas Territories Report Series

Understanding the increase in flood risk within South Sound (Grand Cayman) under various development scenarios

UK Government

Department of Environment
Cayman Islands Government

JNCC

Report Number: 9
Authors: J. Olynik, N.K. Abram, T. Murray-Ramcharan and E. Manca
Publication date: July 2025
ISSN: 2753-6270
Front cover photo: © Eleonora Manca

This report has been produced as part of the JNCC – UK Overseas Territories Report Series for the JNCC-led programme of work: Building Environmental resilience and security in a changing climate through biodiversity conservation in the UK overseas Territories.

JNCC is supporting the UK Overseas Territories to build the resilience of key ecosystems through a nature-based solutions approach. Projects undertaken within the programme work with well-established partners in the UK Overseas Territories governments, and with local stakeholders, to build capacity in monitoring environmental change, integrating environmental evidence into economic policy, and building disaster resilience in the face of climate change. This work is funded with UK aid from the UK government through the Conflict, Stability and Security Fund (CSSF). This work builds upon the CSSF funded, JNCC-led, Natural Capital in the Caribbean and South Atlantic Overseas Territories programme, undertaken from 2016 to 2020, and the Coral Reef Action Plans developed through the UK Overseas Territories Coral Reef Initiative since 2019.

This document should be cited as:

Olynik, J., Abram, N.K., Murray-Ramcharan, T. & Manca, E. 2025. Understanding the increase in flood risk within South Sound (Grand Cayman) under various development scenarios. *JNCC – UK Overseas Territories Report 9.* JNCC, Peterborough, ISSN 2753-6270. https://hub.jncc.gov.uk/assets/1569efa1-6f1d-45e2-a63d-ea9d39206856

Evidence Quality Assurance:

This document is compliant with JNCC's Evidence Quality Assurance Policy.

Summary

Background

This report, part of the JNCC-led UK Overseas Territories Report Series, examines the increasing flood risk in the South Sound Basin, Grand Cayman, under various development scenarios. It is the third phase of a project aimed at understanding the role of natural ecosystems in mitigating flood risks and their environmental implications and funded with UK aid from the UK government through the Conflict, Stability and Security Fund (CSSF). The findings are intended to help further understand flood risks to help inform policy and decision-making for sustainable development and climate resilience in the Cayman Islands.

The South Sound Basin is prone to significant flooding due to its low-lying topography and ongoing developmental pressures. Mangrove loss, increasing impermeable surfaces, and the construction of infrastructure such as coastal roads have exacerbated flooding issues. This study builds on two prior phases (2016–2022) that developed flood models using advanced modelling tools like TUFLOW HPC, emphasizing the critical role of ecosystems like mangroves and coral reefs in flood mitigation (Wood 2021; Carter *et al*. 2025). This third phase of work aimed to improve understanding of impacts from mangrove loss, infrastructure and housing development on flood risk under storm events.

Methodology

High-resolution hydraulic models were undertaken to simulate flooding under two scenarios:

1. **Scenario 1 – Baseline (2021):** Reflecting existing infrastructure and housing developments.
2. **Scenario 2 – Approved Developments:** Including future developments based on hypothetical and approved parcels and proposed road plans.

Three flood events were modelled: a Category 3 hurricane-induced tidal surge (from a south-west direction) and 25-year and 100-year rainfall events. Data layers, including updated soil and land use maps, digital terrain models, and material classifications were integrated to improve model accuracy. Flood depths, extents, and differences between scenarios were analysed.

Key Findings

Flood Depths and Patterns

- Tidal surge simulations revealed a minor increase (5 cm) in maximum flood depth under Scenario 2 compared to Scenario 1 but showed significant redistribution of floodwaters due to elevated new developments.
- Rainfall events demonstrated more pronounced increases in flood depths, with maximum depths rising by 9 cm (25-year event) and 11 cm (100-year event) in Scenario 2. Mean depths also increased notably, affecting residential areas.

Floodwater Redistribution

- Scenario 2 developments displaced floodwaters to adjacent areas, exacerbating flooding in mangroves, existing residential zones, and areas outside the South Sound Basin.
- The South Sound Marine Protected Area (MPA) is at risk of increased runoff, sedimentation, and pollutants, threatening its ecological integrity.

Environmental and Planning Implications

The findings underscore the importance of preserving and restoring natural ecosystems like mangroves for flood mitigation. New developments reduce the basin's water storage capacity, increasing flood risks and costs of property damage and disruption. Additionally, runoff from urbanized areas poses risks to marine habitats. Effective drainage planning, ecosystem conservation, and sustainable development practices are essential.

Recommendations

- **Model Improvements:** Incorporate actual flood depth measurement data for model validation, simulate combined rainfall and tidal surge events, incorporate existing/planned drainage, and further refine soil and geology data.
- **Further Studies:** Update models with new development plans and ground-truth data and explore additional mitigation measures.
- **Policy and Planning:** Prioritize nature-based solutions, enhance drainage infrastructure, and evaluate flooding impact of development on adjacent areas.

This study highlights the critical balance required between development and environmental resilience, advocating for informed decision-making to ensure sustainable growth and disaster preparedness in Grand Cayman’s South Sound Basin and beyond.

Contents

1. Introduction

1.1. Background

In 2021, the Joint Nature Conservation Committee (JNCC) conducted a project to evaluate the significance and economic value of the Cayman Islands' natural capital in safeguarding its built infrastructure against coastal and inland flooding. This project was funded by the UK Government's Conflict, Stability and Security Fund (CSSF) and in collaboration with the Cayman Islands Government's Department of the Environment (DoE) and the Hazard Management Department Cayman Islands (HMCI). The project used modelling techniques to simulate coastal storm surge and inland flooding in response to various hurricane and rainfall events. The information generated from this analysis was intended to aid the Cayman Islands Government in formulating plans, policies, and procedures aimed at increasing resilience to natural disasters and enhancing on-island capabilities for preparedness and recovery from storm events.

Phase 1 (Wood 2021) of the project delivered inland and coastal flood models for Grand Cayman, Little Cayman and Cayman Brac. The coastal simulations were obtained using a wave propagation model known as SWAN (Booij *et al*. 1999), while the inland flood simulations were obtained using the TUFLOW HPC hydraulic modelling software (BMT WBM 2016). Through these models, the role of nature in mitigating flood risks was assessed by considering different scenarios for the state of coral reefs and mangroves, including baseline, degraded, and enhanced conditions. The flood depth outputs were used to estimate flooding impacts in terms of damage to property, which was used as a means of economic valuation of coastal protection services.

Phase 2 (Carter *et al*. 2025) included improvements to the coastal and inland flood models and verification of flood extents through comparisons to historic flood data. The work further quantified flooding for extreme weather event scenarios, and under different scenarios for coral reefs, mangroves, and seagrass. The economic valuation was updated using the revised model results. The project also listed potential Nature-based flood mitigation solutions, and the model results were used to identify locations where they could be implemented. Notably, the mangrove wetlands in the South Sound Basin – adjacent to the highly populated George Town – was highlighted as a key area, and it was noted that "Such features [mangrove wetlands] serve a significant role in terms of flood water storage, and therefore the protection of existing ponds and wetlands is a key Nature-based Solution."

Discussions with the Cayman Islands DoE confirmed the significant and frequent flooding issues experienced in the South Sound Basin, located in the south-west of Grand Cayman (Figure 1). Consequently, this area was chosen as a case study for a scenario-based inland flood modelling study, due to its historical and persistent overland flooding issues that is affecting existing residential areas. Furthermore, with an expected rapid increase in development over the next decade, the situation is projected to worsen. The South Sound Basin has already experienced the loss of mangroves, seagrass, damage to reefs, and storm-related destruction. The existing mangrove system has been impacted by the construction of a coastal road and other inland developments, leading to the accumulation of floodwater on the landward side of the coastal road. The sole drainage pipe in this area empties into an adjacent Marine Protected Area (MPA). Ongoing development projects within the region further contribute to the displacement of mangroves, exacerbating the local flood risk. Current development initiatives are already experiencing flooding because of heavy rainfall. Future planned projects, such as a new road and residential housing, may further impact the flooding patterns in South Sound by modifying the local topography and increasing the extent of impermeable surfaces. Any increase in inland floodwater within more urbanised areas could result in higher levels of sediment and pollutants carried by runoff, posing severe consequences for marine habitats including seagrass beds and coral reefs present within the adjacent MPA. These habitats, and the ecosystem services they provide, are threatened by climate change induced pressures which are hard to address locally. Controlling runoff, pollution and increased sediment loads reaching seagrass beds and reefs are one of the most effective ways to bolster their health and resilience to climate change (Rogers & Ramos-Scharrón 2021). Resolving the issues of inland flooding and storm water drainage within the South Sound region and mitigating the worsening of these events is of paramount importance due to its rapid development.

Figure 1. Map showing the South Sound Basin (in red boundary) in south-west Grand Cayman, overlaid on a 2021 aerial photograph (courtesy of the UK Hydrographic Office).

1.2. Aim

The aim of this study (Phase 3) was to enhance the understanding of the potential impacts of ongoing and planned development projects on the extent and depth of flooding in the South Sound Basin, under certain storm events. To achieve this, high-resolution TUFLOW HPC hydraulic models were developed for the South Sound Basin, to compare flood levels under different development scenarios, and under one tidal surge event and two rainfall events. This study aimed to provide valuable insights into the potential effects of development and mangrove loss on flooding patterns in the area, whilst building capability within the DoE to rerun these models at will under other scenarios. This information can be used to support planning and decision making, help inform ongoing assessments (e.g. Environmental Impact Assessments), and scope opportunities for Nature-Based Solutions (NbS) in the area.

