DENVER
THE MILE HIGH CITY

APPENDIX:
WATER AND STORM WATER MANAGEMENT

Imperviousness Statistics for Denver

- Buildings Make Up 30% of Impervious Surfaces in Denver
  - Remaining 70% are roads, driveways, parking lots, and sidewalks
- Approximately 40% of Surfaces in Denver are Impervious (Includes DIA)
- Amount of Impervious Surfaces in Denver are Projected to Increase by 30% - 40% by 2040 (CU Boulder, unpublished data)

Summary of Studies – Impacts on Runoff

Authors	Location	Peak Flow Reduction	Average Annual Reduction in Runoff	Comments
Moran, et. al. (2004)	Goldsboro, NC	78.00%	62.00%	Extensive roof
	Kinston, NC	87.00%	63.00%	Extensive roof
MacMillan (2004)	Toronto, ON	85.00%, 82.00%, 68.00%, 46.00%	54.90%	System includes storage tank, peak flow reduction depended on storm size and decreased with larger storms
Portland Environmental Services (2013)	Portland, OR	96.00%	50.00%	
	Portland, OR	83.00%	-5.00%	Site required irrigation
	Portland, OR	88.00%	70.00%	
Speak, et. al. (2013)	Manchester, UK	N/A	65.70%	Intensive roof
EPA (2009)	University Park, PA	N/A	>50%	Extensive roof, almost 100% retained in summer, <20% retained in winter
Glass (2007)	Washington, DC	N/A	74.00%	
Murillo, et. al. (2016)	Bogota, Columbia	N/A	73.00%	Studied 15 extensive roofs
EPA (2014)	New York, NY	N/A	37.00%-66.00%	Studied four extensive roof, percent retention decreases as storm size decreases
USGS (2010)	Ipswich, MA	N/A	>50.00%	

Factors Influencing Green Roof Runoff Retention

- Storm Event Size and Intensity
- Antecedent Precipitation
- Temperature
- Green Roof Configuration
  - Substrate Depth
  - Rooftop Slope
  - Plant Coverage
  - Drainage Configuration
  - Orientation
  - Location of Unvegetated Areas

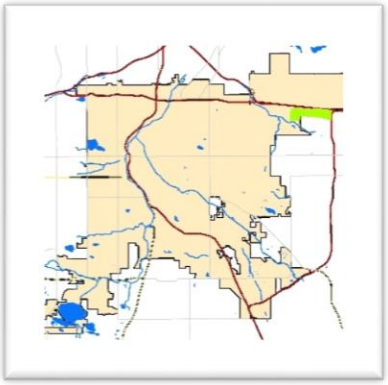
Water Quality Impact

Green Roofs Do Not Address Primary Sources of Storm Water Pollutants in Receiving Waters

Basin Area	626 Acres
Amount of Impervious Area	502.3 Acres
Total Roof Area	168 Acres
Total Amount - Other Impervious Areas	334.3 Acres

Green Roofs Initiative Example

	Existing
Basin Area	626 Acres
Amount of Impervious Area	502.3 Acres
Percent Imperviousness	80.2%



	With Green Roofs
Roof Area , Bldgs. >25,000 sq. ft.	147.7 Acres
Required Green Roof Area	14.8 Acres
Impervious Area with Green Roofs	487.5 Acres
Percent Imperviousness	77.9%

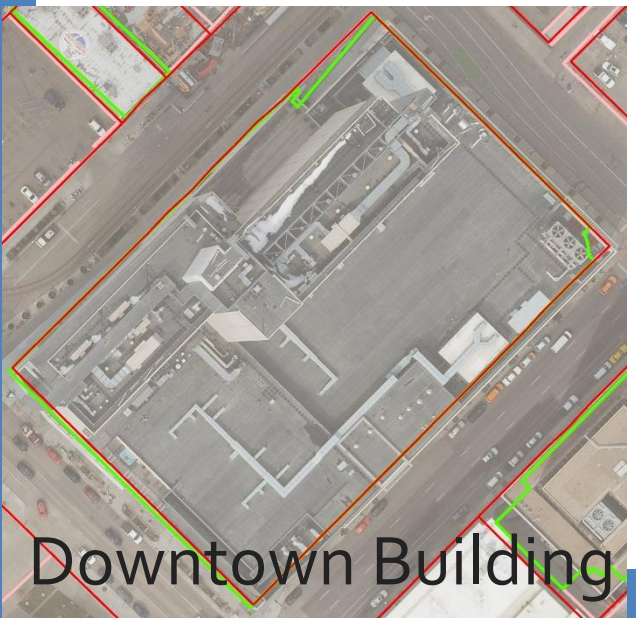
Green roofs result in a 0.7% - 2.3% decrease in basin imperviousness in an industrial area.
Green roofs result in a 4.2% - 14.1% decrease in basin imperviousness in urban areas with high density and 60% green roof coverage requirements.
Benefits are greater in denser areas will less pervious areas on the ground

