# Effective Impervious Area for the City of Minnetonka


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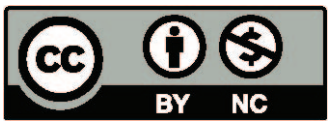


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## Executive Summary

Effective Impervious Area (EIA) is the percentage of area in a given watershed that contributes to outflow volume within a given pipeshed during a storm event. EIA is of concern for urban hydrologists as the volume of water that flows into the underground pipeshed compared to the volume of rainfall over a given watershed can affect many aspects of stormwater management. If too much water flows into the pipeshed for a given event flooding can occur. Also, storm water which is received from an impervious area has a much greater possibility of containing high levels of pollutants, sediment, and other contaminants of interest. This water often discharges downstream without receiving treatment before entering the receiving water body. Precipitation which falls upon pervious land has a greater chance of infiltration, and therefore has a lower possibility of causing harm to nearby bodies of water.

Effective impervious area is also needed in a variety of engineering applications. Specifically, the EIA is needed as an input when modeling infiltration rate, outflow volume, and a variety of other watershed aspects in computer programs such as the Storm Water Management Model (SWMM).

The EIA was found for two areas of Minnetonka for which we had flow monitoring data; one residential and one commercial. The results for EIA were then applied to larger watersheds within Minnetonka to give an estimate of the EIA for areas which did not have flow monitoring data.

For this work two different methods to determine EIA were used; the GIS method and the method of Boyd et. al. The method of Boyd et. al took into account flow monitoring data and runoff volumes and was used as a more accurate approach to finding EIA as it accounted for only the sections of the watershed that contributed runoff directly into the pipeshed. The GIS method was a more simple approach and did not require any field data but only accounted for the total impervious areas of the watershed, rather than the connected impervious areas. As a result, the percent difference between the method of Boyd et. al and the GIS method was used as a calibration when determining the EIA using what was obtained from the GIS method for the larger area of the Minnetonka watershed.

## 1. Introduction

The reason for performing effective impervious area (EIA) studies is to better understand certain aspects of watershed analysis. By having a more accurate estimation of EIA, the problems in a watershed can then be dealt with properly. Also, EIA is a very important parameter when modeling a watershed in computer programs such as Storm Water Management Model (SWMM).

Impervious areas contained in watersheds are of particular concern for engineers. These areas effect many aspects of stormwater management. Stormwater which is received from impervious area has a much greater possibility of containing high levels of pollutants, sediment, and other contaminants of interest. This is due to the fact that precipitation which falls on impervious land travels rapidly to receiving bodies of water. Because storm sewers are in place to transport water from impervious areas, this water often goes without receiving treatment before entering the receiving water body.

Precipitation which falls upon pervious land has a much greater chance of infiltration, and therefore has a lower possibility of causing harm to nearby bodies of water. Thus, having or creating a watershed with substantial amounts of pervious land is both beneficial and desired for stormwater quality. Infiltration practices are being introduced to many watersheds which contain large amounts of impervious land cover. By routing runoff from impervious areas to some type of infiltration practice, the amount of runoff which runs directly from impervious areas to receiving water bodies can be reduced. This approach deals with changing the amount of impervious area which is directly connected to storm sewers and therefore is also connected to the receiving water bodies. This connected impervious area is often referred to as effective impervious area. Implementing practices to change the EIA can be very beneficial to the receiving water body of a watershed as far as water quality.

Impervious areas of concern in the Lake Minnetonka watershed include but are not limited to streets, driveways, parking lots, rooftops, and patios. It can easily be seen that the main contributors to the total impervious area are concrete and asphalt structures along with rooftops. However, the EIA is more helpful and insightful in the watershed study than total impervious area. Estimation of the EIA of the watershed was addressed in two separate ways.

The first method for determining the EIA was through rain gauge and runoff data (Boyd et al.,1993). Rainfall-runoff data and flow monitoring locations were provided for one residential and one commercial area located in the city of Minnetonka. Through comparison of the precipitation and rainfall-runoff data, a relationship between the two could be developed. By using Boyd's method, this relationship was developed and the outcome was a best fit estimation of EIA.

