Original Research Article

Evaluating the Effectiveness of Low Impact Development Practices against Climate Induced Extreme Floods

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ABSTRACT

Short but extreme flooding events have been frequent and severe globally due to climate change and urbanization in recent years. Similarly, researchers, scientists, and water managers are suggesting the application of sustainable flood management strategies such as Low Impact Development (LID) to mitigate the impacts of such extreme flooding events. However, most of these strategies have primarily been evaluated using historical precipitation events, which may not accurately represent the impact of climate-induced flooding events, which are projected to become more extreme. In this context, this study assesses the effectiveness of LIDs in combating climate change-induced flooding events. The North American Regional Climate Change Assessment Program (NARCCAP) climate model was applied in this study to quantify the magnitude of future projected storm depths, which are expected to increase due to climate change. Similarly, Personal Computer Storm Water Management Model (PCSWMM) was used to develop a rainfall-runoff simulation model and to assess the effectiveness of three LID techniques (Permeable Pavement, Green Roof, and Bio-Retention Cell) in reducing surface runoff under various climate scenarios. The results revealed that due to climate change, peak discharge, and total flooding volume are expected to increase by 37.72% and 88.73%, respectively. Furthermore, the study demonstrated that applying LID strategies decreases peak discharge, offering a viable solution to tackle flooding events induced by climate change. The results illustrated the performance of permeable pavement was superior in reducing the peak discharge by up to 28.57%. Similarly, applying green roofs and bioretention cells reduced the peak discharge by up to 19.93% and 14.25%, respectively.

Keywords: Floods, NARCCAP, PCSWMM, LID, Climate change

1. INTRODUCTION

Flooding is among the costlier and most disastrous natural hazard that significantly impacts human society, causing extensive damage and disruption to millions of populations worldwide. The 2017 Louisiana floods and Hurricanes Harvey, Irma, and Maria show the devastating effects of flooding on local communities (1). About $6.2 billion in damage was caused by flooding on the Mississippi River and its tributaries in numerous states in 2019 (2). Floods kill more individuals throughout the US than tornadoes, hurricanes, or lightning each year (3). Similarly, Mallakpour and Villarini pointed to the strong evidence of increase in flood frequency in the last 50 years (4). This is further compounded by the projected increase in the global urban population, which is expected to increase by 2-3 billion by 2030 (5). Therefore, it can be anticipated that urban areas will be much more vulnerable and susceptible to upcoming flooding. Climate change and urbanization are among the top contributors to urban flooding (6). In urbanization, naturally permeable surfaces are replaced with impervious covers, such as concrete and asphalt, which causes a reduction in soil infiltration capacity, resulting in increased surface runoff during precipitation events that overwhelm urban infrastructure and lead to flooding (7). In this context, providing a sustainable solution to urban flooding is becoming crucial, which is expected to increase with the synergetic impacts of climate change and urbanization.

Climate change is consistently proving damaging global effects on the environment. Global hydrological processes are being exacerbated by climate change, leading to unpredictable precipitation events with irregular patterns and increased intensity, which in turn is causing more frequent and severe flooding events (4,8). Industrial activities combined with current lifestyle functions are causing resources and weather patterns on earth to change drastically. Particularly, flooding is becoming a more significant concern due to the consequences of the changing climate. Besides, unusually heavy precipitation events are becoming worse and more prevalent than at the beginning of the twentieth century (9). Urban populations and infrastructures have become more vulnerable due to the significant amplifying impacts of climate change and urbanization (10). Urbanization growth increases impervious terrain, and removing green landscapes eliminates the barrier to which water previously penetrated. In recent years, urban flooding has become more frequent and devastating, causing damage to the infrastructure, properties, environment, and human lives (11). Extreme rainfall events caused by the unpredictable nature of the changing climate and increased surface runoff from changing land use are the primary causes of this catastrophic hazard (12–14). As a result, it is becoming increasingly important to seek out an appropriate stormwater management strategy.

The traditional methods of stormwater design follow the assumption that the climate scenario is static, which means the rainfall pattern will not change. However, the drainage system and the stormwater infrastructure built following this conventional assumption may be exceeded in the long run (15). Therefore, the predicted climate change scenarios should be used by considering the change in rainfall patterns to account for uncertainty regarding the changing climate. Due to this reason, urban flooding is frequent and can be reduced and managed using the LID strategy (16). Unlike traditional stormwater and drainage management practices, LIDs employ simple, inexpensive, and straightforward solutions such as permeable pavement, bio-retention cells, green roofs, etc., which are not restricted to preserving the watershed (17). LID strategies are gaining attention worldwide because of their capacity to alleviate the flooding impacts, promoting sustainability and eco-friendliness (18,19). LID aims to mimic natural hydrological processes by reducing runoff and enhancing infiltration, providing regional flood-mitigating benefits. The type of LID combined with the watershed features are important when conducting realistic and practical assessments. Previous studies have examined various low-impact development (LID) strategies for managing urban flooding, including green roofs, permeable pavement, bioretention cells, infiltration trenches, rain barrels and vegetated swales (20–23).