2. Method

2.1. Development Scenarios

The scope of work within this study included two development scenarios under three flooding events. These included:

Scenario 1 – Baseline (2021): This scenario represented the baseline state of South Sound with existing and ongoing developments as of 2021 based on 10 cm resolution aerial photography (Figure 2a). This scenario served as the baseline to measure additional impacts of development on flooding.

Scenario 2 – Approved Developments: This scenario represented a likely future development scenario for the South Sound drainage basin based on existing development plans (Figure 2b).

(a)

(b)

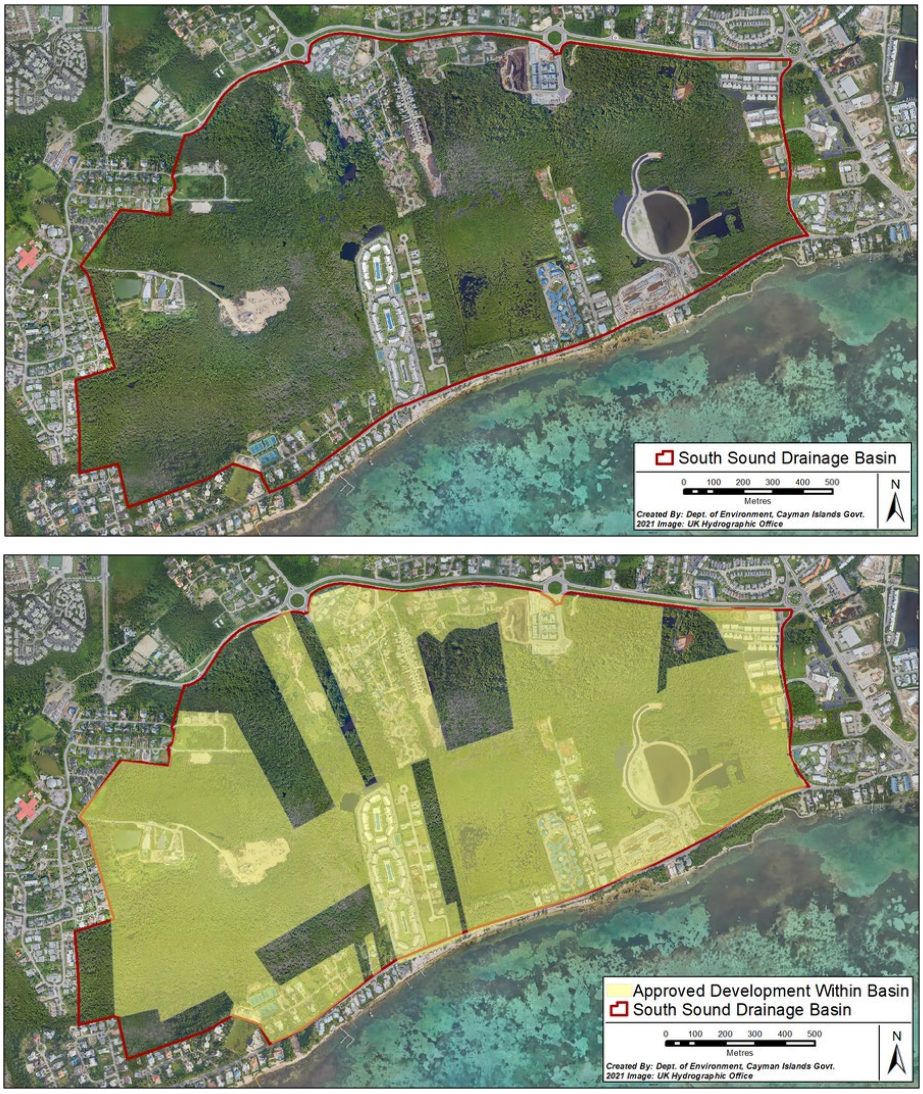


Figure 2. South Sound Basin (demarcated in red) under: (a) Scenario 1 with land use as per the 2021 photography; and (b) Scenario 2 with approved developments demarcated in yellow. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

2.2. Data Preparation

To enable this study to better assess flood extents and depth within and outside of the South Sound Basin, the model required higher resolution and more detailed input data than previously used in the first two phases (Wood 2021; Carter *et al*. 2025). To enable this, the following data sets were generated for the wider analysis boundary extent for the Scenario 1 models, with edits to a number of input layers for Scenario 2 edited within the South Sound Drainage Basin (see Figure 1).

2.2.1. Land-use/land cover classification layer

A land-use/land cover classification was developed to inform infiltration rates within the model, across the study region. To do this, existing land-use/land cover dataset for 2018 was provided by the DoE along with a high-resolution 2021 aerial photograph – originally provided by the UK Hydrographic Office (UKHO). For Scenario 1, the land use/land cover shapefile of the wider study area was modified from 2018 to 2021, through on-screen digitising methods in ArcGIS 10.1 and based on the 2021 photograph. This was done to, (a) create a layer for our selected baseline year (2021); and (b) to improve the classification of the features within the region. The original dataset had 10 broad classes, comprising of seven vegetation types, one class for waterbodies, a class for ‘urban’ and another for ‘man-modified without trees’. As the land use/land cover classes are assigned values to help inform the model of their friction and permeability, we included new classes such as buildings, roads, carparks/driveways etc. to enable more appropriate values to be assigned, thereby increasing the number of classes from 10 to 18 (see Figure 3(a)).

For Scenario 2, land parcel data was available, and the DoE identified those parcels where developments had been approved. This allowed us to understand which areas of mangroves would be converted to developments. Approved road data was also available for a number of the large public roads within the region, and a detailed development plan was also obtained for the south-west quadrant of the South Sound Basin. In cases where no plans were available for an approved development parcel, land cover was interpolated based on characteristics of nearby developed parcels. The land use/land cover used for Scenario 2 Approved Development can be seen in Figure 3(b).

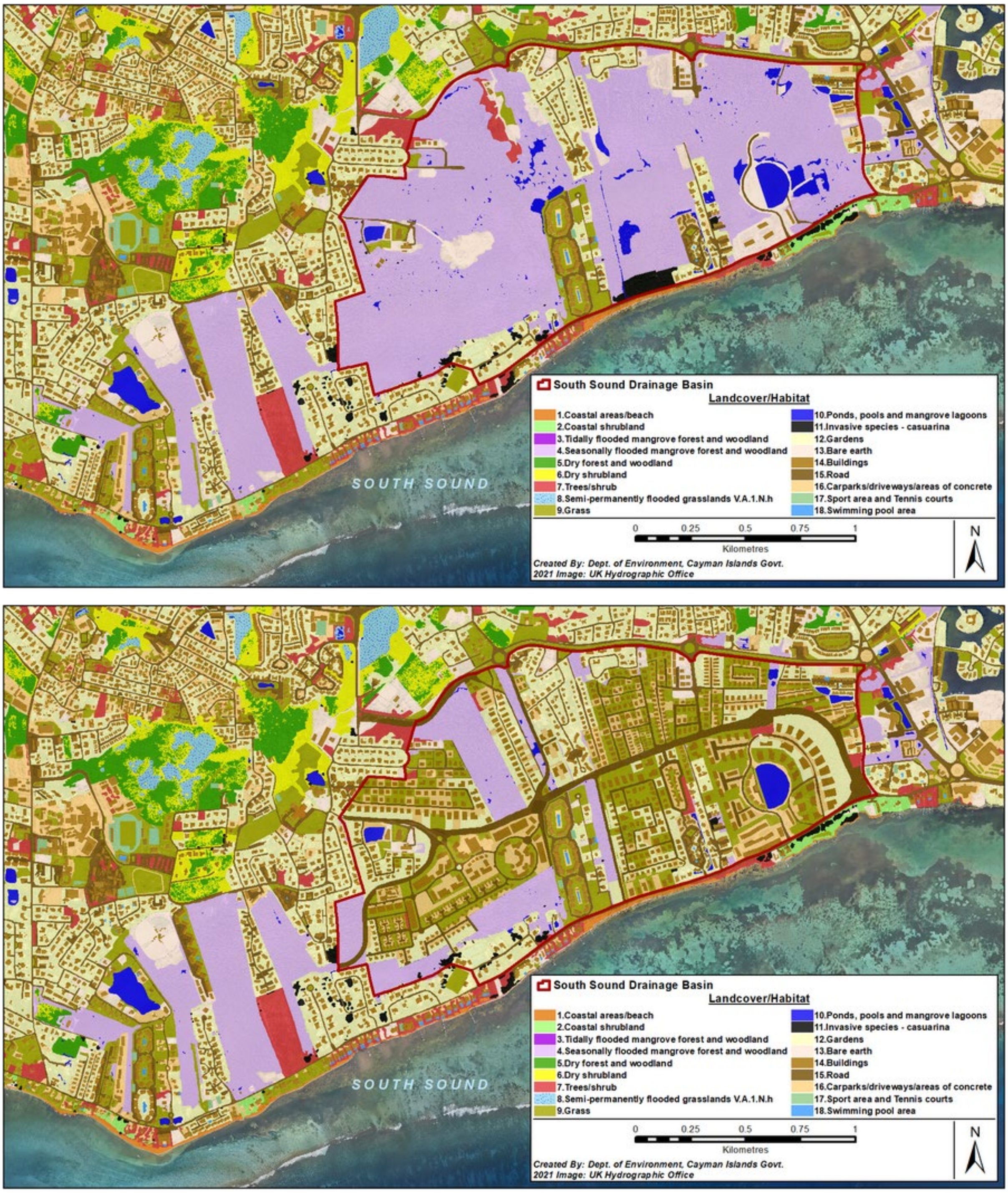


Figure 3. South Sound land use/land cover classification for (a) Scenario 1 Baseline, and (b) Scenario 2 Approved Development. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

2.2.2. Material and Land cover

Each land-use/land cover type was given a material ID to assign parameters including Manning's n roughness coefficient, fraction impervious, and initial and continuing rainfall losses (see Table 1). This information was added to the land use/land cover layer via a .csv file for use in TUFLOW HPC hydraulic model. Values were determined by comparing those found within a literature search and assigning the values that most suited our land-use/land cover classes.

