City of Flagstaff
Drywell Feasibility Study

November 13th, 2020

Matthew Scragg, Tanner Fuhrmann, & Abdulaziz Alkanderi

CENE 486: Engineering Design Capstone
Fall 2020

Introduction

Project Purpose

- Older neighborhoods constructed without extensive stormwater management planning

- Can drywells be utilized in Flagstaff?

Considerations

1. Can a retention/drywell system handle on-site runoff?
2. If so, can the system retain some flow generated off-site/upstream?

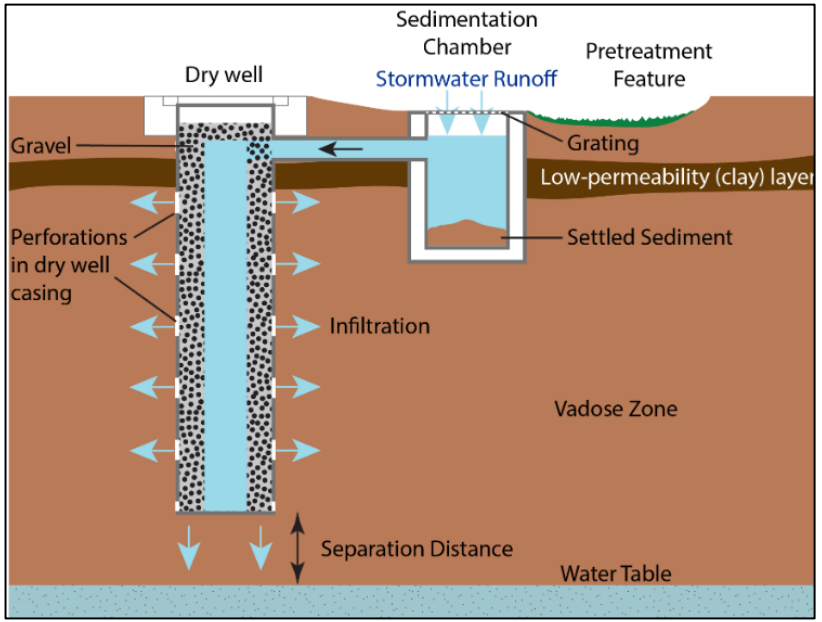


Figure 1: Typical Drywell Design [1]