One study noted that the influence of LIDs on runoff diminution in sub - catchments is determined not only by LID type and size, but also by sub-catchments features and geophysical placement in the watershed relative to other sub - catchments (24). In addition to the watershed characteristics, climate change predictions are region specific. Another study emphasized the acquired results cannot be extrapolated to other regions of the globe, but the approach is relevant (25). This is due to the various future projected scenarios of climate change and its uncertainty. In addition, many studies do not incorporate climate change projections when assessing LID performance. In order to more accurately forecast streamflow amount and quality under erratic climate conditions and to offer knowledge regarding novel adaptation measures for preserving the quality of the water and ecological system performance characteristics, maintaining urban stormwater systems under changing climate phenomenon is an essential first step (26). This is why it's imperative to conduct studies that consider different climate change scenarios and prepare assessments measuring the accuracy of each study for future urban planning.

Most of the previous studies demonstrated the excellent performance of LID strategies with their performance variations depending on various factors such as watershed characteristics, soil types, climatic regions, and drainage areas. Qin et al. (22) identified that swales and permeable pavement can reduce flood volume by up to 14.4% and 20.1%, respectively. Similarly, Zahmatkesh et al. (24) used permeable pavement, rainwater harvesting, and a bio retention cell and discovered that peak runoff was reduced by 8% to 13% on average . More literature on the effectiveness of various LID on watersheds and at the urban scale can be found in (27–29). With the goal of determining the LID approaches and comprehending the effects of possible future climatic scenarios, this study investigates the impacts that climate change will have on an urbanized watershed and demonstrates the effectiveness of mitigating measures that must be established to ensure the safety of the region.

With this motivation, this study evaluates the performance of three LID strategies (i.e., Permeable pavement, Green roof, and Bio-retention cell) against the climate-induced flooding events in the urban watershed. This study applied the PCSWMM model to develop the hydrological model of the urban watershed. PCSWMM is a comprehensive tool that allows for the modeling of complex urban hydrological systems and the evaluation of the performance of BMPs in mitigating the impact of flooding. Similarly, this study used data from the North American Regional Climate Change Assessment Program (NARCCAP) to determine the climate change scenarios. NARCCAP provides high-resolution climate projections for North America under different climate scenarios based on global climate models. The NARCCAP data enabled the selection of climate scenarios relevant to the study area representing potential future climate conditions. Using the NARCCAP data and PCSWMM, this study evaluated the performance of different LIDs in mitigating the impact of flooding in an urban watershed under various climate change scenarios. The contributions of this research are:
Evaluating the impacts of climate change on urban hydrology regarding peak discharge and flood volume.
Analyzing the impacts of three LID strategies against the climate-induced flooding events in the urban watershed.

2. MATERIAL AND METHODS

2.1 Study Area

This research proposed the Ellerbe Creek watershed for evaluating the effectiveness of LID during climate-induced flooding events. The proposed study watershed is in Durham County, North Carolina, as shown in Fig 1.

Durham County is located within the northeastern, central part of North Carolina state and is home to over 326,000 residents with a median household income of $67,000. According to history, rainstorms are frequent in Durham, and it's severity is increasing every year, leading to recurrent flooding, which is expected to continue for the next 30 to 80 years (30). According to Sears (31) in 2009, flooding following a torrential downpour caused a vast trench to appear in Durham, and it had length, width, and depth of about 200 yards, 100ft, and 15ft, respectively.

The area of study watershed is around 60 km^2 and is a highly residential urban watershed. The population density of Ellerbe Creek is the highest of Durham's watersheds. Stormwater in Ellerbe Creek watershed is channeled down both sides of a ridge, eventually leading to a large river basin. Water typically flows from the southwestern part of the watershed to Jordon Lake, then to the Cape Fear River, and finally to the Atlantic Ocean (32). The urbanized Durham watershed extends from 35.97° N to 36.07° N latitudes and 78.81° W to 78.99° W longitudes. The watershed has one USGS precipitation station at latitude 36°01'43" and longitude 78°54'09", which will be used to calibrate and validate the hydrological model.

