CHAPTER ONE
Boulder's Urban Forest Benefits Stormwater Runoff

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"Water is one of the fundamental elements of life, especially in a semi-arid region such as ours. The health and sustainability of Boulder County is inextricably linked to the quality of its watershed."[1]

Riparian:
Zones that border streams, springs, wet meadows, marshes and ponds. These areas have distinctly different vegetation than adjacent areas or have species similar to surrounding areas that exhibit a more vigorous or robust growth form.

Pervious surfaces:
Surfaces that absorb water and allow it to percolate down through the root and soil system. Generally thought of as green or vegetated areas, and include grass, trees, and landscaped areas.

Groundwater discharge:
Water moves through water - bearing formations, known as aquifers, and eventually surfaces in discharge areas, such as streams, and lakes.

Introduction

Large volumes of stormwater runoff are unique to urban areas. Undeveloped, natural lands absorb most falling rainwater to a much greater extent than urban areas covered by pavement and buildings. Rainfall running over city streets and parking lots washes many pollutants deposited by automobiles and other sources off of these impervious services and into nearby waterways, affecting both the quality and quantity of the water. Increases in the amount and the force of water in these waterways can lead to stream bank erosion, as well as flora and fauna displacement.

The City of Boulder has mitigated some of these detrimental effects by cultivating extensive urban forests. Tree canopies intercept falling rainwater, reducing its erosive potential before hitting the ground. Trees are typically planted in permeable areas, and surrounded by other vegetation such as grass and shrubs. The soil and root systems of these "green areas" work together to absorb stormwater, preventing it from becoming runoff. This not only reduces the overall quantity of runoff, but also increases water quality because trees and surrounding vegetation are capable of taking in and breaking down several pollutants.

History of Boulder's Watershed

Before settlement in the area of Boulder Creek Watershed, native land cover consisted mainly of forested areas in the foothills, and short grass prairie containing very few trees. The City of Boulder, although nestled up against the mountains, was settled on the plains, a semi-arid environment that only supported trees in **riparian** areas due to their intense need for water to survive. The primary forces affecting the creek's hydrology were climate and weather.[3] Weather data recorded from 1893 to the present shows an average annual precipitation of less than 20 inches per year in the Boulder area.[4] Virtually all surfaces could be considered **pervious**, and much of the rain that fell was absorbed and utilized by the soil and root systems of the vegetation cover. When the ground became fully saturated, water that could not be absorbed then percolated through the soil as **groundwater discharge** and entered into Boulder's stream system in a clean, filtered state.

Population Growth in the City of Boulder[2]

	1970	1980	1990	2000
Population	66,870	76,685	83,312	91,606
Households	21,500	28,674	34,681	40,200
Average Household Size	2.80	2.40	2.18	2.09

New buildings and roadways are built to accommodate growth, increasing the overall amount of impervious surfaces within a watershed.

The demands of settlement and urban development have completely changed the structure of Boulder Creek and surrounding watershed. Because the creek has been dammed, and **impervious surfaces** now cover a considerable area within the watershed at lower elevations, it is considered urbanized. These surfaces are a part modern urban infrastructure, but have far-reaching detrimental effects upon the local environment.

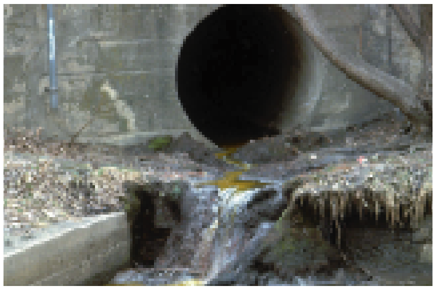
Impervious surfaces:
Consist of roads, sidewalks, parking lots, rooftops and any other surfaces in the urban environment that do not absorb water. Urban soils are often considered impervious due to a high level of compaction.

Stormwater runoff:
Precipitation that does not infiltrate into the ground, but instead is transported to another location via impervious surfaces.

