ENVISIONING THE POSSIBILITIES OF A DIGITAL CITY:
A CASE STUDY OF RAIN GARDENS AS FLOOD CONTROL IN AUSTIN, TEXAS

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INTRODUCTION

With the advent of new technologies such as Lidar, it has become increasingly possible and cost effective to gather high resolution geographic data. The scientific community is now presented with the opportunity to use this data to explore and answer questions that were previously un-answerable or that could not be answered to a very accurate degree. This report provides an in depth analysis of one way Lidar data can be used. The potential for rain gardens to attenuate 100-year flooding is examined through a case study of the detention pond on Great Northern Boulevard in Austin, Texas. Additionally, a brief discussion is included of other uses for high resolution 3D data and lessons learned from this project.

CASE STUDY

The question of rain gardens as flood control is explored through the analysis of a detention pond located on Great Northern Boulevard, near the intersection of MOPAC and Far West Boulevard. The pond is located within the HUC-12 watershed number 12-0902050306, drains to Shoal Creek and is owned by the City of Austin. See Figure 1. *The specific question asked is: Could this detention pond be replaced by rain gardens located at single family homes within the pond's watershed?* In accordance with City of Austin design standards (Reference 1), it is assumed that the pond attenuates runoff from 100-year storm events. Thus, the equivalent system of rain gardens would also provide protection from 100-year flooding.

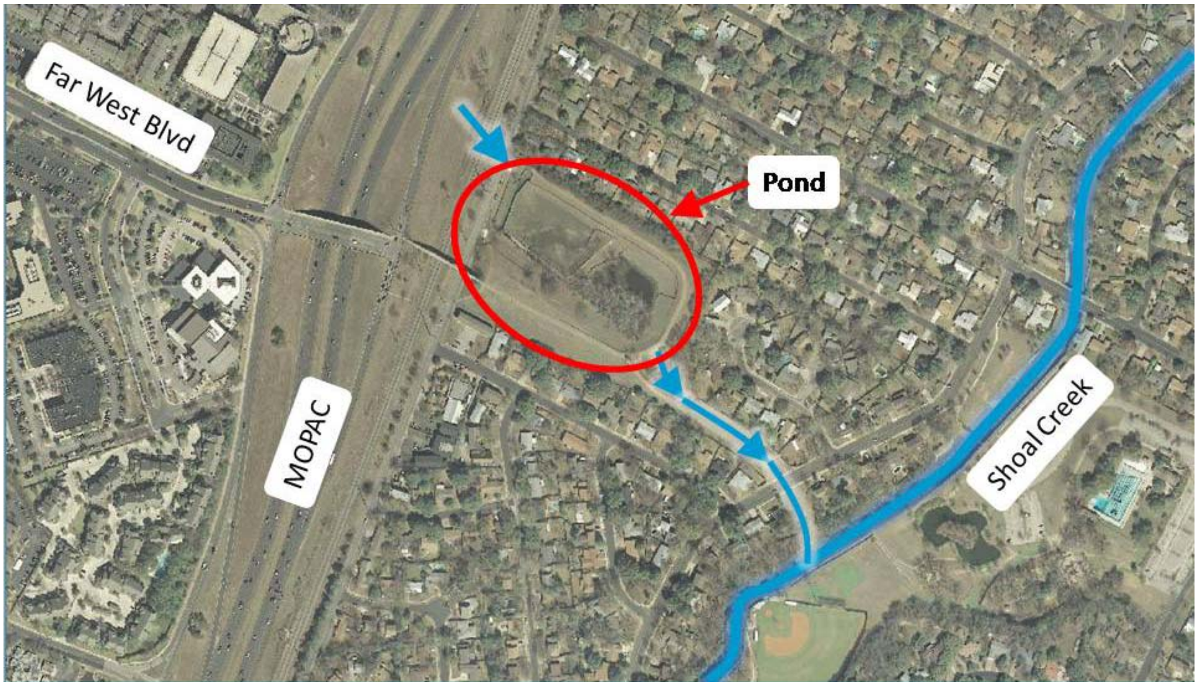

Figure 1: Detention Pond Location Map

Historical Flooding

Historical stream flow data was acquired through Cuahsi's HydroDesktop program and is displayed below (Figure 2, Reference 2). The red circle indicates peak flow from the Memorial Day floods of 1981, the worst flooding disaster Austin has endured in recent memory. During this storm, Shoal Creek experienced 100-year flooding and many homes in the immediate pond vicinity were severely flooded. This graph also demonstrates the ephemeral nature of many streams in Texas; periods of low or no flow are followed by large peak flows lasting for short periods of time.