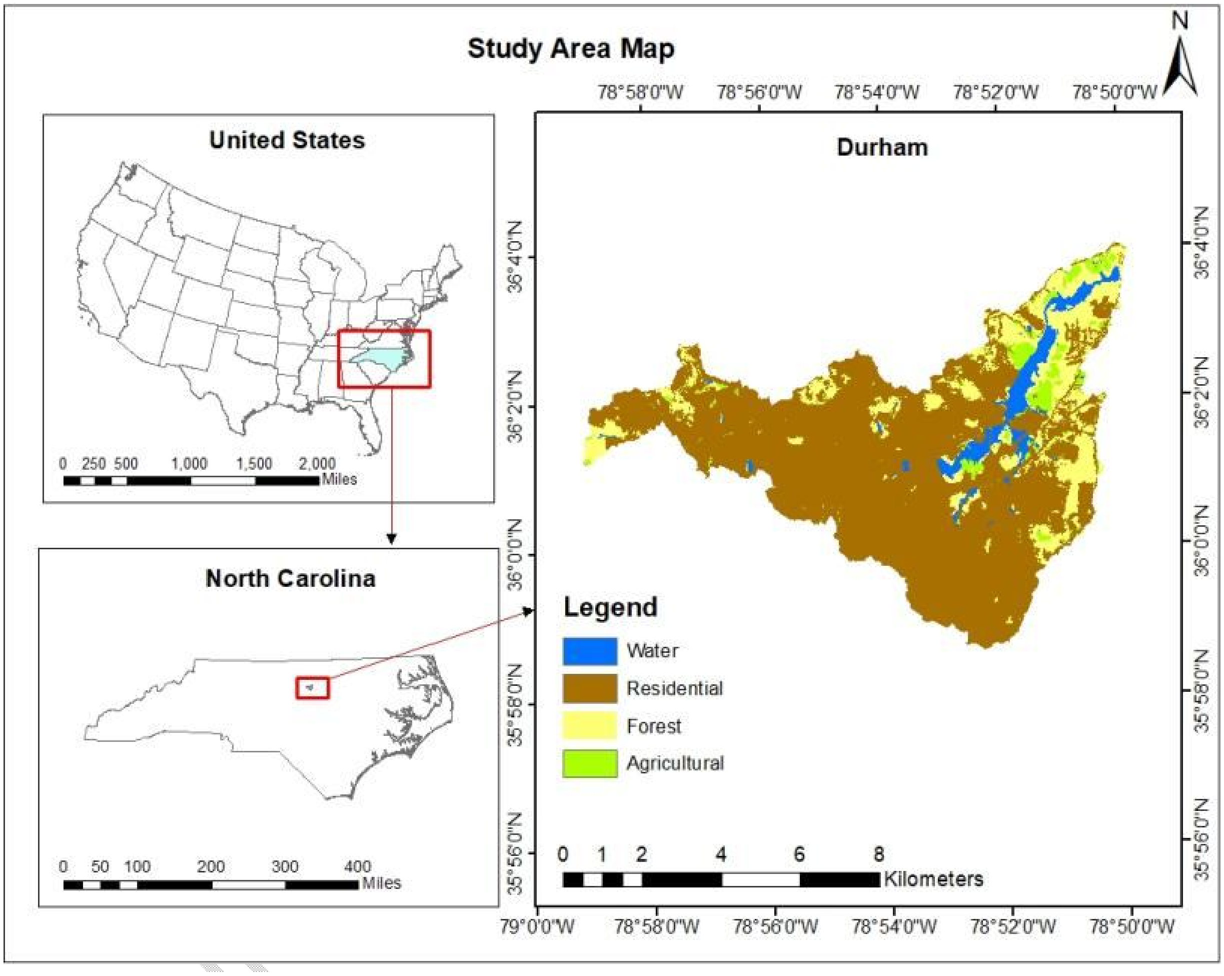

Fig 1: **Map depicting the Durham watershed, North Carolina along with Land use pattern.**

2.2 Data

The data used in this study and their sources are listed in

Table **1**. The Digital Elevation Model (DEM), Land Use and Land Cover Data (LULC), Soil Group Data, Impervious Data, and Curve Number (CN) Grid are the primary data used for hydrological analysis. These data are prepared in ARC-GIS for this study area and then imported into PCSWMM for creating hydrological model. The DEM provides details on the elevation and slope of the watershed. Details about the potential runoff generation of each grid cell within the watershed are provided by creating the CN grid using the union of LULC and soil data. The area or percentage of land covered by impervious surfaces such as buildings and roads, which can increase runoff and decrease groundwater recharge, is represented by impervious data. Furthermore, the watershed's geometry data, including the river centerline, bank lines, cross-section, and Manning's n value, was created in HEC-RAS and then imported into PCSWMM, which is used to divide the watershed into different subbasins. Similarly, North American Regional Climate Change Assessment Program's (NARCCAP) climate models were used to calculate the study area's historical and projected design storm depths, and PCSWMM was used for hydrologic modeling.

Table 1: Data and their sources

Data	Source
Watershed Boundary	Streamstats
DEM (1 meter)	National Map viewer
Precipitation	United States Geological Survey (USGS) water data
Land Use Land Cover	Multi-Resolution Land Characteristics Consortium (MRLC)
Discharge	United States Geological Survey (USGS) water data
Soil	Geospatial Data Gateway

2.2.1 NARCCAP Climate Model Data

NARCCAP simulates climate change at high resolution. Global Climate Models (GCMs) and Regional Climate Models (RCMs) provide the model with boundary conditions and characteristics. RCM characteristics included for this model include vegetation type, land surface, grid size, vertical coordinates, boundary layers, dynamics, and lateral boundary treatments. Six RCMs and four GCMs were provided for 30 years (1971-2000) of historical data and 30 years (2041-2070) of future data. For future climate change studies, the NARCCAP project provides high-resolution climate model data. According to Thakali et al. **(15)**, NARCCAP data are available in 50-km spatial and 3-hourly temporal resolutions.

2.2.2 North American Regional Reanalysis (NARR)

The performance and forecasts of NARCCAP were evaluated using the North American Regional Reanalysis (NARR). The NARR project enhances past global reanalysis by incorporating data for observed rainfall and using an advanced land surface model. Hence, NARR has effectively combined an enhanced depiction of atmospheric circulation throughout the troposphere with a more realistic depiction of land hydrology and land-atmosphere interaction (15,33).

2.3 Methodology

The methodology used for this study is highlighted in this section. The historical and future depths of the study were determined using the NARCCAP climate model in the initial phase. Similarly, the PCSWMM hydrological simulation was run using the projected depth obtained from the NARCCAP climate model. LID was used to evaluate the PCSWMM model's performance against climate-related extreme events.