The second method used was a GIS based approach using satellite images to estimate the EIA(Han and Burian, 2009). Using ArcGIS and the tools provided within the program, the impervious sections of the watershed could be identified. The impervious land areas could be compared with the total area of the two locations previously mentioned. From this an estimate of EIA could be developed.

Finally, the two approaches for EIA estimation were compared to verify results. Also, the difference between the Boyd method and GIS method was found in order to enable use of the GIS approach across non-monitored areas. By knowing how much error the GIS approach contained in comparison the Boyd method in the commercial and residential areas with provided monitoring data, the GIS approach could be used to determine estimations of EIA in different areas. This allowed an estimation of EIA for surrounding areas with similar land usage to be found, even though precipitation and runoff monitoring data was only provided for these two relatively small areas within the watershed.

# 2. Methodology

## 2.1 GIS Analysis

Geographic Information Systems (GIS) is a tool which allows visualization of data on a map to see patterns in a given area of land. Traditionally GIS has been used for geographically related topics such as urban planning, cartography, and environmental impact assessment reports as each require the synthesis of geographic consideration and quantitative analysis.

With respect to this study, GIS was used to determine the percent area of land that will route rainfall from a given storm event to become runoff into the drainage system without infiltrating into the soil, also known as the Effective Impervious Area (EIA). The method to accomplish this task was proposed by Han and Burian (2009). Specifically, given an area of land different layers could be created within GIS to separate what would be considered to allow infiltration or what areas produce runoff directly routed to storm sewers. If a given portion of land produced impervious runoff (i.e. rainfall onto roadway and flows directly into catch basin), a polygon under the impervious layer was created and delineated so that it covered the entirety of the portion of land that covered the impervious area. This process was repeated over every segment of land within the watershed given that would produce runoff into gutters, catch basins, or open sewers and compared to the total area of land to give the percent impervious area for the watershed given.

The types of land considered as impervious and produce runoff directly into the underground pipe system were roadways, sidewalks, rooftops, pools, and patios. Two areas of land, one commercial (Hedberg Drive) and one residential (Tapestry Lane), within Minnetonka were analyzed. As the commercial segment had a higher density of roadways, sidewalks, and buildings it was assumed that it would provide a higher percent impervious area than the residential watershed. Images of the watersheds taken into account can be seen in figures 3 and 8 of the report.
Below is an example displaying impervious areas that were quantified according to the aerial images.

Figure 1: Example of impervious areas shown in GIS

As the commercial segment had a higher density of roadways, sidewalks, and buildings it was assumed that it would provide a higher percent impervious area than the residential area. Images of the watersheds taken into account can be seen in figures 3 and 8.

Once the impervious areas were found for the commercial and residential areas, GIS was used again to determine impervious areas for larger areas of the Minnetonka watershed. Within this larger area, commercial and residential areas were separated by the EAI found using the Boyd method corresponding to that type of development and applied to that respective area in order to provide consistent results.

## 2.2 Method of Boyd et. al

The method produced by Boyd et. al (1993) determines EIA given rainfall depth and runoff depth data collected in the field. Upon constructing a plot of the rainfall depth and runoff depth using integrated data from each storm, a best fit line can be produced. The slope of this best fit line corresponds to the percent of watershed area giving flow to the outlet, also known as the percent EIA (see figures 1 and 2).

This work used runoff depth data taken from fourteen storms of which seven applied to the commercial and seven to the residential areas. Rainfall depth data was collected by a single rain gauge which was close enough to each the commercial and residential areas so that the numbers could be used for both. The runoff volume was then obtained from given flow monitoring data and converted to a depth using the area of the watershed and the duration of the storm.

As recommended by the Method of Boyd et. al, Points more than 2 mm above the best fit line were taken out of the data as they represent data in which the effective impervious area of land is not the major contributing factor to runoff, but could rather be attributed to something such as rainfall intensity. Thus, finding the optimal regression line (and therefore EIA) was an iterative process as the slope was to be recalculated after the exclusions which could result in further data eliminations that needed to be made.

