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Simulating future trends in stormwater runoff at a university campus related to climate and land use changes

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Stormwater management is essential for the management of sewerage and stormwater systems as insufficient drainage can result in flood damage and impact public health. During the planning of new infrastructure at Campus I of the Royal University of Phnom Penh, it was observed that a hydrological assessment had not yet been completed. Without such an assessment, climate change and poor land-use planning may result in more frequent flood events in the future. Thus, this study aims to quantify the potential impacts of changes to stormwater runoff related to climate change and an increase in the area of impervious surfaces on campus. PCSWMM modeling software was employed to simulate surface runoff volumes flowing to the catchment of the Building D pond. Three different scenarios for rainfall intensity (2, 5, and 10-year return period) and five scenarios for changes to impervious area (10%, 30%, 50%, 70% and 100%) were used in the simulation. A baseline was also established by analysing rainfall intensity, land use characteristics, and topography in the catchment area. Under present conditions the volume of the Building D pond is about 18,933 m^3 with a surface area of 6,173 m^2. The average permanent water volume of the pond is about 9,916 m^3, with a remaining storage capacity of 9,016 m^3. It is estimated that the pond will flood within one hour of intense rainfall (63.70 mm/h) under these conditions. The surface runoff volume for the Building D catchment was estimated for a range of scenarios. It was found that even under intense rainfall (63.70 mm/h); the pond would not flood if measures were implemented to reduce the impervious area on campus by 10%. This shows that preserving permeable surfaces in the

catchment is likely to reduce the frequency of flood events on campus over a range of climate change scenarios.
Keywords: stormwater, PCSWMM modeling software, climate change, surface runoff, Royal University of Phnom Penh

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Introduction

Stormwater management is essential for mitigating the negative impacts caused by combined sewage-stormwater flood events due to insufficient drainage. These events often result in flood damage and poor public health outcomes (Barbosa et al., 2012). Stormwater runoff contains sediment, which often fills drainage channels, resulting in flooding (Livingston & McCarron, 1992; Chebbo et al., 1996; Liao et al., 2014; JICA, 2016, 2017). Effective stormwater management remains a challenge in both developed and developing countries (Goldenfum et al., 2007; Irvine, 2013; Smith, 2001; Chaosakul et al., 2013) such as in Malaysia (IRDA, 2011), Cambodia (Phyrun, 1996), China (Liao et al., 2014), and the United States (Parkinson & Mark, 2005; EPA, 2009).

The Royal University of Phnom Penh (RUPP) is one of the oldest and largest public universities in Cambodian and consists of three campuses. Campus I, the study area selected for this research is located about 5 km west of the center of Phnom Penh. The recent 'RUPP Vision' contained an Infrastructure Development Plan for 2014-2018 for Campus I (Royal University of Phnom Penh, 2018b). A number of new buildings were planned. Currently there are five ponds on campus that play a crucial role in stormwater management. These ponds store stormwater flows from rainfall events, as well as wastewater produced on-site. Without a detailed understanding of the hydrological response of each pond or the impact of an increased area of impervious surfaces, further infrastructure development has the potential to cause serious flooding and public health problems. This study aims to assess the potential impacts of increased surface water runoff related to an increase in the impervious area within the catchment of the Building D pond at RUPP and more intense rainfall due to climate change.

Study area and methodology

This study takes place at Campus I of the Royal University of Phnom Penh, which covers an area of approximately 20 ha. There are five main ponds at the campus, with a total area of approximately 3 hectares. They include the: [1] 'Big pond' in front of Main Building (1.8 ha), [2] 'IFL back pond' (0.30 ha), [3] 'Building D pond' (0.41 ha), [4] 'IFL front pond' near the car parking lot (0.21 ha), and [5] 'CJCC pond' (0.16 ha). The Building D pond is arguably the most polluted and flood-prone. It is the final retention pond for wastewater flows and also regulates stormwater flows before they are pumped to an external open canal.

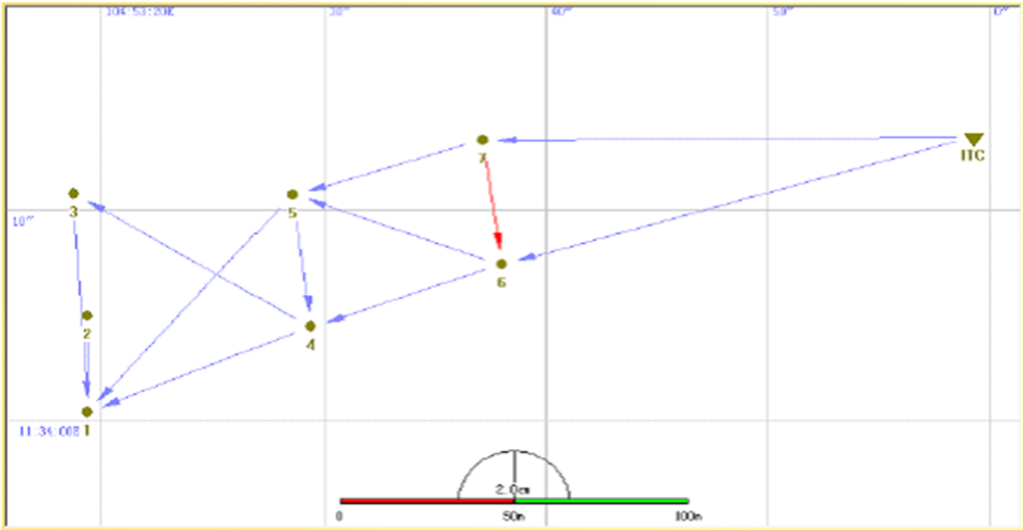
Rainfall

A Davis Vantage Pro2 Plus weather station purchased with financial support from the University of Manchester was installed on the roof of the Cambodia-Korea Cooperation Center (CKCC) to record rainfall and other weather data at 1-minute intervals. This data was then converted to 5-minute intervals for use in the PCSWMM modeling software to determine a baseline value for stormwater runoff for comparison with future scenarios for rainfall intensity linked to the impacts of climate change.