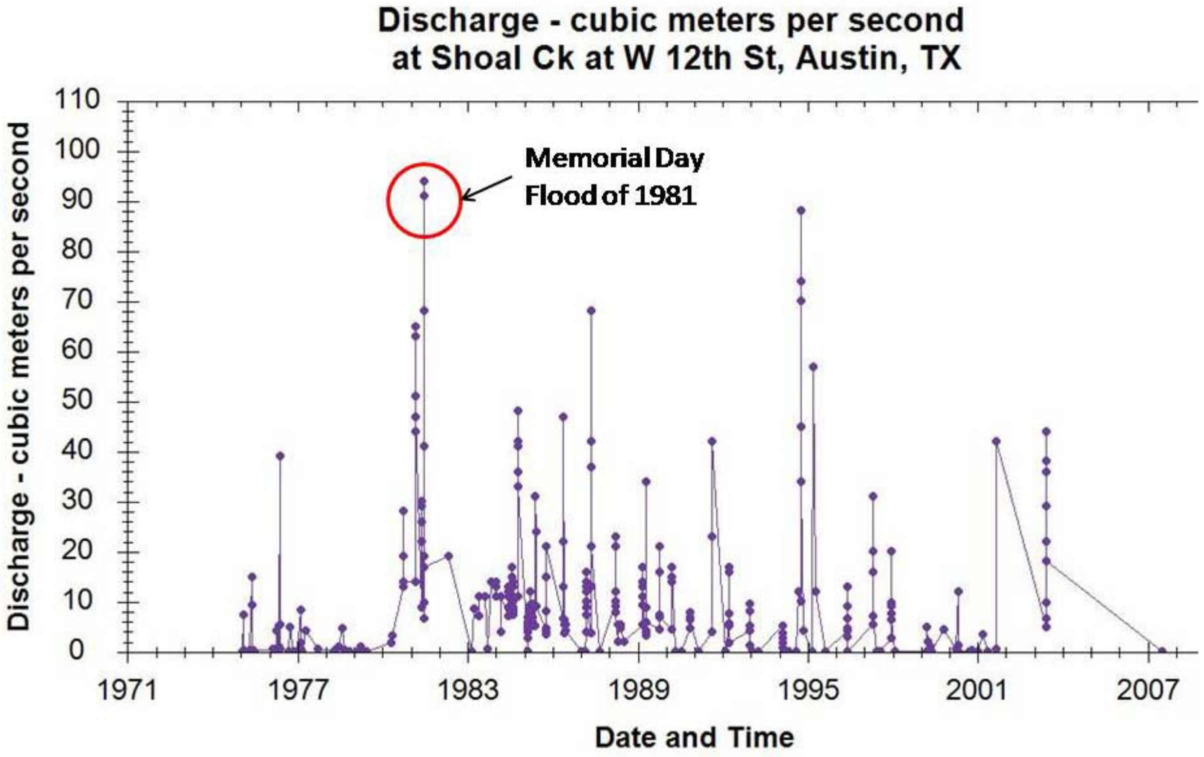

Figure 2: Historical Flooding at Shoal Creek and 12th Street

Data

All data used in this project is available publically. Lidar and aerial image files were downloaded from the Capital Area Council of Governments, an organization of central Texas public entities and governments that hosts elevation data for the area (Reference 3). Stream line, land use, building footprint and transportation feature shape files were acquired from the City of Austin GIS Data Sets website (Reference 4).

Watershed Analysis

To determine if the pond can be replaced by rain gardens, the pond watershed area and volume were needed. Calculating the pond watershed involved the following steps:

1. <u>Convert Lidar files to a Digital Elevation Model (DEM)</u> The Lidar file resolution was 1.8 meters (approximately 6 feet), so the first conversion to raster used a cell size of 6 feet.

However, there remained too many No Data cells. The raster cell size was increased until only a few No Data cells remained; the final cell size was 15 feet (Figure 3).

2. <u>Recondition DEM with stream lines and AGREE method</u> City of Austin vector stream lines were converted to a raster file and the DEM was reconditioned by "carving" the AGREE cross-section along these stream lines. The AGREE method cross-section presented by Dr. Tarboton (Reference 5) was scaled to a reasonable width for the stream flowing into the pond (Figure 4). Green space along the stream was measured from aerial images to determine an approximate stream width of 50 feet. This was used as the AGREE cross-section width.
3. <u>Flow Accumulation and watershed delineation</u> After pits in the reconditioned DEM were filled, D8 flow direction and flow accumulation rasters were created (Figure 5). From the flow accumulation raster, the watershed draining to the pond inlet was delineated (Figure 6).

The pond watershed area is 107 acres.