Once the EIA area was calculated using the method of Boyd et. al, it was then compared to that found using the GIS method, using the method of Boyd et. al as a more "true" value as it takes into account the connected impervious area (EIA), whereas the GIS method gives the entire impervious area of the watershed. The comparison was implemented by applying the percent difference in EIA found between the Boyd method and GIS method for the watersheds with monitoring data available to the larger watersheds which did not have monitoring data.

# 3. Results

## 3.1 Boyd Method Results

### 3.1a Commercial Area (Hedburg Drive)

After completing the Boyd method for the commercial area around Hedburg Drive we were able to see the data and its corresponding effective impervious area. After plotting all 14 storms and running a regression line through the data, it can be seen in Figure 1 that the data correlates well to be 99.4%. The slope to the linear function corresponding to our data points will provide the estimated effective impervious area. It is estimated that the commercial area has a 54.7% effective impervious area. Having a 54.7% EIA makes sense because the area is commercial with large impervious areas of roadways and parking lots.

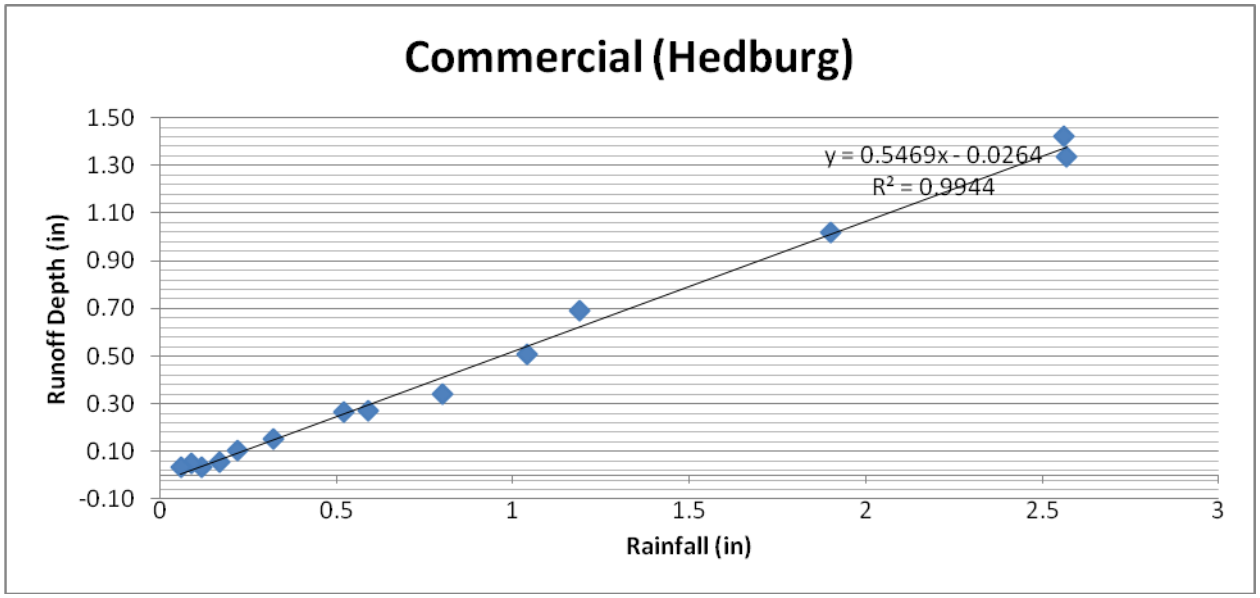


Figure 1: Commercial (Hedburg Drive) Boyd method results

| | |
|---|---|
| Boyd Method Effective Impervious Area [%] | 54.7 |

*Slope of line correspond to effective impervious area, with each point corresponding to a storm event
**Data from each storm can be seen in appendix of report

### 3.1b Residential Area (Tapestry Lane)

After completing the Boyd method for the residential area around Tapestry Lane we were able to see the data and its corresponding effective impervious area. After plotting all 14 storms but excluding 3 from the from the regression line, it can be seen in Figure 1 that the data correlates well to be 99%. Excluding these three storms was an iterative process. To begin, only one storm (7/17/10) was excluded and then a regression line was fitted. A second storm (8/31/10) was excluded and a regression line was fitted again. Finally a third storm (9/2/10) was excluded and a regression line was fitted to be 99%. After excluding the three storms it is estimated that the commercial area has a 17.7% effective impervious area. The results shown make sense considering that this area is a residential area with many lawns and areas that have pervious ground.