2.3.1 Design Depth

The NARCCAP and NARR climate models were used to study the effects of climate change on precipitation events with a return period of 6hr 100 years. NARCCAP offers 3hr precipitation data series, which were converted into 6hr precipitation data series, as well as design storm depths for 10 NARCCAP models, and NARR was calculated at the grid scale for the watershed.

2.3.1.1 Frequency Analysis

In this research, data from the NARCCAP and NARR climate models were available in gridded format with a specific spatial resolution. The Generalized Extreme Value (GEV) method is a commonly used methodology for analyzing the frequency of extreme events in non-stationary conditions. One of the method's strengths is its ability to account for the covariance and skewness of annual maximum statistics. Therefore, this approach was used to evaluate the 6hrs 100 years design storm depths for the climate model. Kharin et al. (34) and Mailhot et al. (35) have used the same approach in their studies. The data were pooled for regionalization by dividing each maximum by a median of the same data set for each grid which can also be found on study by (36). Four neighboring grids of the watershed's centroid were used for regional frequency analysis. The use of multiple grids was selected because of an advantage over a single grid (37). This process was performed to access the design storm depths for all of the climatic models.

2.3.1.2. Delta Change Factor

To calculate the delta change factor, the projected storm depth was divided by historic storm depth for each of the model. Two of the models were discarded from further study as they provided negative delta change factor. Further, more models were eliminated from study by comparing the historic design storm depth with that of NARR. Finally, three models were chosen for further investigation.

2.3.2 Hydrological analysis using PCSWMM

The Storm Water Management Model is a dynamic model that can simulate water quantity and quality in urban and rural landscapes for single events and long-term scenarios (38,39). A customized stormwater modeling software called PCSWMM combines a geographic information system (GIS) with the SWMM computational engine. SWMM calculates surface runoff using non-linear reservoir theory and takes hydro-logic abstractions such as surface depression accumulation and infiltration on pervious surfaces into account. Runoff occurs in pervious locations when rainfall exceeds infiltration rate and depression storage is full, but runoff occurs in impermeable zones when rainfall exceeds depression storage depth. The Water Delineation Tool (WDT) in PCSWMM was used to construct flow slope, direction of flow and contributing area layers for each sub-catchment depending on the target sub-catchment size. These layers were then utilized to generate the streams and flow path layers, which were required for the development of the Conduits layer in the PCSWMM system. The Conduits layer represents the water delivery lines that connect system nodes, and its irregular cross-section is described by the Transect object. The Transect Creator and Tran-sect Editor tools were used to construct transects based on topography data given as DEM layer. Input features such as Manning's roughness, entry and exit node inverts, and length are also considered by the Conduits layer.

2.3.3 Low Impact Development (LID)

In order to handle and control flooding, an innovative strategy called LID can be used in urban watersheds. To simulate the effectiveness of various LID techniques in reducing stormwater runoff volume and rate, PCSWMM provides several LID controls. These LID controls include elements like infiltration trenches, rain gardens, green roofs, bioretention cells, and permeable pavements. Incorporating LID controls into the PCSWMM model can help with the evaluation and selection of appropriate LID practices for a specific location, supporting the development of efficient stormwater management plans meant to lessen the adverse effects of stormwater runoff on the environment. Event-Based Modeling research using PCSWMM was carried out to assess the efficiency of LID in controlling runoff during stormwater events. While establishing LID controls in each sub-catchment, the study evaluated the watershed's performance under a base scenario (BS) with a 100-year return time and three future climate scenarios (CS). The goal was to evaluate LID's effectiveness in regulating runoff. The design and execution of various LID techniques in the sub-catchments were part of the analysis.

2.3.4 Model Evaluation

PCSWMM processes such as calibration and validation ensure that the model accurately depicts the system under study. When a model is calibrated, its parameters are changed to best match the observed data; when a model is validated, its performance is assessed using data not used in the calibration process. These steps ensure that the model can be used successfully for planning and decision-making while increasing the accuracy and dependability of the model's predictions. In this study, the model was calibrated for one flood event and then validated for two other flood events. To verify the accuracy, statistical metrics such as the coefficient of determination (R^2), root mean square error (RMSE), and Nash-Sutcliffe efficiency (NSE) coefficient were used. The formula for calculating the above-mentioned statistical parameters is as follows:

$$\boldsymbol{R^2} = \frac{\sum_{j=1}^{N}(q_{j,o} - q_{j,s})^2}{\sum_{j=1}^{N}(q_{j,o} - \overline{q}_o)^2} \qquad 1$$

$$\boldsymbol{RMSE} = \left(\frac{\sum_{j=1}^{N}(q_{j,o} - q_{j,s})^2}{N}\right)^{1/2} \qquad 2$$

$$\boldsymbol{NSE} = 1 - \frac{\sum_{j=1}^{N}(q_{j,s} - q_{j,o})^2}{\sum_{j=1}^{N}(q_{j,o} - \overline{q}_o)^2} \qquad 3$$

Where $\boldsymbol{q_{j,o}}$ is the observed flow, $\boldsymbol{q_{j,s}}$ is the simulated flow at time t=*j*, $\boldsymbol{\overline{q}_o}$ is the average observed and *N* is the total number of observations.

R^2 denotes the amount of variation in measured data that the model explains, ranging from 0 to 1. Higher values indicate less error variance, and values above 0.5 are usually considered acceptable (40). Similarly, the NSE ranges from -infinity to 1, with 1 indicating a perfect fit between observed and modeled data, and values greater than 0.5 are generally regarded as acceptable (41). An RMSE value of zero indicates a perfect fit. RMSE values less than half the standard deviation of the measured data may be regarded as low and is also suitable for model evaluation (42).

