Assessment of current and projected stormwater runoff dynamics before major land use changes at SUNY Purchase College

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Abstract

Excess stormwater in urbanized settings is a risk to local ecosystems and inhabitants. Impervious surfaces in urban areas are the largest contributors to excess stormwater, since water cannot be transpired or infiltrate into the ground the way it would in a vegetated space. Current stormwater runoff conditions were analyzed in two sections of the SUNY Purchase College campus, the least-developed of which will be altered during building for the Broadview Senior Living facility. The timing and duration of runoff events was measured on both sites with water level sensors accessed remotely from May through October of 2020. Both sites were assessed for three characteristics of stormwater runoff delay to initial runoff (D_i), delay to peak runoff (D_p), and runoff duration (R_D). Characteristics of rain were additionally assessed total rain, rainfall average, rain duration, peak rain, and an index of storm size. The results of unpaired t-tests show that runoff from West 2 is faster than East-West Road in many of the characteristics studied. Because expected change in impervious surface at East-West Road is known, predictions were made for future runoff times. Showing that East-West Road will become 25% faster overall and more like West 2 than it is now, which could increase instances of flooding downstream from Purchase without proper abatement.

Introduction

Urbanization

Urbanization refers to the landscape changes that come with increases in population density (USGS, n.d.). Urbanization of previously undisturbed ecosystems can cause serious harm to both the environment and the humans living both the area and beyond. What was previously pervious vegetated area is paved over with impervious asphalt, concrete, and tiles for parking lots and streets, sidewalks, and roofs of buildings. In the absence of impervious surfaces, stormwater from non-major storms is not a hazard. However, when there are impervious surfaces, stormwater that would have otherwise transpired, infiltrated into the ground, or runoff into local waterbodies at a reasonable rate can no longer do that. Instead, large quantities of water flow over impervious surfaces before rapidly draining into local waterbodies.

This excess water is a hazard to buildings, cars, and local inhabitants. To account for this, cities and urban areas construct grey stormwater infrastructure such as elaborate pipe systems, whose only purpose is to divert the stormwater away (Redfern, 2016). These types of grey infrastructure were the norm until the passing of the Clean Water Act in the 1970s, which promoted the implementation of green infrastructure (Subramanian, 2016). As a result, cities have begun to implement green infrastructure such as bioswales, green roofs, and porous pavements.

Green infrastructure can be multi-purpose, for holding water and sustaining many ecosystem services that are lost when cities are built. There can be pushback from both an accounting and stakeholder point of view because it can be hard to justify green infrastructure in city budgets, and citizens sometimes feel that green infrastructure is an eyesore and rally against it (Maltser, 2019; Suppakittpaisarn et al., 2019; Miller and Montalto, 2019).

Urban Streams

“Urban stream syndrome” is a term used to refer to the many ways that streams in the vicinity of urban areas are degraded. Impervious surface is a factor for all of these degrading effects. When it rains, anything on that surface is washed down the drain to be put into local water sources. Urban waterbodies are subject to increased pollutants (e.g. leaked car oil), sedimentation (e.g. particles from construction), and nutrient inputs (e.g. fertilizer) as well as decreased diversity and base flow (figure 1) (Walsh et al., 2005; Fletcher et al., 2013). Areas downstream from the urban area are subject to increased flooding and flashiness because of the grey infrastructure dumps large amounts of water over a short period of time when rain occurs (Walsh et al., 2005; Subramanian, 2016). To attempt to decrease downstream flooding, there is gray infrastructure such as detention basins, which holds the water for a short period before releasing it into the waterbody (Fletcher et al. 2013). Green infrastructure can prevent flooding by detaining it in something like a bioswale and

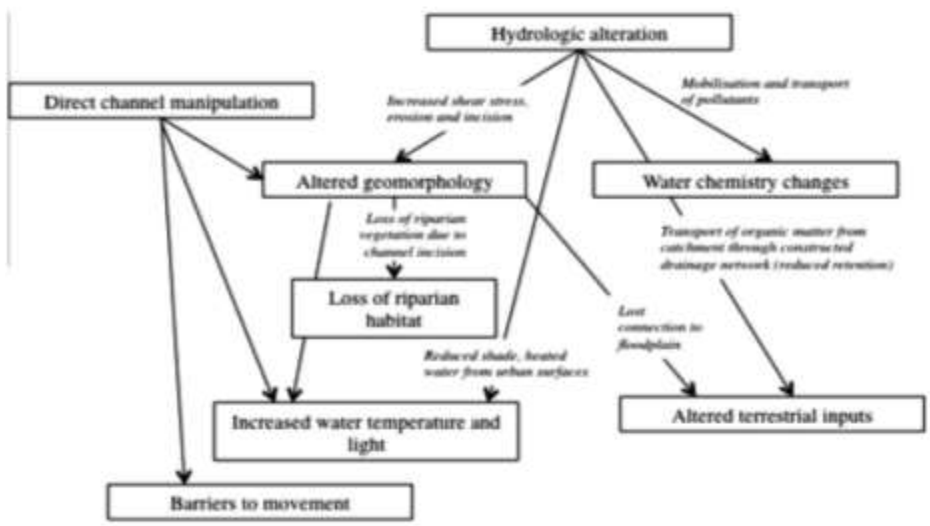

Figure 1 *An illustration of how urban water is degraded (Fletcher et al., 2013).*

allowing water to infiltrate through porous pavement, keeping water in the area it fell in and restoring groundwater levels (Fletcher et al. 2013).

Blind Brook Watershed

The land that the Purchase College campus occupies has changed hands many times over the last several hundred years. The 500-acre campus has gone from land stolen from the Munsee Lenape and Wappinger tribes to farmland owned by settlers John Thomas and later the Chisholm family to its current developed campus founded by Governor Nelson Rockefeller in the 1960’s (Purchase College (2), Purchase College (3), Purchase College (4)). The College is located in both the Long Island Sound watershed and the Blind Brook subwatershed (figure 2).