Project Location

CAL Ranch
2530 N Fourth St
Flagstaff, AZ 86004

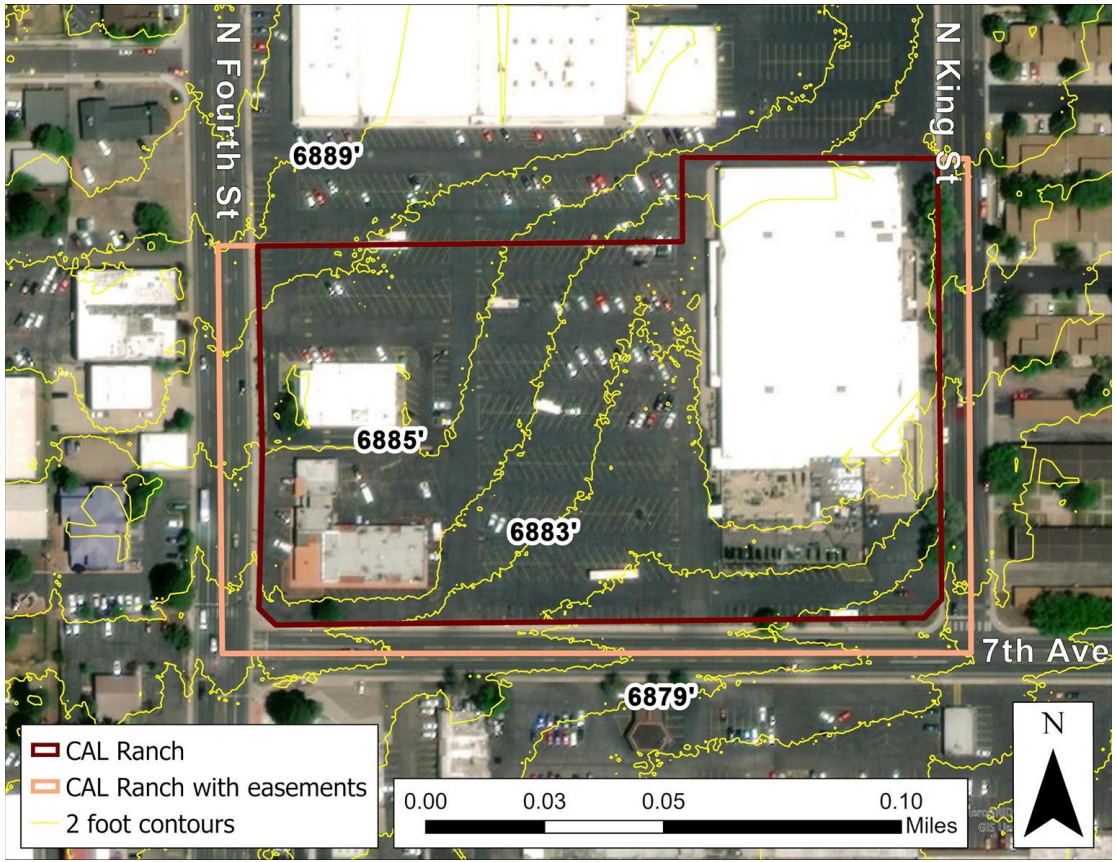


Figure 2: Site Location and Easements Areal

Project Development

- Data Acquisition
- Off-site hydrology
- On-site hydrology
- Subsurface Percolation Test
- Drywell/Retention Basin Design
- Alternative Designs
- Cost Analysis
- Impact Assessment

Figure 3: Flooding at Route 66 & Lockett Rd, June, 2018 [2]

Off-Site Watershed Delineation

- Watershed Characteristics
  - USDA Web Soil Survey
  - NOAA Atlas 14 Precipitation
  - 1.5 foot grid elevation model from City of Flagstaff LiDAR

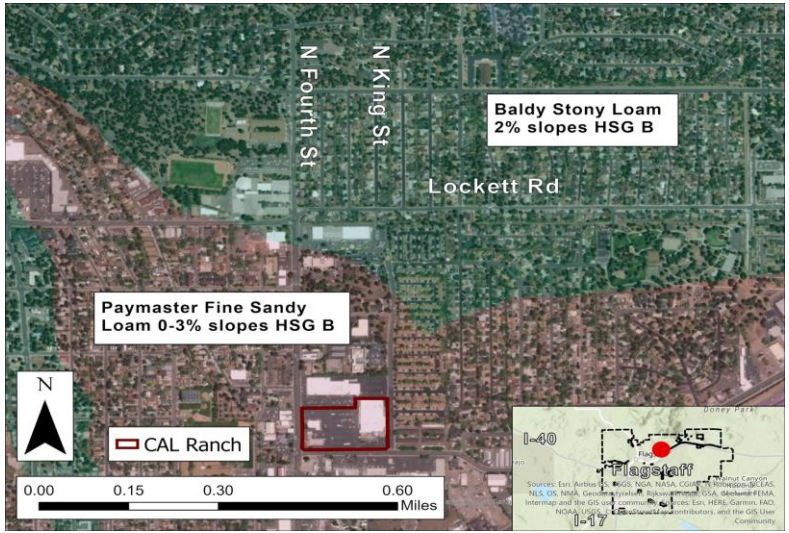


Figure 4: Soil Map showing Soil Name and Hydrologic Soil Group (HSG)