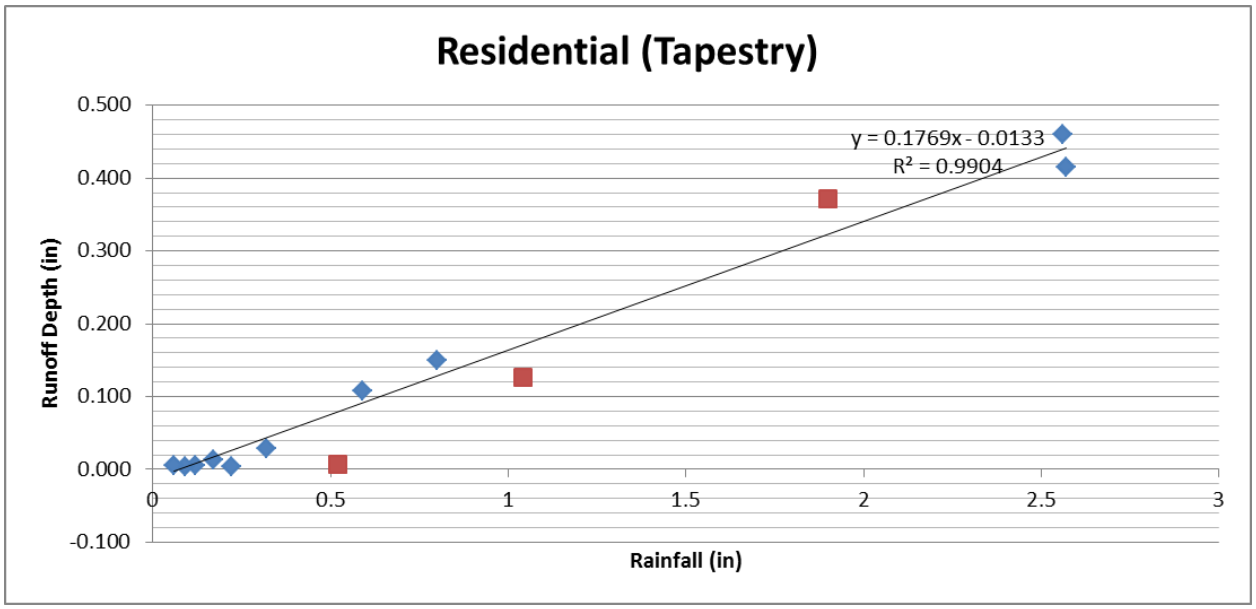


Figure 2: Residential (Tapestry Lane) Boyd method results

| | |
|---|---|
| Boyd Method Effective Impervious Area [%] | 17.7 |

*Slope of line correspond to effective impervious area, with each point corresponding to a storm event
**Data from each storm can be seen in appendix of report
***Excluding Storms (red data points): 7/17/2010, 8/31/2010, 9/2/2010