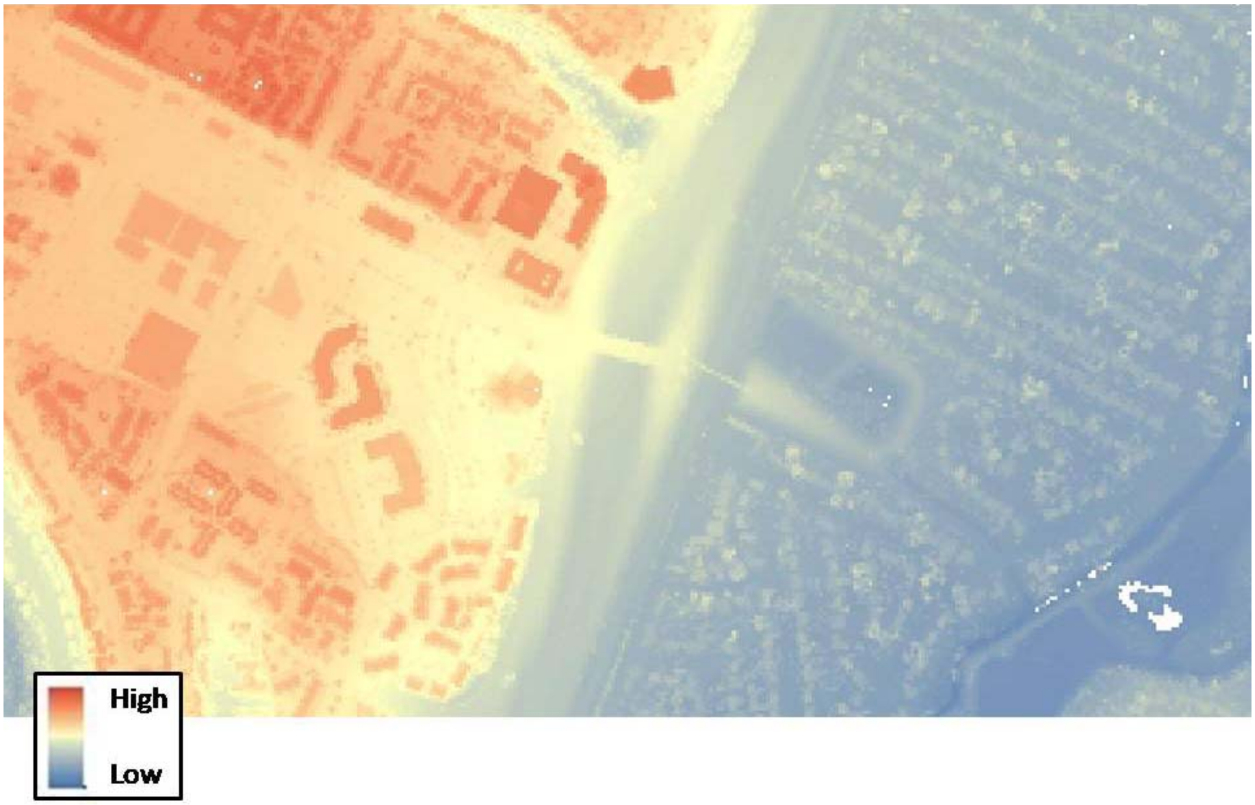

Figure 3: Digital Elevation Model (DEM) created from Lidar files

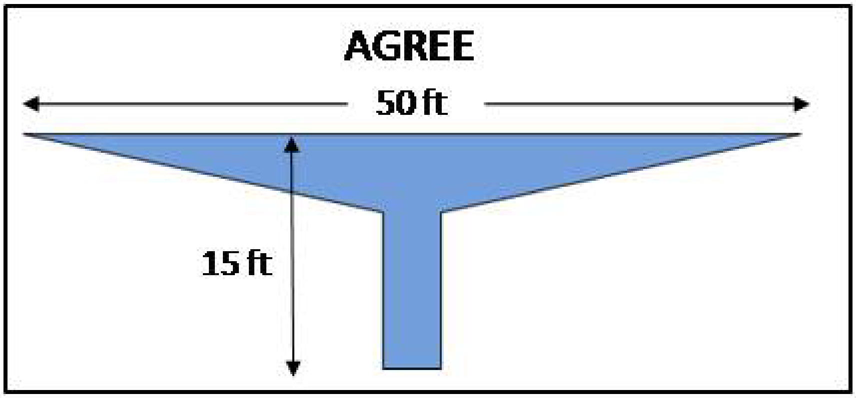

Figure 4: AGREE Method Cross-section

Figure 5: Flow Accumulation Raster

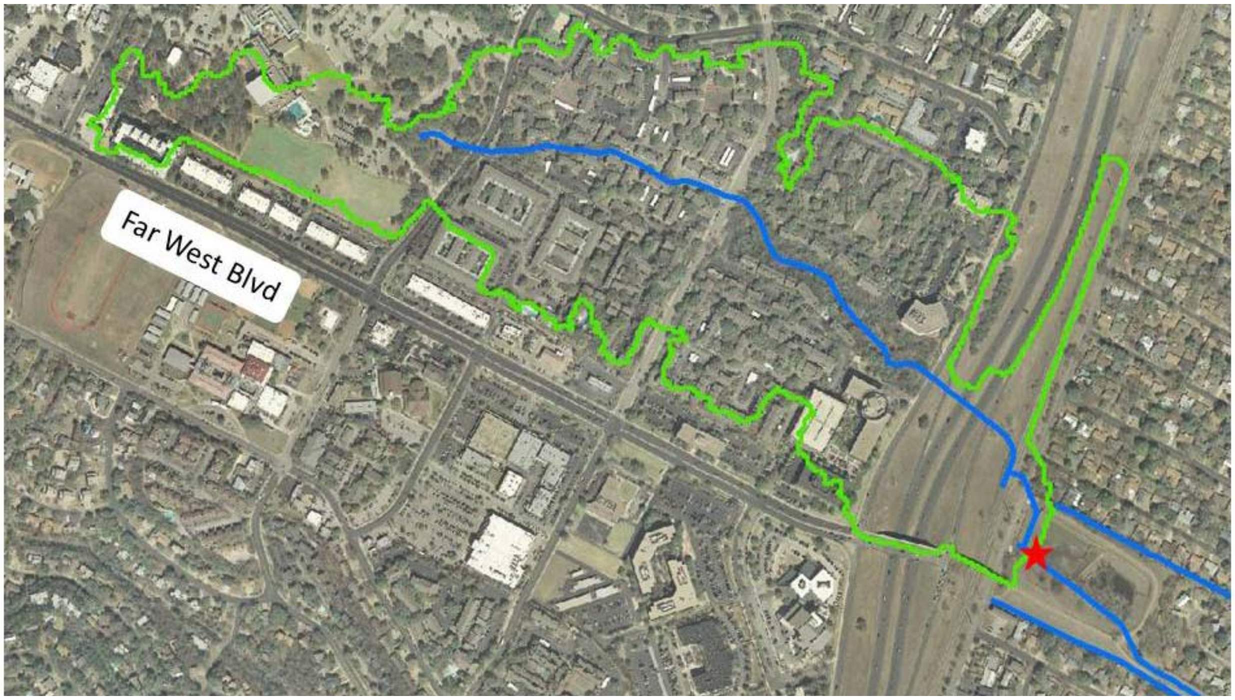

Figure 6: Pond Watershed Boundary

Detention Pond Analysis

Pond volume was calculated using the ArcGIS Cut and Fill tool. This tool subtracts one DEM from another and tabulates results as cut (positive values) or fill (negative values). First, an artificial DEM was created with an elevation of 10 feet for all cells except those at the pond. Pond cells were given an elevation equal to the outflow weir elevation. This artificial DEM was subtracted from the original DEM and the resulting fill volume represents the pond volume (Figure 7).