Table 1: Table showing the 18 land use/land cover classes along with their Material ID, their assigned Manning's n value, as well as initial/continuing loss and fraction impervious values.

Material ID	Manning's n	Initial/ Continuing Loss	Fraction Impervious	Comment
1	0.024	5,2	-	1.Coastal areas/beach
2	0.1	5,2	-	2.Coastal shrubland
3	0.15	30,5	0.8	3.Tidally flooded mangrove forest and woodland
4	0.15	30,5	0.6	4.Seasonally flooded mangrove forest and woodland
5	0.1	30,5	-	5.Dry forest and woodland
6	0.07	20,4	-	6.Dry shrubland
7	0.1	30,5	-	7.Trees/shrub
8	0.03	20,2	-	8.Semi-permanently flooded grasslands
9	0.03	10,2	-	9.Frass
10	0.02	-	-	10.Ponds, pools and mangrove lagoons
11	0.1	-	-	11.Invasive species - casuarina
12	0.04	10,2	-	12.Gardens
13	0.02	5,1	-	13.Bare earth
14	1	2,0	1	14.Buildings
15	0.016	2,0	1	15.Road
16	0.014	2,0	1	16.Carparks/driveways/areas of concrete like material
17	0.014	2,0	-	17.Sport area and Tennis courts
18	0.02	-	1	18.Swimming pool area
99	0.04	0,5	-	99.Default value

2.2.3. Digital Terrain Model (DTM)

Terrestrial LIDAR data was collected in November 2021 by Fugro, organized and funded by the UKHO. The collected data resulted in a Digital Surface Model (DSM) and a Digital Terrain Model (DTM) at a 1 m resolution. However, these models contained numerous "No Data" gaps, with the DSM gaps mainly consisting of water/standing water areas and the DTM gaps including water/standing water, buildings, and paved roads. To create a continuous DTM surface which is required for TUFLOW flood modelling, the Elevation Void Fill function within ArcGIS Pro was employed. Further, the resulting DTM was adjusted to be relative to local mean sea level by subtracting the difference between the vertical datums used in data collection. The DTM was then resampled to a 2 m resolution using bilinear interpolation to reduce file size. Separate DTMs were created to represent Scenario 1 (baseline, Figure 4(a) and Scenario 2 (approved development, Figure 4(b).

For Scenario 2, changes to the DTM were undertaken within those land parcels that were approved for development, with changes in elevation estimated based on: (a) If a portion of the parcel had already been filled or developed, then an average bare ground elevation of that filled/developed area was extrapolated to the entire parcel; and (b) If development had not yet started on a land parcel, then an average 'bare ground' elevation of neighbouring properties/developments was used to estimate the elevation of the future development.

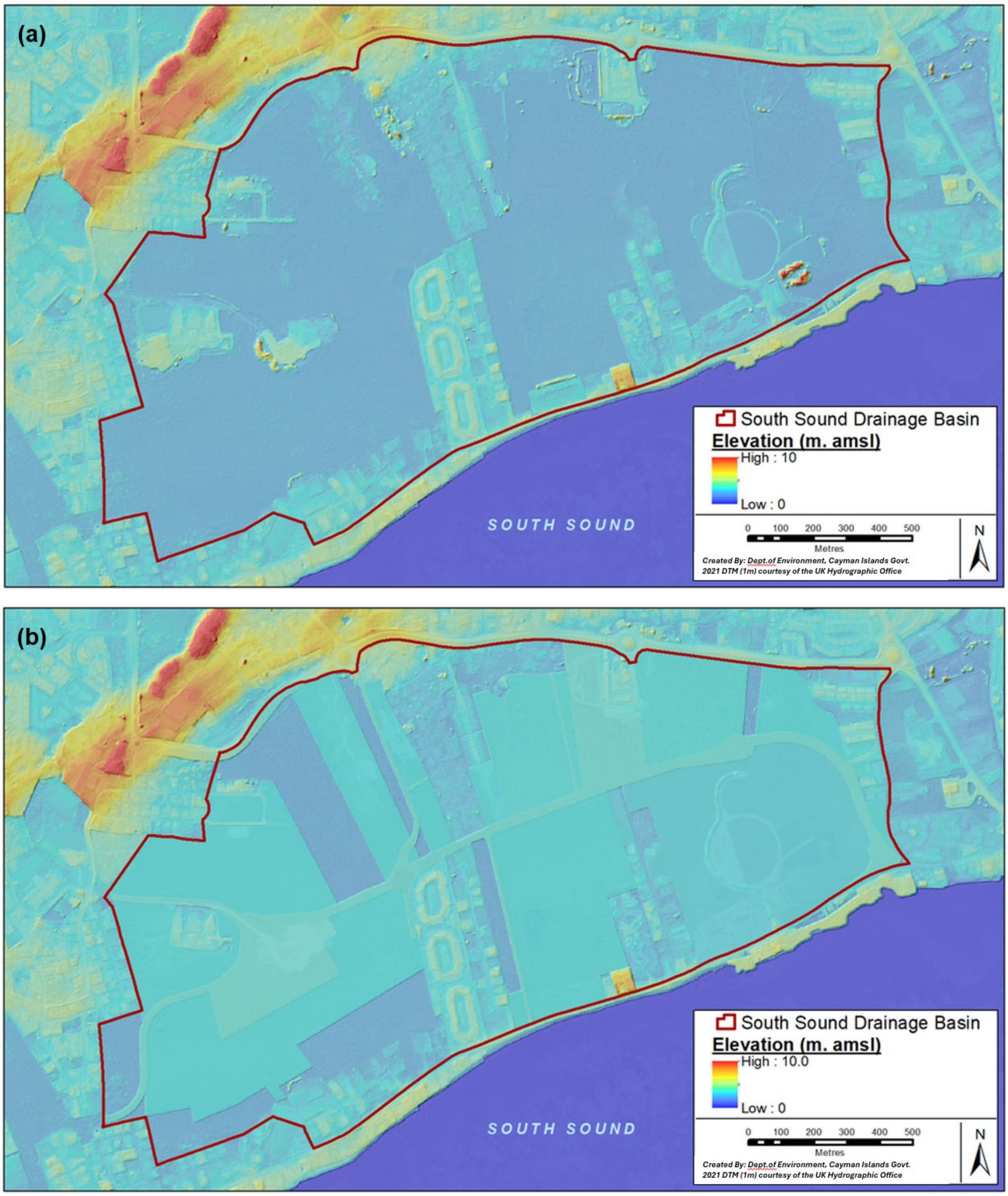


Figure 4. South Sound Drainage Basin (red outline) with Digital Terrain Models (DTM) for (a) Scenario 1 Baseline, and (b) Scenario 2 Approved Development. DTM data (1 m resolution) courtesy of the UK Hydrographic Office.

2.2.4. Tidal Surge and Rainfall Input

For both development scenario's the model was run for one hurricane-induced surge event and two rainfall events. Input data for tidal surge inundation and duration and expected rainfall amount and duration were previously generated during Phase 1 and 2 using SWAN wave models and historic rain gauge data, respectively (Wood 2021; Carter *et al*. 2025). For this study (Phase 3), we used these same input data from the previous modelling phases for the tidal surge and rainfall events.

Tidal surge event: The tidal surge event (driven by atmospheric pressure and wind) simulated maximum surge heights for a Category 3 hurricane (1.5 m storm surge and 57.6 m/s wind speed) – with additional water height via waves approaching from the south-west, which was used to scale the base tidal curve to generate a synthetic storm surge timeseries with a 52-hour duration.

Rainfall events: The rainfall events simulated a 25-Year return period (4% Annual Exceedance Probability or AEP or 1 in 25 chance of flooding) and a 100-Year return period (1% AEP or 1 in 100 chance of flooding), both with a duration of 48 hours based on the Hurricane Ivan rainfall hyetograph profile developed as part of Phase 1. AEP refers to the chance that a flood of a particular size is experienced or exceeded during any year.

2.2.5. Soils and Infiltration

In addition to the (surface) materials layer described in Section 2.2.2, a soil layer is also required for the TUFLOW HPC hydraulic models that estimates water loss after surface infiltration. For the initial flood modelling completed in Phases 1 and 2, no soils data were available. Instead, available data on the geology for Cayman Islands were used as a proxy for soil information (see Figure 5(a)), which were assigned suction, hydraulic conductivity, and porosity values that were associated with a comparable United States Department of Agriculture (USDA) soil type. The Ironshore geology group was assigned a USDA soil type of 2 "Clay Loam" (very low porosity) and the bluff geology group was assigned a USDA soil type of 5 "Sand" (highly porous).

Following a validation exercise, it was found that the results from the initial South Sound models – using the soils/geology layer from the previous phases – overestimated infiltration in some parts of the Bluff group extent (i.e. sand) and underestimated some areas defined as Ironshore (i.e. clay loam). Using a combination of historical images, habitat mapping, elevation, and local knowledge of the South Sound Basin area, a new soils map was created by DoE (Figure 5(b)). Areas of high elevation were estimated to be porous rock and were assigned a USDA soil type of 4 (i.e. sandy loam – porous). Low elevation areas that are currently dotted with seasonally flooded wetland and were historically areas of mangrove were assigned a soil type of 2 (i.e. clay loam – low porosity). All other areas that were originally part of the Ironshore formation and did not fall into either one of the above categories was assigned a soil type of 3 (i.e. silt loam – slightly porous).