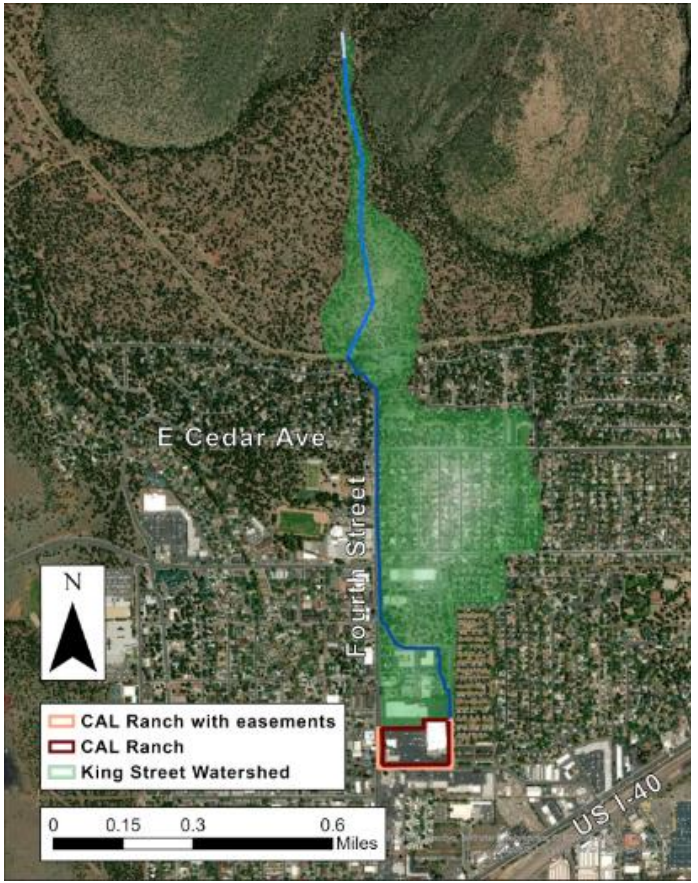


Figure 5: King Street Watershed and Flow Path

Off-Site Peak Flow and Street Flow Capacity

- Off-Site Peak Flow, NRCS CN Method (TR-55)

Table 1: King St. Flow Capacity

u/s elev	6882.23	ft
d/s elev	6875.20	ft
Longitudinal length	507.3	ft
CL elev	6882.36	ft
Gutter elev	6882.13	ft
Low point elev	6881.65	ft
width from curb to low point	6	ft
Manning's n	0.015	
Pavement cross slope, Sx	0.0800	ft/ft
Longitudinal cross slope, S	0.0139	ft/ft
CL to curb flow width, T	22	ft
Street Flow Capacity, Q	**248.5**	**cfs**

Table 2: Graphical Peak Discharge Method

Graphical Peak Discharge Method		
Rainfall depth, P (100-year 24-hour)	4.45	in
Composite curve number, CN	84.22	
Initial abstraction, Ia	0.37	in
Ia/P	0.08	
Unit peak discharge, qu	100.00	csm/in
Drainage area, Am	0.27	mi^2
Runoff, Q	2.79	in
Ponding factor, Fp	1.00	
Peak discharge, qp	**74.2**	**cfs**

On-Site Peak Runoff

Drywell/Retention Basin Inflow

-100-year recurrence interval

-6 hour storm duration

Table 3: Rational Method Peak Runoff

Rational Method Peak Runoff		
Antecedent Precipitation Factor, Cf	1.25	
Weighted Runoff Cofficeint, C	0.95	
6-hour 100-year Rainfall Intensity, I	0.503	in/hr
Area, A (w easement)	9.39	acres
Peak Runoff, Qp	5.61	cfs