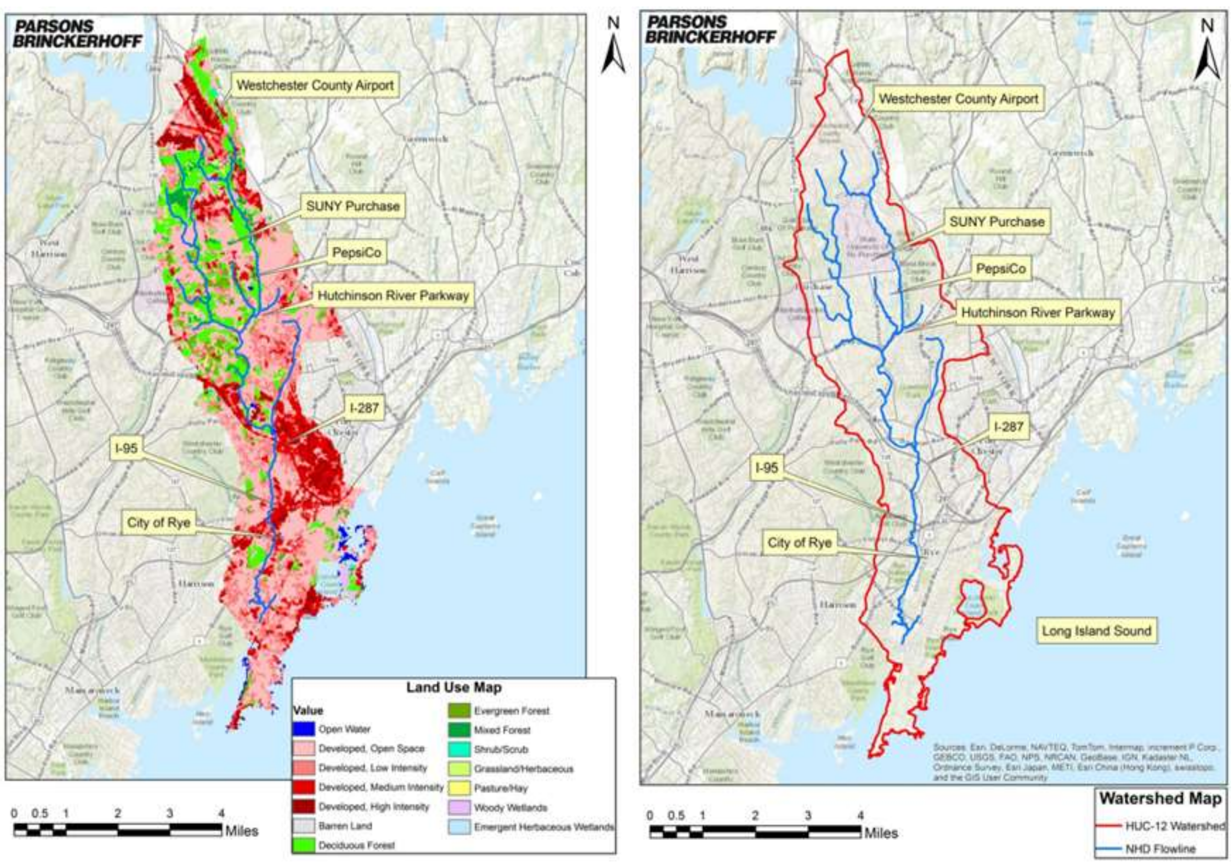

Figure 2 *Land use and watershed maps of the Blind Brook subwatershed (Parsons Brinkerhoff, 2014).*

Blind Brook is a coastal stream that is an important part of the Westchester ecological community. Two of its tributaries run on either side of the campus before they connect further south. Since Blind Brook flows into the Long Island Sound at Milton Harbor, it will contribute to the Sound's overall health. Blind Brook is listed as an impaired waterbody due to stormwater runoff (NYS DEC 2018). The Sound experiences eutrophication because of excess nutrients, so it is important to ensure Blind Brook is not further degraded. There are also many hectares of land in between Purchase and the harbor, leaving many areas that are susceptible to flooding. Areas downstream from Purchase, such as the City of Rye, have experienced regular flooding from Blind Brook, so it is important that any development done on the campus does not worsen this reality (Parsons Brinckerhoff, 2014).

Broadview Senior Living Facility

Purchase college has continued to develop since its original construction. Over the past decade, the college has added both residence halls and new academic buildings. As part of the College's "Think Wide Open" slogan and commitment to life-long learning, plans have been in progress since 2002 to build a residential senior living facility on the campus (Divney Tung Schwalbe 2017, Purchase College (1)). As of 2021, plans for the facility were approved, and building is expected to begin during the summer. Plans for the facility include spaces for students and residents of the facility to come together and learn from each other (Divney Tung Schwalbe 2017, Purchase College (1)). Specially constructed facilities ("The Learning Commons") will facilitate this inter-generational learning, where the campus community can come together for performances, scientific studies, and much more (Broadview Senior Living, n.d.). The college will run this facility as a non-profit, with 25% of the proceeds going to hire full-time faculty and the remaining 75% allocated as funding for student scholarships. The facility will also be a resource for student employment and new academic programs.