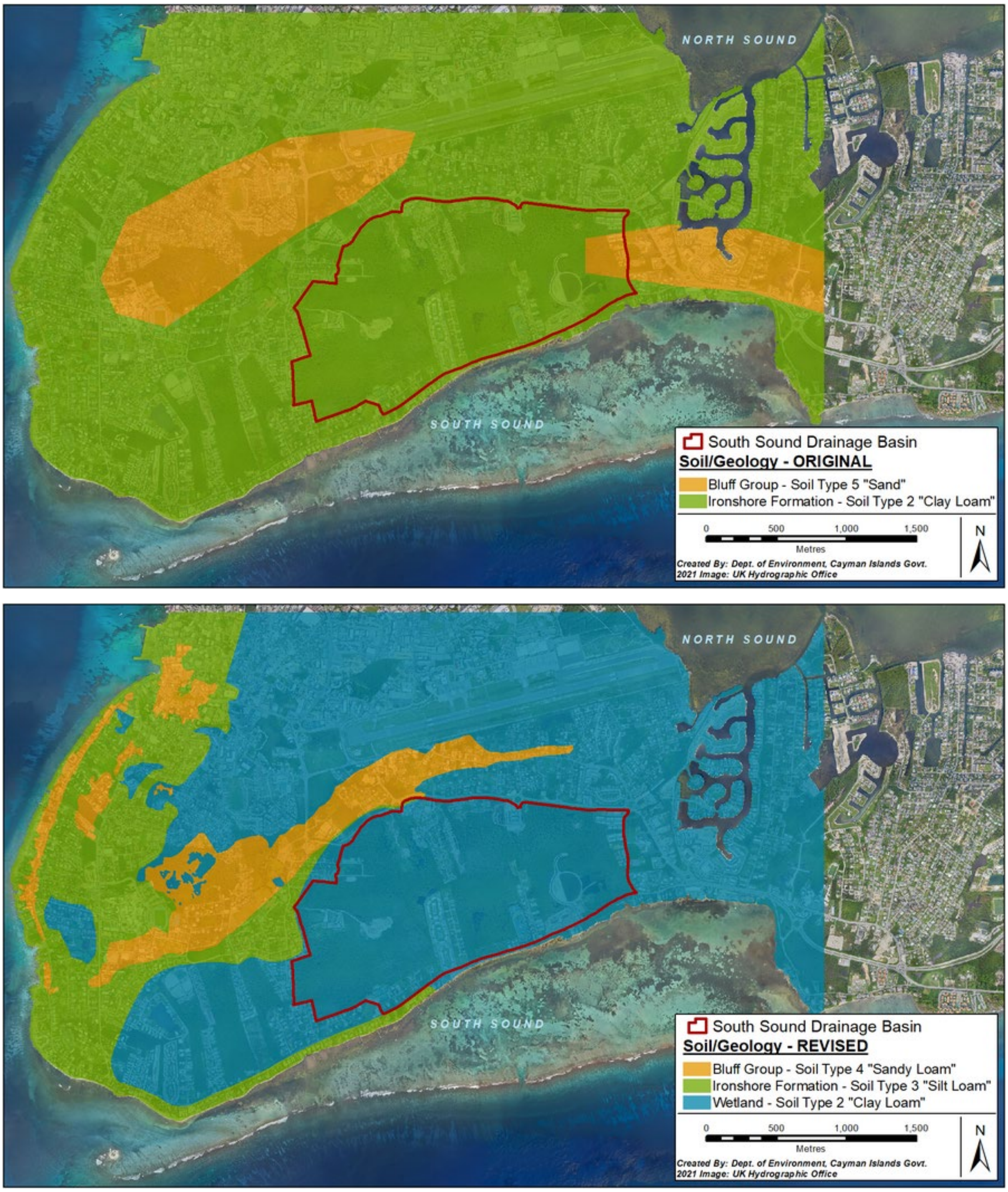


Figure 5. South Sound Drainage Basin (red outline) with: (a) the original soil/geology layer used by Woods in Phase 1 and 2; and (b) with the newly created soil/geology layer, developed by the Cayman Islands Department of Environment. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

2.2.6. Other GIS Layers

To improve the accuracy of the shoreline, high resolution (10 cm) aerial photograph was used to digitize the land-sea boundary within ArcPro. The DTM for the South Sound Basin was then clipped to the shoreline's spatial extent, and the clip region's northern and eastern extents were set approximately 5km away from the actual mangrove basin.

2.3. TUFLOW HPC hydraulic models

2.3.1. Adjusting TUFLOW control files

The TUFLOW HPC hydraulic models previously developed in Phases 1 and 2 were used as a starting point for developing the high-resolution model for the South Sound Basin area. The boundary and code file extents were updated to incorporate the data and changes described above, and the new DTMs were added to the topography folder. Control files and commands were also updated, and batch files for model startup were created.

2.3.2. Running TUFLOW

The TUFLOW HPC hydraulic models were run by DoE and were configured to simulate the three different storm events: a Tidal surge event from a Category 3 hurricane from the southwest with a 52-hour duration, and a 25-year and 100-year rainfall event with 48-hour duration. All events were executed for each of the development scenarios (1 and 2).

Initially, the models were created with a cell size of 10 m to identify any potential issues. However, the final outputs were generated using a 3 m cell size, which was determined to be the optimal resolution in terms of balancing simulation time, accuracy, resolution, and the extent of the model. To ensure the reliability of the outputs, all results underwent a quality check utilizing the TUFLOW viewer plugin within QGIS software.

3. Results

3.1. Maximum Flood Depths within the South Sound Basin

Maximum flood depth maps and maximum and mean flood depth values were generated for both Scenarios and for each storm event model run (Figures 6 to 8, Table 2).

Across all three storm events, the models for the tidal surge demonstrated the highest maximum flood values (over 1.5 m) and highest average flood depths (over 0.7 m) (Table 2), reflecting the low-lying nature of the South Sound region, and its vulnerability to flooding. For the **tidal surge model scenarios** – under a Category 3 hurricane coming from the south-west (SW) – the maximum flood depth for Scenario 2 (approved developments) was 1.59 m, which was marginally deeper than the baseline scenario (by 5 cm, see Table 2). However, the average depth across the South Sound Basin showed just a 3 cm difference, between scenarios, with Scenario 2 having slightly less average flood depth (Table 2). Whilst there were small differences in maximum and mean depths for the tidal surge model, Figure 6 shows very different spatial patterns of flooding between the two development Scenarios. This is likely due to raised elevations occurring for new developments in Scenario 2 (see Figure 6b).

Both rainfall models saw an increase in the maximum and mean flood depths from Scenario 1 to 2 (Table 2). The **25-year rainfall event** model saw an increase of maximum flood depth from 76 cm to 85 cm, and an increase from 22 cm to 37 cm with an increase in developments in the South Sound Basin (Table 2). For the **100-year rainfall event** the increase was larger, with maximum flood depth increasing from to 76 cm to 87 cm, but with the average depth being 32 cm and increasing to 42 cm in Scenario 2 (Table 2). For the flood extent and depth maps, there were significant visible changes in flood depth and extents between the two scenarios for both rainfall models (see Figures 7 and 8). In fact, across these models, flood water seemed to have been displaced from areas with new development to other areas, especially those that retained mangroves but also to areas that were not so prone to flooding (as per Scenario 1) that already have existing development (largely residential areas) (Figures 7 and 8).

Table 2. Maximum (Max.) and mean flood depths in metres (m) for Scenarios 1 (Baseline) and 2 (Approved Development) for tidal and two rainfall events within the South Sound Basin.

Scenario	Category 3 hurricanes from SW (tidal surge/waves)	25-year event with 48-hour duration (rainfall)	100-year event with 48-hour duration (rainfall)
Scenario 1 (Baseline)	Max. = 1.54 m (5.1 ft) Mean = 0.76 m (2.5 ft)	Max. = 0.76 m (2.5 ft) Mean = 0.22 m (0.7 ft)	Max. = 0.76 m (2.5 ft) Mean = 0.32 m (1.0 ft)
Scenario 2 (Approved Development)	Max. = 1.59 m (5.2 ft) Mean = 0.73 m (2.4 ft)	Max. = 0.85 m (2.8 ft) Mean = 0.37 m (1.2 ft)	Max. = 0.87 m (2.9 ft) Mean = 0.42 m (1.4 ft)