Percolation Test for Drywell/Basin Design

- Falling Head Percolation Test used to Determine Hydraulic Conductivity

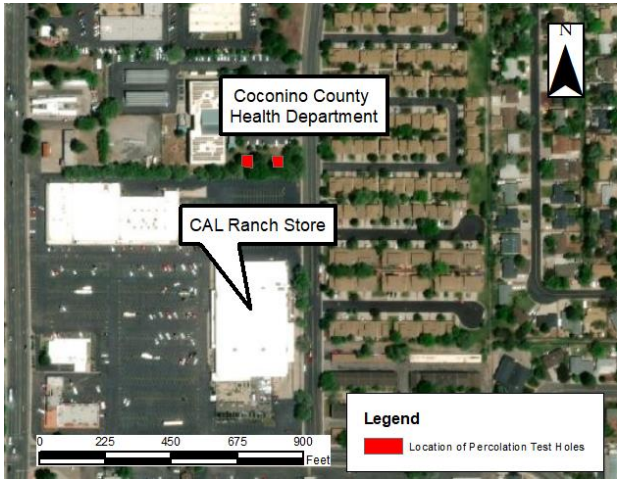


Figure 6: Location of Percolation Test

Figure 7: Percolation Test Hole

Table 4 : Percolation Test Results

Test 1	East	West
Time (hours)	Depth (in)	
0	6.0000	6.0000
0.5	4.5000	4.4375
1	3.0000	3.0000
1.5	1.5000	1.5625
	Hydraulic Conductivity, K (in/hr)	
	3.000	2.875

Test 2	East	West
Time (hours)	Depth (in)	
0	6.0000	6.0000
0.5	4.5000	4.5000
1	3.0625	3.1875
1.5	1.6250	1.8750
	Hydraulic Conductivity, K (in/hr)	
	2.875	2.625

Drywell/Retention Basin Outflow (Infiltration)

Hvorslev Drywell Flowrate Equation

$$Q = (2\pi KLH) / \ln[(2L/r) + \sqrt{(1+(2L/r)2)}]$$

where Q = drywell percolation rate (cfs)
K = hydraulic conductivity (ft/s)
L = length of screened portion of the drywell (ft)
H = height of the drywell (ft)
r = radius of the drywell (ft)

Retention Basin Infiltration Rate

$$Q = 0.5\ K\ A$$

where Q = volumetric retention basin infiltration
K = hydraulic conductivity
A = basin bottom area
0.5 = retention basin de-rating factor of safety

(per Maricopa County Retention Design Standards)

- On-site Inflow

- Hydraulic Conductivity = 2.625 in/hr
- Max Drain Time = 36 hours

- Retention Basin Dimensions
- Drywell Dimension
- # of Drywells

- Outflow through infiltration

Drywell/Retention Volume and Drain Time Check

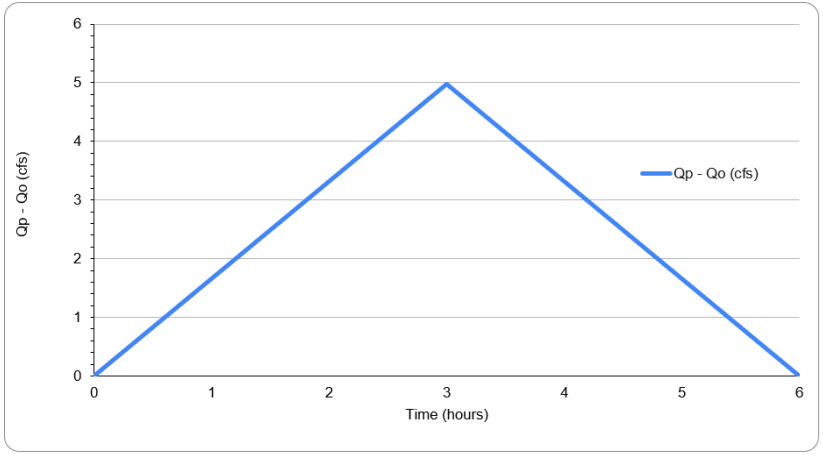


Figure 8: Hydrograph of Qin-Qout

- 170x170 ft Retention Basin
- 10 Drywells

Table 5: System Drain Volume and Time

System Drain Volume and Time		
Drywell Drain Volume in 36 hours	19061	ft^3
Retention Drain Volume in 36 hours	37,560	ft^3
Total Design Drain Volume in 36 hours	56621	ft^3
Drain Volume ≥ required retention volume?	TRUE	
System Drain Time	**35.81**	**hr**