Urbanization Affects Water Quality

Even a small percentage of impervious surfaces can be extremely harmful to the aquatic/riparian environment. Extensive research conducted worldwide provides evidence that stream degradation occurs with as little as 10% impervious cover.[6] These surfaces collect pollutants deposited from the atmosphere, leaked from vehicles or derived from other sources. During storms, accumulated pollutants are quickly washed off and rapidly delivered to aquatic systems as **stormwater runoff**. In a large-scale storm event (2 inches of rainfall), all deposited pollutants are diluted by massive amounts of rainwater, but in a more typical small-scale storm event (0.5 inch), highly concentrated and polluted stormwater would, without interference, flow directly into Boulder's waterways. These small storms are responsible for most pollutant washout, also known as the "first flush" effect.[10] Urban stormwater runoff is the second most common source of water pollution for lakes and estuaries, and the third most common source for rivers nationwide.[11]

Urban stormwater runoff entering hardscaped drainage area of a parking lot.



Often, runoff is directly discharged into nearby waterbodies without adequate water quality treatment. Boulder Creek at the intersection of Broadway and Arapahoe.

The total runoff volume for a one-acre parking lot (Runoff coefficient = 0.95) is about 16 times that produced by an undeveloped meadow (Runoff coefficient = 0.06).[7]

"States report that 40 percent of the waters they surveyed are too contaminated for basic uses, such as fishing and swimming… Insecticides in urban streams, largely from use around homes and in gardens, parks, and commercial areas, frequently occur at levels of concern for aquatic life and may be a significant obstacle for restoring urban streams."[8]

"With urbanization, stream channels expand catastrophically to consume adjacent land never before affected by either flooding or erosion, sediment inundates low-lying areas seemingly far away from active channels, stormwater facilities are overwhelmed by frequent flows far beyond their design capabilities, and populations of aquatic organisms are decimated. Nearly all of these problems result from one underlying cause: loss of the water-retaining function of the soil in the urban landscape."[9]

Peak flow:
The highest flow encountered in a waterway, including periods of high rainfall and prolonged periods of wet weather.

The Chain of Events That Lead to Polluted Water

Transportation routes, buildings, construction, and recreational pathways are neccessary in urban areas

Increased impervious and compacted surfaces

Increase in stormwater runoff and decrease in water infiltration

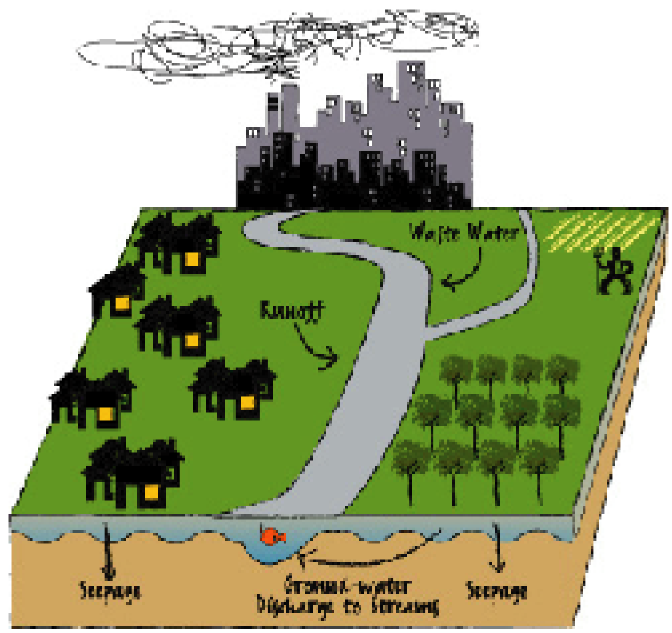
More water carries more pollutants and other sediment loads, reaching a river or other body of water at a quicker rate. Less water is available to replenish the groundwater supply.