The pond volume is 2.06×10^6 cubic feet.

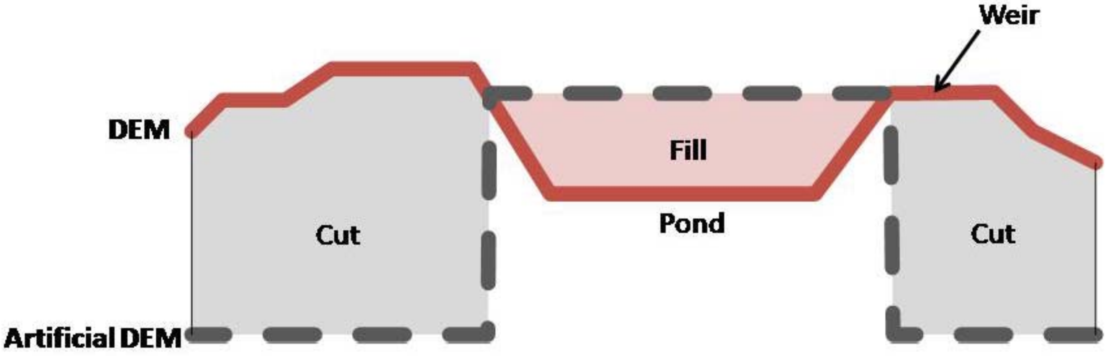

Figure 7: Cross-section for Cut and Fill Tool

Watershed Land Use

In order to determine the feasibility of replacing the pond with rain gardens at single family homes, the City of Austin land use files were examined with the intent of determining the area of single family lots within the watershed. However, the land use files reveal that there are no single family homes within the watershed. The largest land use type is Multi-family Housing followed by Civic use, Roads and Office space (Figure 8, Reference 6).