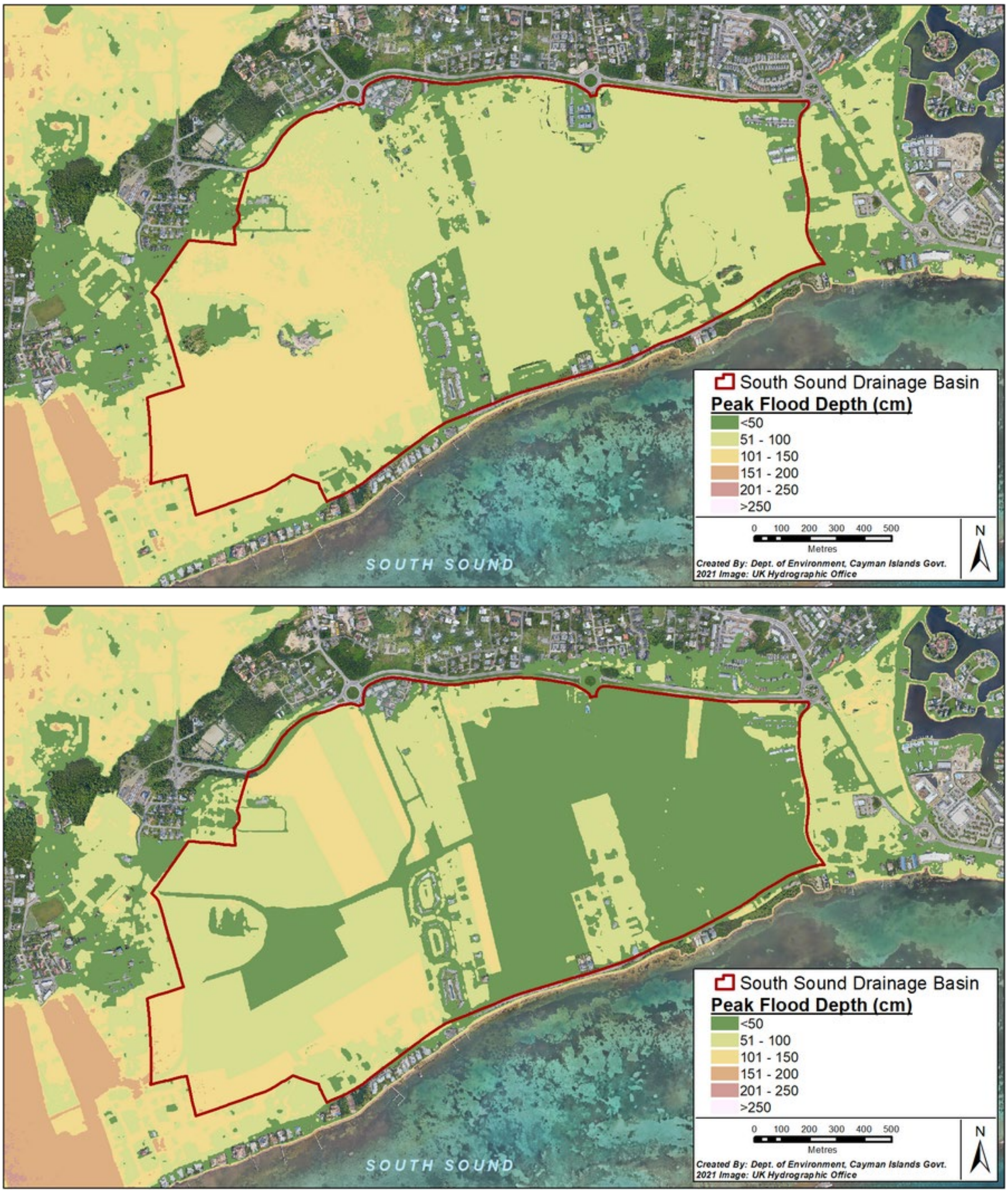


Figure 6. Maximum Depth Map for the South Sound Basin for the Tidal Surge event from a Category 3 hurricane from the south-west, for: (a) Scenario 1 Baseline; and (b) Scenario 2 Approved Developments. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

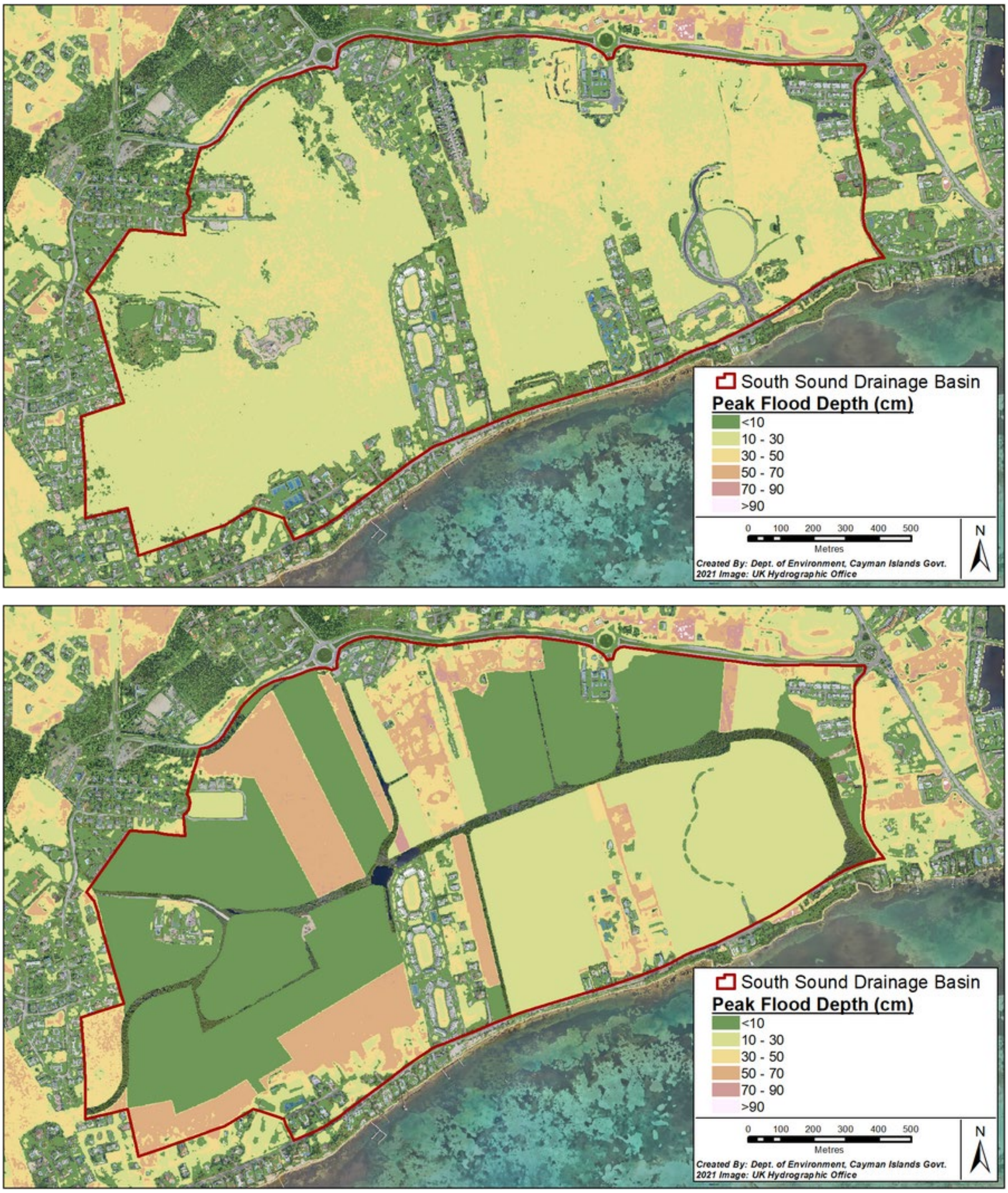
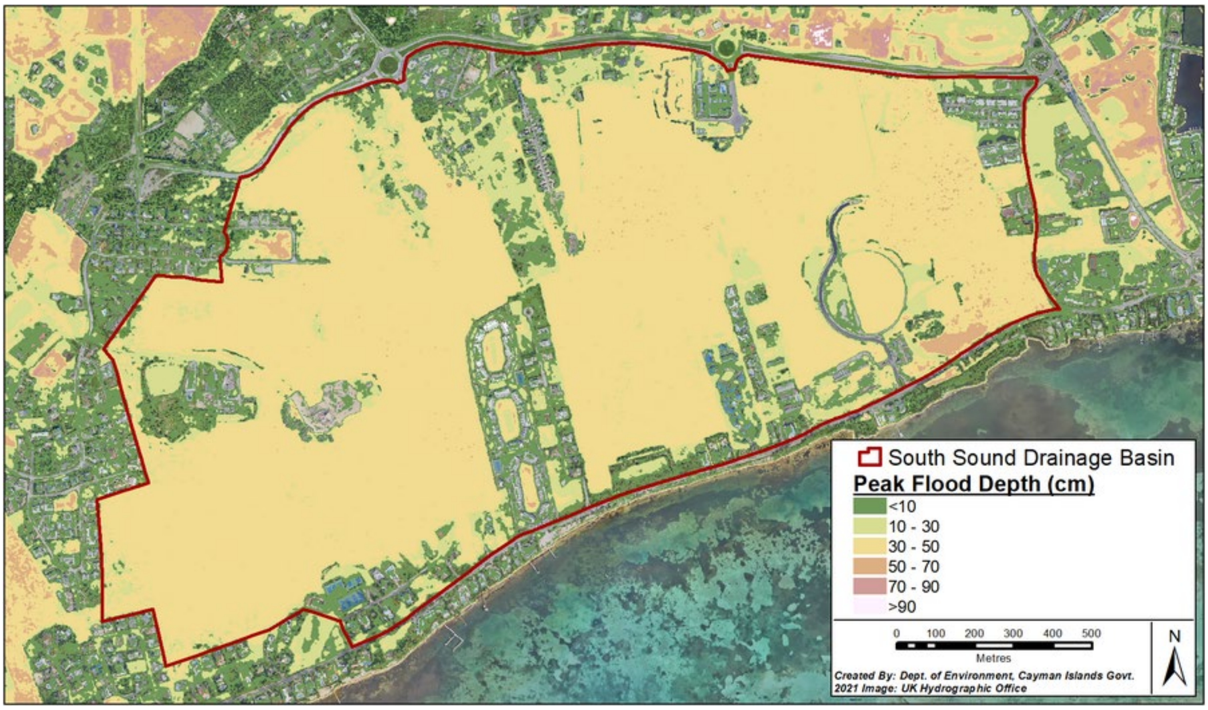


Figure 7. Maximum Depth Map for the South Sound Basin for the 25-year Rainfall Event, lasting 48 hours, for: (a) Scenario 1 Baseline; and (b) Scenario 2 Approved Developments. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.