Table 6: Required Retention Volume

COF Triangular Hydrograph Retention Volume		
Mimimum Retention Volume per LID Requirement	34086	ft^3
Number of Drywells	10	
Storm Duration for Qpeak (rational method) = Qi	6	hours
On-Site Time of Concentration, Tc	3.19	minutes
Inflow Time, Ti	6.053	hours
Inflow Time, Ti	21791.4	secs
Inflow Rate, Qi	5.61	cfs
Drywell and Retention Outflow Rate, Qo	0.436894	cfs
Retention Volume, V	56321	ft^3

Retention Basin and Drywell Design

- 170x170 ft Retention Basin
- 10 Drywells
  - 3 foot radius, 10 ft depth
- Retention Volume = 56,321 cubic feet
  (2086 cubic yards)

Table 7: Final Retention Basin Dimensions

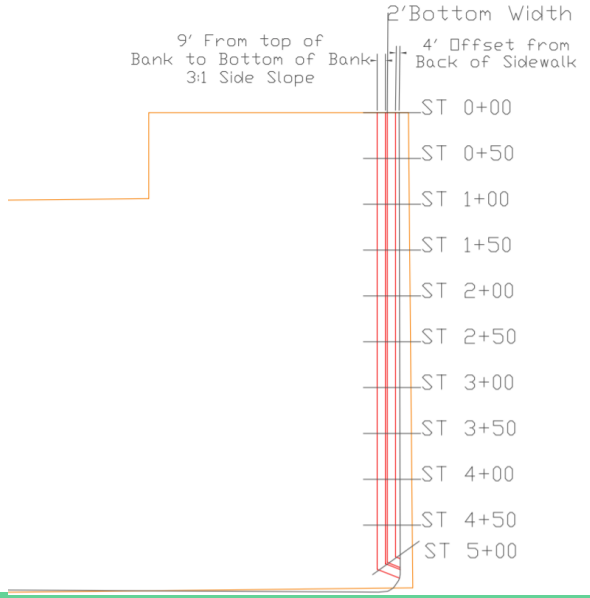
Final Retention Basin Dimensions		
Freeboard	1.00	ft
Retention Basin Length	170	ft
Retention Basin Width	170	ft
Retention Basin Height + Freeboard	3.00	ft
Full Retention Basin Water Depth	2.00	ft
Retention Basin Volume	56321	ft^3

Off Site Flow Routing Design

- Cost to raise north east Corner Elevation:
- Fill: 218 cubic yards
- Typical fill price of similar size: $50/cubic yard [3]
- Raw Total Cost: $10,900

- Cost to Implement a swale along east side of property:
- Typical swale price: ~$20 per linear foot [4]
- Total swale length: 500 ft

: $11,000



Retention Basin, Drywell Plan, and Redevelopment Earthwork

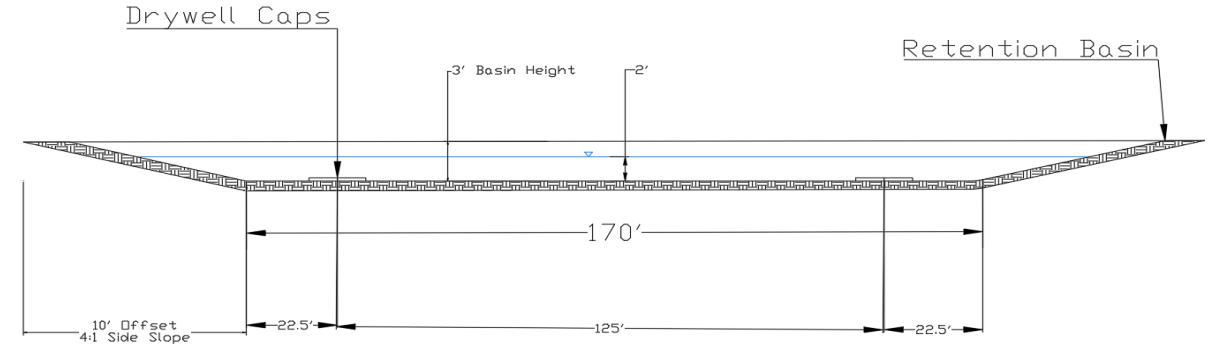
- Fill: 218 cubic yards
- Cut: 21,962 cubic yards
- Net: 21,744 cubic yards cut