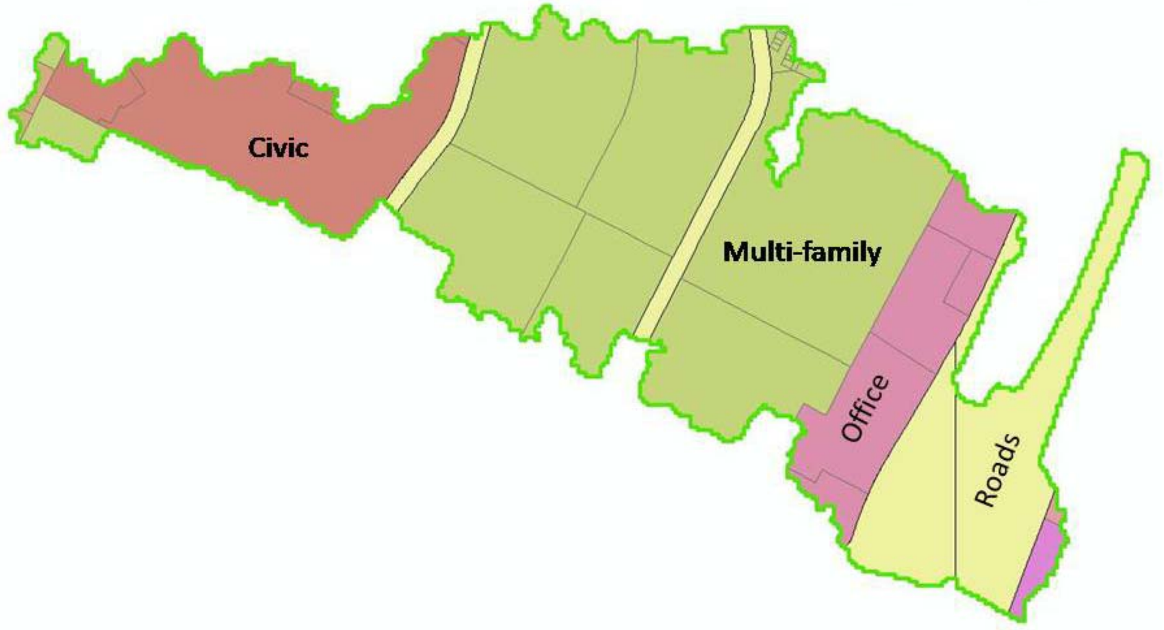

Figure 8: Pond Watershed Land Use Types

Revised case study questions

Due to land use differing significantly from the anticipated results, the original case study question was revised. Certainly, rain gardens can be constructed at commercial property as a means of attenuating storm water runoff. And, a typical rain garden located on a single family lot can be analyzed for comparison.

<u>Revised Question #1</u>: Can rain gardens located on commercial property replace the detention pond?

<u>Revised Question #2</u>: Can a rain garden located at a typical single family lot attenuate 100-year flooding?

Typical Rain Garden Design

Before proceeding further, a typical rain garden design is needed. The chosen design is based on technical guidelines published by the Low Impact Development Center in Maryland (Reference 7). The design allows for a maximum of 4 inches of standing water above 30 inches of soil (0.2 porosity). Water leaves the garden through an underdrain system with the assumption that water does not infiltrate into the soil below (Figure 9).

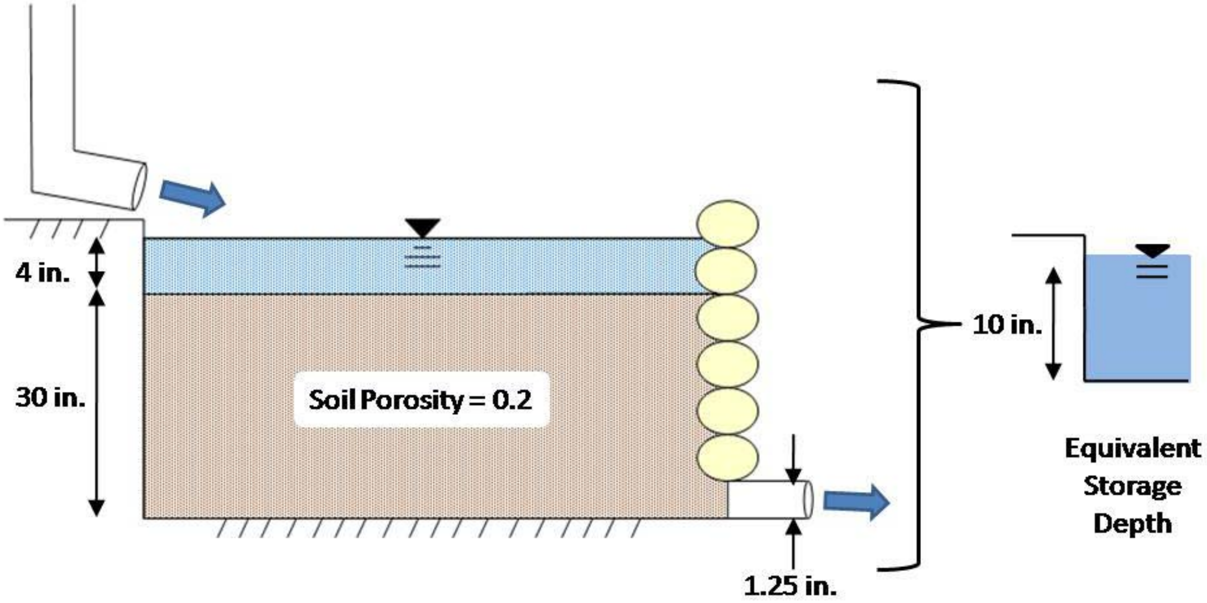

Figure 9: Typical Rain Garden Design

Feasibility Assessment: Rain Gardens and Commercial Property
To determine if replacing the pond with rain gardens is realistic, the required area of rain gardens was calculated and found to be 56.8 acres. This area was divided by the total watershed area to obtain the average percent of area that rain gardens would cover in order to attenuate 100-year flooding, which was 53%. Finally, the average percent of pervious cover per lot was calculated. It was assumed that pervious cover is the amount of space available for constructing rain gardens without undertaking expensive measures such as reconfiguring or removing buildings or parking lots. The pervious cover percent was 56%. See calculations in Figure 10.