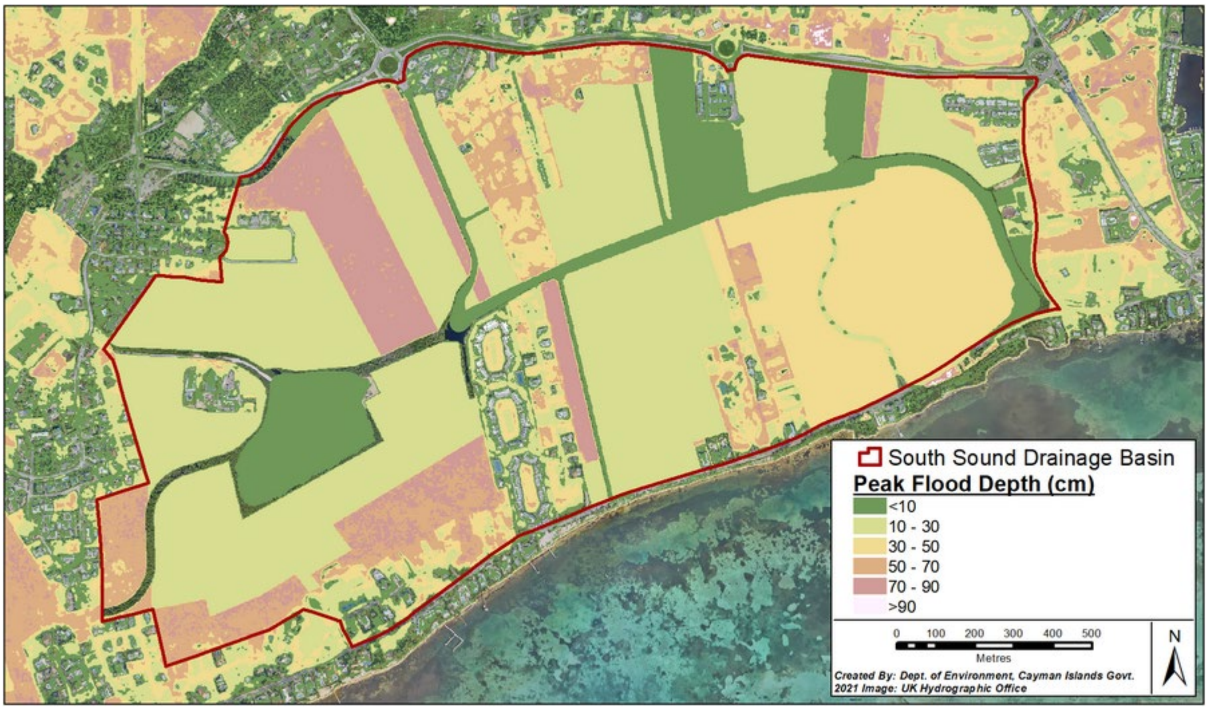


Figure 8. Maximum Depth Map for the South Sound Basin for the 100-year Rainfall Event lasting 48 hours, for: (a) Scenario 1 Baseline; and (b) Scenario 2 Approved Developments. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

3.2. Flood Depth Difference within and outside of the South Sound Basin

Flood depth difference maps were created by subtracting the maximum flood depth values of Scenario 1 (baseline) from Scenario 2 (approved development) for the tidal surge and both rainfall events (see Figures 9 to 11). These Figures show flood differences both within and outside of the South Sound Drainage Basin. Further results have been calculated for flood depth differences outside of the South Sound Basin (Table 3).

For the three storm model contexts (tidal surge and rainfall events) models predicted significant areas that would experience less flooding with an increase in developments, but these were largely in areas that would be developed and therefore see an increase in elevation (Figures 9 to 11). However, the decrease in flooding in these areas likely caused the displacement of water to other areas (Figures 9 to 11). Within the South Sound Basin, areas with an increase in flood depth are the mangrove areas, and many areas of existing residential developments. Moreover, outside of South Sound Basin there are large areas that will see more flooding due to the developments under Scenario 2.

For example, it is estimated that an area of 1 km^2 outside of the South Sound Basin would see an increase of flooding for the tidal surge model with the maximum increase in flood depth reaching 75 cm (and average being 16 cm) (Table 3, Figure 9). For the 25-year rainfall event, changes in development would see 0.73 km^2 outside of the South Sound Basin being more flooded, with maximum increases of 38 cm (averages of 12 cm) (Table 3, Figure 10).

Whereas for the 100-year rainfall event, changes in development patterns would see a region totalling 1.1 km^2 experiencing worse floods, with maximum increases of 39 cm (and averages of 12 cm) (Table 3, Figure 11). In fact, with the 100-year Rainfall event significant areas would see an increase in flooding between 14–26 cm (Figure 11), which is also demonstrated in a profile graph of a transect across this model, as shown in Figure 12.

Table 3. Flood depth difference (i.e. Scenario 2 minus Scenario 1 values) for the three models, as well as calculations on flooding impacts outside of the South Sound Basin.

Depth Differences		**Category 3 hurricanes from SW (tidal surge/waves)**	**25-year event with 48-hour duration (rainfall)**	**100-year event with 48-hour duration (rainfall)**
Flood Depth Difference results within of the South Sound Basin	Maximum Depth Difference (Scenario 2 - Scenario 1)	Range: -0.98 m [-3.2 ft] (less flooding) to 0.75 m [2.5 ft] (more flooding)	Range: -0.41 m [-1.3 ft] (less flooding) to 0.51 m [1.7 ft] (more flooding)	Range: -0.52 m [-1.7 ft] (less flooding) to 0.39 m [1.3 ft] (more flooding)
Flood Depth Difference results outside of the South Sound Basin	Area Affected Outside of Basin Delineation	1.03 km^2 (254.5 acres)	0.73 km^2 (180.4 acres)	1.12 km^2 (276.8 acres)
	Maximum. Increase of Flooding Depth Outside of Basin Delineation	0.75 m (2.5 ft)	0.38 m (1.2 ft)	0.39 m (1.3 ft)
	Mean Increase of Flooding Depth Outside of Basin Delineation	0.16 m (0.5 ft)	0.12 m (0.4 ft)	0.12 m (0.4 ft)

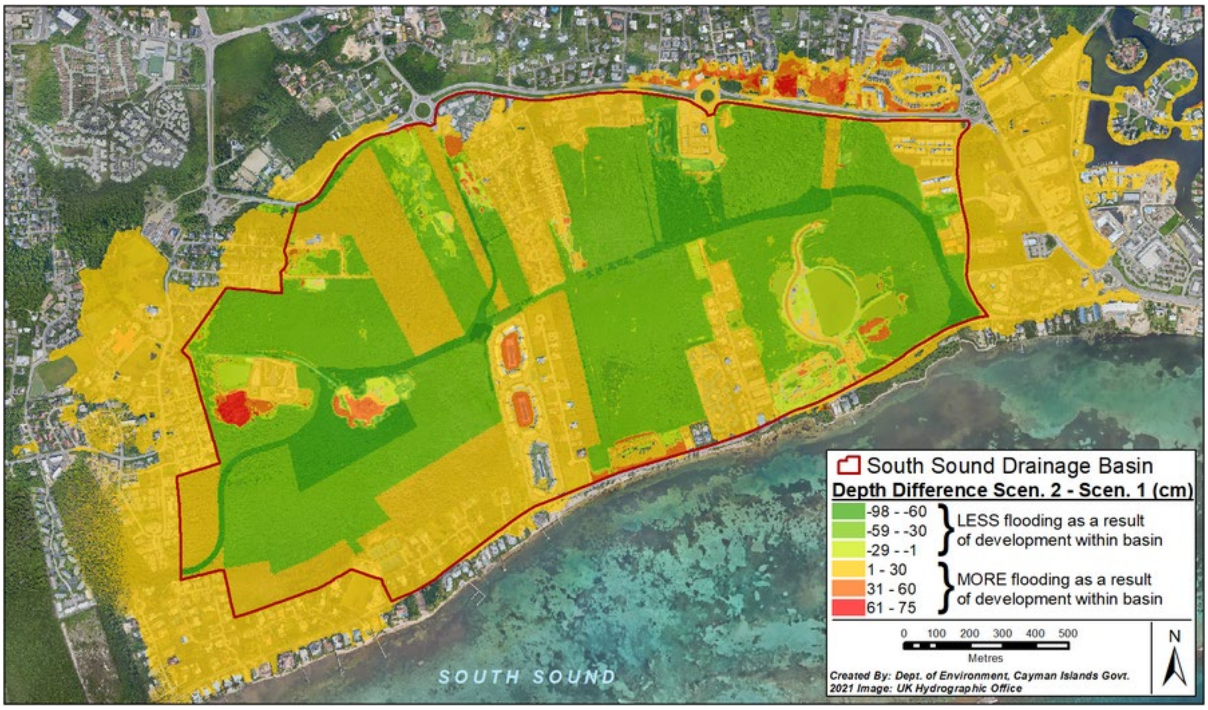


Figure 9. Maximum Depth Difference Map for South Sound (i.e. Scenario 2 minus Scenario 1 values) for the Tidal Surge model from a Category 3 hurricane from the south-west. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