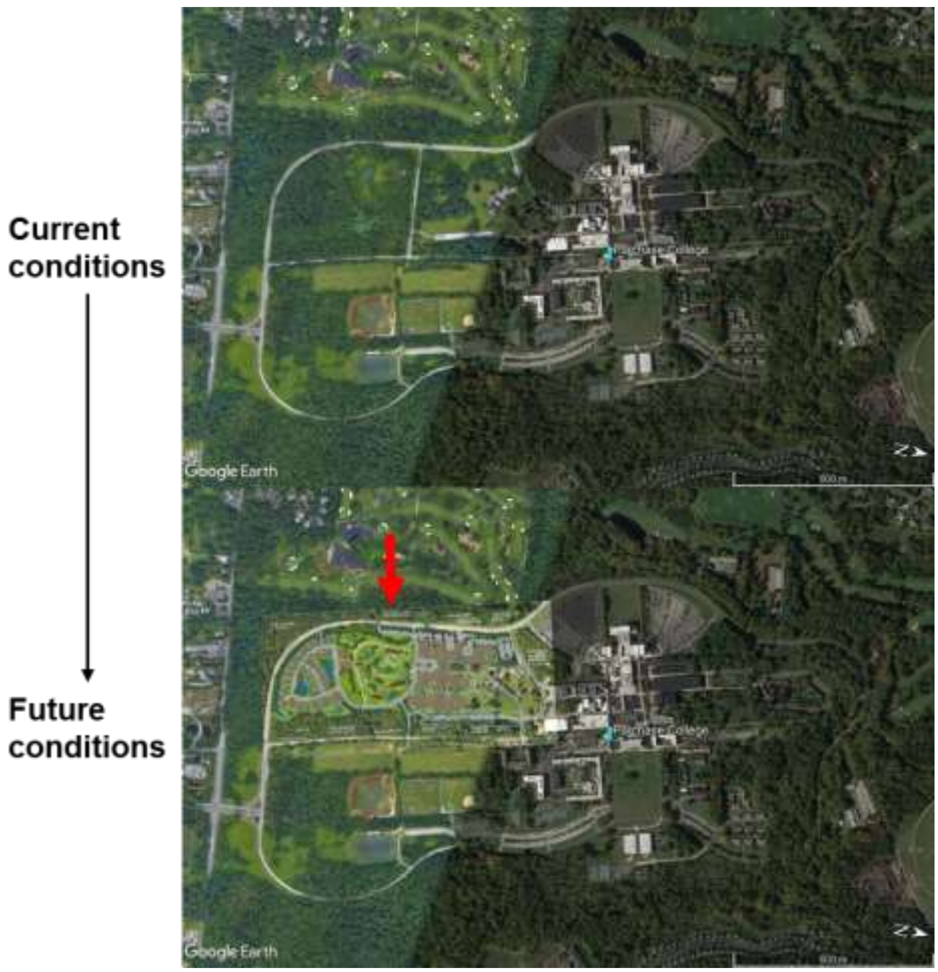

Figure 3 *Current conditions vs. future conditions on the Purchase campus.*

Broadview will be built on 40 previously undeveloped acres in the southwest portion of the campus (Divney Tung Schwalbe 2017) (figure 3). Construction will result in many land use changes, as the site currently contains woodlot that serves as habitat and food sources for local species and several wetlands, which are very sensitive to disturbances. The facility will have 385 residential units in total. 339 of those units will be in a four-story apartment building behind the admissions building. The remaining 46 units will be arranged in 29 single-story cottage-style buildings separated by a vegetated walking area (figure 4).

Figure 4 *An artist's rendering of the future Broadview facility layout (Divney Tung Schwalbe, 2017).*

Construction of Broadview will include several types of green infrastructure including rain gardens and green roofs to attempt to mitigate any harmful effects construction and the final facility may have (Divney Tung Schwalbe, 2017). The college has also pledged to set aside 80 acres of land that will be preserved and undeveloped as long as the college is in operation. The environmental impact statement for Broadview states that there may be long-term permanent impacts to stormwater because of the land cover changes. It also states that this increase in impervious surface will not worsen off-site flooding on the Blind Brook because of the green infrastructure being built.

Study Purpose

This study evaluates the current conditions of stormwater runoff on 8.62 undeveloped acres of the site that will be converted into the Broadview facility. It will serve as a basis for future studies with similar purposes after the facility is completed. It looks at three important characteristics of runoff: (1) the delay from the start of rain to the start of runoff (D_i), the delay from the beginning of runoff to peak runoff (D_p), and (3) the duration of the runoff (R_D). We would expect to see a large time difference between the mostly impervious West 2 site and the mostly vegetated East-West Road site where West 2 is the faster site.

Materials and Methods

Data Collection

Stormwater runoff quantity measurements were taken from the West 2 drainage pipe and the East-West Road drainage pipe (figure 5). Rain data was taken from the Weather Station located in the bioswale at the bottom of the West 1 parking lot in between East-West Road and West 2 (figure 5). The HOBO RX3000 sensors and weather stations were purchased through a grant given to the college by the Regional Economic Development Council and installed by Paola Valencia (ENV ’20) for her senior project (Tallaferro, 2015). Data was collected and stored remotely via the cloud and accessed on the HOBOlink website. This study took place over six months, from

May through October of 2020, to ensure there was no snowfall mixed in with the rain events. Maps of the campus and study sites were made using Google Earth Pro.

Figure 5 *Site and sensor locations on the Purchase campus.*

Site Descriptions

This study consists of two sample sites in the western half of the SUNY Purchase College campus (figure 5). The West 2 site consists primarily of asphalt parking lot in poor condition as well as a small section of vegetated area. The site is 8.85 acres in total. There are 7.73 acres (87.4%) of impervious asphalt and 1.11 acres (12.6%) of vegetated area covered in grass (figure 6).

Figure 6 *West 2 land cover types (green=vegetation, gray=asphalt).*

The East-West Road site consists primarily of vegetated woodlot but also includes part of the road and the runoff from the admissions building for the college. Impervious surface makes up 0.59 acre (6.9%) of the 8.62 acre site, while the other 8.03 acres (93.1%) consist of woodlot and grass patches (figure 7).

Figure 7 *East-West Road land cover types (green=vegetated area, gray/blue=impervious surface).*

Data Analysis

When the data collection portion of this study was complete, data from each sensor was downloaded and analyzed. For each month, all rain events were separated and analyzed for several factors. The weather station data was analyzed for the rain duration (minutes), average rain intensity (mm), peak rain amount (mm), total rain amount (mm) of each storm. The West 2 and East-West Road sensors were both analyzed against the weather station data for D_i (minutes). The sensors were analyzed individually for D_p (minutes) and for R_D (minutes).