Bathymetric and topographic survey

Seven static reference points were identified for use as topographical benchmarks at RUPP Campus I in August 2017. These points were determined using three sets of CamNav T300 GNSS receivers (Horizontal: 2.5mm + 0.5ppm RMS & Vertical: 5mm + 0.5ppm, RMS) to triangulate networked static points with a known reference point at the Institute of Technology, Cambodia (ITC) as a benchmark. For this survey, a five-second interval was used for measuring the static points, with the baseline approximately 700 m away from reference point. In total, six sections were surveyed, maintaining the static survey as part of a triangulated loop involving at least one of the three receivers remaining in place (Figure 1). For example, Section 1 was surveyed as part of a triangulation of the data from ITC, and Points #7 and #6. Then, one receiver was moved to point #5 and triangulated with data from Points #7 and #6 for Section 2. Successive sections were triangulated using the same procedure of moving most distant station to a new control point for Sections 3, 4, 5 & 6, as shown in Figure 1. Horizontal (X, Y) data were referenced to a national coordinate system benchmark (UTM WGS84, Zone 48N) and height data (Z) was transformed from ellipsoidal height to orthometric height (geoid model EGM2008). These static data points were adjusted using Compass Solution software (Version 1.7.0 Copyright 2014-2020) to ensure centimeter scale accuracy. As the RMSE was not acceptable for all baseline points, this software was also used to further process the data by making adjustments to provide millimeter accuracy. The coordinates for each of the seven benchmarks was then finalized.

Figure 1. Triangulation loops for the three GNSS receivers used to determine a statistical baseline.



In total, 401 real-time-kinetic (RTK) points were collected twice, with 69 points collected in August 2017 and 332 points collected in February 2018. Sixty-six of these points were collected at the ground level of a building. To survey most of the RTK points, one T300 receiver was used as a base station at Point #4 (near the flag pole), while the other two receivers were used as rovers to collect 3D RTK data (x, y, z). These data points were collected for five seconds at each point to minimize errors to less than 15mm. The 66 RTK points collected from the ground level of the buildings within the Building D pond catchment area were used to determine an average ground floor elevation for each building. Using an assumption that the ground floor elevation of each building was completely level; an extra 836 ground elevation points were generated. An extra 438 points were also collected using a CST

Berger Auto Level (SAI 24X) between the 1st and the 10th of January 2017 to better understand the topography of the Building D catchment area. This auto level survey was conducted using 41 straight-line transects at 20-meter intervals.

A total of 313 of bathymetric survey points for the Building D pond were collected between January 2017 and February 2018. The bathymetric survey was conducted manually using a pole to measure the depth of the pond along 17 transect lines from north to south and 20 transect lines from west to east. Assuming a high slope change from the bank to an elevation of 10 m, a short transect line at 2.5 m interval was used for this survey, while other transect lines were recorded at 5 m intervals. The bathymetric survey was conducted over a time period where the water level in the water level in the pond is likely to have changed. Thus, a global water level (WL16U) was installed between the 8th of January and the 14th of February, 2018 (X: 487912.222, Y: 1278880.034 and Z: 7.62) to obtain water depth data at 5-minute intervals. These data were used to adjust the bathymetric data to reduce errors associated with changes in the depth of the pond. The ground elevation of the pond was then determined using the adjusted bathymetric, comparing water depth with ground elevation data with reference to a benchmark (X: 488171.743 and Y: 1278776.169) collected with the CamNav T300 GNSS receivers on the 11th of August 2017.

To surface topography of the Building D pond catchment was then further analyzed by combining the 313 points collected from the bathymetric survey, 417 static and RTK points, 438 auto-level points, and the 836 ground floor elevation points. After cleaning this dataset of errors and accounting missing values, a dataset of 1926 survey points remained for use in the simulation. However, only the 1820 data points from Building D and within 30 m of the Building D sub-catchment were used for the topographic interpolation, with 90% of these points used for training the data and 10% used for testing the data. Two inverse distance weighted (IDW) interpolations were then used in ArcGIS (Ver. 10.5) to calculate the storage capacity of the Building D pond, the average slope of Building D, and the STEM building sub-catchment size.

Catchment delineation and impervious area

The Campus I catchment, Building D pond sub-catchment, and STEM building sub-catchment were delineated using Google Earth high-resolution satellite imagery downloaded on the 15th of January, 2018. A time series percentage change from pervious and impervious area in each catchment and sub-catchment between 2000 and 2017 was also generated based on this imagery. However, only recent pervious area could be analyzed by digitizing the high-resolution satellite imagery as the present condition of pervious and impervious area needed to be used as an input for the PCSWMM model.