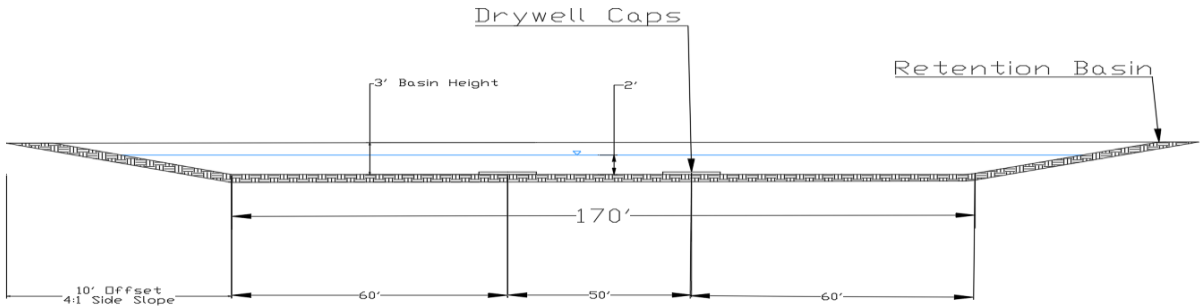
Earthwork Cost: $1,087,200

Figure 9: Plan of Retention Basin, Developed Topography, and Drywells in Relation to Existing Parcel