Rain events were analyzed for significant differences in D_i, D_p, and R_D. The rain events were then categorized into small, medium, and large groups based on the total rain amount (mm), peak rain amount (mm), average rainfall (mm/10min), and rain duration (minutes) for each storm. The average of each small, medium, and large group was at least one standard deviation away from the average of every other group. Lastly, based on how many times a rain event was categorized as a small, medium, or large group, an index of storm sizes (small, medium, and large) was created and analyzed.

Once grouped, the data was normalized by $\log_{10}$ transformation and the data was loaded into RStudio for group analysis. RStudio was used to create boxplots, perform statistical tests, and visualize said statistical tests. Significance was set to be less than 0.05 for this study.

Results

Over the course of this study, 43 rain events were recorded and analyzed. Unpaired t-tests assessed the differences between East-West Road and West 2. Each characteristic of runoff had at least one statistically significant result.

Delay to Initial (D_i)

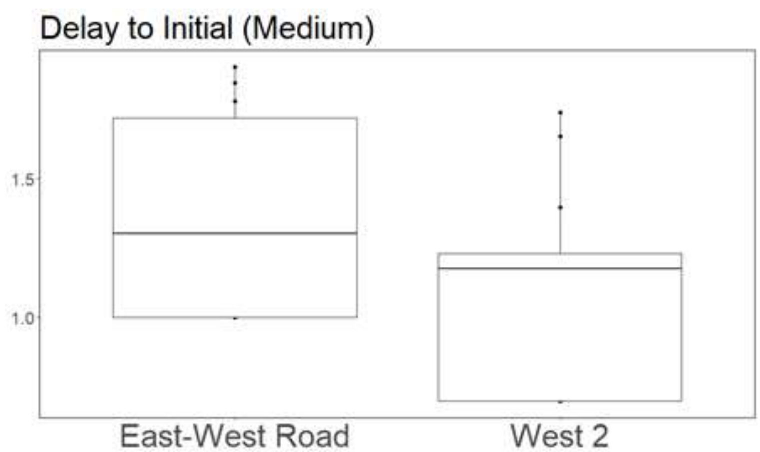

Figure 8 *The boxplot for D_i for medium sized storms.*

Unpaired t-tests showed significant results for D_i for only one out of 18 categories (figure 8). For medium-sized storms, there was a significant statistical difference in D_i between East-West Road and West 2 (unpaired t-test, t=2.31, P=0.028). The mean for

East-West Road (mean=1.4 + 0.15 CI, N=16) was larger than for West 2 (mean=1.12 + 0.15 CI, N=16).

Delay to Peak (D_p)

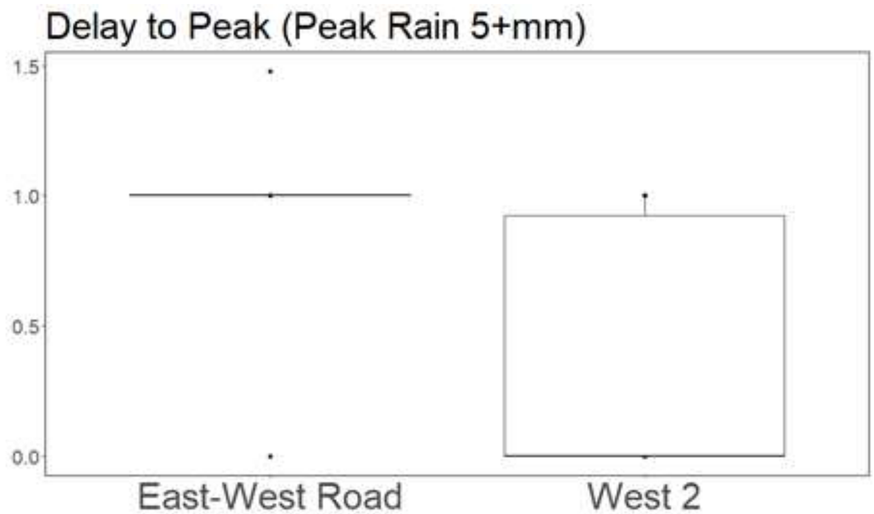

Figure 9 *The boxplot for D_p for peak rain greater than 5mm.*

T-tests for D_p showed significant results for rain events where the peak rain amount exceeded five millimeters (unpaired t-test, t=2.23, P=0.038) (figure 9). The mean D_p for East-West Road (mean=0.85 + 0.27 CI, N=10) was larger than for West 2 (mean=0.37 + 0.28 CI, N=10).

Runoff Duration (R_D)

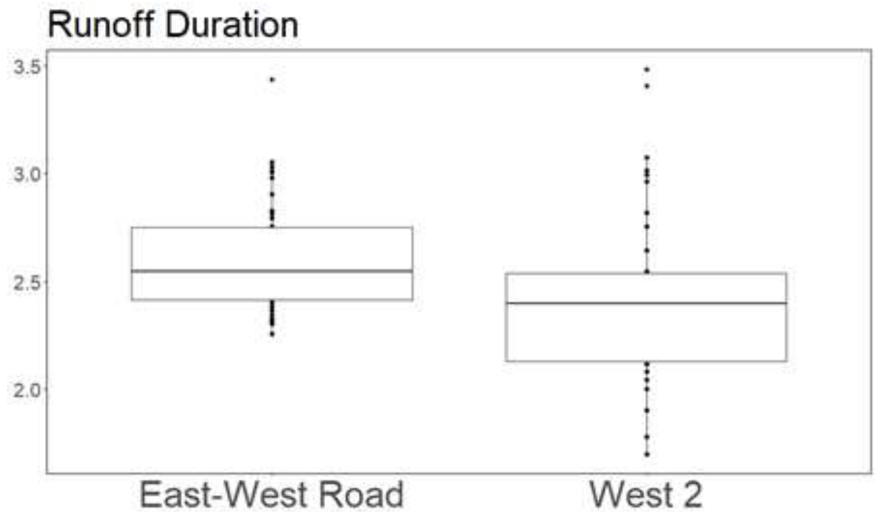

Figure 10 *The boxplot for R_D for all storms.*

For all 43 rain events R_D showed a significant statistical difference between East-West Road and West 2 (unpaired t-test, t=2.52, P=0.014) (figure 10). The mean R_D was larger for East-West Road (mean=2.6 + 0.07 CI, N=43) than it was for West 2 (mean=2.42 + 0.1 CI, N=43).