Drainage and sewage system mapping

The drainage system to the east of the Building D pond includes nodes, conduits, and outfalls. These were also mapped in relation to the observed data in terms of flow direction, the size of drainage system, the invert ground level, the maximum level, and sediment height. This data for the sewerage and drainage system data connected to the Building D pond catchment was collected between the 25th of March and the 25th of April, 2018. A staff member of the campus was interviewed to draft a preliminary map of the system and determine the number of pumps and their direction of flow on a seasonal basis. The first draft of map was verified with the staff member ahead of on-site data collection, measuring pipe nodes, diameters, heights and sediment heights using a crowbar, scaffolding planks, and measuring tape. The type of pipes installed was also recorded. On the 29th of March and the 3rd of April, 2018, two GNSS Reach RS receivers were used to conduct static and RTK surveys to determine the coordinates and elevation of each node. A known static point near the RUPP flagpole (X: 488171.743, Y: 1278776.169, Z: 11.4195) was used as a reference point for the survey. The RTK data was then compiled in Microsoft Excel prior to being transferred to ArcGIS software (version 10.5) to map the drainage system.

Flow rate and water level

There was only one flow meter available for the study; however, there are seven outfalls flowing to the Building D pond. Thus, only the flow from one outfall could be selected for long-term flow monitoring. The STEM building outfall (X: 487960.429729, Y: 1278926.11455, Z: 6.0951, pipe's diameter = 0.3 m) was selected as the most appropriate outfall and the flow, in terms of water level and flow velocity was recorded at 5-minute intervals between the 22nd of August, 2017 and the 22nd of January, 2018. The entire dataset was then cleaned and analyzed using descriptive statistics to determine an appropriate time period for a rainfall-runoff simulation informed by a more detailed understanding of dry flow patterns.

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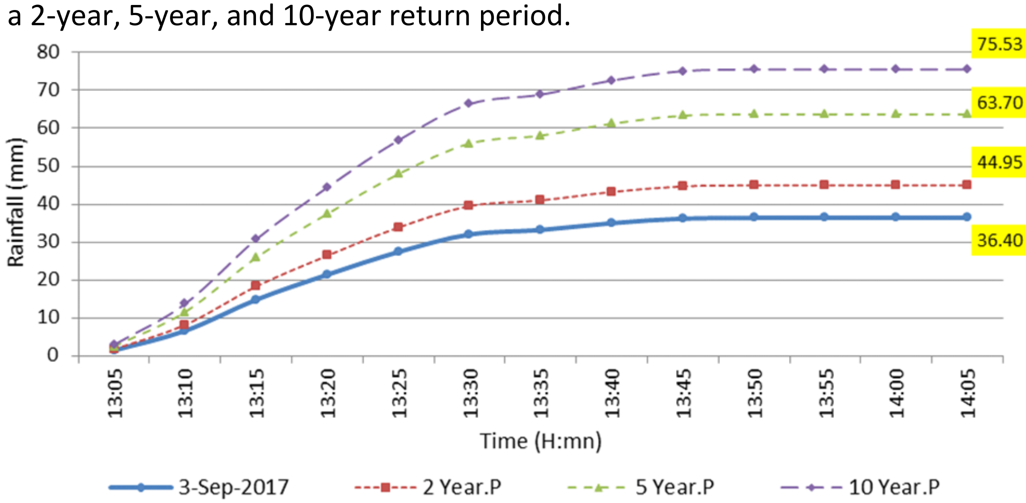
Surface runoff simulation

The PCSWMM model, developed by EPA SWMM, was used to estimate surface runoff for a one-hour period of rainfall from the STEM building and the Building D pond sub-catchment (Figure 2).

Figure 2. 5-minute rainfall intensity for selected rainfall patterns calculated for a 2-year, 5-year, and 10-year return period.



The model applying the Green-Ampt infiltration method to conduct an analysis using Manning's equation to estimate the maximum depression storage, assuming N-impervious and N-pervious were 0.011 and 0.1, respectively. To examine the change in surface runoff for each of the sub-catchments, two main types of scenarios were considered. These included changes to the impervious area (representing infrastructure development) and rainfall intensity changes (representing predicted climate change impacts). For infrastructure development, five alternative scenarios were considered including an increase in impervious areas of 10%, 30%, 50%, 70% and 100 % of the STEM building sub-catchment and Building D pond sub-catchment. For the predicted climate change impacts, it was assumed that rainfall intensity will increase in the future. Thus, three scenarios were considered including a 2, 5 and 10-years return period for hourly rainfall in Phnom Penh based on a previous study (JICA, 1999)

Findings and Results

Results from the topographical survey

Table 1 presents the elevation points of several buildings at RUPP including, the CKCC Building, Building D, Building B, the STEM building, study office, Building A, the swimming pool and library. The points were measured using a topographic method to determine the proportion of wastewater that would flow to the Building D catchment using a reference point of above mean sea level (AMSL). The study office had the highest elevation point with an average of 11.59638 m across 13 measurement points. Four other buildings had a mean elevation point only slightly lower than the study office, including the swimming pool (11.561 m), Building A (11.47143 m), Building B (11.4174 m) and the CKCC Building (11.162 m). Building D had the lowest mean elevation (8.295 m), while the STEM Building had a mean elevation of 8.98375 m and 9.112 m, respectively. Each of these buildings is at least 8 m above AMSL and the wastewater produced by each building is pumped to Building D catchment. The area of the pond, excluding the island in the middle, is approximately 6173 m^2 and the potential water storage volume is 18932.29 m^3, calculated on the basis of the plain height being 8 m.

