Response to Anonymous Referee 2

General comments:

2.1. This manuscript develops an integrated modeling framework to simulate urban flooding caused by rainfall, tides, and groundwater using MODFLOW and FLO-2D. While the idea to combine a surface water model and a groundwater model is intriguing for flooding research, this manuscript suffers many writing and technical deficits.

A. **The methodology is not well written and is vague. Details about coupling the FLO-2D model and MODFLOW-2005 model are not well explained. Also, Model setups, including boundary conditions and parameters, are not clear.**

B. **Although model calibration is mentioned in the Abstract, I don't find descriptions of model calibration in the methodology, data, and results. If the model was not calibrated, then the results and analyses would not be convincing.**

C. **The title has the phrase "rainfall-groundwater interaction", but the interactions are not discussed in the manuscript.**

D. **The manuscript fails to provide compelling evidence of interactions among rainfall, tides, and groundwater in the study area. Based on my reading, it seems that the rainfall and tides do not have strong interactions with groundwater in urban areas due to the imperviousness of pavements. High water tables in the study area may be caused by flow from other areas. If the interactions are not significant, then the integrated modeling framework is not useful to the study area.**

E. **Most figures have very poor readability. Some figures are too busy and confusing (e.g. Figures 1-3, 10-12); and some figures fail to convey meaningful information. Please see the specific comments for details.**

F. **The writing is redundant and irrelevant in many places. For example, it is not necessary to provide detailed information about the well-known models (MODFLOW and FLO-2D) in methodology section. Also, most of discussions are irrelevant to the modeling results. Please see the specific comments for details.**

Based on these serious issues, the manuscript deserves a significant revision. I would not recommend to accept this manuscript for publication.

Authors' actions and comments:
We thank Reviewer #2 for pointing out several constructive criticisms of this manuscript. We proposed a revised version of the manuscript that cleans all irrelevant and unnecessary text, we clarified the confusing parts, specifically for methodology and discussion sections, and we integrated and adjusted the manuscript to address major concerns and remarks by Reviewer #2. To our view, the paper presents novel findings for the following reasons:

1. Several methodologies have been applied to simulate the influence of the water table in lowland watersheds characterized by porous permeable soil. Nevertheless, a large portion of these methodologies are based on qualitative and/or statistical approaches. In recent years

numerical models have slowly been incorporated into groundwater studies, with only a few that use physically-based models to account surface-subsurface water interactions (Yu et al. 2019, Yang & Tsai 2020, Su et al. 2020). This manuscript aims to address this research gap by presenting a loosely-coupled methodology that links two numerical models (FLO-2D and MODFLOW-2005) to simulate surface and subsurface hydrology, producing reasonable results. Here we demonstrate the capabilities of an integrated modelling framework with the potential to simulate compound flooding events.

2. The nature of this paper is heavily linked to a numerical modelling scope, as the manuscript tries to highlight the value of the water table as a key flood driver that can potentially trigger groundwater-induced flooding, with the potential to exacerbate flood conditions. The proposed modelling framework advances understanding on flood modelling at regions with complex urban settings like the Arch Creek Basin or Miami-Dade County, characterized by specific topographic and hydrogeology (flat terrain, porous soil, unconfined aquifers) and subject to surface-subsurface water interactions. Regions prone to groundwater-induced flooding should consider the influence of the water tables in their vulnerability analyses to simulate the influence of groundwater-induced flooding.

3. We developed a simple groundwater model that is based on local modelling efforts (Hughes & White, 2016, Sukop et al. 2018). For simplicity, we approximated the aquifer to be a 2D in the horizontal axis and 1D in the vertical axis. Considering that most of the water table interactions occur in the first aquifer layer of the regional model (≈ 7 meters) and the short simulation time of the selected events (64 and 84 hours), we presume that differences in the modelling set up compared to the regional model will not be significant for the purpose of this study. Future work should explore the use of multiple aquifers to assess the differences in the water table dynamics.

4. Despite the lack of quantitative evidence (water level observations), the model was calibrated by using an official dataset that displays properties that have experienced repetitive flood losses across the study area. Figure 11-12 display reasonable results where all spot observations fall within the simulated flood depths. In addition, Figure 13 provides visual evidence (VGI imagery) of flooded conditions for Tropical Storm Andrea. The water table plots show that rainfall-induced flooding is responsible for the flooding conditions in the selected locations as the water table did not exceed the surface elevation.

Action taken: Please find our responses to each comment below including how we plan (following the NHESS review process) to adjust the manuscript. We made our best to address major remarks (A to G) as explained in the following points:

A) ***The methodology is not well written and is vague. Details about coupling the FLO-2D model and MODFLOW-2005 model are not well explained. Also, Model setups, including boundary conditions and parameters, are not clear.***

We agree with Reviewer #2 that the methodology section contained redundant information about both modelling frameworks and the coupling methodology was not properly explained and requires editing.

Action taken: The methodology section has been fully restructured as requested (lines 208 to 369).

4.1 Hydraulic Model: FLO-2D

FLO-2D is a physically-based volume conservation model that combines hydrology and hydraulics to simulate the propagation of water dynamics in urban, riverine, and coastal environments for flood hazard mapping, floodplain delineation, flood vulnerability assessments and mitigation planning (O'Brien et al., 1993). The flood routing model applies the dynamic wave approximation to the momentum equation to calculate the average flow velocity across the square grid system one direction at a time in eight potential flow directions over the floodplain. Hydrological processes are represented as rainfall data over the computational domain or as input hydrographs that can be specified in the channel, floodplain, or along the coasts. Various attributes (elevations, roughness coefficient), components (channel, infiltration, storm drain) and features (streets, hydraulic structures) can be incorporated into the FLO-2D model to produce more refined simulations (O'Brien, 2011). Details are described elsewhere (Annis and Nardi, 2019; Grimaldi et al., 2013; Peña et al., 2021; Peña and Nardi, 2018).

4.2 MODFLOW-2005

MODFLOW-2005 is a fully distributed model developed by the USGS that simulates groundwater flow in aquifer layers (confined or unconfined) using a block-centered finite-difference approach (Harbaugh, 2005). The spatial discretization of the aquifer(s) into grid elements computes the horizontal and vertical flow stresses of the hydrogeological system (water heads, recharge, zetas) at the center of the cell. Similarly, the model offers several solvers for matrix equations, as well as subsidence, observations, surface-water routing, and transport packages. Technical documentation on the model description and groundwater flow equations is presented in Harbaugh (2005).

4.3 Coupling surface-groundwater models

The main factors determining the coupling process between FLO-2D and MODFLOW-2005 include the algorithms' mathematical solver compatibility to calculate and transfer the exchanged volumes in opposite directions within a fully integrated framework and share consistent spatial and temporal scales.

In terms of the spatial scale, a perfect match between FLO-2D and MODFLOW-2005 surface elevation layers is necessary for the surface and subsurface water interactions to happen. This agreement is subject to identical geographical position, reference system, size resolution, and topographic cell elevations (Fig. 4). Although the coupled models can have variations in the number of cells and domains, FLO-2D cells must overlap the MODFLOW-2005 grid domain system to compute results and transfer the output data from one model to another and vice versa until the end of the simulation.

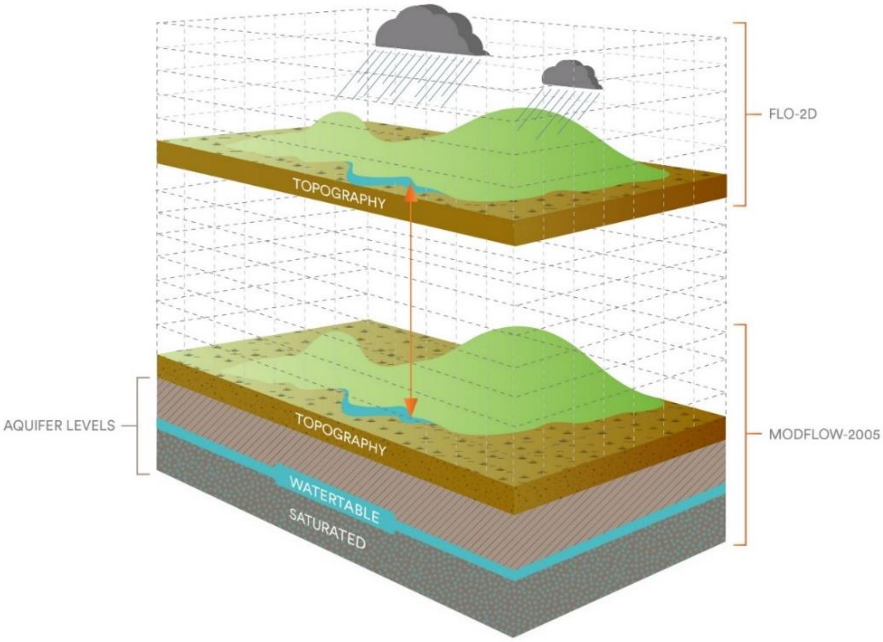


Figure 1. Spatial compatibility between FLO-2D and MODFLOW-2005.

A significant advantage in the coupling process is that both numerical codes are written in FORTRAN programming language and shared the same explicit finite difference method simulating all physical processes simultaneously in a fully integrated framework. Nevertheless, FLO-2D and MODFLOW-2005 design structures present significant operability differences to perform calculations. Both numerical algorithms solve the two- and three-dimensional equations independent from each other to satisfy their respective numerical stability criteria and accuracy. For this reason, a loosely-coupled linking technique in order for FLO-2D and MODFLOW-2005 to exchange output in a synchronized systematic way and simulate the surface-subsurface interactions within the same modelling framework. In MODFLOW-2005, the simulation is divided into a series of stress periods within which specified data are constant. Each stress period, in turn, is divided into a series of time steps. The solution of the finite difference equations can be written in matrix form as:

$$[A]\{h\} = \{q\}$$

where $[A]$ is a matrix of the coefficients of the head for all active nodes in the grid, $\{h\}$ is a vector of head values at the end of time step n for all grid nodes, and $\{q\}$ is a vector of the constant heads for each timestep.

MODFLOW-2005 has three internal nested loops, the stress period loop (outer), time step loop (intermediate), and iteration loop (inner). A predetermined procedure is implemented at the beginning as a routine setup function to read the domain set-up (i.e., grid resolution, number of layers, and simulation time), model data in the form of boundary conditions, aquifer hydraulic characteristics (i.e., hydraulic conductivity, specific storage, transmissivity), initial head conditions, and selected solution method.