Pond Volume	2,062,863	ft^3	From GIS Cut and Fill tool
Equivalent Rain Garden Depth	0.83	ft	From RG design
Required Rain Garden Area	2,475,435	ft^3	Pond Vol / RG depth
	56.8	acres	
Total Watershed Area	106.7	acres	From GIS
Rain Garden Area as Percent of Total Watershed Area	**53%**		RG acres / Watershed acres

Total Pervious Cover Area on Lots	2,441,547	ft^2	From GIS
Watershed Lot Area	4,355,380	ft^2	From GIS
Pervious Cover as percent of Watershed Lot Area	**56%**		Pervious Cover / Lot Area

Figure 10: Pond and Rain Garden Calculations

In order to replace the pond, for a give 100 units of space, 53 units need to be covered by rain garden. And, those 53 units need to fit into an available space of 56 units. This is not very realistic; there would certainly be pervious area, such as under trees, that would not be available for rain garden construction on a practical level.

Feasibility Assessment: Rain Gardens and Sample Single Family Home
For comparison, a typical single family home was analyzed to determine if a rain garden that attenuates 100-year flow to pre-development conditions would realistically fit within available space. The home chosen is located several blocks north of the pond and is inhabited by this report's author. Although this house is not located within the pond's watershed, it is typical of homes and lot sizes within the watershed.

Analysis began by converting the City of Austin 100-year design storm, given in terms of cumulative rainfall depth, to intensities at regular time intervals (Figure 11 and Reference 8).

Time hr	Cumulative Precipitation Depth In	Incremental Precipitation Depth in	Intensity in/hr	Pre-Develop Q cfs	Post-Develop Q cfs
0	0	0	0	0	0
0.25	2.29	2.29	9.16	0.2136	0.6094
0.5	3.04	0.75	3.00	0.0700	0.1996
1	4.37	1.33	2.66	0.0620	0.1770
2	5.66	1.29	1.29	0.0301	0.0858
3	6.11	0.45	0.45	0.0105	0.0299

Figure 11: 100-year Storm

Next, the roof area was calculated from the City of Austin building footprint file (Figure 12). For this analysis, only runoff from the roof is considered.

Figure 12: Sample Single Family Home Footprint, Area is 2987.5 ft^2

Then, the Rational Method was used to calculate roof runoff and results using two different C values were plotted. First, flow was calculated using a C value corresponding to "roofs". Then, to model pre-development conditions, flow was calculated for a C value corresponding to "pasture land" (Reference 9). See Figure 11 above. Finally, a rain garden was sized by routing the roof runoff hydrograph though the typical rain garden design using Level Pool Routing. To simplify these calculations, soil suction head and hydraulic conductivity were neglected and the rain garden was modeled as a reservoir with the equivalent storage depth of 10 inches. The resulting rain garden was 800 square feet. See Figure 13 and Reference 12.