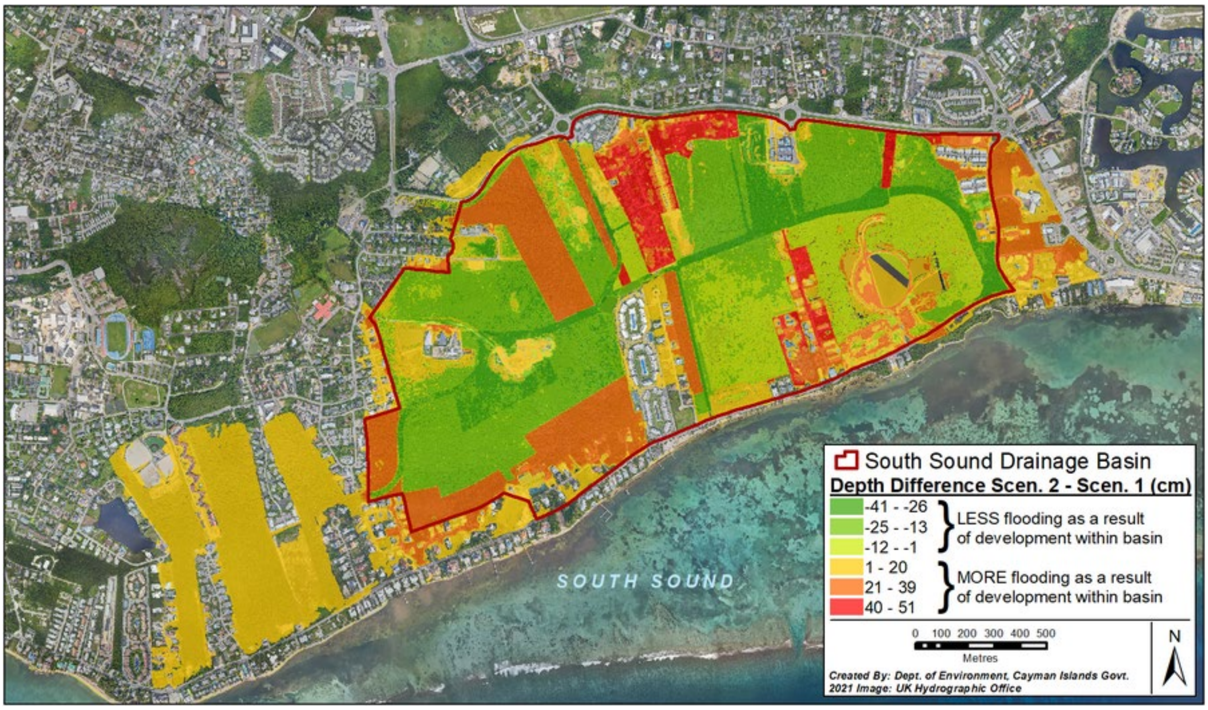


Figure 10. Maximum Depth Difference Map for South Sound (i.e. Scenario 2 minus Scenario 1 values) for a 25-year Rainfall Event lasting 48 hours. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

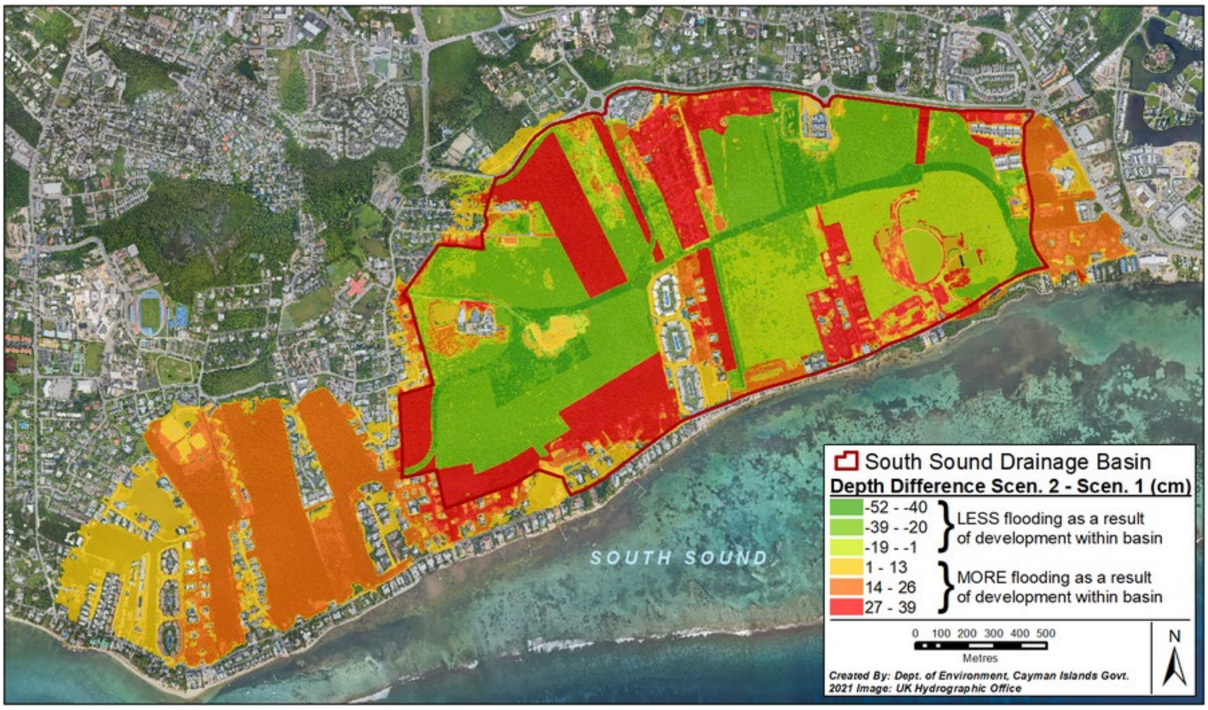


Figure 11. Maximum Depth Difference Map for South Sound (i.e. Scenario 2 minus Scenario 1 values) for a 100-year Rainfall Event lasting 48 hours. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

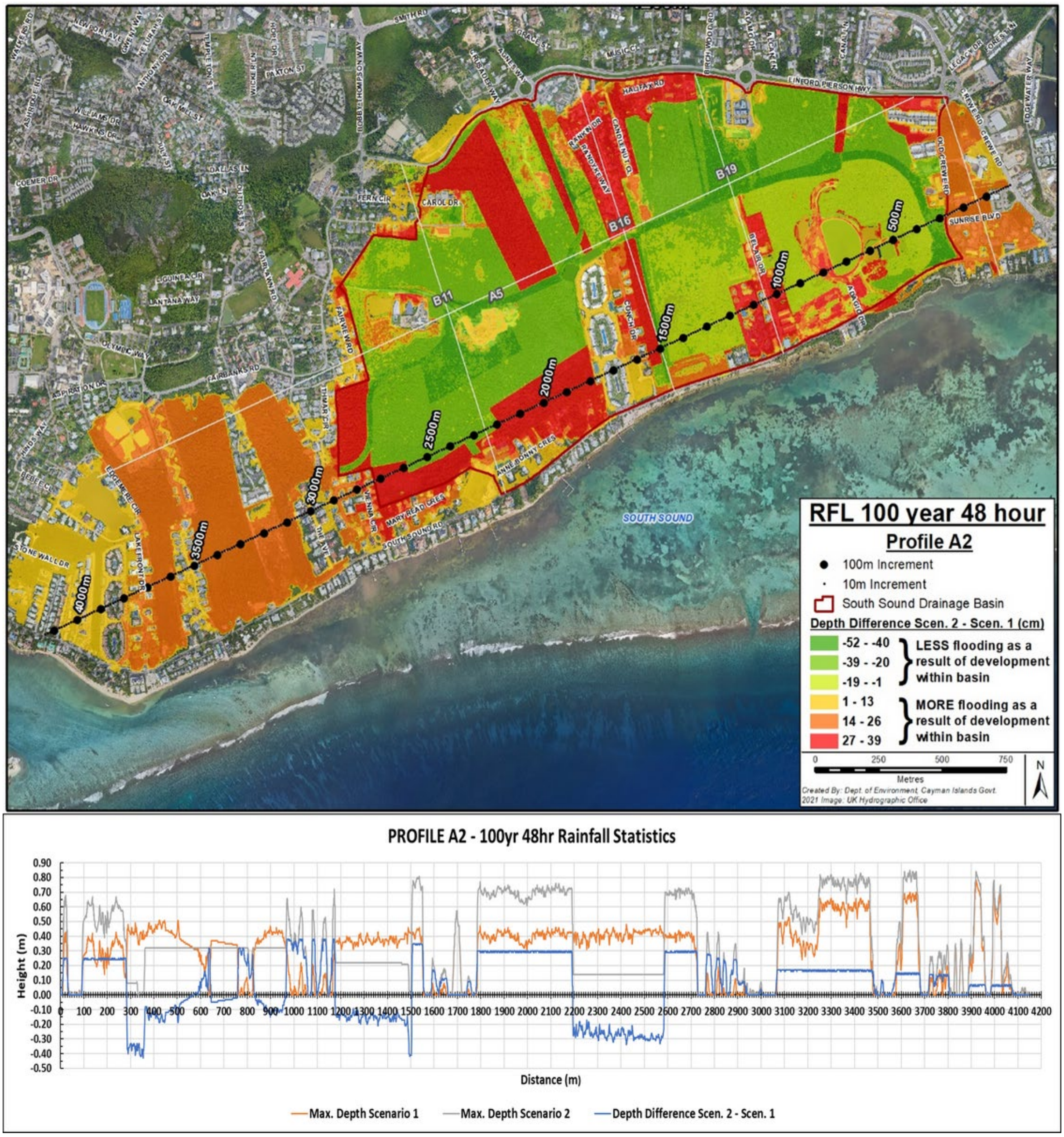


Figure 12. Maximum Depth Difference Profile of flooding for South Sound Basin (Scenario 2 minus Scenario 1) for a 100-year Rainfall Event lasting 48 hours. Background 2021 aerial photograph courtesy of the UK Hydrographic Office.

4. Discussion

4.1. Scenario Comparison

4.1.1. Tidal Surge

The results of simulating a tidal surge from a Category 3 hurricane from the south-west showed a minor increase in the basin's maximum flood water depth in Scenario 2 (1.59 m) when compared with Scenario 1 (1.54 m) (Table 2). Although the difference in the maximum depth between Scenarios was relatively small (5 cm), the increases in flood depth were significant in areas with pre-existing development (> 50 cm in some cases) (Figure 6). This was due to the changes in elevation associated with an increased number of developments in Scenario 2 (Figure 4), effectively reducing the water storage capacity of the basin. It is also likely that there was a reduction in water infiltration due to increased surface area of impermeable materials, such as asphalt and concrete (Figure 3). The friction factor of materials would also be reduced as the Manning's n coefficient for mangroves/wetlands (0.150) is greater than that of concrete/asphalt (0.014) (Table 1). Meaning that there would be less energy dissipation due to friction for the tidal surge.