The outer loop is responsible for calculating the resulted heads for each timestep from defined boundary conditions, including specified heads (i.e., time-variant or head boundary packages), specified flux (i.e., recharge or wells), and head-dependent flux (i.e., drain, evapotranspiration or river recharge). The intermediate loop accounts for the total simulation time, as well as additional output processing, and the inner loop for calculation purposes to approximate the head solution until the maximum number of iterations is achieved. At the end of the iteration loop, specified output control files are created in the form of heads, budget terms, or flow in the domain. The intermediate and outer loops repeat until all timesteps are completed for all stress periods (Harbaugh, 2005).

FLO-2D works with variable time steps that are automatically adjusted internally based on stability criteria requirements. Because FLO-2D uses an explicit finite difference method to solve the surface water equations, its time step is usually much smaller than that defined for the MODFLOW-2005 model, resulting in an increasing number of 2D computational sweeps to match the MODFLOW-2005 simulation time (FLO-2D, 2018). A time-synchronization scheme was developed to achieve the coupling, as the MODFLOW-2005 intermediate loop is in charge of transferring the information between models. For example, the FLO-2D iterative calculations start until reaching MODFLOW-2005 time step one. Then, the MODFLOW-2005 intermediate loop performs its respective calculations from time step one and is shared in both directions to continue with the following time step (Nalesso, 2009). The process repeats itself until the simulation time of FLO-2D is completed. Similarly, MODFLOW-2005 can experience numerous stress periods during the simulation. Fig. 5 depicts the time step synchronization procedure between both models.

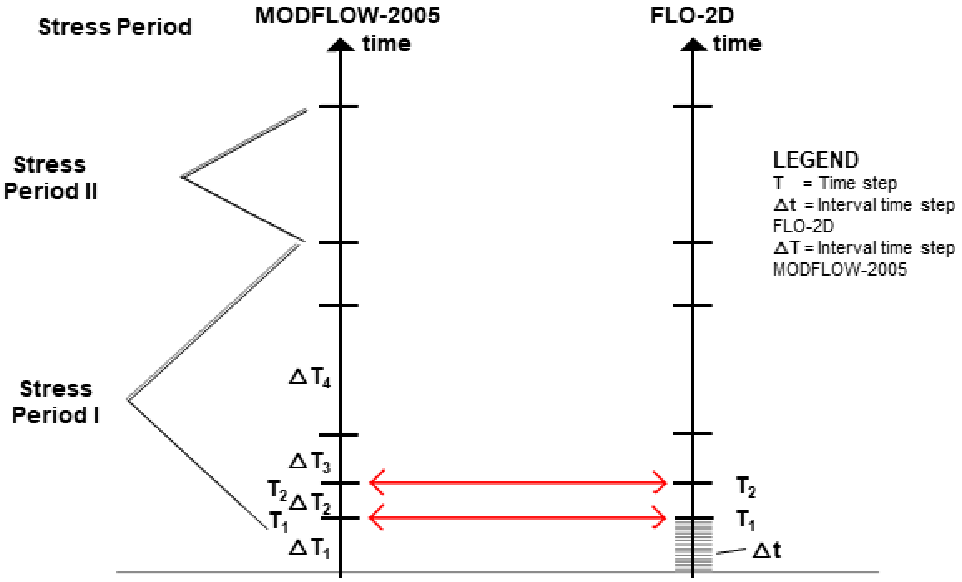


Figure 2. Time-step synchronization of FLO-2D and MODFLOW-2005.

The Green & Ampt method (1911) was selected for being the most complete function available in FLO-2D that calculates the accumulated volume of water that infiltrates from the surface layer into the soil and is transferred to MODFLOW-2005 as recharge. The unsaturated zone is not considered in the coupling methodology as the infiltrated volume travels directly to the water table. Rainfall intensity predominantly influences the infiltration process as runoff and is generated when the maximum infiltration capacity is exceeded. Several variables are accounted for in the Green & Ampt infiltration function, including initial abstraction, hydraulic conductivity, soil porosity, volumetric moisture deficiency (initial and final soil saturation conditions), soil suction and soil storage depth.

The development of the Green & Ampt method in FLO-2D is based on the application of Darcy's Law principle that the infiltration process begins as soon as the surface water moves in a vertical direction through the permeable medium and can be written as:

$$\frac{\Delta F}{\gamma} - ln\left(1 + \frac{\Delta F}{\gamma + F(t)}\right) = \frac{K_w}{\gamma}\ \Delta t$$

Where:

ΔF = change in infiltration over the computational time step

K_w = hydraulic conductivity at natural saturation (mm/hr)

γ = $(PSIF + Head) * DTHETA$

$PSIF$ = capillary suction (mm)

$Head$ = incremental rainfall for the time step plus flow depth on the grid element (mm)

$DTHETA$ = volumetric soil moisture deficit (dimensionless)

$F(t)$ = total infiltration at time t

Δt = computational time step

Fullerton (1983) developed an explicit equation ΔF by using a power series expansion for infiltration with respect of time to approximate the logarithmic term in the latter equation:

$$\Delta F = \frac{-[2F(t)-K_w\Delta t]+[(2F(t)-K_w\Delta t)^2+8K_w\Delta t(\gamma+F(t))]^2}{2}$$

Fig. 6 provides a schematic representation of how the simulated groundwater heads of MODFLOW-2005 are incorporated in the infiltration methodology of FLO-2D. The infiltration methodology was developed under the principle of hydrostatic pressure and the assumption that the piezometric head is similar to the datum elevation in unconfined aquifers (Nalesso, 2009). The soil saturation percentage is determined based on the surface flow and water table levels. The infiltration calculation continues as long as the water table levels are lower than the terrain elevation. Conversely, the water exchange can also occur in the opposite direction due to a sudden rise in the water table. If the groundwater heads calculated in MODFLOW-2005 are higher than the surface depth in FLO-2D, the depth of water from groundwater will be added to the surface depth. The infiltration calculation is switched off at each node as long as the saturation condition persists, meaning that infiltration will not be calculated until the soil absorption capacity is reestablished.

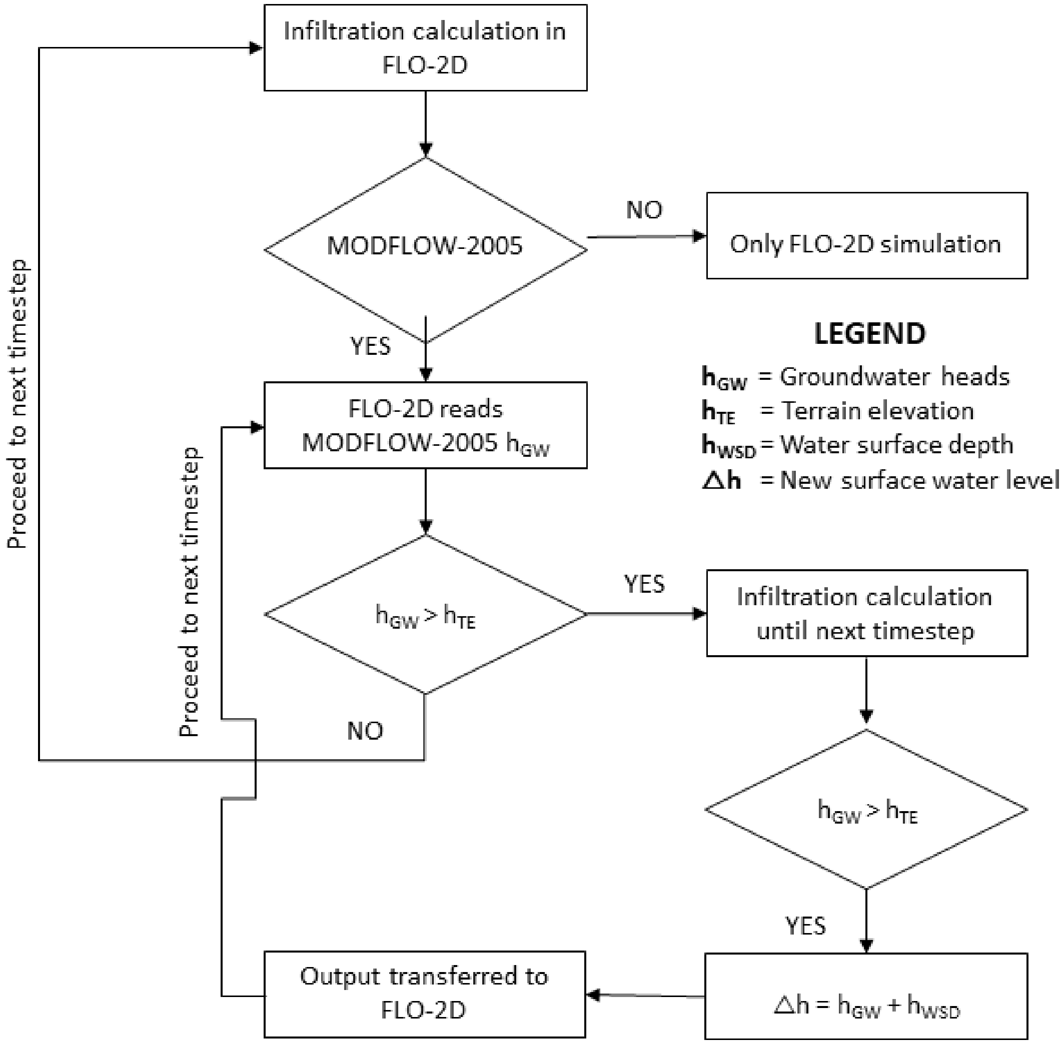


Figure 3. Conceptual diagram of the infiltration methodology incorporated in the coupled FLO-2D and MODFLOW-2005 that illustrates the influence of groundwater heads in the infiltration calculation. Adapted from (Nalesso, 2009)**.**

4.4 Model configuration and set-up

The FLO-2D hydraulic model requires a grid of square cells to represent the topography of the floodplain domain. The structured grid size of the computational domain defines the hydraulic model resolution. The LIDAR DTM was used as source floodplain topographic information, and an interpolation algorithm was implemented to produce a resampled DTM floodplain model to be used as input elevation of the hydraulic model. The nearest neighbor interpolation method was selected to resample data from the high-resolution 2 m LiDAR to a 20m resolution (42,621 cells).