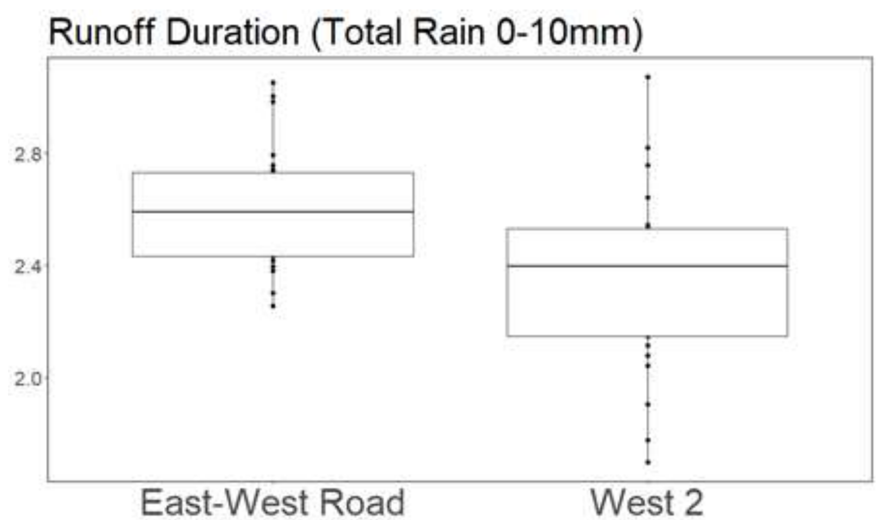

Figure 11 *The boxplot for R_D where total rain was between 0-10mm.*

Significant statistical difference in R_D was found for rain events where the total rain was between 0-10 millimeters (unpaired t-test, t=3.16, P=0.0029) (figure 11). The mean for East-West Road was larger (mean=2.59 + 0.07 CI, N=25) than the mean for West 2 (mean=2.35 + 0.11 CI, N=25).

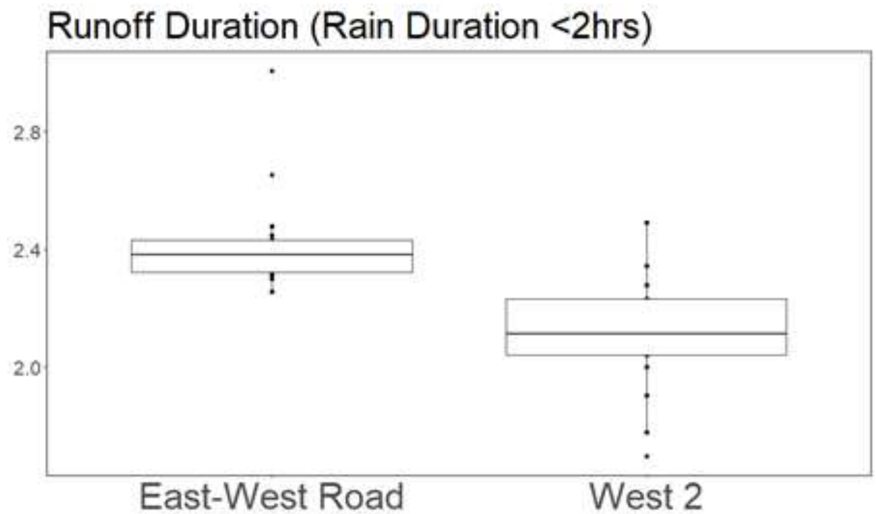

Figure 12 *The boxplot for R_D when rain duration was less than two hours (120 min).*

For rain events that lasted less than two hours (120 minutes), significant statistical difference between the two sensors was found (unpaired t-test, t=4.73, P= 4.54e-05) (figure 12). The mean for East-West Road was larger (mean=2.42 + 0.07 CI, N=17) than West 2 (mean=2.12 + 0.09 CI, N=17).

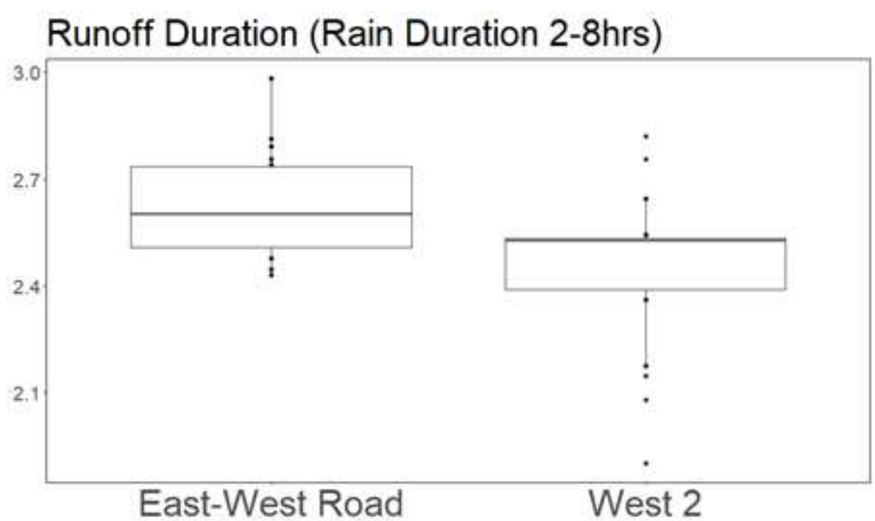

Figure 13 *The boxplot for R_D where rain duration was between two and eight hours (120-480min).*

For rain events that lasted between two and eight hours (120-480 minutes) significant statistical difference was found between the two sites (unpaired t-test, t=2.72, p=0.01) (figure 13). The mean R_D for East-West Road (mean=2.62 +0.06 CI, N=20) was larger than mean R_D for West 2 (mean=2.46 + 0.09 CI, N=20).