## 3.2 GIS Results

### 3.2a Commercial Area (Hedburg Drive)

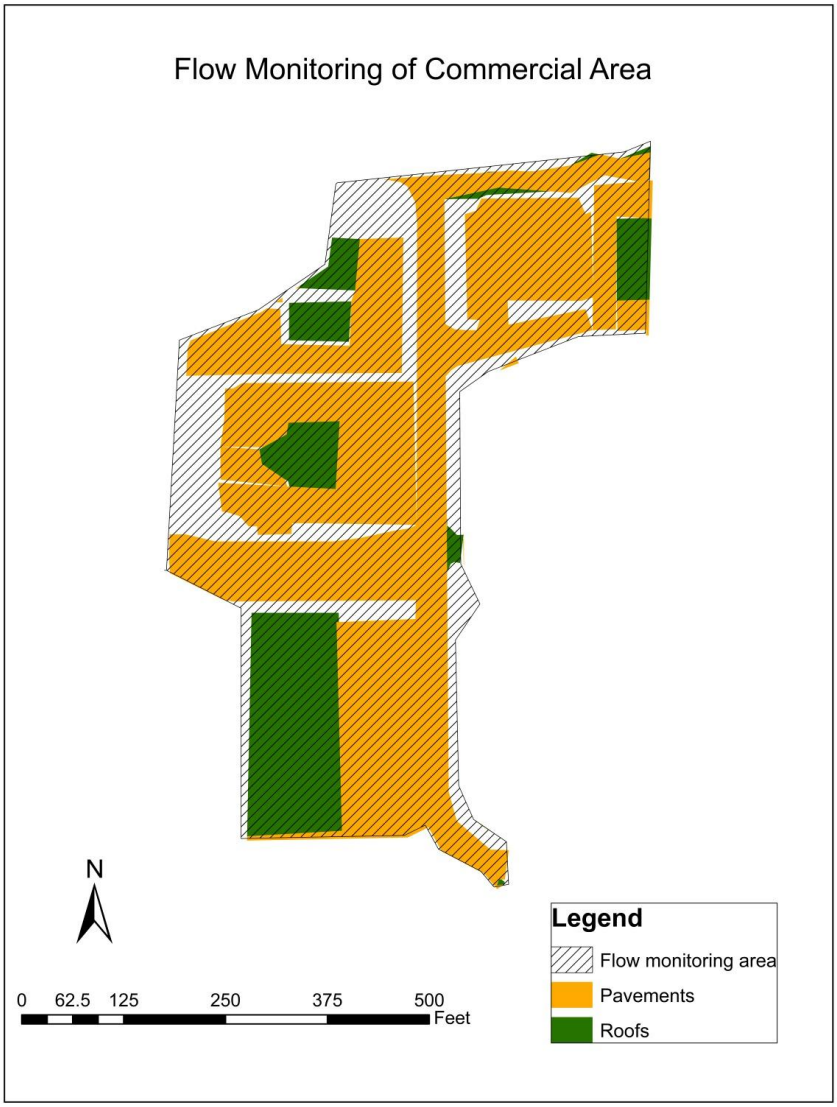


Figure 3: Hedberg Drive (commercial) area GIS method results

Table 1: Commercial monitored area results

| Surface | Area(ft^2) |
|---|---|
| Roof | 61669 |
| Pavement | 198934 |
| Impervious | 260603 |
| Total | 297159 |
| | Percentage(%) |
| GIS Percent Impervious(%) | 87.7 |
| Ratio | .623214 |