In addition to the topographic features, a detailed representation of the built environment is relevant for urban flood modeling in order to simulate the flow wave propagation dynamics realistically. All buildings in the domain (7827 features) were imported to the FLO-2D computational domain. The polygon vectors are represented as Area Reduction Factors (ARF = 1) where the grid element surface area is considered impervious and is removed from potential water interactions.

Rainfall and tides were considered for the hydrologic forcing, setting the precipitation over the grid system and tide levels in the easternmost cells to represent the Biscayne Bay's coastal conditions. Both time series are structured on a one-hour basis and are presented in the following section. The inclusion of the storm drain system, French drains, surface water control structures and pump stations in the modelling framework is beyond the scope of this study.

The infiltration method selected for the case study was the Green & Ampt. Global soil parameters correspond to the urbanized and permeable surfaces characteristics. Considering that MDC is characterized by the water table response to rainfall events, conservative infiltration estimates for the impermeable surfaces were selected to account for the influence of the French drains in the system. For simplicity, the Manning roughness coefficient was assumed as 0.40 for green land cover areas and 0.04 for the impervious urbanized environment, canal bed, and Biscayne coast.

Bathymetric measures were available for the Little Arch Creek River. A 1D hydraulic model with natural cross-sections was imported into FLO-2D extending from NE 143rd Street to structure G-58 located downstream of the Enchanted Forest Elaine Gordon Park. Official bathymetry from the Biscayne shore, Keystone Island, and Sans Souci canals was not available for this study due to jurisdiction restrictions. To compensate for the missing geometry, aerial imagery Google Earth was used to measure the canal's width, while a 10-meter bottom elevation was used as constant depth based on the Miami Florida Intracoastal Topography database from the Oleta River.

Concerning MODFLOW-2005, a simple model was developed based on the regional groundwater model of MDC developed by USGS (Hughes & White, 2016) using an advanced version of MODFLOW-2005 that applies the Newton-Raphson formulation (MODFLOW-NWT) with the Surface-Water Routing (SWR1) Process to simulate comprehensive surface and groundwater hydrologic conditions on a 15 meter grid resolution; the second model consists of a local 1D MODFLOW that simulates the influence of the water table on flooding conditions in an upper portion of the Arch Creek Basin (Sukop et al., 2018).

The boundary area applicable to the Arch Creek Basin was extracted from the regional model using the ModelMuse graphical user interface (Winston, 2009), and the grid spacing across the model was regenerated to a 20 meters resolution. The spatial discretization of the model on the horizontal axis consists of 265 columns and 285 rows for a total of 75,525 cells. The Biscayne aquifer is simplified to be a one-layer 35 meters thickness compared to the three layer units of the regional hydrogeological system. Taking the upper aquifer parameters as reference, the hydraulic conductivities ($Kx \approx 1{,}890$ meter/day), specific storage ($Ss = 1.27\ e^{-5}$) and specific yield ($Sy \approx 0.376$) vary across the domain. Four boundary conditions are assigned in respect to the hydrological forcing in the study area. The Time-Variant Specified-Head (CHD) package feature in the easternmost boundary represents the tide conditions of the Biscayne Bay and the ocean-side water levels from Canal C-8 in the southern boundary edge. In respect to the groundwater heads, the General-Head Boundary (GHB) package was used to set the water table levels from gauge station G-852 in the westernmost boundary of the domain. MODFLOW-2005 package solvers were customize based on the local groundwater model. The stress periods are structured in one-hour to match the FLO-2D time steps, and the groundwater flow calculations are under transient state.

After the modelling set-up, the compatibility process validates the perfect agreement between the surface layers of FLO-2D and MODFLOW-2005 in order for the loosely-coupled model to link the floodplain-aquifer hydrodynamics. If so, FLO-2D will act as the base hydraulic model responsible for simulating precipitation and ocean levels with the support of MODFLOW-2005 to simulate the groundwater heads, creating a compound flood modelling framework for surface-subsurface water interactions (Fig. 7).

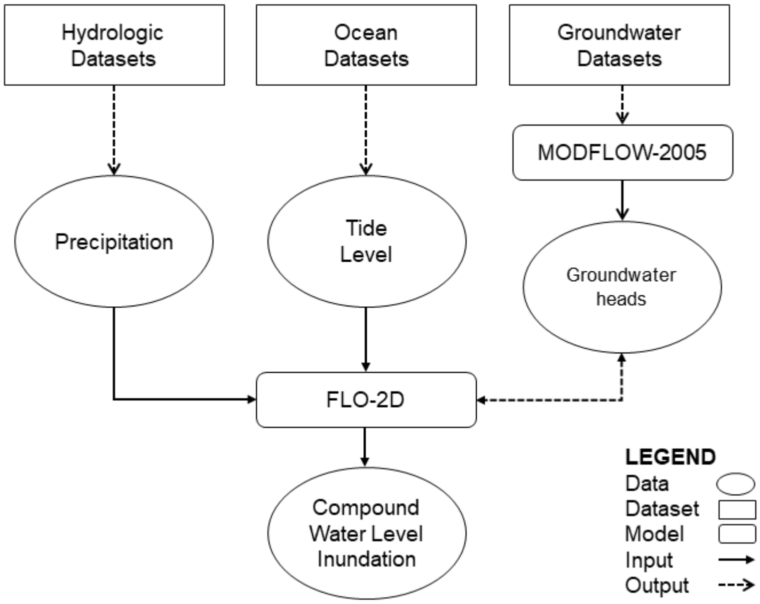


Figure 1. Flowchart representing the CF simulation using FLO-2D as the base hydraulic model. The hydrologic, ocean, and groundwater datasets were obtained through observations. The surface hydrology was incorporated as rainfall and coastal boundary conditions in FLO-2D. The groundwater heads were calculated in MODFLOW-2005 and transferred in an iterative manner to FLO-2D every time a MODFLOW-2005 time step is reached (Fig. 6). Adapted from Santiago-Collazo et al. (2019)

B) ***Although model calibration is mentioned in the Abstract, I don't find descriptions of model calibration in the methodology, data, and results. If the model was not calibrated, then the results and analyses would not be convincing.***

Although the manuscript does not include rigorous calibration that is usually required when testing a novel or applied modelling methodology due to the lack of observation data, a calibration approach based on an official property database that have experienced repetitive flooding losses is compared with the simulated flooding conditions. The properties fall within the simulated flood inundation extent. In the context of this research, we demonstrate that surface-subsurface water interactions are localized in the Arch Creek Basin.

In addition, VGI imagery from Tropical Storm Andrea (Fig 12) were used to validate the water table plots with the simulated flood depths, producing reasonable results (Table 3).

Information regarding the model calibration has been inserted in the following sections:

Abstract (lines 25-26)
Due to limitations in water level observations, the model was calibrated based on properties that have experienced repetitive flooding losses, and validated using image-based volunteer geographic information (VGI).

Introduction (lines 104-106)
Finally, the coupled model results were calibrated based on official database from FEMA, and validated using volunteered geographic information (VGI) flood observations from the study area

Data Description (line 199-204)
FEMA's severe repetitive loss properties program is designed to provide grants and financial assistance to residential properties that have experienced frequent flood losses over the years (FEMA, 2021). Currently, seventy-five properties have requested financial assistance for property acquisition or to recoup with some of their investments due to flood damages in the Arch Creek Basin (Miami-Dade, 2017). The database stores detailed information on the date of loss, building type, flood zone designation, type of insurance and claim payments between 1995 to 2015, providing a clear footprint of flooding risk hotspots and flood prone communities. This dataset will be used to calibrate the flood inundation maps.

Results (line 384-395)
Simulating surface-subsurface water physical processes through physics-based flood modelling frameworks is relevant and meaningful to better assess the severity of groundwater-induced flooding in low elevation coastal environments characterized by porous permeable soil. Fig. 9 illustrates the simulated maximum inundation depths corresponding to the magnitudes of Tropical Storm Leslie, Tropical Storm Andrea, and the 25 May 2020 storm. Tide levels per se do not pose significant threats to infrastructure as the coastal waters remain within the channels. Fig. 10 illustrates the emergence of the groundwater heads to the surface as a result of the increase in the water table. The simulation proves reasonable in terms of maximum flood depth and extent due to the similarities in the hydrologic conditions, being Tropical Storm Leslie the most severe of all three storms. FEMA's records on properties subject to frequent flooding were used as a calibration approach to verify a match between the model results with flood observations. Although the available records do not specify the observed inundation depths, an agreement between the property locations and maximum water levels may offer sufficient evidence that the model provides reasonable results

(Fig. 11). The calibrated results and display of the water table timeseries in selected locations for Tropical Storm Leslie are shown in Fig. 12-13.

Conclusions (line 490-494)
Considering Miami's hydrogeomorphology is one of the most complex globally, the compounding effects of flood drivers may respond differently in diverse geographic settings. Therefore, further research should consider the proposed modeling framework to assess the CF risk in different geographical regions prone to multiple flood drivers, specifically in areas that have access to post-event flooding maps in the form of remote sensing products or VGI data for calibration and validation purposes.