From the data collected from the auto level installed in the Building D pond (X: 487911.493, Y: 1278879.788, Z: 5.326) between the 8^{th} January to the 14^{th} February, 2018, it was observed that the average water level in the pond was 1.13 meters, which corresponds to 6.456 m AMSL (n = 12086, std. =

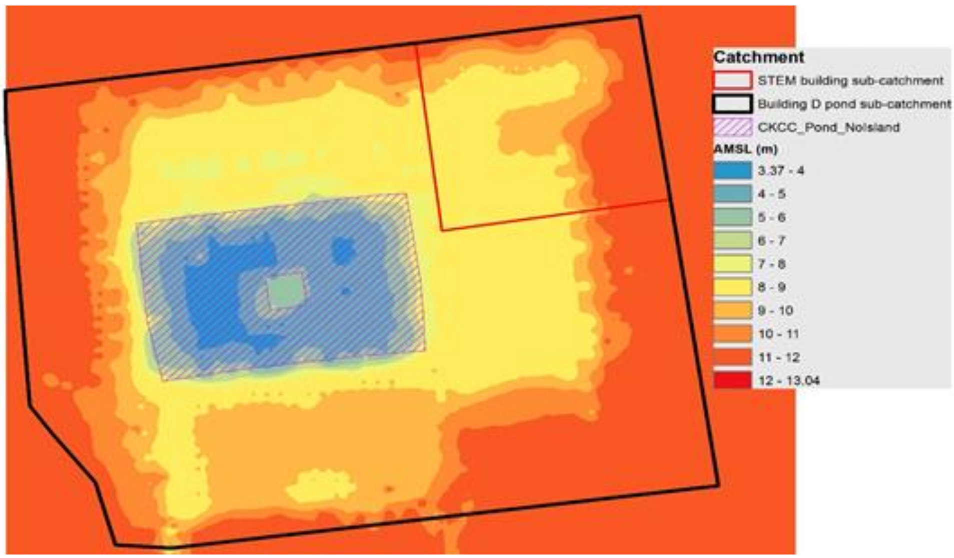
0.074). This suggests that most of the time, there is 9,916 m^3 of water stored in the pond, with a surface area of 5,631.96 m^2. Thus, there is a capacity for a further 9,016.07 m^3 of stormwater and wastewater to be stored in a flood event (Figure 3).

Table 2. Ground level elevation of each building at Campus I.

Building	Points	Average	Std. Error	Minimum	Maximum
Building CKCC	4	11.162	0.185872	10.841	11.288
Building D	4	8.295	0.089808	8.201	8.394
Building B	10	11.4174	0.038487	11.366	11.483
STEM building	4	8.98375	0.096893	8.87	9.138
Study office	13	11.59638	0.131215	11.301	11.751
Building A	14	11.47143	0.074564	11.32	11.617
Swimming pool	5	11.561	0.205342	11.32	11.943
Library	12	9.112	1.301047	7.717	11.575

The impervious area of the RUPP campus, within the Building D pond and STEM Building sub-catchments was measured in hectares over the period between 2000 and 2017. For the first five years, the impervious zone in Building D Pond sub-catchment was unchanged at 19.73% of the total area (0.87 ha out of 4.39 ha). However, in 2007 the impervious area increased to 1.14 ha, and again in 2012 to 2.26 hectares or 51.38% of the total area. By 2017, the impervious area had reached 2.64 ha or approximately 60% of the total area. The impervious area of the STEM building catchment area increased from about one-fifth to one-third (0.18 of 0.62 ha) between 2000 and 2010 and then remained stable until 2015. The impervious area again increased to close to 50% (0.29 hectares) in 2016 and one-year later covered two-thirds of the total area. This growth is consistent with the overall increase in impervious surfaces throughout Campus I at RUPP. The impervious surface of the campus doubled in size from 3.32 ha to 6.63 ha out of a total of 20.38 ha between 2000 and 2008. This area again increased to 7.46 ha in 2010, and 9.54 ha in 2017 and now covers approximately half of the campus (Figure 4).

Figure 3. A map showing the boundaries of the STEM building and the Building D pond sub-catchments with elevation data.



Storm and wastewater infrastructure and level measurement

A preliminary study of the drainage infrastructure at RUPP revealed a complex array or junctions, pumps stations, outfalls, wastewater and septic tanks, as part of the drainage and sewage network (Figure 5). The system is used to drain wastewater and stormwater from the campus and comprises 94 different junctions (55 for sewerage and 39 for drainage), 3 pump stations, 17 outfalls, 5 wastewater tanks, and 8 septic tanks.

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The raw flow and water level data taken in 5-minute interval for the STEM building outfall suggest that a flood event correlates to a water level above 300 mm and dry outfall flow conditions correlates to water level below 100 mm. Thus, this dataset was cleaned to remove any values outside of these limits for the simulation. The clean data comprised 24,073 data points with a maximum and minimum value of 124.092 mm and 0 mm, respectively, with a standard deviation of 16.2859 mm. The median value was 2.6771 mm, while the average was 12.4657 ± 0.1049mm at a 95% confidence interval (CI (95%)) of 0.2057.