3. RESULTS

3.1 PCSWMM calibration and validation

Precipitation data, topographic data, and hydraulic properties of urban watershed were extracted and applied to mimic the hydrology of the study watershed. The hydrological model must be verified before it can be applied for further investigation. Therefore, the PCSWMM model was calibrated by modifying the curve number of each sub catchments and manning's n value of the river until the simulated discharge hydrograph matches with the observed hydrograph. Similarly, the hydrology model was validated for other events to determine the accuracy of the model calibration. This study uses the precipitation and discharge data obtained from USGS 360143078540945 and USGS 02086849, respectively for the calibration and validation of PCSWMM model. For calibration purposes, one event that occurred on May 27, 2022, was used, while two separate events on August 31, 2020, and September 29, 2020, were utilized to validate the model which is shown in

Fig **2**. The study analyzed the proximity between the observed and simulated flow time series to assess the model's efficacy in calibration and validation. The statistical indices values obtained during the calibration and validation of the hydrological models are listed in

Table **2**.

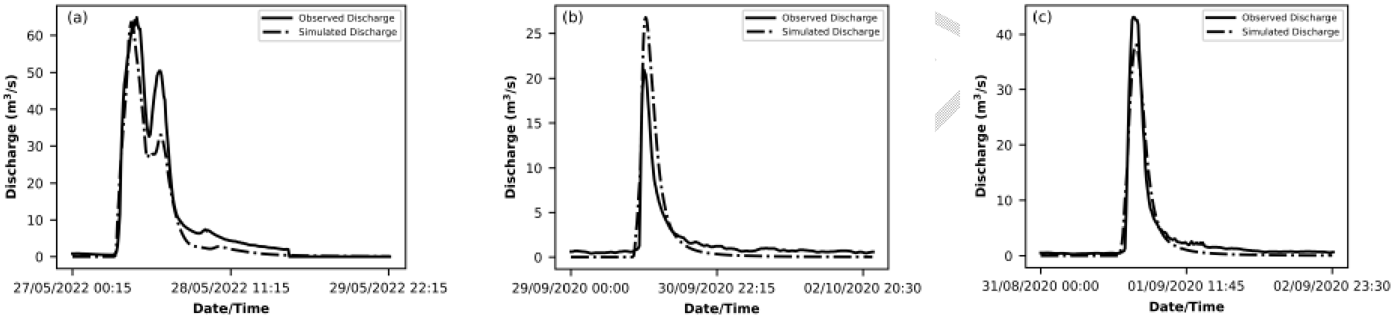

Fig 2: Graphical Representation of Observed and Simulated Discharge during (a) Calibration and (b), (c) Validation

The R^2, RMSE, and NSE values were 0.96, 45.30 m^3/s and 0.89 respectively during the calibration period. Similarly, the average R^2, RMSE, and NSE values were 0.93, 20.95 m^3/s and 0.80 during validation period.

Table 2: Statistical Evaluation of Observed and Simulated Discharge Hydrograph for Watershed

Events	**Date**	**Statistical Parameter**		
		R^2	**RMSE (m^3/s)**	**NSE**
1	27-May-2022	0.96	45.30	0.89
2	29-Sep-2020	0.92	21.00	0.67
3	31-Aug-2020	0.94	20.90	0.93

The selection of PCSWMM for this study was influenced by the benefits mentioned by Ahiablame et al. (43) and Akhter et al. (44), as the program can simulate hydrological and hydraulic responses to changes in land use and climate, generate peak stormwater flows using data from rain gauges and sub-catchments, and be used in urban catchment areas up to 100 km^2 in size.

3.2 Effects of Climate Change on Streamflow

The climate change scenario potentially influences urban runoff compared to the baseline scenario. Delta change factors calculated from NARCCAP data were used to better understand the possible consequences of climate change on hydrologic processes. Use of NARCCAP model allows to capture and include changes in precipitation patterns predicted by various RCM-GCM combination enabling a thorough evaluation of uncertainties related to climate change scenarios. This study examines the impact of several climatic scenarios based on ten sets of RCM-GCM combinations. For all climate models, historical and projected 6hr 100yr design storms were estimated, as well as a delta change factor for each NARCCAP model was calculated. The delta change factor, as well as the 6hr 100yr historical and projected depth, are shown in Table 3. The historical depth of 36.34mm was computed using the NARR model and compared to the observed historical depth of each NARCCAP model. NARCCAP historical depths greater than NARR historical depths and delta change factors less than one were omitted from further investigation. Only three of the models indicated in Table 3 were used to demonstrate the influence of climate change: RCM3-GFDL, RCM3-CGCM3, and HRM3-HADCM3. The three models stated above are designated as CS2.04, CS1.38, and CS1.03, where CS stands for climate scenario, and the values 2.04, 1.38, and 1.03 reflect the delta change factor for that model, respectively.

Table 3: Table showing the historic and projected 6hr-100yr depth and delta change.