C) ***The title has the phrase "rainfall-groundwater interaction", but the interactions are not discussed in the manuscript.***

We agree with Reviewer #2 that the title of the paper may cause confusion because groundwater-induced flooding conditions are localized in low-elevation areas within the Arch Creek Basin. For this reason, the manuscript title and the narrative have been modified throughout the document. Now the manuscript title reads "Compound flood modelling framework for surface-subsurface water interactions"

D) ***The manuscript fails to provide compelling evidence of interactions among rainfall, tides, and groundwater in the study area. Based on my reading, it seems that the rainfall and tides do not have strong interactions with groundwater in urban areas due to the imperviousness of pavements. High water tables in the study area may be caused by flow from other areas. If the interactions are not significant, then the integrated modeling framework is not useful to the study area.***

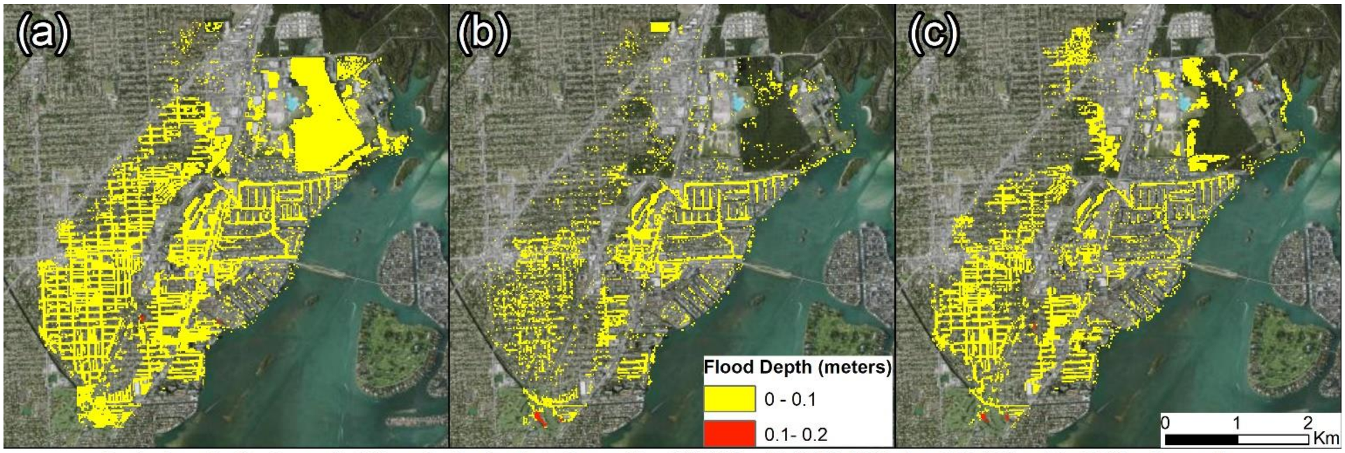
We really appreciate this concern raised by Reviewer #2.
As mentioned in previous comment 2.1C, the narrative has been improved to clarify the main contribution of this manuscript, presenting the coupling framework between FLO-2D and MODFLOW-2005 to simulate surface-subsurface water processes in localized areas where the water table levels exceed the surface elevation. Thus, we demonstrate that the programming and exchange of information is effective, overcoming important programming obstacles, such as considerable operability differences in their respective numerical codes (lines 276-311)

The three selected events are characterized by heavy precipitation, regular tide levels and unusually high water tables. The storm surge levels do not cause coastal flooding and only increase the water levels on the coast and waterways, having a minimal impact on the flooded area. Nevertheless, the coastal boundary conditions influence the groundwater levels, as the tidal signal can be observed in locations near the coast (Figure 12 b-c-d-e) (lines 408-412).

"The groundwater plots illustrate the effect of tidal and groundwater boundary conditions on the behavior of the simulated water table, in turn demonstrating the importance of both variables in the modeling set-up and influence in subsurface dynamics, as a cyclic high-low pattern characterizes the tide fluctuations of the Biscayne Bay (Fig. 12b – 12e) compared to the defined water heads behavior from well G-852 in the western boundary of the domain (Fig. 12a, 12f). In terms of residential damage, Tropical Storm Leslie and Tropical Storm Andrea may be considered the costliest events in the Arch Creek Basin as both account for 60% of the reported claims (25 and 17 respectively) (Table 2).”

Although it is possible that the highwater tables in the study area may be caused by flow from other areas, the response of the water table to rainfall events is clearly displayed in Figure 8b-c. Many gauge stations nearby the study site and in Southeast Florida report the same behavior.

The demonstration of significant surface-subsurface water interactions is also provided in Figure 10



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 2. Spatial distribution of groundwater-induced flooding for Tropical Storm Leslie (a), Tropical Storm Andrea (b), and 25 May 2020 event (c).

(line 388 – 389)

Fig. 10 illustrates the emergence of the groundwater heads to the surface as a result of the increase in the water table.

And (line 398-402)

The groundwater flood maps for Tropical Storm Leslie (37.17%), Tropical Storm Andrea (13.87%) and the May 2020 event (20.82%) are showed in Fig. 10. The simulation demonstrates that slight variations in the water table depth (Fig. 8) can exacerbate groundwater emergence extent, resulting in ≈ 10 cm across the Arch Creek Basin. Interestingly heavy precipitations scenarios with very high water tables over extended periods of time (May 2020 event) are more likely to trigger groundwater induced flooding compared to very high precipitation with high water table levels (Tropical Storm Andrea).

- ***E) Most figures have very poor readability. Some figures are too busy and confusing (e.g. Figures 1-3, 10-12); and some figures fail to convey meaningful information. Please see the specific comments for details.***

We thank Reviewer #2 for pointing out this concern. We acknowledge that Figures 1-3, 10-12 were too busy and must be improved, as well as the captions. For this reason, most of the Figures have been redesigned to improve their readability. The captions have also been improved to provide more details.

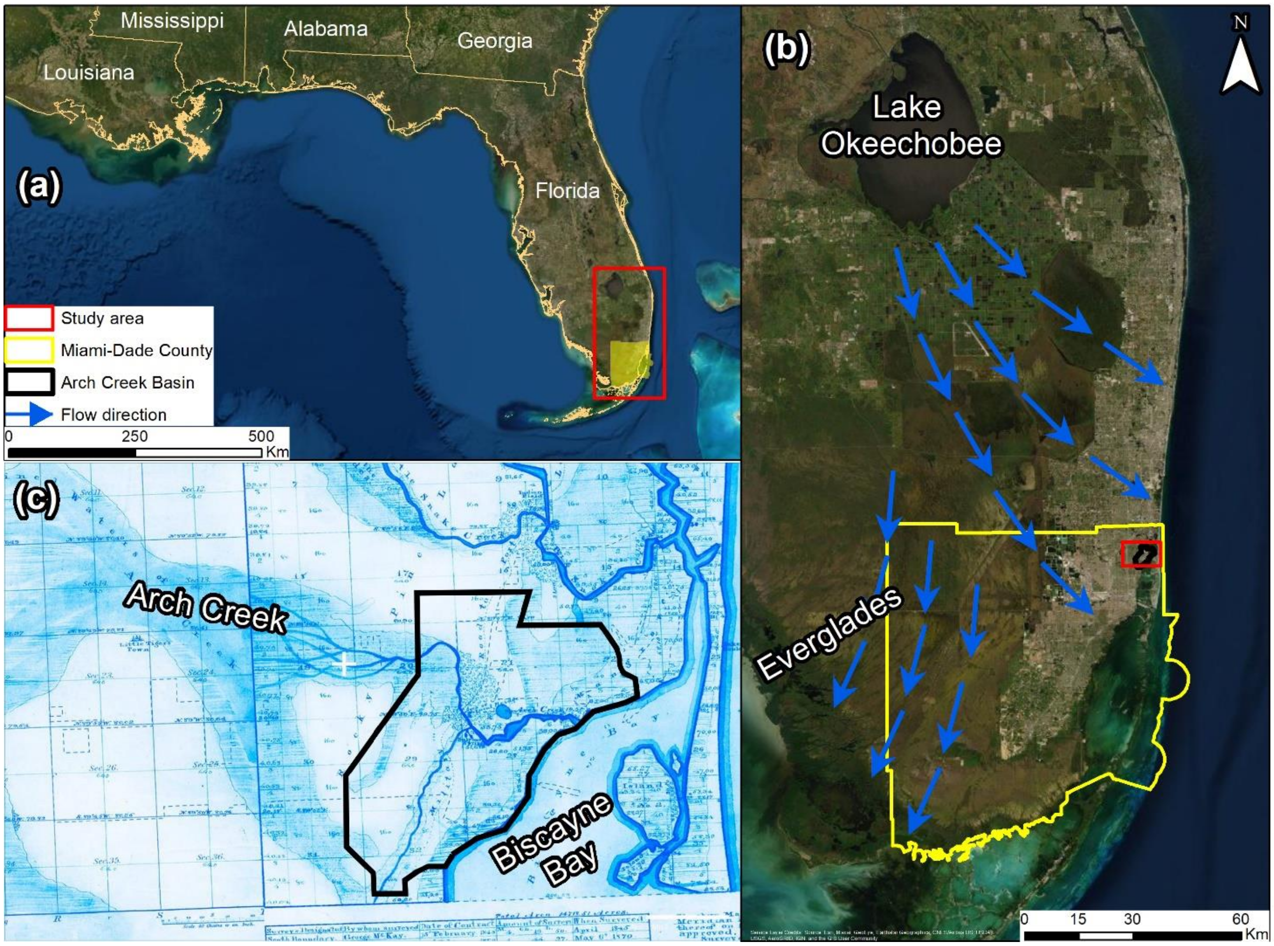


Figure 3. Location map of the study area. (a) MDC located in Southeast Florida, USA (b) current Everglades water flow from Lake Okeechobee towards the Atlantic Coast and Gulf of Mexico, and (c) land survey from 1870 that illustrates the natural flow direction of the Arch Creek to discharge into the Biscayne Bay prior urbanization (Miami Herald, 2019).