Results:
1. **Polluted streams, rivers, lakes and other bodies of water**
2. **More frequent flooding**
3. **Lower base flows for streams and rivers**
4. **An overall decrease in water quality**

Urbanization and Water Quantity

When natural flow paths in the watershed are replaced or supplemented by paved gutters, storm sewers, or other elements of artificial drainage, the most common effects of urbanization on a watershed are reduced infiltration, decreased travel time, and significantly increased **peak flows** and runoff.[5]

One method of dealing with stormwater is to hardscape stormwater management systems that collect runoff from pavement and route it to detention basins, typically underground tanks or vaults built to gather stormwater and to slow its entrance into streams. Regional stormwater management regulations are designed to handle the 100-year flood event. However, on average across the United States the majority of rainfall events generate less than 1 inch of rain in 24 hours, and typical summer storms in Boulder bring less than 0.5 inches of rain.



Point-source contamination can be traced to specific points of discharge from wastewater treatment plants and factories or from combined sewers. In agricultural areas, enriched soil and sediment can transport considerable amounts of some nutrients, such as organic nitrogen and phosphorus, and some pesticides, such as DDT, to rivers and streams.

Flooding of Bear Creek occurred in the late 1960's. Erosion, like that in this photo, is caused when stream banks become unstable due to lack of deep-rooted vegetation such as trees. The banks are unable to withstand the force of increased stream flow caused by large volumes of stormwater runoff entering the stream over a short period of time.

It is these smaller storms that have been overlooked by traditional stormwater management practices. Frequent, small rainstorms carry the greatest amount of concentrated pollutants; pollution generated by these types of rainfall events is most treatable onsite with trees and vegetation, a process called **bioretention**.

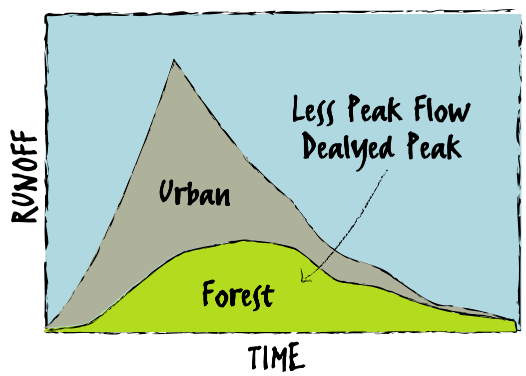
Bioretention:
An alternative management strategy that uses native ecosystems and landscape processes to enhance stormwater quality. Permeable soils and vegetation are both critical components of bioretention areas.

Trees, the Missing Piece:
The Relationship Between Vegetation and Stormwater Mitigation

Trees and other vegetation not only provide a method of reducing stormwater runoff volume, but also are responsible for removing pollutants from the water itself through **bioretention** and filtration. Trees are capable of treating stormwater at the source, and provide us with a feasible method of reducing the impact of stormwater upon urban watersheds.

Trees and Water Quantity

Interception of falling rain by tree foliage prevents precipitation from directly hitting the ground, therefore reducing its erosive potential. A typical Boulder afternoon thundershower brings less than 0.5 inches of rain (considered a small storm event), much of which never reaches the ground but instead gets evaporated back into the atmosphere. In a larger storm event, rainfall eventually cover the surfaces of the tree (foliage, twigs, branches, trunk) and slowly drips to the ground, with most of force of impact removed. The areas beneath trees are usually porous, therefore allowing much of the water that does fall from the tree to be absorbed by the soil and root system; the result is that much of the stormwater is retained on site in an area with high canopy cover.



Due to the slowing of water movement by trees, peak flow is delayed and dispersed over a longer period of time by forested areas than in areas of impervious surface.[12]

Trees and Water Quality

In order to protect the riparian habitat, it is necessary to not only slow and reduce the entry of stormwater runoff into the streams so as not to physically disrupt or displace the aquatic flora and fauna, but to provide some sort of filtration to remove significant amounts of pollution from the water itself. Suspended particles, resulting from soil erosion and increased carrying capacity of quickly moving water, also degrade water quality.