Green Roofs have a Significant Water and Water Quality Benefit

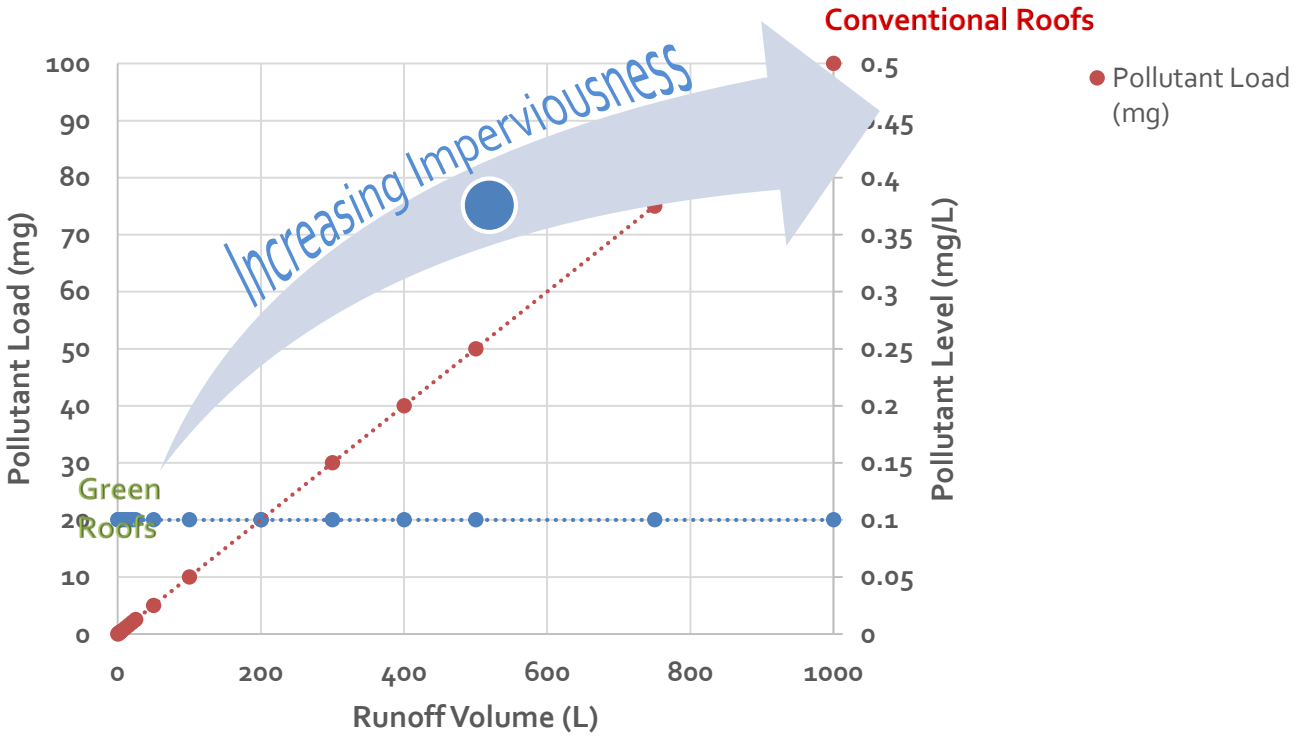
Green roofs result in a **4.2% - 14.1%** decrease in basin imperviousness in urban areas with high density and a 60% green roof coverage requirement.