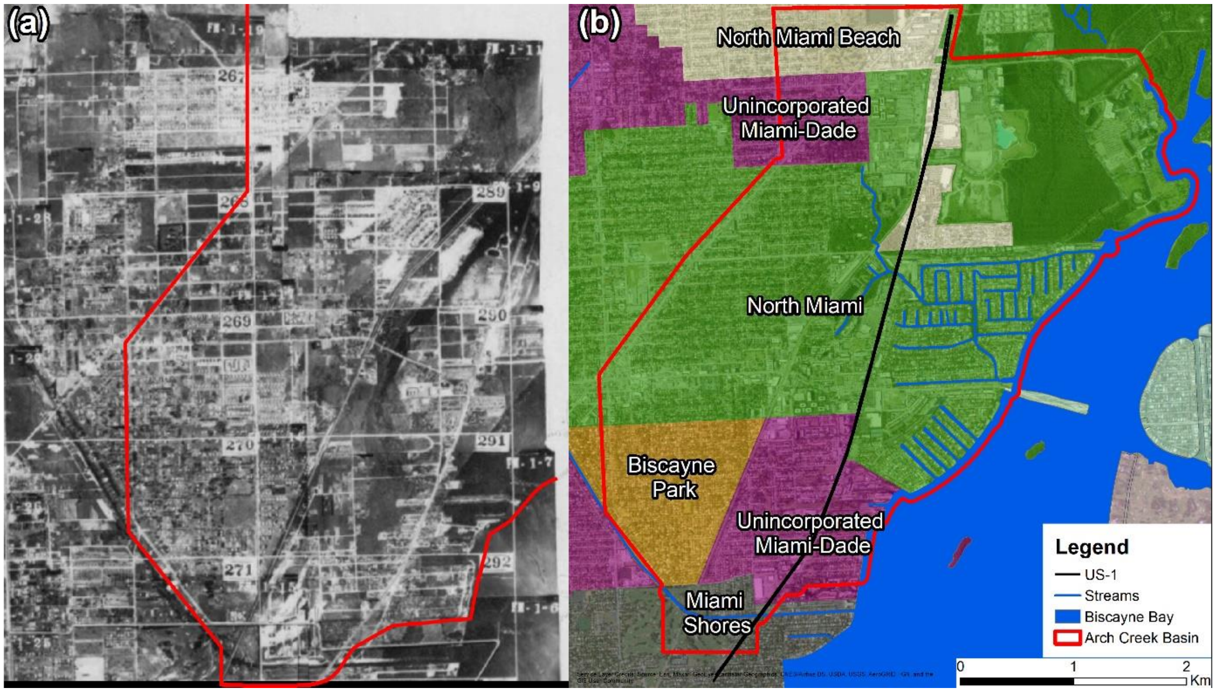


Figure 4. Aerial photography that compares historical (1948) and current urbanized environment in the study area. (a) Major civil and drainage works contributed to the rapid urbanization of the Arch Creek Basin; (b) Municipality map, including North Miami, Biscayne Park, North Miami Beach, Miami Shores and Unincorporated Miami-Dade (U.S. Department of Agriculture, 1948).

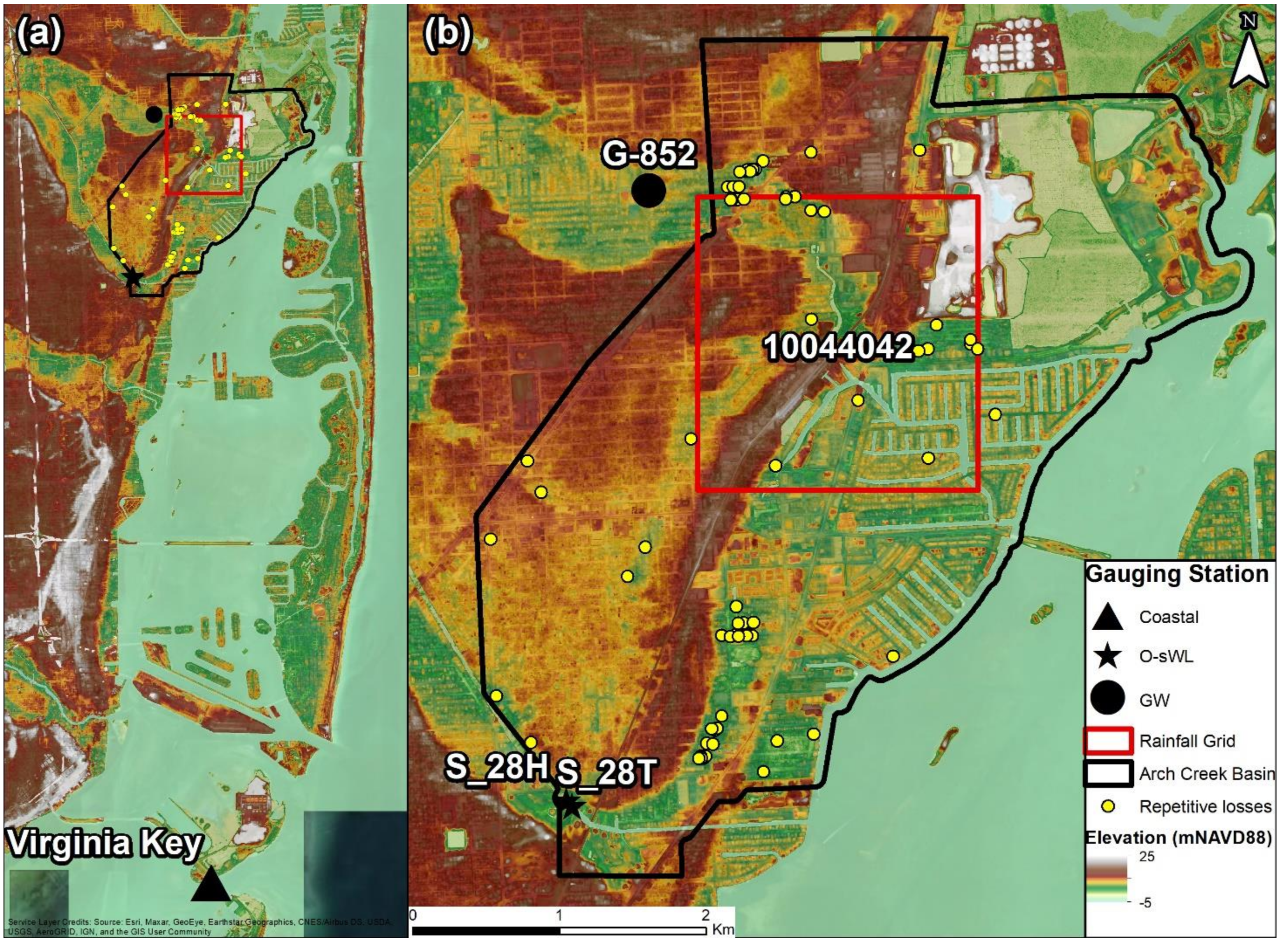


Figure 5. Geographical location of selected data in the study site. (a-b) Topographic map showing the location of the Arch Creek Basin (black polygon), and the distribution of closest gauging stations to the study site (black markers), rainfall grid (red square), and properties that have experience severe repetitive losses due to flooding events (yellow).

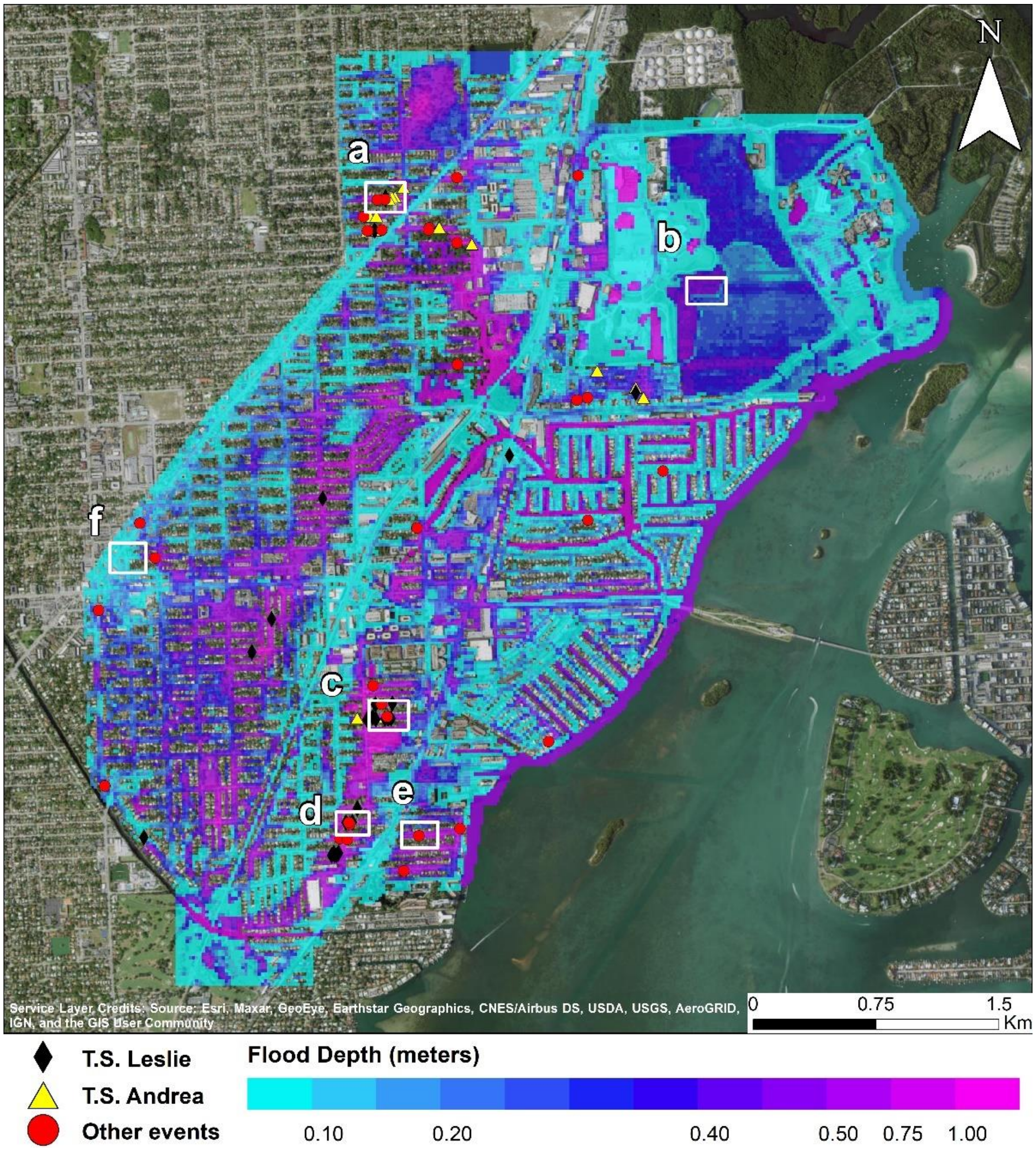


Figure 6. Distribution of maximum flood depths for Tropical Storm Leslie. The markers indicate repetitive loss properties caused by Tropical Storm Leslie (black), Tropical Storm Andrea (yellow) or other storm events (red). Maximum flood depths at six sample locations (white) are presented in Fig. 11.