Figure 4. Change to the impervious area of Campus I between 2000 and 2017.

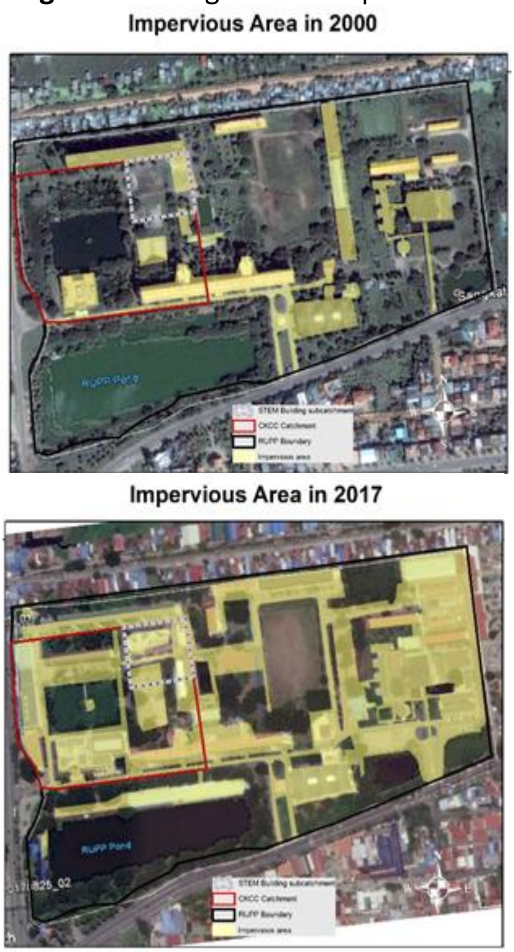


Figure 5. Map of the drainage and sewer system at RUPP Campus I.

The water flow level from the Building D outfall, taken at 5-minute intervals for the week between the 28th of October and the 30th of November, 2017 were then analyzed further (Figure 6). This week was considered as ideal as there had been no rain for 24 hours before the sampling and the outfall was not flooded during this period. Either scenario may have otherwise affected the analysis of the dry flow.

A peak water level of 40.7268 mm and a trough of 0 mm was recorded during this week, with a mean value of 4.8357 ± 0.1881 and a standard deviation of 8.1245 mm (n = 1865, CI (95%) = 0.3689). Between the Monday and Friday of this week, when both the peak and trough were reached, the mean value of the water value was lower at 4.6464m ± 0.3568 with a standard deviation of 8.5641 mm (n = 4.6464, CI (95%) = 0.7008). On the weekend, the peak was reduced to 39.1971 mm but the mean value increased to 5.4895 mm ± 0.326, with a standard deviation of 7.8337 mm (n = 576, CI (95%) = 0.6410).

Figure 6. Time series data for rainfall events and the outfall water level from the STEM building sub-catchment between the 25th of August 2017 and the 18th of January, 2018 recorded at 5-minute intervals.

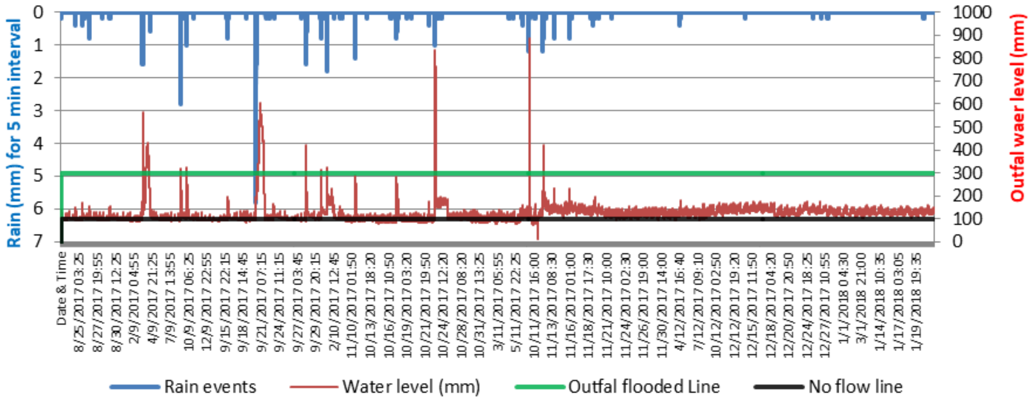
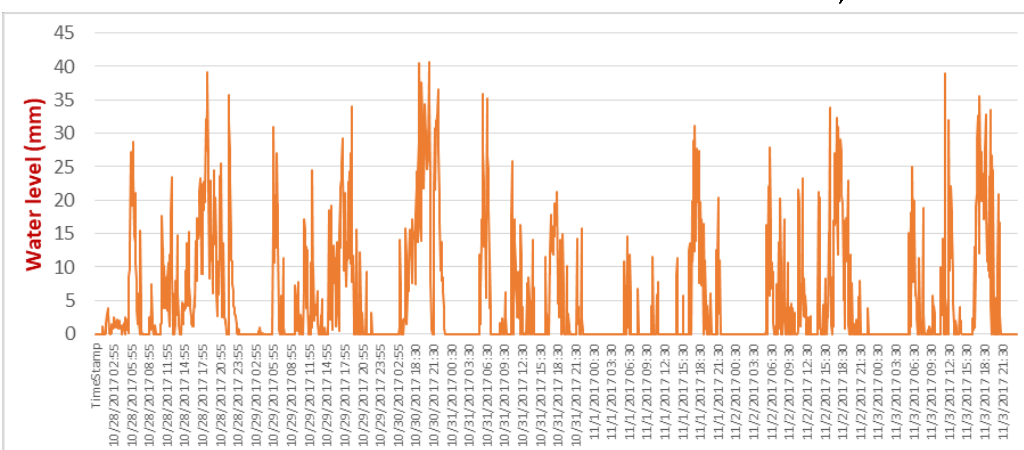


Figure 7: Dry flow water levels at 5-minute intervals at the STEM outfall for the week between the 28th of October and the 3rd of November, 2017.