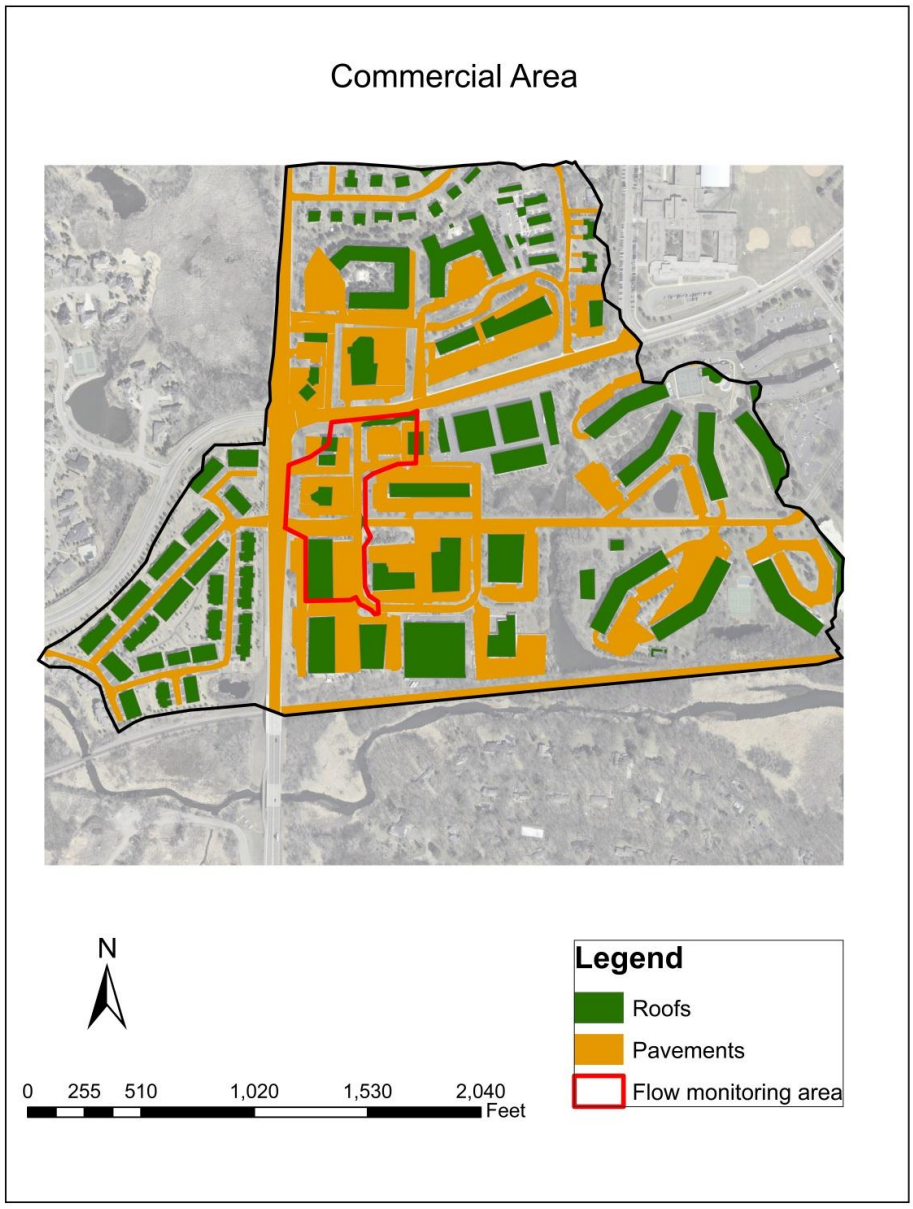


Figure 4: Extended commerial area GIS method results

Table 2: Extended commercial area results

| Surface | Area(ft^2) |
|---|---|
| Roof | 5641616 |
| Pavement | 919948 |
| Impervious | 1481564 |
| Total | 2644762 |
| | Percentage(%) |
| GIS Percent Impervious(%) | 56 |
| Corrected GIS EIA(%) | 34.9 |
| Ratio | 0.623214 |

### 3.2b Residential Area (Tapestry Lane)

Figure 5: Tapestry Lane GIS method results

Table 3: Residential area results

| Surface | Area(ft^2) |
|---|---|
| Road | 163435 |
| Roof | 118342 |
| Total Impervious | 281777 |
| Total Area | 1190578 |
| | Percentage(%) |
| GIS Percent Impervious(%) | 23.7 |
| Ratio | 0.746835 |

Figure 6: Residential (Tapestry Lane) extended GIS method results

Table 4: Residential extended area results

| Surface | Area(ft^2) |
|---|---|
| Road | 636509 |
| Roof | 565308 |
| Total Impervious | 1201817 |
| Total Area | 53253643 |
| | Percentage (%) |
| GIS Percent Impervious | 22.6 |
| Corrected GIS EIA | 16.9 |
| Ratio | 0.746835743 |

## 4. Discussion

Using the method of Boyd et al. it was found that the effective impervious areas for the commercial and residential areas were 54.7% and 17.7% respectively. We took these results to be more accurate than those found using GIS as they took into account actual precipitation volume and outflow data from various storms. Though the method of Boyd et. al gave a better approximation of the EIA and was simple to use if the rainfall and runoff depths were known, it did not provide insight into which areas within the watershed contributed to impervious runoff. If future projects similar to this are to be completed by the City of Minnetonka it is recommended that this method be used given that monitoring is available and that an acceptable number of storms have been recorded for the area to be analyzed. Various sources of error also can occur using the method of Boyd et. al from things such as depression storage in the watershed which reduces runoff volume at the outlet, if the soil was saturated at the time of sampling causing less infiltration into the soil, or if the rainfall for the storms observed had a high intensity causing runoff from the pervious areas.