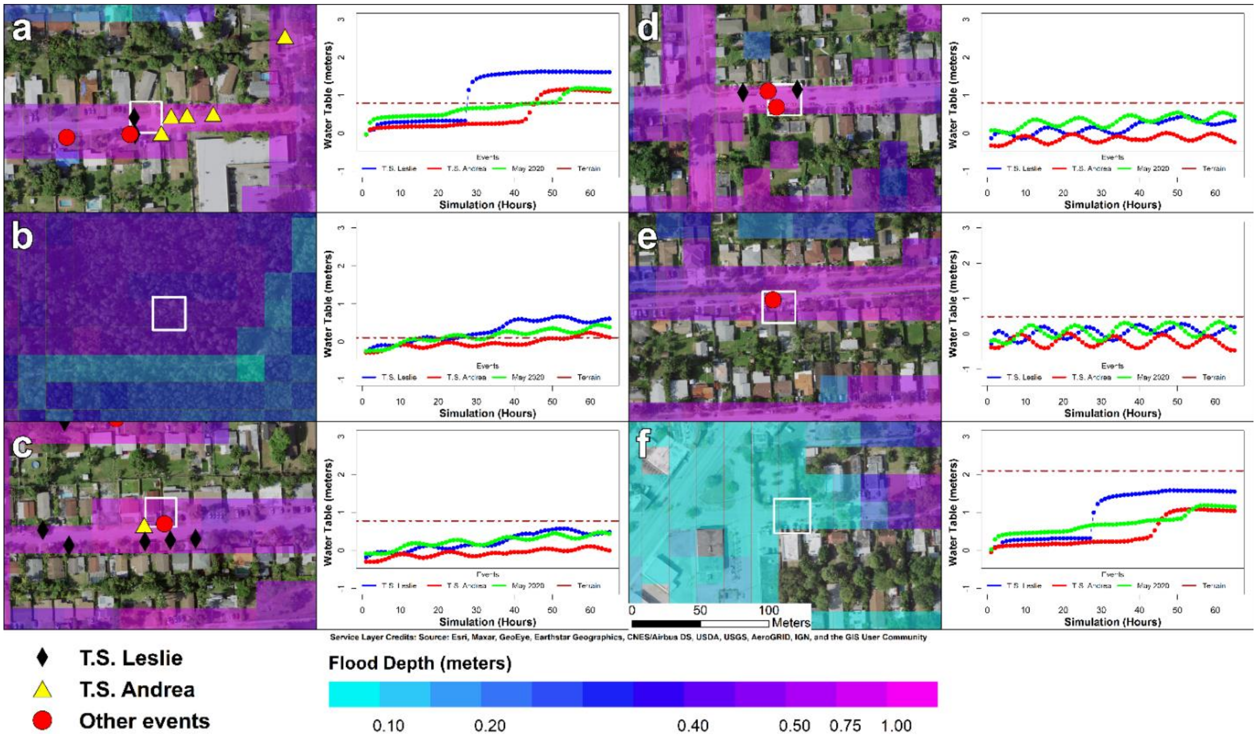


Figure 7. Six sample locations (Fig. 10) are selected to observe the maximum flood depths for Tropical Storm Leslie (left). The markers display repetitive loss properties that have been affected by Tropical Storm Leslie (black), Tropical Storm Andrea (yellow), and other storm events (red). The water table timeseries (left) display the behavior of the groundwater heads during Tropical Storm Leslie (blue line), Tropical Storm Andrea (red line) and the 25 May 2020 event (green line) at a specific location (white). Results demonstrate that the simulated water table (right pane) exceeded the surface elevation (brown line) on two locations leading to groundwater-induced flooding (a-b) while the rest are driven by pluvial flooding (c-d-e-f).

F) ***The writing is redundant and irrelevant in many places. For example, it is not necessary to provide detailed information about the well-known models (MODFLOW and FLO-2D) in methodology section. Also, most of discussions are irrelevant to the modeling results. Please see the specific comments for details.***

We thank Reviewer #2 for pointing out this concern. We proposed a revised version of the manuscript that cleans all irrelevant and unnecessary text, and we clarify the confusing parts, specifically for methodology (206-243, 370-379) (see comment 2.1A) and discussion sections (439-467).

"The results of this investigation determined that areas in the Arch Creek Basin below 1.0 meter elevation are potentially vulnerable to groundwater-induced flooding (Fig 10, 12a, 12b). Similar results were obtained by Sukop et al. (2018) who found that precipitation as the main trigger for rainfall-induced and groundwater-induced flooding in elevations below 0.9 meters and 1.5 meters respectively, with tidal fluctuations and sea level rise increasing the shallow water table, contributing to the reduction of the storm drain capacity. The present study also determined that antecedent rainfall events were important in the height of the water table at the start of the rainfall events investigated.

A simple groundwater model was approximated to be 2D in the horizontal axis and 1D in the vertical axis. Considering that most of the water table interactions occurred in the upper aquifer layer of the regional model (≈ 7 meters) and the short simulation time of the selected events (64 and 84 hours), we presume that differences in the modelling set up are not significant compared to the regional model and can be considered adequate for the purpose of this study. Additional work may be necessary for the coupled model to be fully operational as the groundwater model should represent the heterogeneous aquifer system to assess the sensitivity of the water table dynamics.

Seasonal water table fluctuations are expected throughout the year, presenting a higher level frequency during the winter and spring seasons due to climate variability and hydrological forcing (Gurdak et al., 2009; Taylor and Alley, 2001). Nevertheless, as we observed with Tropical Storm Leslie and Tropical Storm Andrea, the potential rise of groundwater levels to the surface during dry season cannot be ruled out since the hydraulically non-restrictive nature of the carbonate strata in MDC allows for rapid infiltration and high recharge rates during heavy precipitation events. The hydrologic forcing input and modeling results suggest that the joint occurrence of a high-intensity short-duration precipitation (> 50 mm peak, 250 mm total) with already high groundwater levels (> 1 meter) result in a CF event. Further research on linking multivariate statistical analysis with coupled hydrodynamic modeling frameworks may prove beneficial to identify thresholds that trigger CF conditions (Couasnon et al., 2018; Jane et al., 2020; Moftakhari et al., 2019; Saksena et al., 2019; Sebastian et al., 2017; Serafin et al., 2019).

Although this investigation determined that rainfall and tide levels alone did not produce significant flooding, the modeling efforts did not include storm surge flooding that are often accompany by large hurricanes (Zhang et al., 2013). Nonetheless induced storm surge flooding conditions and sea level rise projections are beyond the scope of this study, future work on assessing the impact of high tide and storm surge induced flooding are fundamental to assess CF events and future flood risk scenarios (Obeysekera et al., 2019)."

G) ***Based on these serious issues, the manuscript deserves a significant revision. I would not recommend to accept this manuscript for publication.***

We really appreciate this concern raised by Reviewer #2. All previous comments have been really helpful to improve the quality and narrative of the manuscript.

As a result, we elaborate on the importance of developing a model capable to simulate surface-subsurface water interactions (Introduction, Lines 95-109), clarify the coupled modeling framework and mathematical compatibility between models (Methodology, 206-311), model configuration (Methodology, 313-368), flood events (371-379), results (381-435) and discussion (439-467).

Replies to the specific comments are reported below.

Specific comments:

2.2. Line 23: I don't find any methodology and results about model calibration throughout the manuscript.

Authors' comment: We agreed with Reviewer #2 that the original version of the manuscript did not properly explain the calibration procedure.

Action taken: This comment has been previously addressed on comment 2.1B

2.3. Line 85: Please spell out the full name of MDC.

Authors' comment: We agree with Reviewer #2 that MDC needs to be spell out and requires editing.

Action taken: The sentence has been restructured as requested (Line 87)

2.4. Line 129: Where is Miami? In section 2.2, it would be better to focus on the rainfall around the study area rather than in a large scale.

Authors' comment: We agree with Reviewer #2 that section 2.2 was misleading as we were referring to Southeast Florida instead of Miami. The rainfall station at Miami International Airport was used by the Florida Climate Center (FCC) to develop the regional study by Abiy et al. (2019).

Action taken: We replace "Southeast Florida" to "Miami" as requested in Section 2.2.

2.5. Line 190-225: A through introduction to FLO-2D is redundant in a scientific paper. Please condense.

Authors' comment: We agree with Reviewer #2 that fully describing FLO-2D is unnecessary for the purpose of this manuscript.

Action taken: Section 4.1 has been shortened as requested (Lines 206-216) to address comment 2.1A.

2.6. Line 226-263: Again. Please condense the introduction to MODFLOW.

Authors' comment: We agree with Reviewer #2 that fully describing MODFLOW-2005 is unnecessary for the purpose of this manuscript.

Action taken: Section 4.2 has been shortened as requested (Lines 217-224) to address comment 2.1A.

2.7. Line 311-321: Please be specific on how the FLO-2D and MODFLOW-2005 are integrated in the algorithm, which is one of the most important contributions in the manuscript. Currently, the descriptions and figures (Fig.4 and Fig.6) are not clear enough.

Authors' comment: We thank Reviewer #2 for highlighting this point and agree that a further explanation on the coupling methodology is required to bring clarity to the manuscript.

Action taken: Section 4.3 has been revised and improved as requested (Lines 225-311) to address comment 2.1A and 2.1F. In addition, Fig 4 has been removed from the manuscript. Fig. 5 and Fig. 7 have been improved, and a new figure with the infiltration methodology diagram (Fig. 6) has been added.

2.8. Line 357-390: Since this is a modeling study, the manuscript should include more details (statements and figures) about the model set-up. Currently, the boundary conditions and parameters of the model are not clear to readers.

Authors' comment: We agree with Reviewer #2's suggestions that the boundary conditions and parameters are not properly explained and requires editing.

Action taken: Section 4.4 has been fully restructured as requested (Lines 313-368)

2.9. Line 380-385: Based on my knowledge, MODFLOW is not able to directly simulate groundwater flow in karst aquifers. Please justify that the groundwater modeling in this study makes sense.

Authors' comment: We thank Reviewer #2 for pointing out this concern. This statement is not necessarily true for every coastal aquifer. We justified the decision of using MODFLOW-2005 to simulate surface-subsurface water interactions based on the published work by (Hughes & White, 2016) and Sukop et al. (2018) (lines 341-347). The first serves as the regional reference model for the County's strategic planning to evaluate sea-level rise and climate change from a water supply, groundwater modelling and saltwater intrusion monitoring perspective.

To our knowledge, MODFLOW is the trademark and only model use for groundwater modelling simulations in Miami and southeast Florida.

Action taken: A new paragraph was included to present the works that apply MODFLOW in the region (lines 343-349).