Runoff calculation

The results from the simulation of the STEM Building sub-catchment show that an increase in impervious area has little impact of total runoff height. At present, the impervious area is two-thirds of the total area and the runoff level in the simulation is 35.93mm, correlating with a run-off volume of 240 m^3. If the rainfall intensity remained the same and the impervious area was increased by 100%, the simulated height would only increase to 36.59 mm (250 m^3). If it were reduced by 10%, it would decline to 33.06 mm (220 m^3). In the case of the STEM building catchment, the three scenarios for increased rainfall intensity as a result of climate change would a have a more significant impact. For example, for a 2-year, 5-year, and 10-year return period for rainfall, the runoff level would increase to 44.52 mm (300 m^3), 63.36 mm (420 m^3), and 75.24 mm (500 m^3), respectively. For an increase in impervious area of 100%, this would be 45.2 mm (300 m^3), 64.07 mm (430 m^3), and 75.96 mm (510 m^3), respectively. For a scenario, where measures were taken to reduce the impervious area by 10%, the runoff would slightly decline to 41.56 mm (280 m^3), 60.19 mm (400 m^3), and 71.98 mm (480 m^3), respectively.

Figure 8. The result of estimated surface runoff level at STEM building sub-catchment responding to different scenario of changing in [1] percentage of impervious areas and [2] rainfall intensity.

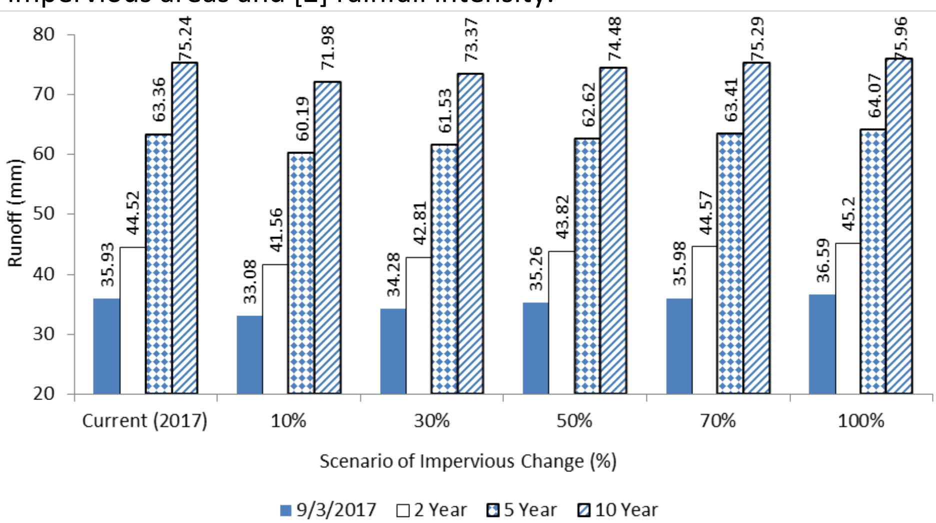


Figure 9. The results of estimated runoff levels at Building D pond sub-catchment responding to different scenarios for [1] the percentage of impervious areas, and [2] rainfall intensity.