The effects of Scenario 2 are best shown in Figure 6, which shows greater flood depths surrounding pre-existing developments and increased flooding of the area outside of the delineated South Sound drainage basin, a direct result of developments within the basin. This is likely due to an overall reduced water storage capacity of the basin. It is also possible that greater flood depths are seen due to roads acting like conduits for water, allowing the tidal surge to reach further inland. Figure 9 illustrates the depth difference between scenarios, green being where flooding is reduced. This corresponds to areas of new development, where the overall elevation increases in-line with ongoing developments in the area. The slightly reduced average water level within the basin (3 cm less in Scenario 2 than Scenario 1) is likely due to the decreased capacity of the basin, causing some spill over into surrounding areas.

4.1.2. Rainfall

The results of simulating flooding from the **25-year rainfall event** showed an increase in the maximum flood depth in Scenario 2 (0.85 m) by 9 cm, when compared with Scenario 1 (0.76 m) (Table 3). Areas of pre-existing development were significantly affected (Figure 7).

Similarly, results from the **100-year rainfall event** also showed an increase in the basin's maximum flood water depth in Scenario 2 of 0.87 m when compared with scenario 1 which was 0.76 m, demonstrating a 11 cm difference (Table 3).

Although the difference in maximum depth was relatively small, the increases in flood depth were significant in areas with preexisting development (up to 0.5 m deeper in some cases). Similar to the tidal surge results, this is likely primarily due to the changes in elevation associated with the new developments in Scenario 2, reducing the water storage capacity of the basin. In addition to infiltration rates, materials also account for rainfall losses during rainfall events. These values are assigned in the materials file alongside other parameters such as Manning's n (Table 1) and act to remove the loss depth from the rainfall before it is applied as a boundary on the 2-dimensional (2D) cells. This simulates water being prevented from reaching the ground, which is useful when modelling processes such as rainfall interception by trees. In this case, the loss of mangrove and wetland habitat for new developments is likely to have reduced rainfall interception, leading to increased water being applied to each cell boundary. This could explain why the negative depth difference values in

Figures 10 and 11 (rainfall) are less negative than in Figure 9 (tidal), as more water is applied in Scenario 2.

The area and depth of flooding outside of the South Sound drainage basin delineation must be noted in all modelled events. With the only difference in flood modelling between Scenario 1 and 2 being the increase of elevations due to development **within the basin**, it is evident that changes in one area can have a very significant impact on adjacent areas.

4.2. Environment and Planning Implications

The results of this simulation study (Phase 3), show that implementing new developments in the South Sound Basin affect the risk of flooding from tidal surge and heavy rainfall events by increasing flood depths around existing developments. As shown in Phase 2, increases in water depth could translate to increased costs from flood damage and business disruption. Careful consideration is required in any development plans that would cause changes in elevation and the removal of critical habitats, such as wetland and mangroves, that intercept rainfall and provide water storage and drainage services. Planning drainage around any new developments would also be critical to managing flood risk.

The southern edge of South Sound borders a Marine Protected Area, which should be accounted for in any drainage plans for the basin. This is because harmful materials from new developments and construction, and general waste and runoff, could affect marine life and impact the marine ecosystem, disrupting the key ecosystem services. Based on the results of Phase 3 modelling, the overall water draining into the MPA would likely increase with the implementation of scenario 2 development plans due to the decreased storage capacity of the basin. Wetland and mangrove ecosystems also play a critical role in regulating water flow in the intertidal zone, including water filtration and regulating salinity and pH levels. The reduction and fragmentation of wetland and mangrove habitat in South Sound, coupled with increased water influx and climate change-induced pressures, could impact these services which could be detrimental to the adjacent MPA. Mangroves are also well known for their carbon sequestration potential.

4.3. Study Caveats and Limitations

4.3.1. TUFLOW Program

The results of this study are simulations of surface flow and water accumulation based on TUFLOW's computational hydraulics and flow equation solver and are therefore subject to all the limitations of the program. Although the input data (rainfall and tidal surge values) was calibrated from historical events, the model results have not yet been validated with ground-level data. Hazard Management Cayman Islands are, however, starting to collect flood water data in this and other flood-prone areas of Grand Cayman that will assist in future validation of models. Also, the DoE are very familiar with this region and know of current flood-prone areas, which has been invaluable in interpreting and validating the results.

TUFLOW algorithms are, however, considered to be reliable and they are widely used for this type of application worldwide. For example, TUFLOW is the industry standard hydraulic modelling software for modelling rivers, their floodplains and surface water flow paths in the UK. It is regularly used by the UK's Environment Agency and Natural Resources Wales and was benchmarked as part of the Environment Agency model benchmarking study and performed well (Environment Agency 2010).

4.3.2. Infiltration data

The models within this study (Phase 3), used a combination of historical aerial photography, habitat mapping, elevation, and local knowledge of the South Sound Basin to develop a new soils map, which was created to better account for infiltration rates. However, this method was limited in a couple of ways. Firstly, the approach taken to improve the soil data was desk-based and due to time and resource constraints no ground-truthing was conducted. Secondly, this method did not account for ground water saturation levels, detailed sub-surface geology and/or any underground drainage infrastructures, which can affect an area's infiltration rate.

For the rainfall model, an initial loss and continuing loss in mm was assigned to different materials to account for additional infiltration losses. Fraction impervious values were also assigned to materials to account for permeability. These values were adjusted from the Phase 2 study and based on a theoretical understanding of water infiltration in different habitats.

4.3.3. Roughness and friction values

TUFLOW accounts for surface roughness via Manning's n coefficient which is used to calculate energy loss due to friction over different surface materials. Some of the Manning's n values for materials found in the literature did not exactly match the classifications used in the habitat materials layer. In this case, the closest matching material was selected and used in the model. Additionally, material values found in the literature often were presented as a range rather than a single value (minimum-normal-maximum) and in these cases the normal values were used. Where conflicting values arose for the same material, a value intersecting the range of both was chosen. However, to increase model performance more refined and accurate values are needed.

4.4. Recommendations for Improvement and Future Work

4.4.1. Model verifications and ground-truthing

Various forms of verification could be undertaken to ground-truth the models. For instance, aerial photography or high-resolution satellite imagery of flooded areas could be used and compared with the model's predicted flood extents. Data available through insurance claims, could also be used for validation purposes, as these would be linked to addresses that experienced flood events and flood dates, thereby providing a reference point to assess flood type and intensity.

4.4.2. Modelling simultaneously rainfall and tidal surge events

Future models that combine rainfall with tidal surge events may provide a better understanding of the cumulative flooding impacts from these flood sources and provide enhanced information for planning and disaster management in the region.

4.4.3. Refining the soils/geology layer

There was no available high-resolution soil or digitized geology data for the Cayman Islands. For the current study, efforts were made to improve the soil layer that was originally used in Phase 2. However, there are still limitations to the improved layer, with scope for a mapping project to assist in generation of better soil and geology data and therefore improved infiltration and permeability information for the flood modelling.

4.4.4. Adding existing and planned drainage systems

One factor that may affect the amount and duration of flood water which remains within the South Sound Basin is the presence of drainage systems. There are existing drainage systems in the area that have not been included within the Scenarios. Further, future developments may include the installation of drainage ditches/culverts etc. that may facilitate the removal of flood water. If drainage data becomes available these could be included in future model re-runs. Further, to facilitate development decisions, various drainage scenarios could be modelled to help inform flood risk mitigation when considering future developments.

4.4.5. Updating development scenario based on existing plans

Within Scenario 2, one development plan for the south-west region of South Sound and road/highway plans was available to develop the Scenario 2 land-use/land cover and elevation input layers for the models. For the remaining 'new development' areas, however, only known land parcels were available. Expert judgement was used to develop the land use/land cover and elevation. The model could be used to support future planning scenarios and rerun as better information becomes available.

References

BMT WBM. 2016. TUFLOW User Manual. https://downloads.tuflow.com/_archive/TUFLOW/Releases/2018-03/TUFLOW%20Manual.2018-03.pdf

Carter, C., England, G., Fawcett, C., Hurt, F., Park, J., Pinder, S. & Thurston, N. 2025. Model development to assess the vulnerability of the Cayman Islands to storm surge and inland flooding and the role of natural capital in mitigating the impacts – Phase 2. UK Overseas Territories Report Series 6, JNCC, Peterborough, ISSN 2753-6270. https://hub.jncc.gov.uk/assets/951346cc-5b22-4202-92d0-8cf4e6ac7032

Environment Agency. 2010. Benchmarking of 2D Hydraulic Modelling Packages SC080035/SR2.

Booij, N., Ris, R.C. & Holthuijsen, L.H. 1999. A third-generation wave model for coastal regions 1. Model description and validation, *J. Geophys. Res. Ocean*. 104 7649e7666, https://doi.org/10.1029/98JC02622

Rogers, C.S. & Ramos-Scharrón, C.E. 2022. Assessing Effects of Sediment Delivery to Coral Reefs: A Caribbean Watershed Perspective. *Frontiers in Marine Science* 8 ISSN 2296-7745. https://doi.org/10.3389/fmars.2021.773968

Wood Environment & Infrastructure Solutions UK Limited. 2021. Model development to assess the vulnerability of the Cayman Islands to storm surge and inland flooding, and the role and value of natural capital in mitigating the impacts. Natural Capital in the UK's Overseas Territories Report Series – Supplementary Report (Caribbean Region). Contracted report to JNCC. https://hub.jncc.gov.uk/assets/94831333-e969-4bc4-9973-ff4ca21399c1

For further information please contact:
Joint Nature Conservation Committee
Quay House
2 East Station Road
Peterborough PE2 8YY
Communications@jncc.gov.uk

jncc.gov.uk
x.com/JNCC_UK
linkedin.com/company/jncc
facebook.com/JNCCUK
youtube.com/JNCC_UKvideo