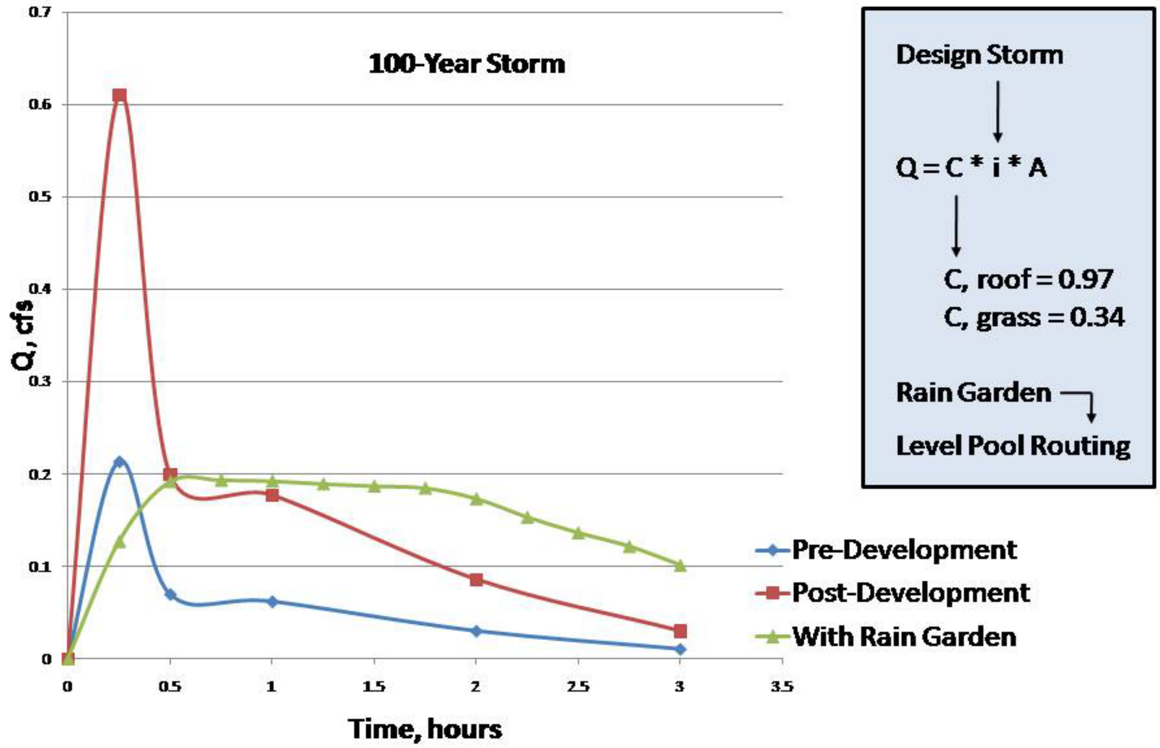

Figure 13: Outflow Hydrographs for Sample Single Family Home

To determine feasibility, the rain garden area as a percent of available lot space was calculated. The result, 12% of useable lot area needed for rain garden, is within the realm of realistic for a quarter acre single family lot with a 1900 square foot house. See Figure 14 below.

Roof Area =	2987.5	ft^2	From GIS
Lot Area =	10863	ft^2	From GIS
Driveway Area =	990	ft^2	From GIS
Lot Area Available for Rain Garden =	6885.5	ft^2	Roof Area - Lot Area - DW Area
Rain Garden Area =	800	ft^2	From Level Pool Routing
Rain Garden as Percent of Available Lot Area=	**12%**		RG Area / Lot Area Available

Figure 14: Sample Single Family Home Rain Garden Calculations

Case Study Conclusions

Although rain gardens are often marketed to the single family homeowner as suggestions for re-landscaping a yard with the intent of attenuating 2- to 10-year flows, this study shows that more is possible. A rain garden sized to accommodate roof runoff from 100-year storms and reduce outflow to pre-developed conditions could certainly fit on a typical ¼ acre single family lot with a medium sized house (approx. 2000 square feet for central Austin, Reference 10).

For commercial property, the ability of rain gardens to detain 100-year flow is less realistic since less of the lot space is available for rain garden construction. In this case, other options such as pervious paving and roof gardens should be considered. Additionally, more complex rain gardens could provide more storage for less area, making highly engineered rain gardens a more realistic option.

Finally, two important aspects of flood control must also be considered. Certainly, flood control structures require maintenance in order to provide the design level of flood protection. And, it may not be prudent to expect individual homeowners to maintain rain gardens that protect their downstream neighbors from flooding; as homes are bought and sold, subsequent owners may not even know what constitutes proper maintenance. It would be easier to ensure correct maintenance at centralized flood control structures, such as the case study detention pond. Secondly, rain gardens would not address water quality from road runoff. Even if rain gardens sufficiently attenuate and filter runoff from individual lots, there may still be a need to include water quality ponds at downstream points.

POSSIBILITIES FOR A DIGITAL CITY

This project provides one example of the types of questions that can be explored with publically available high resolution elevation data. Other areas for investigation include air quality and transportation (Reference 11). A 3D digital model of buildings would provide a means to calculate exchange rates between indoor and outdoor air and thus, analyze the energy consumption of buildings, which accounts for approximately 40% of greenhouse emissions. Transportation issues could also be explored more thoroughly trough a digital model of the entire city. As mandated by the Americans with Disabilities Act, the Texas Accessibility Standards stipulate x, y and z restrictions on sidewalk slopes and other accessible features. However, there is no time component analysis of accessible paths. With a full 3D model of the city, the travel time between locations (not just within one property) could be studied. And, this could be studied for different types of travelers: wheelchair users, folks that can walk but not use stairs, etc. An analysis of this type on the city-wide level could help decide how to best allocate transportation funds.

Finally, one important lesson from this project is to consider the data that was not offered publically. Design information about the pond was not available and was not included in calculations. As a result, calculations may not accurately reflect the required detention volume. Also, neither the pond nor the replacement system of rain gardens was analyzed with design software to determine the outflow hydrographs. In light of this, it is most prudent to consider the exploration of this specific report topic to be preliminary. Likewise, other questions that can be explored with GIS and publically available data may rely on similar assumptions. Despite potential inaccuracies these assumptions may cause, this type of relatively quick investigation can still provide valuable preliminary information for the purpose of directing how larger and more expensive studies are conducted.