"When stormwater travels away from its point of origin through a series of pipes, some of the most effective opportunities to reduce quantity and improve water quality are lost."[14]

Trees in urban areas can protect water quality by substantially reducing the amount of runoff from the more frequent, but less extreme storm events that are responsible for most annual pollutant runoff.[9] Infiltrating and treating stormwater runoff on site can reduce runoff and pollutant loads by 20% - 60%.[13] Trees' extensive fibrous root systems also hold soil in place, reducing further impacts on water quality due to erosion.

Stormwater runoff can be directed toward depressed, vegetated islands in parking lots, where trees can absorb and metabolize much of polluted runoff. The example here, at the corner of Baseline and Broadway, shows the construction process for such islands. Holes must exist in the curb for water to flow into, rather than around, the island.

Phytoremediation:
The use of green plants for environmental remediation. Trees and their associated rhizospheric microorganisms remove, degrade, or contain chemical contaminants located in the soil, sediments, groundwater, surface water, and even the atmosphere.

Evapotranspiration:
Vegetation draws moisture from the ground through roots and releases it into the atmosphere during transpiration.

TOC:
The time required for a drop of water to move from the hydraulically most remote point on a site to the outlet of the site after the soil is saturated and all the minor depressions are filled.

2-inch 24-hour storm event:
Generalized storm classification. 2 inches is the average amount of precipitation that falls in a large scale, 24-hour storm event in this region.

Phytoremediation:
How Trees Help Combat Pollution

Trees can provide two vital functions in remediation of a polluted environment through both the capture and the biodegradation (breakdown) of pollutants. **Phytoremediation** takes advantage of plants' natural abilities to take up, accumulate, and/or degrade constituents of their soil and water environments. Trees are capable of taking up and thereby removing a large variety of organic and inorganic compounds as well as metals from source and non-point source contaminated water; because they are virtually the largest plant in the world, trees may very well be the most efficient method of phytoremediation.

Phytoremediation research has specifically targeted poplars, cottonwoods and poplar hybrids (Genus Populus) for several reasons: rapid growth of trunk and root systems, relatively large leaf size, and high **evapotranspiration** rates. Because of these features the trees operate as an efficient "solar driven pump" that can virtually suck up large volumes of polluted water each day. Research shows different rates of evapotranspiration dependent upon climate and other factors (a dry climate is more efficient at evaporation), but the range is from 1.6 gallons per day(gpd)/tree for a young tree to 53 gpd/tree for a five year old poplar. Pollutants are oxidized as they move from the bottom roots to the upper sections of the crown of the plant. As a result, researchers have come to believe that these tree species can fully metabolize certain pollutants.[15]

Modeling Stormwater Runoff Prevention with CITYgreen

The Stormwater Runoff program within CITYgreen is a modified version of Technical Release 55, or TR-55, a widely used model first developed by the U.S. Natural Resources Conservation Service (NRCS) in 1975.[16] This program utilizes formulas and procedures from the TR-55 model to calculate not only the volume of stormwater retained by the trees and vegetation on site, but also the **time of concentration (TOC)** increase and peak flow reduction[17] during a **2-inch 24-hour storm event**. Parameters of the model include:

- The percentage of general land covers such as tree canopy, grass, shrubs, and impervious surfaces on each site
- Perviousness (or permeability) of the soil
- Slope of site
- Amount of precipitation in specific storm event.

32 sites in Boulder were surveyed in the four land use categories (residential, commercial, industrial, and public); the number of sites selected in each category represents the relative amount of land in the City covered by that particular land use. The method for measuring trees in riparian areas differed due to the fact that mapping individual trees in densely forested areas is very difficult and time consuming. To estimate canopy cover in riparian areas, aerial photos of the entire city were examined and from these, patches of trees and shrubs in riparian areas were digitized. Riparian areas cover approximately 6% of the City of Boulder;[18] digitized trees and shrubs covered approximately 40% of these areas.

Bear Creek, Fall 2000. The banks are lined with both native and non-native trees, all of which are responsible in part for filtering stormwater runoff by directly absorbing pollutants. However, native trees such as cottonwoods have been scientifically proven to be more efficient at phytoremediation.