Retention Basin Cross Section Detail

Not to scale





Drywell Design

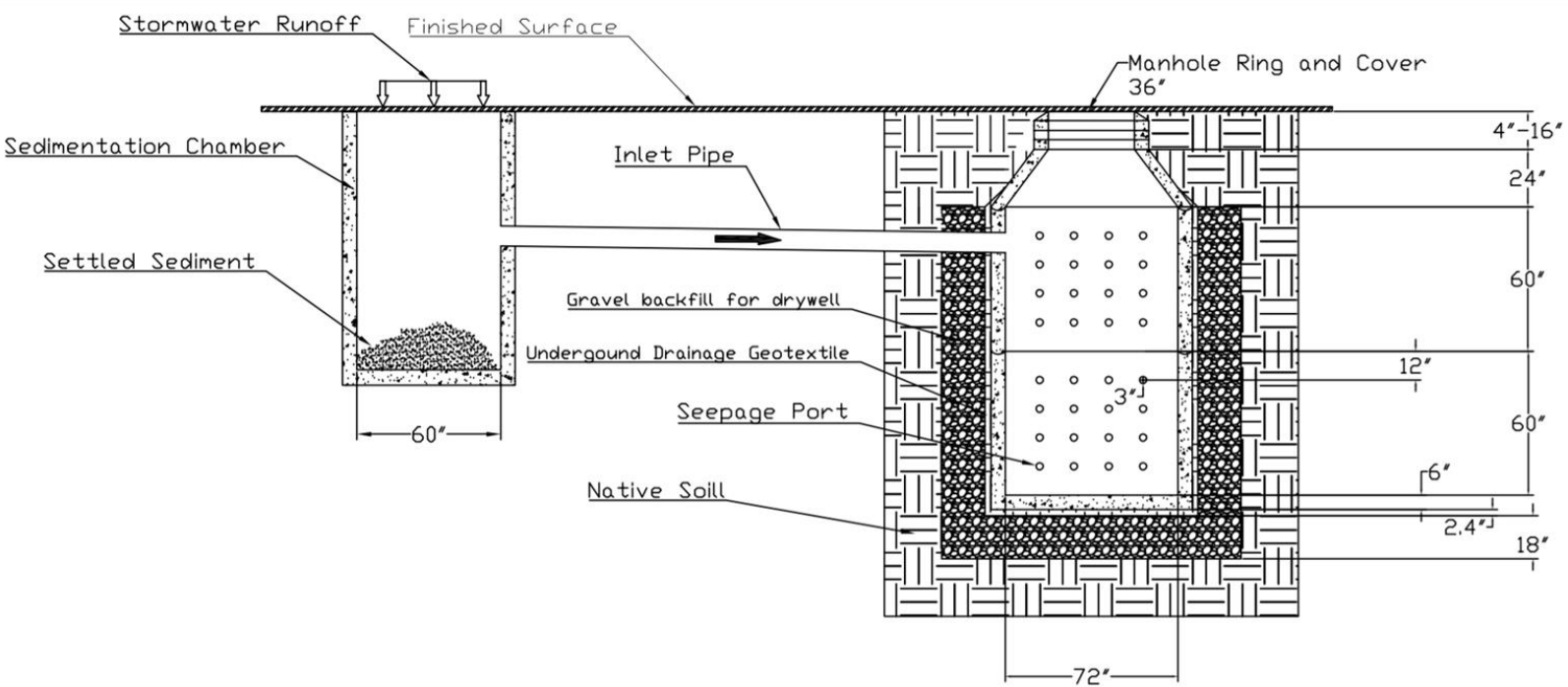


Figure 10: Drywell Design Details

Retention Basin and Drywell Maintenance

- Maintenance need to be recorded and up to date

Figure 11: Drywell Maintenance [5]

Cost Analysis

Table 8: Retention Basin and Drywell Construction Cost Estimate

Excavation Volume	56321	cubic feet
Excavation Cost	$0.75	per cubic foot
Total excavation cost	*$42,240.75*	
Grass + Instillation Cost	$4.69	per square yard
Total grass cost	*$22,457.80*	
Total Retention Basin Constuction Cost		*$64,698.55*
# of Drywells	10	drywells
Cost per concrete drywell + Instillation	$4,951	per drywell
Total Drywell Construction Cost		*$49,510*
Total Retention Basin and Drywell Constuction Cost		***$114,209***

Retention Basin & Drywells vs. Retention Basin only

Retention Basin Only: **210’ x 210’**

Required increase in Retention Basin Area with 0 Drywells: **0.35 acres**

Cost of land per acre: **$666,043**

Value of Land Saved using 10 drywells and 170’x170’ retention basin: **$232,381**

Cost Analysis

Table 9: Detention Facility Volume

Rational Method Pre/Post Peak Runoff and Required Detention Volume		
Antecedent Precipitation Factor, Cf	1.25	
Pre-Development Weighted Runoff Cofficeint, C	0.15	woods, clay soils
Post-Development Weighted Runoff Cofficeint, C	0.95	asphalt, concrete
6-hour 100-year Rainfall Intensity, I	0.503	in/hr
Area, A (w easement)	9.39	acres
Pre-Development Peak Runoff, Qo	0.89	cfs
Post-Development Peak Runoff, Qi	5.61	cfs
Inflow Time (Tc + 6 hours)	6.053	hours
Detention Volume	**51,435**	**ft^3**

Table 10: Detention Facility Construction Cost Estimate

Excavation Volume	51,435	cubic feet
Excavation Cost	$0.30	per cubic foot
Reinforeced Concrete Outlet	$20,000.00	(including labor)
Riprap Cost	$22.22	per cu. yard
Riprap Area	2.67	cu. yards
Total Cost of Detention Basin		***$35,489.83***
Savings over retention/drywell system		***$78,718.73***

Feasibility Determination

- Not Economically Feasible
- $43,229 Price Difference

Impact Assessment

- 7.1: Economic Impact Assessment
  - Reduces flooding
- 7.2: Social Impact Assessment
  - Reputation of contamination
- 7.3: Environmental Impact Assessment
  - Little to none contamination of water table

Figure 12: Flooding Impact in Flagstaff [6]

References

[1] ADEQ, "Implementation Guidelines for Drywells That Use Flow Control and/or Pretreatment Technologies Under the Aquifer Protection Program General Permit Types 2.01 and 2.04," Arizona Department of Environmental Quality, Phoenix, 2012.