"Concerning MODFLOW-2005, a simple model was developed based on the regional groundwater model of MDC developed by USGS (Hughes & White, 2016) using an advanced version of MODFLOW-2005 that applies the Newton-Raphson formulation (MODFLOW-NWT) with the Surface-Water Routing (SWR1) Process to simulate comprehensive surface and groundwater hydrologic conditions on a 15 meter grid resolution; the second model consists of a local 1D MODFLOW that simulates the influence of the water table on flooding conditions in an upper portion of the Arch Creek Basin (Sukop et al., 2018). "

2.10. Line 381: The model is composed of one-layer…

Authors' comment: We agree with Reviewer #2's suggestions that the boundary conditions and parameters were not properly explained and requires editing. We approximated the entire three layer system (Hughes & White, 2016) as a homogenous aquifer (Sukop et al. 2018).

Action taken: This comment has been previously addressed on comment 2.1.3 and 2.9 (lines 343-361).

In addition, the discussion section has been strengthened to address this observation (Lines 446-451).

"A simple groundwater model was approximated to be 2D in the horizontal axis and 1D in the vertical axis. Considering that most of the water table interactions occurred in the upper aquifer layer of the regional model (≈ 7 meters) and the short simulation time of the selected events (64 and 84 hours), we presume that differences in the modelling set up are not significant compared to the regional model and can be considered adequate for the purpose of this study. Additional work may be necessary for the coupled model to be fully operational as the groundwater model should represent the heterogeneous aquifer system to assess the sensitivity of the water table dynamics."

2.11. Line 390: "Groundwater elevations" is not a clear term.

Authors' comment: We agree with Reviewer #2 that the term 'groundwater elevations' is not clear and requires editing.

Action taken: The term has been changed to 'groundwater heads' as requested

2.12. Line 396-416: Redundant. Please condense.

Authors' comment: We agree with Reviewer #2 that section 4.5 is redundant and requires editing.

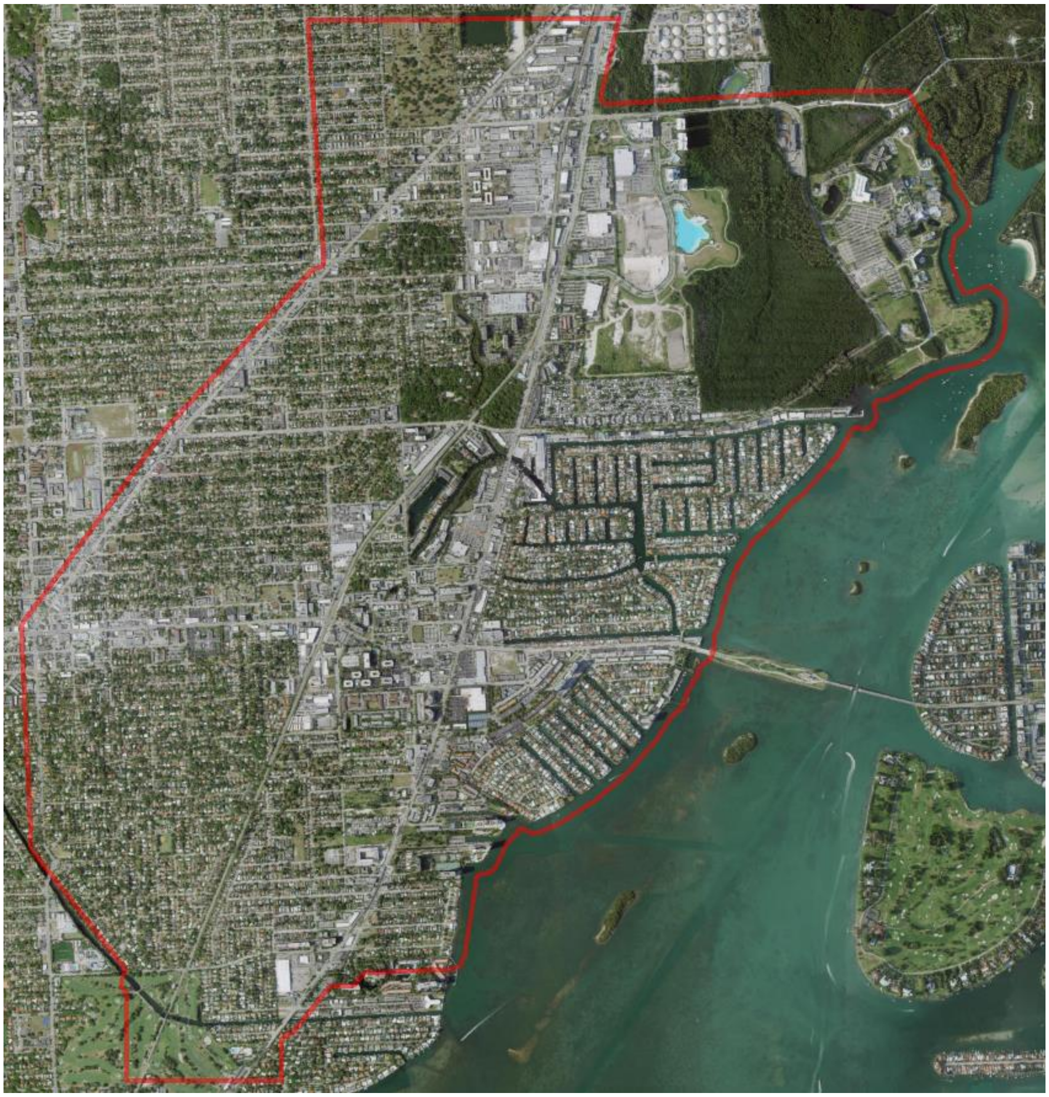
Action taken: Section 4.5 has been fully restructured as requested (Lines 371-379)

2.13. Line 429-430: Please provide the evidence to support that the water from rainfall and tides rapidly infiltrates. Based on my knowledge, infiltration in urban areas should not be significant. High groundwater table should be a result of flow from other regions.

Authors' comment: We thank Reviewer #2 for highlighting this point. Although we agreed that groundwater systems are sensitive to water table levels from other regions, this statement is not necessarily true for the Arch Creek Basin and MDC. The tidal signal can be observed in the groundwater levels as the tides wary in areas near the coast (Fig. 12b,c,d,e).

Similarly, the Arch Creek Basin is not entirely impervious, and the infiltration happens in most of the basin. For example, infiltration is possible in most housing due to the green cover in the front and back. The water table rises as a result of the rainfall infiltration. Many water table gauges (including the presented rainfall events) show this behavior.

Action taken: This comment has been previously addressed on comment 2D.
See satellite image to observe the green cover in the study area.

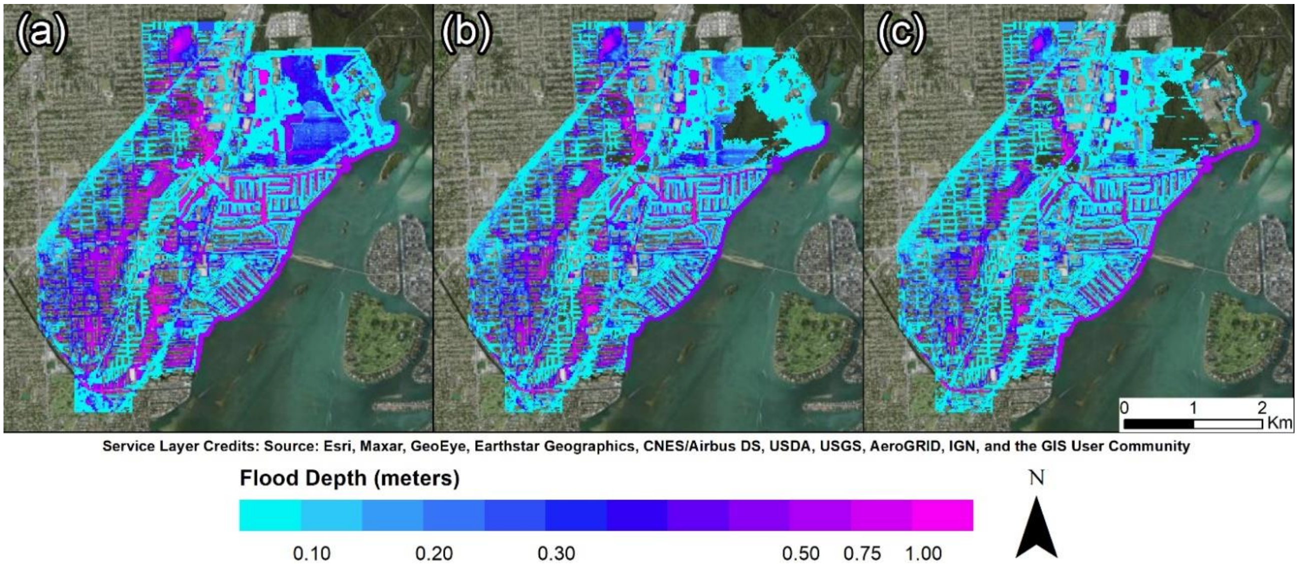


2.14. Line 450-458: I can't find that information in Figure 10 and 11.

Authors' comment: We agree with Reviewer #2 that the statements do not match Figures 10 and 11 (now 12).

Action taken: The results section has been improved and associated statements to Figure 9 (line 386-388),

Fig. 9 illustrates the simulated maximum inundation depths corresponding to the magnitudes of Tropical Storm Leslie, Tropical Storm Andrea, and the 25 May 2020 storm. Tide levels per se do not pose significant threats to infrastructure as the coastal waters remain within the channels.



Service Layer Credits: Source: Esri, Maxar, GeoEye, Earthstar Geographics, CNES/Airbus DS, USDA, USGS, AeroGRID, IGN, and the GIS User Community

Figure 8. Spatial distribution of maximum inundation depths for Tropical Storm Leslie (a), Tropical Storm Andrea (b), and 25 May 2020 event (c).

In addition, Figure 10, (388-389, 398-402), Figure 11 (line 391-394, 402-405), Figure 12 (line 394-395, 405-421) and Figure 13 (line 424-435) have been corrected.