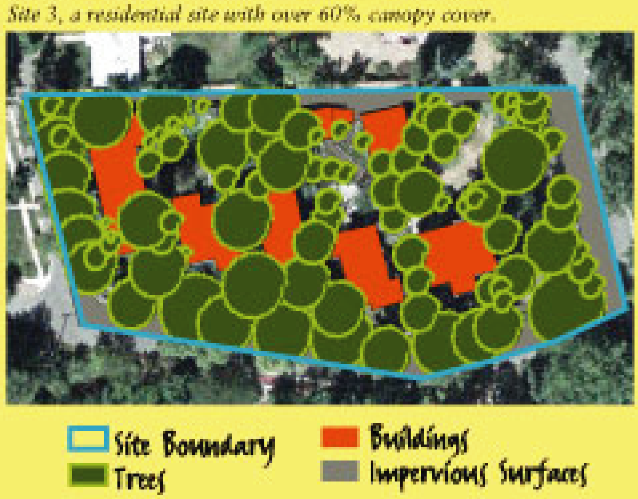
CITYgreen Methods

Data from each site were entered into the CITYgreen Stormwater Model, which required digitizing all surfaces within the site (refer to example). The model was run using a 2-inch 24-hour storm event to determine the volume of stormwater prevented from running off by trees and vegetation on site. The prevented runoff volumes were then averaged among all sites within the particular land use category to determine an average avoided runoff per acre figure. In order to extrapolate the stormwater runoff prevention by all land in that category, the avoided runoff per acre figure was then multiplied by the area of land occupied by that particular land use. For instance, residential land was found to provide 1,234 cubic feet per acre of stormwater runoff prevention in a 2-inch storm event, and occupies 7,752 acres of the City. Therefore: **1,234 ft^3/acre * 7,752 acres = over 9.5 million ft^3 prevented stormwater runoff per 2-inch storm event in all residential areas.** This method was used to determine City-wide avoided stormwater runoff during such a large-scale storm event.

Site 3 Stormwater Statistics

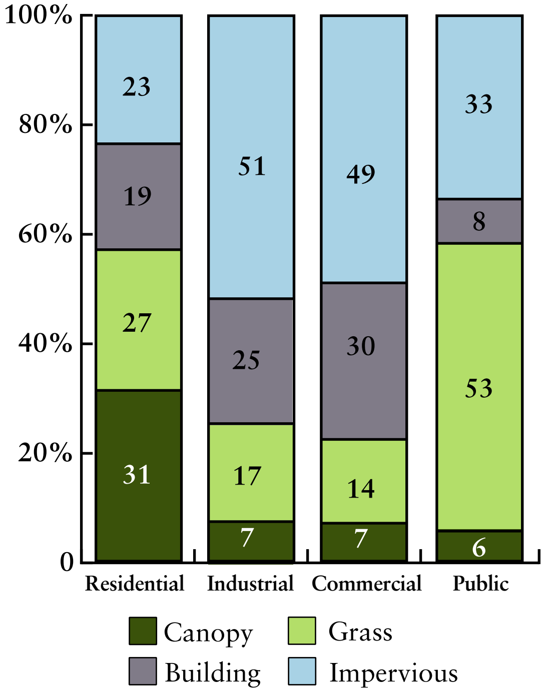
Area	1.52 acres
Land Use	Residential
Number of Homes	5
Tree Canopy	60%
Slope	5.0%
Soil Perviousness	Least pervious
Avoided Runoff	2813 ft^3
Avoided Runoff per Acre	1726 ft^3
Runoff Reduction	55%
TOC Increase	42%
Peak Flow Reduction	62%

Site 3, a residential site with over 60% canopy cover.