Model	Historic 6hr 100yr depth (mm)	Projected 6hr 100yr depth (mm)	Delta
NARR	36.34	_	_
CRCM-CCSM	13.62	17.58	1.29
CRCM-CGCM3	14.83	19.04	1.28
ECP2-GFDL	34.24	26.87	0.78
ECP2-HADCM3	33.32	34.45	1.03
HRM3-GFDL	28.04	33.54	1.20
HRM3-HADCM3	31.04	33.28	1.07
RCM3-CGCM3	34.12	46.99	1.38
RCM3-GFDL	25.23	51.39	2.04
WRFG-CCSM	42.22	43.58	1.03
WRFG-CGCM3	58.14	45.94	0.79

The hydrograph of the Durham watershed's discharge in different climate scenario is shown in

Fig **3**(a). To understand the effect of climate change on runoff, the hydrographs of three scenarios from climatic models are placed alongside the base scenario. The base scenario has a peak outflow of 116.4 m^3/s, while the CS2.04, CS1.38, and CS1.03 scenarios have peak outflows of 158.2 m^3/s, 133.4 m^3/s, and 120.1 m^3/s, respectively. It should be noted that, in addition to the peak outflow, the width of the hydrograph for each CS is greater than the BS when the delta change factor is applied. This was expected because more runoff would be produced at the outlet for a longer period of time when precipitation intensity rose on the application of different scenarios. The highest outflow in the instance of CS2.04 occurred around 4:00 a.m., which is 2 hours and 15 minutes earlier than the peak outflow in the instance of BS. On the other hand, the difference for the other two CS was less than an hour.

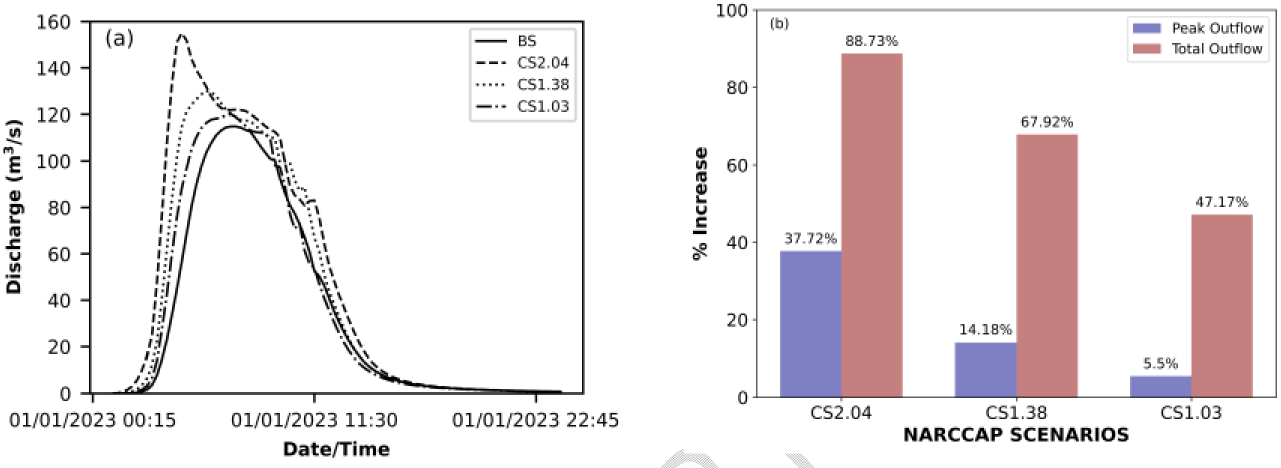

Fig 3: (a) Flood hydrograph at different Climate Scenario, (b) Bar Chart demonstrating the comparison of peak outflow and total outflow

Fig **3** (b) shows a bar graph depicting the percentage increase in peak and total outflow compared to BS. Peak outflow increased by 37.72%, 14.18%, and 5.5%, respectively, which is not a considerable increase over BS. The overall outflow, on the other hand, climbed by 88.73%, 67.92%, and 47.92%, respectively, which is significant when compared to peak outflow. As previously stated, the increased total outflow is related to the longer duration of the flow of water through the exit.

3.3 Performance of LIDs

The inclusion of LID practices in PCSWMM simulation has shown a notable reduction in peak flow rates indicating its usefulness in mitigating stormwater runoff. It will help to control the peak flow rate in case of increased runoff resulting from climate scenarios. Three commonly employed LID practices (Green Roof, Permeable Pavement, and Bioretention Cell) are separately used on the calibrated model of the study region to evaluate the efficacy in different 6 hrs. 100-year CS along with the BS. Overall, integrating LID techniques lowered peak discharge for all scenarios; however, the performance of LIDs varied greatly as shown in Fig 4. LID was used on 20%, 15%, and 9% of the impervious surface, respectively, for the green roof, permeable pavement, and bio-retention cell.