"5.2 Identification of flooding hotspots

The groundwater flood maps for Tropical Storm Leslie (37.17%), Tropical Storm Andrea (13.87%) and the May 2020 event (20.82%) are showed in Fig. 10. The simulation demonstrates that slight variations in the water table depth (Fig. 8) can exacerbate groundwater emergence extent, resulting in ≈ 10 cm across the Arch Creek Basin. Interestingly heavy precipitations scenarios with very high water tables over extended periods of time (May 2020 event) are more likely to trigger groundwater induced flooding compared to very high precipitation with high water table levels (Tropical Storm Andrea). Fig. 11 presents reasonable results between the reported claims and localized flooding, indicating that the housing infrastructure in these neighborhoods are likely to experience additional flood losses at some point in the future. The simulated storm events illustrate that most of the properties experienced moderate to high flood depths (> 0.5 meters) in predefined locations. Although rainfall-runoff is the primary source of flooding in the urbanized Arch Creek Basin, abnormally high groundwater levels triggered groundwater-induced flooding near historic waterways and zones below the County's land elevation flood criteria, with flood depths ≈ 1 meter (Fig. 12a – 12b). The groundwater plots illustrate the effect of tidal and groundwater boundary conditions on the behavior of the simulated water table, in turn demonstrating the importance of both variables in the modeling set-up and influence in subsurface dynamics, as a cyclic high-low pattern characterizes the tide fluctuations of the Biscayne Bay (Fig. 12b – 12e) compared to the defined water heads behavior from well G-852 in the western boundary of the domain (Fig. 12a, 12f). In terms of residential damage, Tropical Storm Leslie and Tropical Storm Andrea may be considered the costliest events in the Arch Creek Basin as both account for 60% of the reported claims (25 and 17 respectively) (Table 2).

Sources of uncertainty in the coupled numerical model could be reduced by increasing the model's resolution and incorporating storm-water infrastructure features (i.e., French drains). For example, the increase of the water table levels could challenge the ability of the storm drain system to convey water towards the Bay, resulting in prolonged flooding conditions, or anti-flood pump stations may alleviate the impacts of flooding by draining water from the streets and swales back to the ocean. Nevertheless, the repetitive loss records only reflect a small percentage of the damaged infrastructure and cannot be generalized at the Basin scale as the property owners may not meet the criteria to file the claim. Therefore, the presented modelling results fall more on the conservative side and might overestimate the real flooding conditions.

5.3 Validation using crowdsourced data from Tropical Storm Andrea

A limited number of real-time crowdsourced flooding observations in the Arch Creek Basin were available for Tropical Storm Andrea (Fig. 13). The visual comparison indicates a spatial agreement between the maximum flood depth of the coupled simulation and the interpreted depth of the crowdsourced data (Table 3). Fig. 12a associates high flow depths (> 0.5 meters) with several properties that have experienced regular flooding conditions, while the crowdsourced photograph displays an estimated inundation depth of 0.20 meters. Despite the model's overestimation, this comparison can be seen as an effective form of validation considering the changes in land use associated with the Arch Creek flow (Fig. 2) and low topographic elevation (Fig. 3b). Regarding Fig. 13b, the US Post Office exhibits chronic flooding in the parking lot. The coupled model exhibits a reasonable level of accuracy in terms of flood depth validation results. Fig. 13c displays stagnant flood water accumulated post-event in a portion of the NE 14 Ave. The results suggest that the rise of the water table do not influence the inundation depth and extents in any of these locations. Despite the limitations on the amount of collected crowdsourced data in the study area, a larger georeferenced dataset including the date and time could improve the reliability of VGI data to validate hydrodynamic models."

2.15. Line 466-474: Figure 12 is too hard to read. I can't follow the statements with the figure.

Authors' comment: We agree with Reviewer #2 that figure 12 (now figure 13) is too hard to read and requires major editing.

Action taken: Figure 13 and associated statements (line 424-435) have been improved for readability purposes. (see comment 2.14)

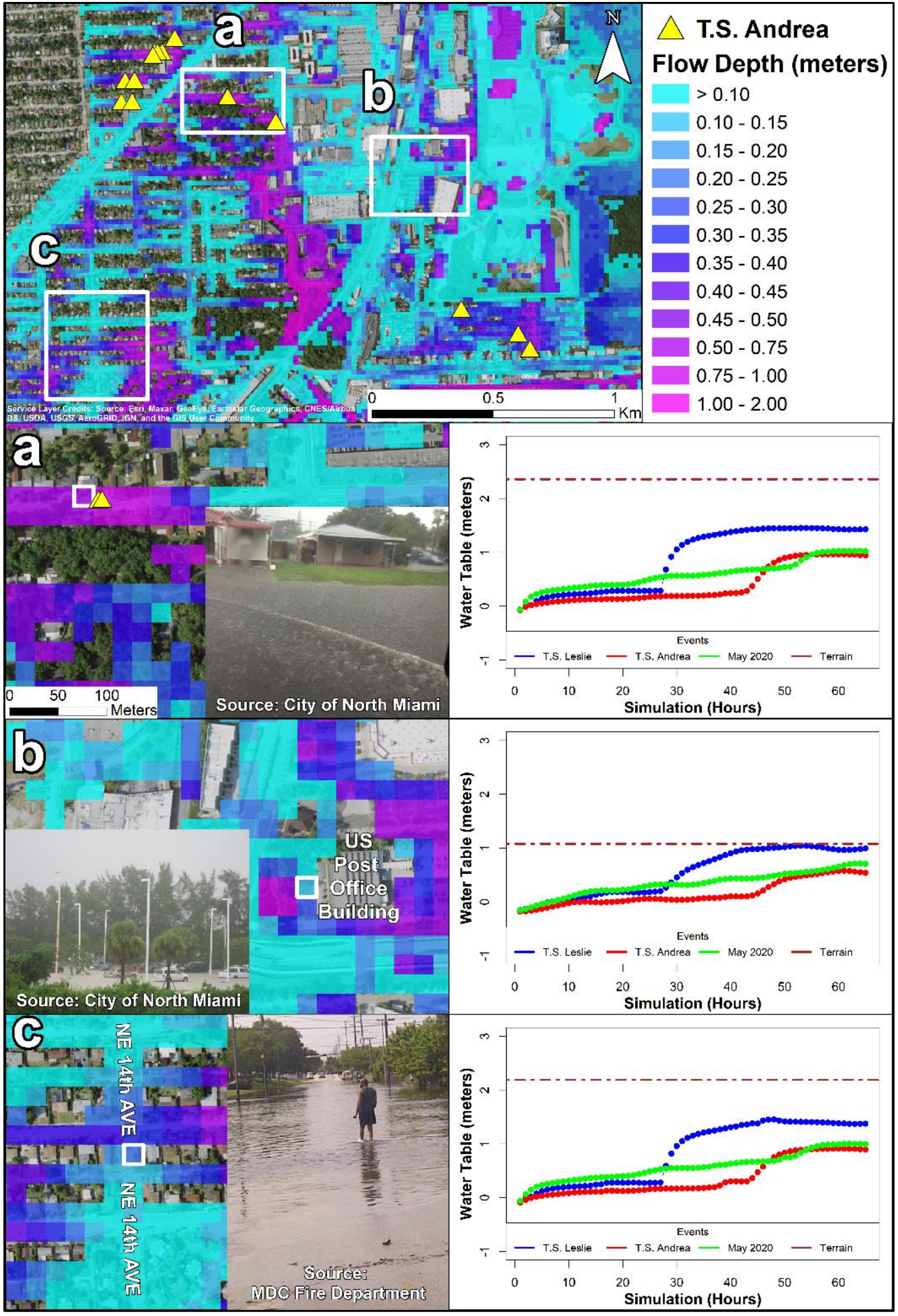


Figure 1. Maximum flood depths for Tropical Storm Andrea in the Northwestern portion of the Arch Creek Basin (top). The marker (yellow) display properties that were affected during Tropical Storm Andrea. Three sample locations (white) are presented as subdomains (a-b-c) and available crowdsourced observations display the flooding conditions at a specific cell (white). The simulated water table timeseries (right pane) show that groundwater heads remained below the surface elevation (brown line); thus, all three locations experienced rainfall-induced flooding.

2.16. Line 485-496: The writing is irrelevant to the model results. It might be put in the introduction section.

Authors' comment: We agree with Reviewer #2 that the content is irrelevant to the discussion section.

Action taken: Lines 485-496 have been moved to Section 2.4 (flood risk and vulnerability) as it provides relevant background information of the study site (Lines 145-162).

2.17. Line 498-499: Please provide associating model results to support the statement.

Authors' comment: We thank Reviewer #2 for highlighting this point.

Action taken: This comment has been previously addressed on comment 2D and 2.13.

2.18. Line 514-520: Irrelevant writing.

Authors' comment: We thank Reviewer #2 for the suggestion.

Action taken: The irrelevant writing and title subsections have been removed. A more concise discussion is now provided (lines 439-467)

2.19. Line 528-535: Irrelevant writing.

Authors' comment: We thank Reviewer #2 for the suggestion.

Action taken: This comment has been previously addressed on comment 2.18

2.20. Line 825: Figure 6 is confusing. Please clarify the meaning of T, DT, and dt.

Authors' comment: We thank Reviewer #2 for the suggested correction. The figure requires additional editing. We apologize for the confusion due to the lack of legend.

Action taken: This comment has been previously addressed on comment 2.1A

2.21. Line 835: Groundwater table in Figure 8a is not influenced by rainfall and tides, compared to the other two figures.

Please justify that the data in Figure 8a is correct.

Authors' comment: We thank Reviewer #2 for pointing out this concern. The water table time series of Figure 8 is not a mistake. As mentioned in section 3.2.3 (groundwater heads) water table levels were reported on a daily basis before October 2007 and Tropical Storm Leslie (2-4 October 2000) falls in this category. The lag on the water table response to precipitation is a time resolution issue by the USGS.

Action taken: No action was taken.

2.22. Line 840: Caption of figure 9 is confusing.

Authors' comment: We agree with Reviewer #2 that caption of figure 9 fails to convey meaningful information.

Action taken: The figure and caption has been improved for readability purposes. This comment has been previously addressed on comments 1.37 and 2.1E

2.23. Line 845: The caption of figure 10 does not match the figure. The color represents flood depth but only water surface elevation is mentioned in the caption. Also, only one storm event is mentioned in the caption but many events are included in the figure.

Authors' comment: We thank Reviewer #2 for the suggestion. We agree that figure 10 requires major improvements as it fails to convey meaningful information.

Action taken: Two figures were created to improve the readability of both figures and captions. This comment has been previously addressed on comments 1.37 and 2.1E