Land Use	Residential	Industrial	Commercial	Public	Riparian	Total
Average Canopy Cover %	31	7	7	6	40	
Avoided Runoff per Acre (ft^3)	1,234	309	316	263	2,125	
Runoff Reduction %	38	6	7	11	98	
TOC Increase	28	5	6	5	88	
Peak Flow Reduction %	45	8	9	15	99	
Acres	7,752	1,016	2,321	2,230	960	14,279
Total Avoided Runoff (ft^3)	9,566,000	314,000	733,000	586,000	2,040,000	13.2 million
Relative Runoff Prevention	72%	2%	6%	4%	16%	

Land Cover and Land Use in the City of Boulder



CITYgreen Results

Using the previously mentioned techniques, stormwater runoff prevention provided by trees within the City of Boulder was estimated at over 13 million cubic feet during a large-scale storm event of 2 inches of rainfall. This stormwater retention effectively reduces the overall volume of water traveling through constructed stormwater management systems by over 12% in this type of storm event. Further modeling of a smaller storm event (0.5 inches of rainfall) shows a much higher percentage of stormwater retained onsite, approximately 87%.

Trees on land in the residential and riparian areas are responsible for the largest portion of stormwater runoff prevention, and also have the greatest effect on increasing the TOC and reducing peak flow.

Discussion

Putting a dollar value on the reduced volume of stormwater has proven difficult, as there are several factors that help determine the value in preventing a cubic foot of stormwater from running off. Trees, shrubs and grass can all help to reduce the size of constructed stormwater detention areas. Careful integration of trees may reduce the need for large detention basins and therefore reduce the costs associated with **detention pond** maintenance and land acquisition.

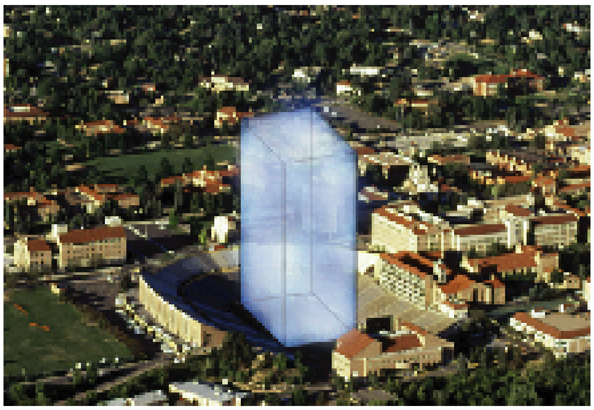
Using data from Urban Drainage and Flood Control District regarding detention areas constructed in the Denver-Metro area, it has been determined that the overall, one-time cost of construction for a typical detention area is approximately $0.80 per cubic foot. These detention areas have a lifespan of 30 years.[19] Using these figures, it was determined that the urban forest saves over $10.5 million in one time costs, or more tan $350,000 annually over the span of 30 years. This estimated value addresses only water quantity, not water quality. In order to estimate the added value provided by trees to water quality, additional research is needed on the impacts of different stormwater retention methods.

Detention Pond:
Vegetated, depressed area that collects stormwater and allows the water to soak into the soil. This infiltration process helps recharge groundwater.

Conclusion

Residential areas support a great number of trees, mostly planted within the last 130 years. Although very few of these trees are considered to be native to the Front Range or even Colorado, their presence has provided the City with a significant amount of stormwater runoff mitigation. The built environment of Boulder has affected and will continue to affect the quality and hydrology of it's water ways, but without these trees and their stormwater benefits, the impact of urbanization upon Boulder's water would be much greater.

"Research has revealed that imperviousness is a powerful and important indicator of future stream quality, and that significant degradation occurs at relatively low levels of development. The strong relationship between imperviousness and stream quality presents a serious challenge for urban watershed managers. It underscores the difficulty in maintaining urban stream quality in the face of development."[5]



Boulder's canopy cover is responsible for retaining 13.2 million cubic feet of stormwater during a 2-inch storm event, roughly equivalent to the volume a 20–story building the size of a football field. Photo courtesy of University of Colorado.

An example of a tree-lined vegetated detention area designed to collect and absorb stormwater runoff.

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