Green roofs result in a **0.7% - 2.3%** decrease in basin imperviousness in an industrial area with a 10% coverage requirement.

Benefits are greater in denser areas where imperviousness is higher.



Reduced Pollutant Load Benefit



Examples - Additional Water Quality Provided by Green Roofs

	Site 1	Site 2
Site Description	3 acre site 90% impervious 80,000 sq. ft. structure 40 hour drain time	10 acre site 80% impervious 10 – 30,000 sq. ft. structures 40 hour drain time
Required Water Quality	0.1 acre-ft	0.27 acre-ft
Required Green Roof Size	0.55 acre	1.4 acre
Extra Water Quality Provided	0.015 acre-ft	0.07 acre-ft
Percent Increase in Water Quality	15%	25%

See Chapter 3, Volume 3, UDFCD for methodology to determine water quality requirements.

Water Quality Impact

Green Roofs Do Not Address Primary Sources of Storm Water Pollutants in Receiving Waters

Average Pollutant Level in Run Off from Roofs and Roads

Metric	Roof Run Off	Road Run Off
pH	6.07	6.9
TSS (mg/L)	47	8,500
Zinc (mg/L)	0.70	1.08
Copper (mg/L)	0.42	0.09
Lead (mg/L)	0.30	0.41
Aluminum (mg/L)	0.49	2.10
Nitrogen (mg/L)	0.02	1.74
Phosphorus (mg/L)	0.22	0.49

[illegible] from first flush monitoring
All conventional roof types included in calculation

Factors Influencing Water Quality Results at a Site

- Growing media
  - Amount of organic matter
- Growing media depth / thickness
- Plantings
  - Presence of plants
  - Plant palette
  - Fertilization needs

Benefits are Conditional

- Water Quality Benefits Vary from Site to Site
- Benefits are all dependent on storm size and time since previous storms
  - Ability to absorb stormwater is decreased if green roof is partially or completely saturated

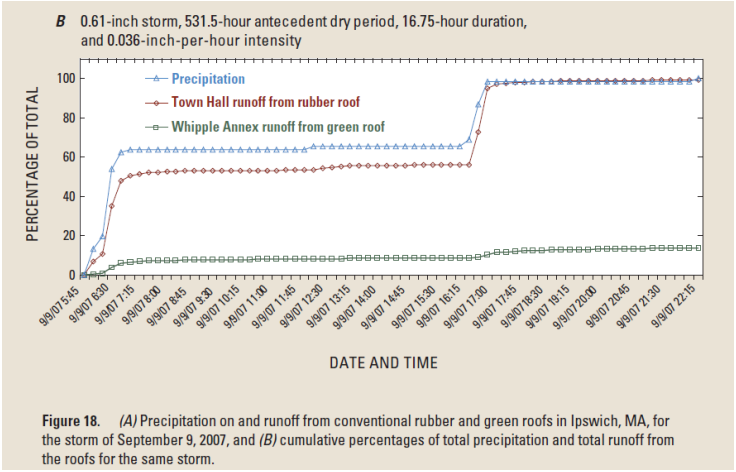


Figure 18. *(A)* Precipitation on and runoff from conventional rubber and green roofs in Ipswich, MA, for the storm of September 9, 2007, and *(B)* cumulative percentages of total precipitation and total runoff from the roofs for the same storm.

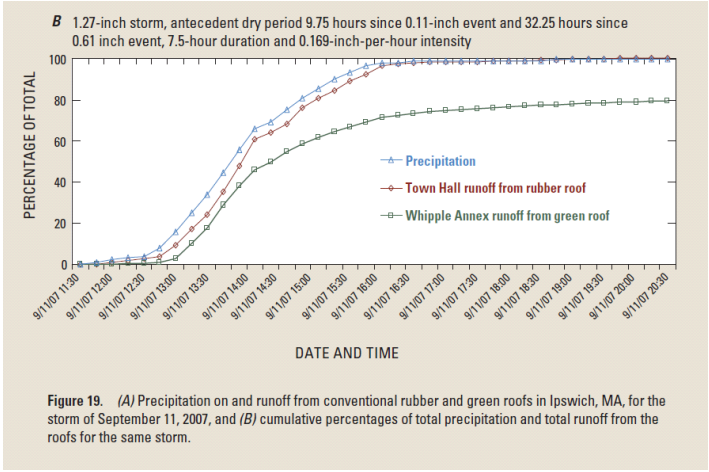


Figure 19. *(A)* Precipitation on and runoff from conventional rubber and green roofs in Ipswich, MA, for the storm of September 11, 2007, and *(B)* cumulative percentages of total precipitation and total runoff from the roofs for the same storm.