[2] Angela Mabe. Arizona Daily Sun. June 18: Flash flooding causes difficult conditions in Flagstaff https://azdailysun.com/news/local/1---june-18-flash-flooding-causes-difficult-conditions-in-flagstaff/article_81b55198-b627-5220-bd85-290314f778b3.html

[3] ADOT, "Estimated Engineering Construction Cost E2C2," Arizona Department of Transportation, 2020. [Online]. Available: https://apps.azdot.gov/Applications/ReportViewerHost/ReportViewer/Viewer.aspx?ReportPath=/E2C2/E2C2BidHistory&cCty=CN&cDistrict=&cItemNbr=&cRoute=&cTracsNbr=&dFromBidDate=11/12/2015&dFromMP=&dFromQty=&dToBidDate=11/12/2020&dToMP=&dToQty=&vcDescript=excava. [Accessed 12 November 2020].

[4] Malvern Borough, "Vegetated Swale," Malvern Borough, Malvern, 2006.

[5] "Severn Septic Service, - *Severn, MD*. https://www.agreatertown.com/severn_md/severn_septic_service_0006088668.

[6] "City of Flagstaff Official Website: Official Website," *City of Flagstaff Official Website*: https://www.flagstaff.az.gov/DocumentCenter/View/63539/Pg9-Milton-flooding?bidId=

[7] ADOT, "Estimated Engineering Construction Cost E2C2," Arizona Department of Transportation, 2020. [Online]. Available: https://apps.azdot.gov/Applications/ReportViewerHost/ReportViewer/Viewer.aspx?ReportPath=/E2C2/E2C2BidHistory&cCty=CN&cDistrict=&cItemNbr=&cRoute=&cTracsNbr=&dFromBidDate=11/12/2015&dFromMP=&dFromQty=&dToBidDate=11/12/2020&dToMP=&dToQty=&vcDescript=excava. [Accessed 12 November 2020].

[8] Malvern Borough, "Vegetated Swale," Malvern Borough, Malvern, 2006.

[9] Edwards, E., Mandler, B. *Dry Wells for Stormwater Management*. September 2017. [Accessed 29 January 2020]. americangeosciences.org

[10] Flood Control District of Maricopa County, "Drainage Policies and Standards," Maricopa County, Phoenix, 2018

References

[11] Buckeye Stormwater Drainage System Design Manual. Town of Buckey Engineering Design Standards. August 2007.

[12] City of Flagstaff Engineering Division Stormwater Management Section, "CITY OF FLAGSTAFF STORMWATER MANAGEMENT DESIGN MANUAL," City of Flagstaff, Flagstaff, 2009.

[13] Arizona Administrative Rules Division, "Arizona Administrative Code," State of Arizona, Phoenix, 2019.

[14] NOAA, "NOAA ATLAS 14 POINT PRECIPITATION FREQUENCY ESTIMATES: AZ," NOAA's National Weather Service Hydrometeorological Design Studies Center (PFDS), [Online]. Available: https://hdsc.nws.noaa.gov/hdsc/pfds/pfds_map_cont.html. [Accessed August 2020].

[15] NRCS TR-55. Urban Hydrology for Small Watersheds. United States Department of Agriculture National Resource Conservation Service. June, 1986.

[16] Chow, VT. Open-Channel Hydraulics. McGraw-Hill Publishing. 1959.

[17] USDA Natural Resource Conservation Service, "Web Soil Survey," United States Department of Agriculture, Online. [Accessed August 2020]

Questions ?