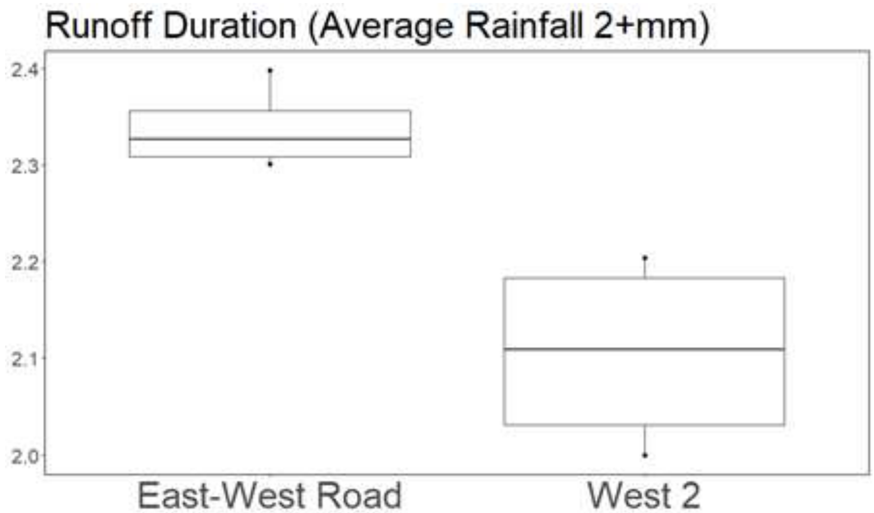

Figure 14 *The boxplot for R_D when average rainfall is greater than 2mm.*

For rain events that had a rainfall average greater than two millimeters, significant statistical difference was found (unpaired t-test, t=4.27, P=0.01) (figure 14). The R_D mean for East-West Road (mean=2.34 + 0.05 CI, N=4) was larger than for West 2 (mean=2.1 + .012 CI, N=4).

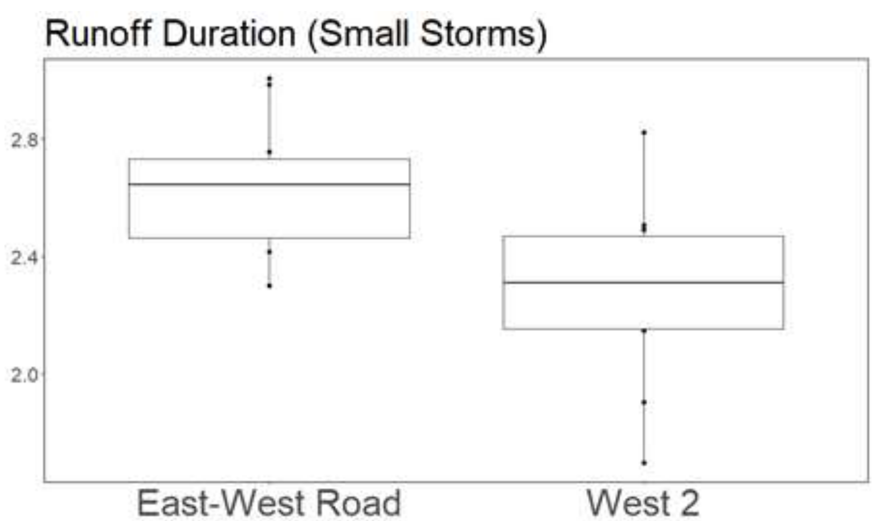

Figure 15 *The boxplot for R_D for small sized storms.*

For small storms, there was a significant statistical difference between both sites (unpaired t-test, t=2.94, P=0.009) (figure 15). The R_D mean for East-West Road (mean=2.64 + 0.13 CI, N=10) was larger than the R_D mean for West 2 (mean=2.28 + 0.18 CI, N=10).

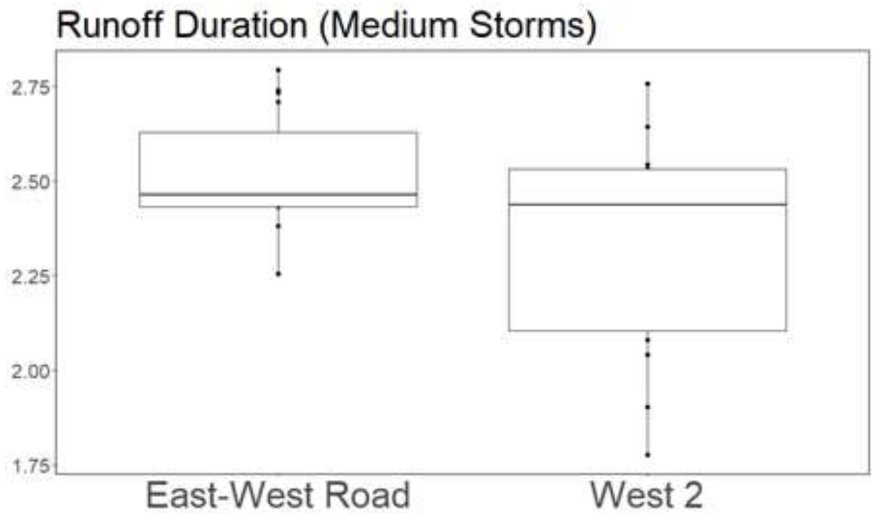

Figure 16 *The boxplot for R_D for medium sized storms.*

For medium-sized storms, there was a significant statistical difference between East-West Road and West 2 (unpaired t-test, t=2.51, P=0.02) (figure 16). The R_D mean for East-West Road (mean=2.53 + 0.07 CI, N=16) was larger than for West 2 (mean=2.32 + 0.13 CI, N=16).