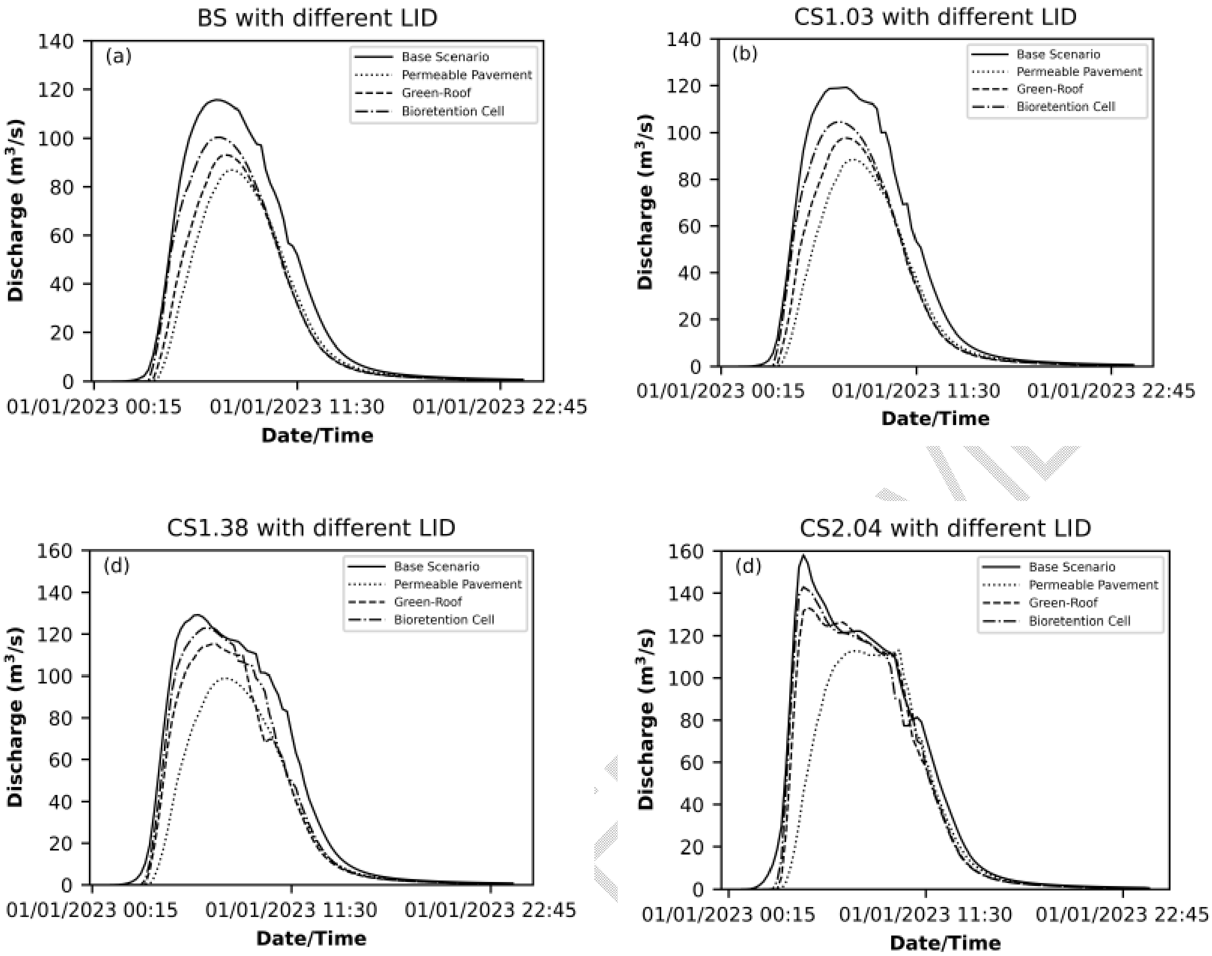

Fig 4: Effect of LIDs in (a) Base Scenario (b) CS1.03 (c) CS1.38, and(d) CS2.04

When LID was applied in a normal 100-year scenario, the permeable pavement option was found to be the most effective with a peak discharge percent reduction of 24.52%; the bioretention cell option was found to be the least effective, with a percent reduction of 13.32%, and the effect of Green Roof was found to be intermediate between them with a percentage reduction of 19.33%. LIDs had a comparable effect on other climate scenarios CS2.08, CS1.38, and CS1.03, however, the effect of reduction by each LIDs choice differed in each CS, as shown in the Fig 5.