Other Issues – Water Resources

- Initiative
  - Conflicts with Colorado water law
- Draft Rules (12/26/17)
  - Conflicts with Colorado water law
  - Does not properly reflect administration of Colorado water law
  - Provides no options for projects without an approved augmentation plan

Water Quality - Outcomes

- Add incentive – green roofs offset for water quality elsewhere on site
- Allow builders to use white roof / onsite water quality combo instead of green roof only – if goal is to reduce heat island effect and improve water quality
- Specify fee in lieu goes to funding regional water quality projects
- Add flexibility to regulations
  - Develop a tool, similar to the water quality scorecard that identifies needs in different areas– water quality / quantity, heat island, etc. - and prioritize for implementation.
- Ability to monitor / identify partners and funding to do monitoring with

Reduction in Amount of Pollutants Reaching Denver's Streams and Lakes

Green / Conventional Roof Comparison

- Decreased runoff
  - Some water that falls on green roofs will evaporate, not runoff
- Treatment of Water
  - Runoff from green roofs contains lower levels of metals
  - Solids retained more effectively by green roofs
  - Green roofs may or may not have a benefit for nitrogen and phosphorus
    - Nutrient levels in discharges from green roofs decrease as a function of time

Reduces Localized Flooding

- Delayed runoff may result in reductions in localized flooding
  - Some of Denver's storm sewers designed to contain the 2 or 5 year storm event
    - Larger storm events result in localized neighborhood flooding
  - Delaying runoff it reduces volume of water to be conveyed

Summary

- Green Roofs
  - Decrease runoff
    - Reduction in imperviousness in one Montbello storm drainage basin
  - Impact varies depending on how recently the previous storm occurred.
- Benefits
  - Reduction in amount of pollutants reaching Denver's streams and lakes
    - Decreased runoff
    - Provides treatment for some pollutants
  - Delayed runoff may reduce localized flooding

Questions from Last Meeting

- How Do Green Roofs Compare to Other Water Quality BMPs?
  - Bioretention
    - Trees or plants on the ground
    - Trade impervious parking for green space at ground level
  - Pervious Pavement
    - Trade impervious surface for pervious surface at grade
  - Retention
    - Holding tank for stormwater

Limited Information Comparing Relative Effectiveness of Green Roofs to Other Practices for Improving Water Quality

More Appropriate to Compare Green Roofs to Other Types of Roofs

Water Quality Capture Volume

- Water Quality Capture Volume (WQCV) - The volume of runoff that a water quality BMP is designed to capture and treat prior to release to receiving waters
  - Applies to water quality and runoff volume
    - Based on site imperviousness, size of tributary area, and stormwater retention time
    - Treatment targets storm events of up to 0.6 inches precipitation
- Requirements for Stormwater Detention are also Based on the Water Quality Capture Volume

Green Roof Benefits

- Primary Benefit - Delay of Peak Flows and Runoff Volume Reduction
  - Benefit varies with storm size, duration, and time between storms
  - Benefit depends on green roof construction
- Secondary Benefit - Water Quality Improvement
  - May be helpful in managing volume for water quality storm events
    - Reduced rooftop runoff = reduced volume treated by in-ground BMPs
  - Green roofs are highly effective at managing typical roof-top pollution but don't provide treatment for other surfaces

Comparison of Two Green Roofs

Downtown Building – 100% Impervious Site

Building Footprint	2.4 acres
Lot Size	2.4 acres
% Imperviousness	100%
Required Runoff Retention	4,450 sq ft
Available Space	0
40% Green Roof Coverage	
Site Imperviousness	61%
100% Green Roof Coverage	
Site Imperviousness	1%