Discussion

Current Conditions

The D_i results show that there is little statistical difference between the East-West Road site and West 2 site. There were many t-test results that indicated there is a practical difference in D_i between the two sites, but only one test returned a significant result.

A source of error here comes from the timing of data collection for all of the sensors used in this study. The Weather station and the East-West Road sensor both collected data every ten minutes starting on the hour (0:00, 0:10, 0:20, etc.). However, the West 2 sensor collected data every ten minutes starting on the five-minute mark of every hour (0:05, 0:15, 0:25, etc.). This discrepancy in data collection was out of the hands of the author and discovered too late to attempt to fix the collection times. The contrasting times of data collection would only affect D_i, because both D_p and R_D are not dependent on when they start and end. To account for the impact that the difference in data collection times would have on D_i, t-tests were run only for storms where the difference in D_i was greater than twenty minutes between the two sites. These tests showed no significant differences, so the original conclusions taken from that data do not change.

D_p measurements would not have been affected by the sensor collection discrepancy. Both sensors only sent data to the cloud every ten minutes, we do not know where in that ten minutes the start of runoff is. However, we can tell when the water in the pipe was reported at its highest and when it is gone completely. There were also many results for D_p that indicate there is a practical difference between East-West Road and West 2, but there was only one result that was significant.

R_D measurements would not have been affected by the sensor collection discrepancy for the same reason as D_p. R_D showed the most significant results, proving that there is both a practical and significant difference in runoff duration between the two sites where West 2 is faster than East-West Road.

The results of the t-tests for each grouping were affected by the number of samples in any given groups being compared. Some groups, such as the rain duration greater than eight hours (480 minutes) group, which only had six rain events to analyze.

Many of the *statistically* insignificant results indicate that there is a trend in East-West Road being faster than West 2. In this case unpaired t-tests can only show if there is a difference in time between the two sites. They can do nothing to tell us if there is a practical difference between the two sites. There was no observational component to this study because it had to be conducted remotely, so there is no way to know how Blind Brook responded to the differences in runoff rate. The change in impervious surface from building Broadview may be the tipping point to more regular flooding downstream from Purchase.

Effects of Current Conditions

There are several possibilities to explain why East-West Road and West 2 were more similar than what would be expected in perfect conditions. Many of these possibilities have to do with the East-West Road site.

East-West Road is not entirely vegetated area. 6.9% of the East-West Road site is impervious surface. Though this is a small portion of the site, those areas may start running off faster than the rest of the site and trigger the sensors earlier than if this had only been vegetated area. This would have been especially apparent in large storms and storms that had a large rainfall average. This would have only affected D_i, because water from that surface would start running off and reach the drainage pipe much quicker than the rest of the area would be expected to.

The East-West Road site is also on an incline of 3-8% (USDA 2017). The force of gravity would pull water down to the drain faster here than if the site had no slope like West 2. This would have made all three aspects of runoff D_i, D_p, and R_D faster even though most of the site is vegetated.

Urban soils are often very compacted (Fletcher et al. 2013). Compaction means that there is little to no space between the soil particles that water can move through. This can make them act much more like an impervious surface than undisturbed soils would. The type of soil will also play a part in determining how much water infiltrates or runs off. East-West Road consists of Paxton fine sandy loam (USDA 2017). This type of soil is well-drained, and moderately permeable in surface layers and less in subsurface layers (USDA, 2017; USDA, n.d.). The compaction combined with the moderately permeable soil surface means water would have trouble infiltrating whether the site was sloped or not. As a result, more water will become runoff instead of replenishing the water table.

The condition of West 2 (figure 17) may also have affected runoff times at that site. The runoff rates of impervious surfaces like asphalt have been shown to be 70 to 100% of water when the surface is pristine (Salt and Kjeldsen, 2018). West 2 is not a pristine surface. It has a reputation among students and staff to be full of

Figure 17 *A view of West 2 from the music building with red circles around examples of damage (February 2020).*

potholes that have only worsened every year through freeze-thawing in the colder months. The presence of cracks and other deformities in pavement has been shown to allow infiltration into the ground below (Salt and Kjeldsen, 2018; Redfern, 2016). This means that the infiltration rate of impervious areas increases as there are more cracks and other deformities. Water ponding in potholes and infiltrating through large cracks would have slowed D_p and R_D at West 2, making it more similar to East-West Road.

Future Changes and Predictions

When Broadview is completed, there will be large changes to the whole East-West Road site (figure 18). For the whole area there will be an increase in impervious surface from 0.59 acres in total to 4.77 acres total. This is a 709% impervious surface increase in just the East-West Road site. The whole facility will be much larger (refer to Figure 3) and will have major implications for runoff in other areas of campus as well.

Figure 18 *Current East-West Road conditions vs. future changes in land use and impervious surface. Green= vegetated areas, gray/blue= impervious surface*

Since the approximate change in impervious surface is known, the new amount of impervious surface can be used to calculate future runoff conditions. Calculations were done by taking the current time difference and dividing it by the difference in impervious area between the two sites. That number was then multiplied by the difference in future and current impervious area at the East-West Road site. The result of that calculation was subtracted from the current East-West Road time average and that result was the prediction of future runoff time. In all cases where there was a significant result, these future calculations were done. Every instance shows a result where D_i, D_p, and R_D would be faster than what they are now (figure 19, figure 20, figure 21). Average runoff time was reduced by 25% overall, but ranged from 7.79% for R_D for all storms and 39.1% for D_p when peak rain is greater than 5mm.