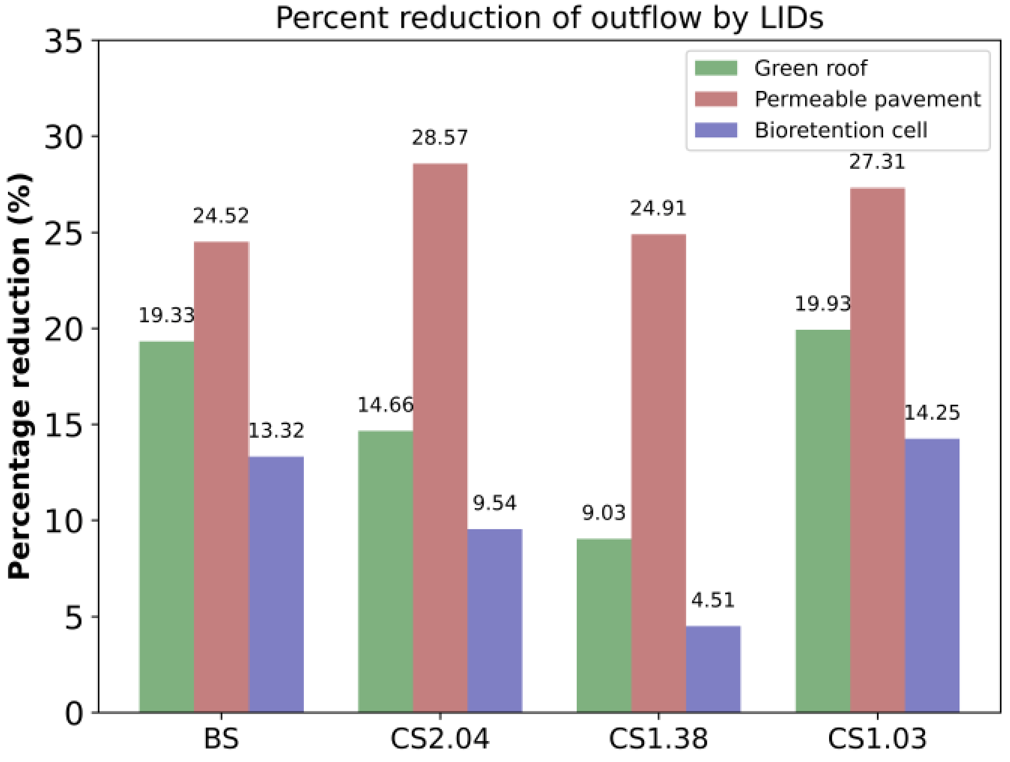

Fig 5: Bar graph showing percent reduction of outflow by LIDs

4. Discussion

The NARCCAP model combinations showed significant diversity in statistical results for 6-hour 100-year design storms, which was attributable to major discrepancies in the formulation and parameterization of the GCM and RCM utilized in the model combinations. This shows the projection uncertainty of climate models, which is reliant on internal variability, model response, and forcing (45). Multiple sets of climate models were selected for the study, and different climate scenarios were considered, as suggested by Fowler et al. (46). Two of the ten RCM-GCM combinations chosen for research revealed a decrease in future design depth. The climate model predicted a 22% decline to a 104% increase. As a result, this study examined climate models with delta change factors ranging from 3% to 104% increased to represent runoff. Similar methods have been used by Acharya et al. (47), and Forsee et al. (48) to demonstrate the effects of climate change.

The findings indicate that the watershed's peak outflow increased by 37.72% compared to an 88.73% increase in total volume for CS2.04. Similarly, the total outflow volume has increased considerably compared to the peak outflow in the cases of CS1.38 and CS1.03, respectively. One possible reason for such a significant increase in total outflow is the watershed's capacity for downstream storage, which holds water for an extended period before gradually releasing it over time, thereby reducing peak outflow. As a result, the area affected by flooding grows during prolonged precipitation because the rainwater cannot escape the watershed. This observed rise in total outflow relative to peak outflow emphasizes the significance of comprehending baseflow's contribution to the system's overall water balance and watersheds' hydrological responses to shifting precipitation patterns.

To evaluate the effectiveness of LID, the results were compared to the other scenarios and the base scenario, with a focus on outflow. The permeable pavement helped to reduce runoff by retaining much of the water. Bean et al. (49) and Fassman et al. (50) research provides additional support for these findings, indicating that LID strategies can be used to reduce the magnitude and frequency of surface runoff. Except for the two CS2.04 examples, the data presented in the graph indicates that LID was generally successful in lowering the peak outflow below the current 100-year peak outflow.

Fig 5 shows that the performance of LID in permeable pavement increased in all CS; however, it is essential to note that the performance of green roofs and bio-retention cells decreased with the increase in precipitation intensity. One probable explanation for this can be that the soils in bio-retention cells and green roofs may approach a saturation point during prolonged precipitation events, making it impossible for them to retain the water and instead causing runoff, which lowers performance. The performance of green roof retention capacity in relation to precipitation intensity and duration has been well documented by **(51–**53). Another possible explanation for the case of bio-retention cells can be that surface infiltration might not be fast enough during increased precipitation intensity, causing an increase in overflow (54,55). Therefore, with the growing acceptance of LID as a tool for reducing the effects of land use changes on watershed processes, watershed managers, landscape architects, and urban planners would benefit from a spatially explicit, mechanistic method for prioritizing LID locations in urban environments. Cost-effective land-use planning can also benefit from identifying the regions where LID would be most beneficial.

5. CONCLUSION

The design, operation, and upkeep of stormwater management structure will face greater uncertainty due to climate change over the course of the next century, a problem that many professionals and decision-makers are only now starting to think about (56). According to Fowler et al. (57) and Halenka et al. (58) the difficulty in quantifying changes in extreme events with gridded climate data was frequently due to the degree of specificity in the geographic data, the mathematical models used to simulate the weather, the forecasting assumptions, and so on. A significant variation in the calculated standard design depths of the climatic model was found in this study, making it challenging to make an accurate future projection. Improved GCMs, ensemble forecasting techniques, and planning for uncertainty, or preparing for a range of potential outcomes rather than depending on a single prediction, are some techniques used to lessen this issue.

The scenario analyses performed for this research show how LIDs might be useful for lowering runoff in the context of climate adaptation. According to the findings, even a modest LID implementation can considerably lower increases in stormwater runoff brought on by increased precipitation. LID is especially attractive as a no-regrets approach to climate change adaptation given the uncertainty surrounding the precise trends and quantity of future precipitation. Since the cost analysis, environmental effect, and water quality monitoring are outside the scope of this paper, this study has only taken LIDs into account for reducing peak discharge. The best LID choice can be chosen in every way if more parameters can be used when choosing LIDs. If those criteria are used in studies, it will be possible to determine which LIDs will be more economical while reducing peak discharge with the most negligible negative impact on biodiversity, air and water pollution, and greenhouse gas emissions.

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