Concerning the number of storms available for this study, it is known that more storms would yield much more reliable results. All watersheds should be considered for improving monitoring systems. Gathering precipitation and runoff data for as many storms as possible would greatly benefit in the task of estimation EIA for engineers. Our recommendation to the City of Minnetonka would be to increase the amount, location, and use of monitoring in as many places as possible in order to develop EIA estimates as effectively as possible and counter the issues surrounding problematic EIA values moving forward. However, if further monitoring data would be too expensive to implement, it is suggested that the city use all monitored data already collected at different locations and further implement the methods outlined in this work to find the EIA.

The GIS method gave results of 53.4% and 23.7% for the commercial and residential areas respectively. These results were then calibrated using the results of the Boyd method to give a more accurate approximation of the effective impervious areas found for various large portions of the Minnetonka watershed that corresponded to either a commercial or residential area. The numbers corresponding to the larger areas of the Minnetonka watershed can be seen in the GIS method results section and can be used to better understand the watershed and give an approximation of the EIA when modeling watershed characteristics in a computer program such as the Storm Water Management Model (SWMM). The calibration was completed merely by applying the percent difference in EIA found between the Boyd method and GIS method for the watersheds with monitoring data available to the larger watersheds which did not have monitoring data. The effective impervious areas for these watersheds can be seen in the results section of this work. The use of the GIS method is recommended only if sufficient monitoring data is not available as an estimate of EIA can be given by merely determining what is assumed to be connected impervious on GIS and comparing with the entire watershed area. However, error can occur while using the GIS method as choosing what is connected impervious is subjective and can be hard to determine as trees and other coverings can block the aerial view of the land.

It was expected that the GIS method would yield larger numbers for EIA than Boyd. This is due to the fact that GIS, in its most basic form, is mainly capable of quantifying total impervious area. Boyd method is used to find EIA, and thus is used to correlate the GIS data’s. The GIS data can then be calibrated with Boyd method data to find reasonable estimates of EIA from total impervious area from satellite images.

## 5. References

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2. Boyd, M.J. *Pervious and Impervious Runoff in Urban Catchments*. Diss. University of Wollongong, 2009. Print.

3. Han, WS, and SJ Burian. *Determining effective impervious area for urban hydrologic modeling*. Journal of Hydrologic Engineering, 14(2): 111-120. 2009. Print.

# 6.Appendix

| | | Storm | | | | | | | | | | | | | |
|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|---|
| | | 17-Jul | 23-Jul | 24-Jul | 27-Jul | 8-Aug | 10-Aug | 8/12-8/13 | 13-Aug | 14-Aug | 20-Aug | 24-Aug | 31-Aug | 2-Sep | 9/2-20/2019 |
| | | Total Precipitation P (in) | | | | | | | | | | | | | |
| | | 1.04 | 0.12 | 0.8 | 0.59 | 0.17 | 2.57 | 2.56 | 0.22 | 0.09 | 0.06 | 0.32 | 0.52 | 1.19 | 1.9 |
| Total Runoff Q (cfs) | Tapestry (Res) | 208.785 | 9.27 | 248.407 | 178.021 | 21.203 | 685.103 | 760.004 | 7.476 | 7.242 | 9.465 | 47.426 | 11.141 | 288.162 | 614.942 |
| | Hedburg (Comm) | 209.767 | 14.257 | 139.729 | 112.459 | 22.678 | 551.235 | 587.093 | 42.791 | 19.765 | 13.789 | 62.407 | 109.411 | 284.398 | 419.896 |
| Delta t (s) | Residential | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| | Commercial | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 | 60 |
| Runoff Depth (in) | Tapestry (Res) | 0.126 | 0.006 | 0.150 | 0.108 | 0.013 | 0.414 | 0.460 | 0.005 | 0.004 | 0.006 | 0.029 | 0.007 | 0.174 | 0.372 |
| | Hedburg (Comm) | 0.51 | 0.03 | 0.34 | 0.27 | 0.05 | 1.34 | 1.42 | 0.10 | 0.05 | 0.03 | 0.15 | 0.27 | 0.69 | 1.02 |

Table: Boyd method storm data