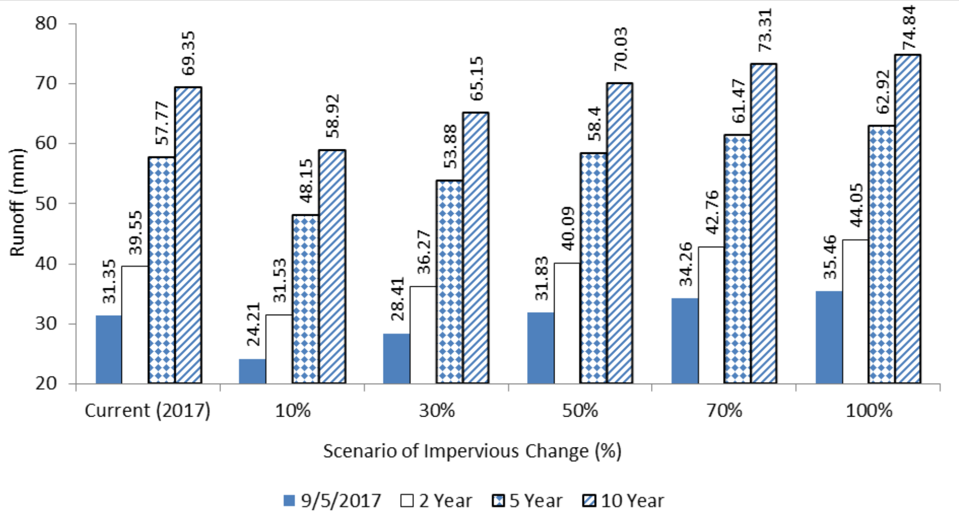
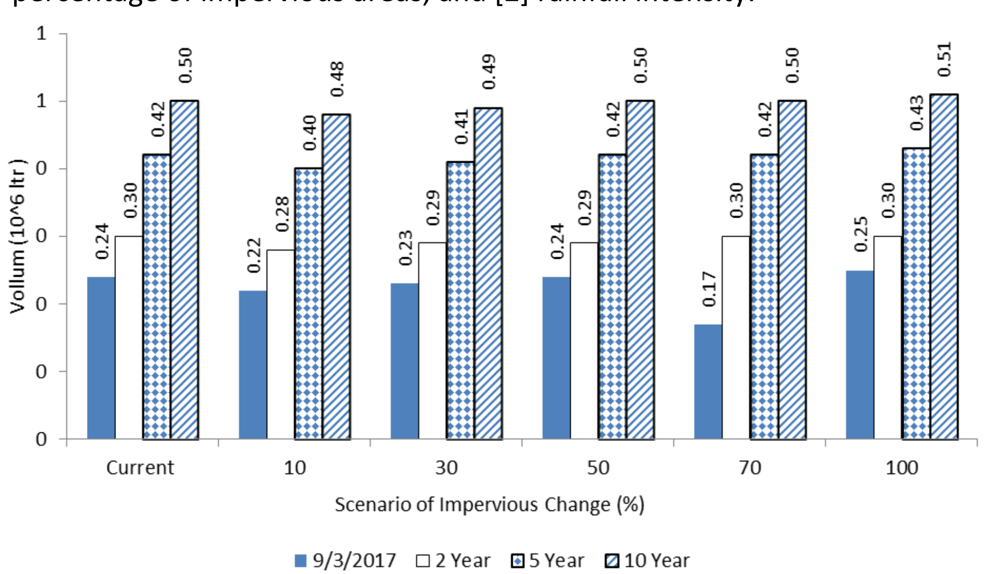


Figure 10. The result of estimated surface runoff volume level at the STEM building sub-catchment responding to different scenarios for [1] the percentage of impervious areas, and [2] rainfall intensity.



For the CKCC Pond, the simulation suggests that each scenario tested would have a more significant effect on the sub-catchment. The level and volume of the run-off based on a simulation of baseline conditions suggests a flow of 31.35 mm (1,520 m^3). Both a 100% increase in the impervious area and a 10% decrease in the impervious area would have a pronounced effect in the sub-catchment. For example, under these scenarios, the runoff would be 35.46 mm (1,590 m^3) and 24.41mm (1,280 m^3), respectively. In addition, increased rainfall intensity would also have a very significant impact on runoff. For example, under the climate change scenarios of a 2-year, 5-year and 10-year rainfall return scenario applied to the baseline, the run-off level and volume would be 39.55 mm (1,900 m^3), 57.77 mm (2,720 m^3) and 69.35 mm (3,240 m^3), respectively. If the impervious surface in the sub-catchment expanded by 100%, this would correlate to a runoff of 44.05 mm (1,970 m^3), 62.92 mm (2,800 m^3), and 74.84 mm (3,320 m^3), respectively. In the case of the 10% reduction in impervious area based on changes to infrastructure development, lower runoff values of 31.53 mm (1,630 m^3), 48.15 mm (2,420 m^3) and 58.92 mm (2,920 m^3) were simulated.

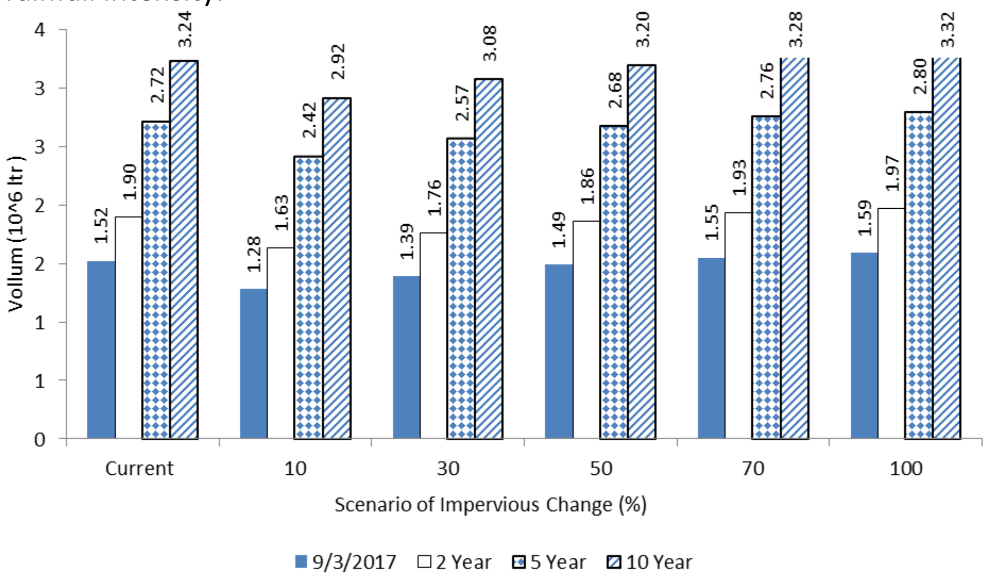
Runoff volume and the Building D pond stormwater flood analysis