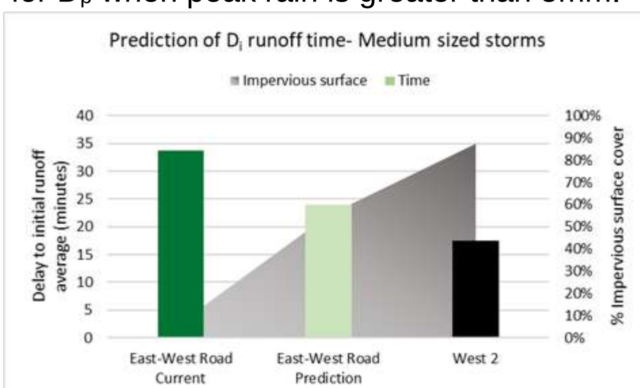

Figure 19 *Future prediction of D_i for medium storms, a 28.97% decrease in runoff time.*

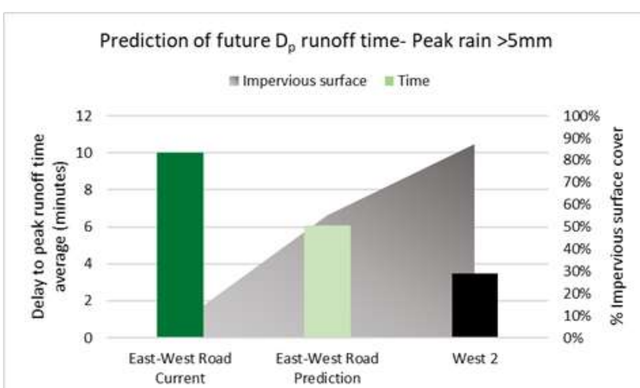

Figure 20 *Future prediction of D_p when peak rain exceeds 5mm, a 39.1% decrease in runoff time.*

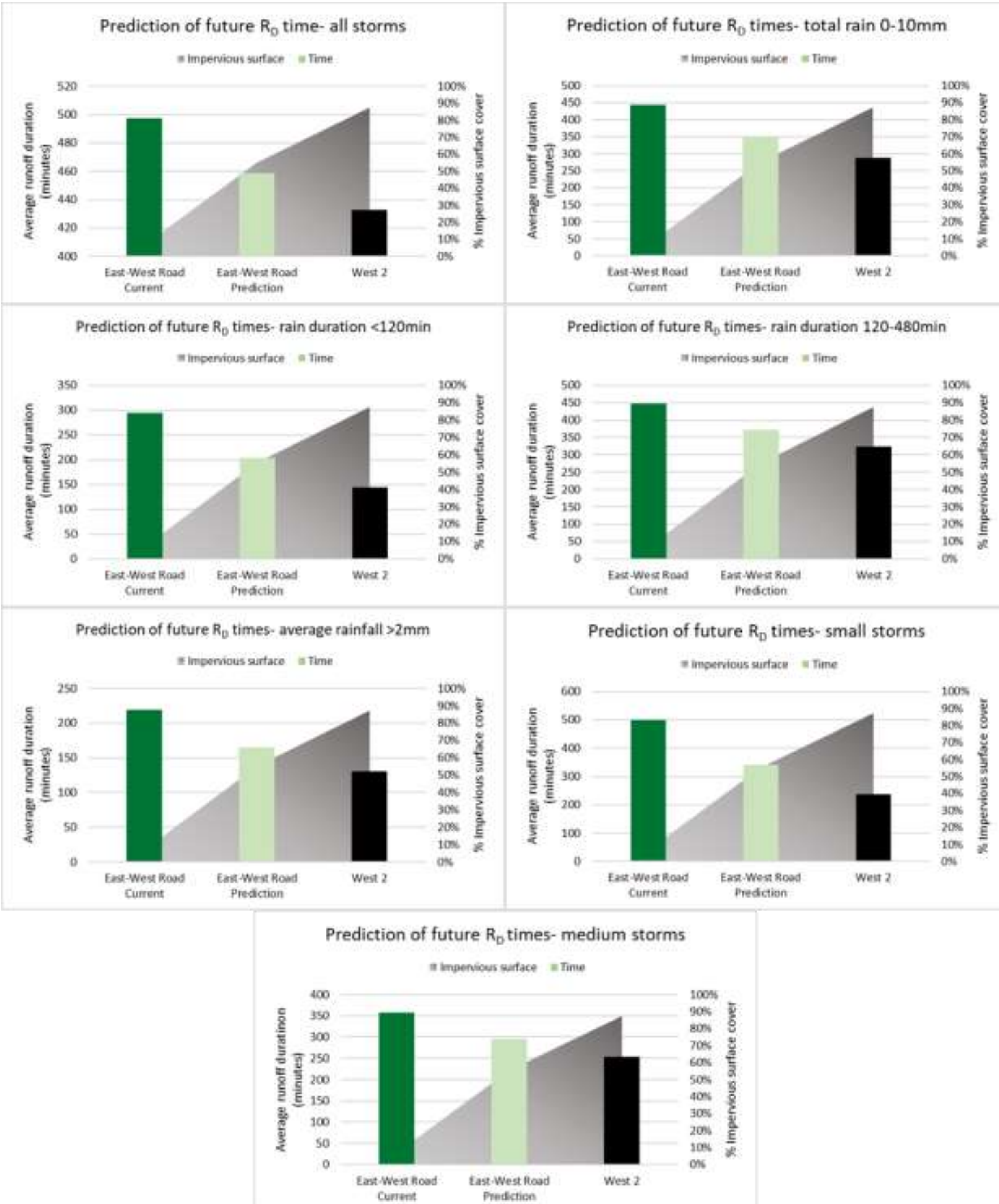

Figure 21 *Future prediction of R_D for 7 groups of storms. A 7.79%, 21.1%, 30.69%, 16.72%, 24.39%,31.56% and 17.52% decrease in runoff times, respectively.*

Conclusions

We cannot let future development further degrade the ecosystems around us. This study shows that there are instances of significant and indications of practical differences between East-West Road and West 2. Both are important for determining the health and flood frequencies of Blind Brook. Slower runoff times are the goal, to prevent downstream flooding and allow for water tables to regenerate, as well as to prevent sedimentation and polluting of local waterbodies. Increased building will lead to permanent changes to stormwater runoff and building a new facility on the Purchase campus is no exception to that rule. In a few years, we will be able to see if the green infrastructure being built with the senior living facility is effective and whether the changes to runoff time predicted here are accurate.

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