REFERENCES

Reference 1: City of Austin. "Drainage Criteria Manual Section 1.2.2." Last updated December 2010. http://austintech.amlegal.com/nxt/gateway.dll/Texas/drainage/cityofaustintexasdrainagecriteriamanual?f=templates$fn=default.htm$3.0$vid=amlegal:austin_drainage$anc=

Reference 2: Consortium of Universities for the Advancement of Hydrologic Science, Inc. "HydroDesktop." Last edited Nov 8 at 5:34 PM by jirikadlec2, version 53. http://hydrodesktop.codeplex.com/

Reference 3: Capital Area Council of Governments. "Information Clearinghouse." Accessed October 2011. http://www.capcog.org/information-clearinghouse/geospatial-data/

Reference 4: City of Austin. "GIS Data Sets." Accessed October 2011 ftp://ftp.ci.austin.tx.us/GIS-Data/Regional/coa_gis.html

Reference 5: Tarboton, David G. 2011. "Session 9: Watershed and Stream Network Delineation Using DEMs" and "Session 10: Exercise 4 – Watershed and Stream Network Delineation." Lecture for CE 394K.3 GIS in Water Resources, Fall 2011, University of Texas at Austin. http://www.caee.utexas.edu/prof/maidment/giswr2011/giswr2011.htm

Reference 6: City of Austin. "Land Use Survey Methodology." Accessed October 2011. http://www.ci.austin.tx.us/landuse/survey.htm#gis

Reference 7: Low Impact Development Center. "Rain Garden Design Templates." Last updated February 11, 2008. http://www.lowimpactdevelopment.org/raingarden_design/templates.htm

Reference 8: City of Austin. "Drainage Criteria Manual Appendix B, Table 1." Last updated December 2010.
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Reference 9: City of Austin. "Drainage Criteria Manual Table 2-2." Last updated December 2010.
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Reference 10: City of Austin. "Single Family House Size Data: Trends and Existing Conditions for Austin Neighborhoods." Accessed November 2011.
http://www.ci.austin.tx.us/demographics/downloads/house_sizes3.pdf

Reference 11: Special thanks to Dr. Corsi, UT Civil Engineering Professor, and Amanda Hickman, NYC Transportation Advocate, for discussions that shaped this paragraph.

Reference 12: Rain Garden Level Pool Routing Calculations – See next page

Reference 12: Rain Garden Level Pool Routing

Pond Bottom Elev = 1 ft
Pond Bottom Area = 800 ft^2
Pond Top Elev = 1.83 ft
Pond Top Area = 800 ft^2
# of Low Level Outlets (N) = 5
Elev of Low Level Outlets = 1 ft
Dia of Low Level Outlets = 1.25 in 0.1 ft
Orifice Coefficient (Cd) = 0.8
gravity = 32.2 ft/s^2

Delta T (DT) = 15 min 900 sec

Delta Elev = 0.10375 ft
Delta Area = 0 ft^2

Delta Elev = (Top Elev - Bot Elev)/8
Delta Area = Top Area = Bot Area

Q LLO = N*Cd*A*(2gh)^.5

Q Weir = Cw*L*H^(3/2)

Q Total = Outflow
S = Cum Vol

										2S/DT + O
	Elev	**Bot Area**	**Top Area**	**Avg Area**	**Vol**	**Cum Vol (S)**	**Q LLO**	**Q Weir**	**Q Total**	**2S/DT +Q**
Bottom	1.00	N/A	800	N/A	0	0	0.000	0.0	0.000	0.000
S1	1.10	800	800	800	83	83	0.062	0.0	0.062	0.247
S2	1.21	800	800	800	83	166	0.108	0.0	0.108	0.477
S3	1.31	800	800	800	83	249	0.139	0.0	0.139	0.693
S4	1.42	800	800	800	83	332	0.165	0.0	0.165	0.903
S5	1.52	800	800	800	83	415	0.187	0.0	0.187	1.109
S6	1.62	800	800	800	83	498	0.207	0.0	0.207	1.313
S7	1.73	800	800	800	83	581	0.225	0.0	0.225	1.516
S8	1.83	800	800	800	83	664	0.241	0.0	0.241	1.717

Reference 12: Rain Garden Level Pool Routing

(Inflow1 + Inflow2) + (2*S1/DT - Outflow1) = (2*S2/DT) + (Outflow2)

Time (hrs)	Time (mins)	Inflow	Inflow1+Inflow2	2*S1/DT-O1	2*S2/DT + 02	O2	2*S2/DT
0	0	0	0	0.00	0.00	0.000	0.00
0.25	15	0.6094	0.6094	0.00	0.6094	0.127	0.48
0.50	30	0.1996	0.8090	0.36	1.1640	0.192	0.97
0.75	45	0.1996	0.3992	0.78	1.1788	0.194	0.99
1.00	60	0.1770	0.3765	0.79	1.1681	0.193	0.98
1.25	75	0.1770	0.3539	0.78	1.1369	0.190	0.95
1.50	90	0.1770	0.3539	0.76	1.1117	0.187	0.92
1.75	105	0.1770	0.3539	0.74	1.0913	0.185	0.91
2.00	120	0.0858	0.2628	0.72	0.9842	0.174	0.81
2.25	135	0.0858	0.1716	0.64	0.8088	0.153	0.66
2.50	150	0.0858	0.1716	0.50	0.6736	0.137	0.54
2.75	165	0.0858	0.1716	0.40	0.5723	0.122	0.45
3.00	180	0.0299	0.1158	0.33	0.4445	0.101	0.34