In STEM Building sub-catchment simulation, there was not much difference in the level of surface runoff even with a significant increase in impervious area. This is because the sub-catchment is quite small (0.62 ha) and as discussed in a previous section contributes a much smaller run-off volume compared with the CKCC building sub-catchment for all rainfall intensity scenarios. However, the Building D pond sub-catchment currently carries a much more significant run-off volume (1,520 m3) as the area is comparatively quite large (20.38 ha). In this case, changes to both the impervious area in the sub-catchment and rainfall intensity result in a more significant change to run-off volume. This means that changes such as putting in lower the amount of impervious area by 10% in the second sub-catchment will have a much more pronounced effect on flooding.

To analyze the potential for a flood event to affect the Building D pond caused by stormwater flows, several scenarios of rainfall intensity, changes to impervious area in the catchment, and rainfall duration were considered. It was found that if all the stormwater collected at Campus I is directly discharged to the Building D pond, then the pond will flood after one-hour of rain at an intensity of 63.70 mm/h (5-year return period) as surface runoff volume in this event would be 11,740 m^3; while the water storage capacity of the pond is only 9,016 m^3. However, in another scenario, where the current impervious area (60.03%) is applied and only the stormwater from the Building D pond sub-catchment discharges stormwater runoff into the Building D pond, a rainfall intensity of 218.4 mm/day would be required to flood the pond.

Furthermore, if hypothetically, the pervious area of the catchment was increased by a further 50%, this level of rainfall intensity would not cause the pond to flood. This highlights the minimal impact of stormwater collected within the STEM building sub-catchment on the Building D pond due to its small area compared to the storage capacity of the pond. For example, even if the runoff volume from the STEM building sub-catchment area was based on a totally impervious area and a maximum rainfall intensity of 75.53 mm/h (10-year return period) experience over 10 hours, this would only still only account for a 5,100 m^3 run-off volume. This analysis assumes that [1] the pumps in the Building D pond are not operated, [2] there is no dry inflow into the pond, [3] water evaporation and groundwater infiltration into the pond are not considered, and [4] groundwater storage capacity is not included in the simulation.

Figure 11. The simulated runoff volume from the Building D pond sub-catchment under varying scenarios [1] percentage of impervious area, and [2] rainfall intensity.



Conclusion

The topography of Campus I at RUPP was studied based on 1,820 elevation points collected as part of a hydrological assessment. This data showed that the elevation of Campus I ranged from 3.3696 to 13.1761 AMSL. An IDW interpolation of the elevation data based on pair-test training of a small area ground with an independent dataset showed no statistically significant difference between the mean values of the two datasets. The Building D pond sub-catchment was estimated to have an average elevation of 9.0510 AMSL (SD = 2.1536) with a low elevation of 3.3713 AMSL. This sub-catchment was estimated to have an average slope of 10.1317 % (SD =

12.1679). The average of elevation and slope of the STEM building sub-catchment was 9.7707 m (SD = 1.2302) and 8.2155% (SD = 10.1699), respectively.

The topography of the Building D pond was used to estimate a pond volume of 18932.29 m^3 and a pond area of 6,173 square m^2. The mean permanent volume of water in the pond was estimated to be 9916.22 m^3. Thus, an extra combined stormwater and wastewater load of up to 9016.07 m^3 could be stored before the occurrence of a flood event. At RUPP there has been a trend at Campus I for the proportion of impervious areas to gradually increase from 16.31% to 46.80% between the 2000 and 2017. In 2017, the percentage of impervious area in the Building D pond catchment area was 60.03%, while STEM building sub-catchment was 68.44%.

The stormwater and wastewater infrastructure at Campus I is complex with 94 different sewerage and drainage junctions, 3 pump stations, 17 outfalls, 5 wastewater tanks and 8 septic tanks and some uncertainty about flow direction and the capacity of groundwater storage. Future studies should focus on clarifying these details to improve simulation results. Notwithstanding this, the simulation results showed a positive correlation between the surface runoff volume, an increasing impervious area in the sub-catchment, as well as for rainfall intensity. The total runoff volume at RUPP was calculated to be 36.40 mm/h, which with an impervious area of 46.8% or a total runoff volume of 6370 cubic m^3. This figure increases to 15220 m^3 if a simulation is performed with a rainfall intensity of 75.53 mm/h and impervious area of 100%.

The aim of the hydrological assessment was to analyze the potential of flood events in the Building D pond from stormwater flows. It was assessed that the pond is likely to experience more flood events in the future due to pressure from an increasing area of impervious surfaces and increasing rainfall intensity. Under present conditions, the pond is likely flood within an hour, if all the stormwater in the catchment was directly discharged into to the pond with a rainfall intensity of 63.70 mm/h (5-year return period). However, this same amount of rainfall would not flood the pond if the impervious area on campus is reduced by 10%. The study has shown that the preservation of pervious area in the catchment is likely less flood frequency in the Building D pond under the pressure of climate change. Based on this study, we conclude that the preservation of pervious areas in the catchment is likely to reduce the occurrence of flood events in the Building D pond in the event of increased rainfall intensity as a result of climate change. The pervious areas of the campus should be increased to increase the water storage capacity of the catchment and reduce run-off volumes.

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