Industrial Facility – 67% Impervious

Building Footprint Site	5.75 acres
Other Impervious Surfaces	4.7 acres
Lot Size	15.4 acres
% Imperviousness	67%
Required Runoff Retention	14,825 sq ft
Available Space	5 acres
10% Green Roof Coverage	
Site Imperviousness	64%
100% Green Roof Coverage	
Site Imperviousness	30%

Important Points to Take Away

- Water Quality Benefits from Green Roofs are Secondary to Delay of Peak Flows and Reduction in Volume of Runoff
  - Focus should be on delay of peak runoff and volume reduction
  - Water quality should be considered site-wide and integrate green roofs with in-ground BMPs
- Green Roof Stormwater Benefits May Prove Most Useful in Neighborhoods with
  - Higher Building Density
  - Nuisance Flooding
  - Existing, or planned, high imperviousness (60-70%+)

QUESTIONS?

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Denver's Stormwater Capture / Treatment Requirements

- §56-111 DRMC:

  (a) …each developer of land within the city has a duty to provide on his/her property all reasonably necessary drainage and detention facilities to ensure the adequate drainage and control of … stormwaters which fall or develop on his/her property or which contribute runoff to his/her property.

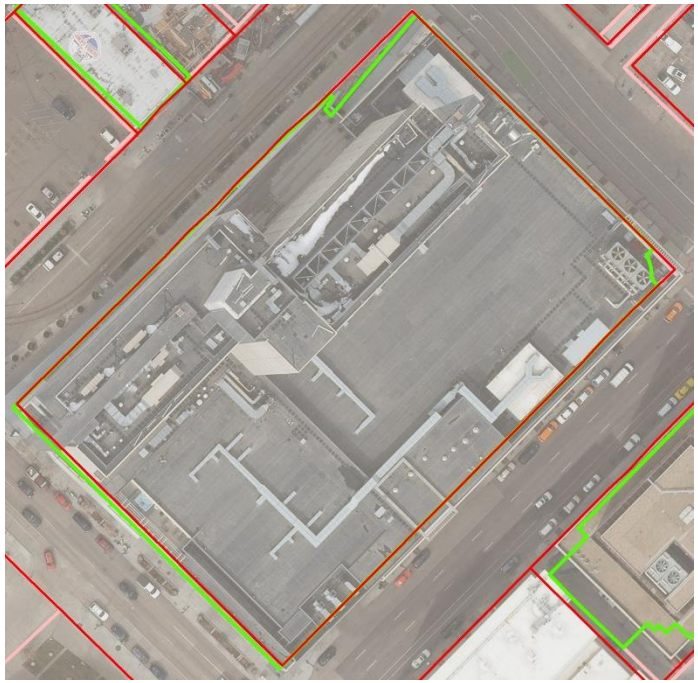
  (b)…each developer/redeveloper of land conducting projects that disturb one (1) or more acres of soil, including projects less than one (1) acre that are part of a larger common plan of development or redevelopment, has the duty to prevent or minimize water quality impacts from the completed project.

Perviousness/Imperviousness

- Pervious surfaces allow water soak into the ground, impervious surfaces do not, instead creating runoff.

Pervious Surfaces	Impervious Surfaces
Grass	Roads and Sidewalks
Dirt, Sand, or Gravel	Roofs
	Parking Lots and Driveways

Downtown Building



Industrial Facility

Note: Photos are not at the same scale.

Other Types of Water Quality BMPs

- Traditional
  - Extended Detention Basin
  - Constructed Wetlands (Pond or Channel)
  - Permeable Pavement
  - Sand Filter
  - Retention Pond
  - Underground Treatment
- Green Infrastructure
  - Bioretention (Rain Gardens or Porous Landscape Detention
  - Grass Buffer
  - Grass Swale
  - Curb-Side Planters

Source: UDFCD (2012). Criteria Manual, Volume 3, Chapter 6

Assessment of WQ BMP Effectiveness

Studies conducted by the International Stormwater BMP Database

- Most recent summary report available at:

http://www.bmpdatabase.org/Docs/03-SW-1COh%20BMP%20Database%202016%20Summary%20Stats.pdf

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