Managing Stormwater to Protect Water Resources in Mountainous Regions of Colorado

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1. Introduction

Like much of the Front Range of Colorado, Clear Creek County is defined by its landforms, climate, vegetation, and focused population centers (Fig. 1-1). The physiographic characteristics of the county include high peaks, great relief, rugged terrain, steep slopes, and shallow soils. The climate varies from semi-arid to alpine with elevations above 10,000 feet receiving an average of 25 inches or more of moisture per year. Vegetation varies from alpine tundra above timberline to thick stands of evergreen forest with interspersed mountain meadows and communities of aspen trees. The population in this mountainous county is sparse with 39 or fewer residents per square mile. However, because of the rugged terrain and dominance of federally owned land, most of its residents are concentrated along mountain flanks and stream valleys. The residents of the unincorporated portions of the county and certain municipal and commercial entities rely largely on groundwater for their water supply. With the exception of narrow alluvial aquifers along stream systems, this water supply is limited by the fractured, crystalline rock aquifers that store this resource. Increasing population growth and development have raised concerns about the sustainability of the groundwater resource. The purpose and focus of this study is to identify and promote stormwater management technologies and practices that may be implemented locally to protect and conserve water resources through mitigation of detrimental impacts caused by land disturbances and modifications associated with land development.

Natural runoff results when rainfall or snowmelt exceeds the capacity of the ground to absorb the additional moisture. The tendency of an area to produce runoff as overland or channelized flow depends upon vegetation, soils, geology, slope and climate. Naturally vegetated or undisturbed ecosystems produce little to no runoff from the vast majority of precipitation events. For example, on undeveloped property on the plains of the Denver Front Range area there is less than one runoff event a year (Urbonas, 2006). The native environment has and continues to evolve towards optimum management of excess water through evapotranspiration, infiltration, and natural runoff. While runoff is part of the natural hyrologic cycle, man-made hydrologic modifications that accompany development have increased the volume of stormwater runoff significantly. Land use modifications by human activities, particularly urbanization and agriculture, can alter natural drainage patterns and infiltration that recharges groundwater. Added impervious surfaces, soil compaction, and vegetation removal dramatically change the movement of water through the native environment. Runoff increases as interception, evapotranspiration and infiltration are reduced affecting not only the characteristics of the developed site but also the watershed in which it is located. Stormwater discharges have emerged as a national problem because both the flow of water and water quality is altered as the land is urbanized or developed. Stormwater has been identified as a leading source of pollution for all waterbody types in the United States (EPA, 2007).

Pollution prevention is central to federal, state, and local stormwater management programs. Appropriately designed, constructed, and maintained stormwater control measures reduce the volume of runoff, attenuate peak flows and remove pollutants. The emphasis of this study is to minimize water losses from the watershed through promotion of stormwater management strategies that maintain runoff and infiltration at their predevelopment levels. The best outcome is to not produce excess stormwater runoff volumes in the first place, rather to maintain a site's predevelopment hydrology. Achieving this objective addresses additional benefits such as: reduced erosion, sedimentation, and pollutant loading. We can maintain the predevelopment hydrology by controlling the amount and impact of impervious surfaces at the watershed or community level and through implementation of both structural and nonstructural strategies that absorb and infiltrate excess runoff.

As stormwater management has evolved, new practices and techniques have come with their own terminology to describe them. The goal of many modern management practices is to emulate the environment's natural hydrology prior to development. Examples of these modern practices include:

- Environmental Site Design (ESD) – this concept attempts to mimic natural systems along the entire stormwater flow path through a cascading series of design practices throughout the development site. ESD concepts are considered in the early planning stages, implemented during construction and sustained into the future as a low maintenance natural system.
- Green Infrastructure – this concept also utilizes natural systems such as forests and wetlands and their functional values to capture, clean and reduce stormwater runoff using plants, soils, and microbes. This may consist of site-specific management practices commonly called low impact development techniques (LID) that mimic the predevelopment hydrology by absorbing and infiltrating precipitation where it falls.
- Low Impact Development (LID) – this term is used to describe distributed and decentralized controls that infiltrate, filter, store, evaporate, and detain runoff close to its source with the goal of mimicking pre-development hydrology.

- Watershed Management – many communities are implementing this concept to address the nexus between land development and water quality and quantity on a scale that transcends political boundaries.

Although terminology differs for these progressive stormwater management concepts, the underlying goals are very similar. The message is particularly pertinent to the rural mountain communities of Colorado, that is: address stormwater runoff through natural systems as close to the source as possible, to maintain the area's predevelopment hydrology. While much of the modern stormwater literature refers to "mimicking" predevelopment hydrology, we use the term "maintain" predevelopment hydrology as this is more consistent with Colorado water administration. Traditional stormwater practices were developed with flood control in mind and promote collection and conveyance of precipitation from all storms away from the site to prevent localized property flooding. This has the unintended consequences of conveying water from small storms out of the watershed, increasing flood flows, concentrating pollutants, causing channel impacts, and reducing groundwater recharge (National Research Council, 2009). While flood control and detention structures are necessary for large storm events, complementary stormwater management techniques are needed to address water resource impacts during the smaller more frequent storms.

Applicability

This manual was written to introduce, educate, and provide general guidance for implementing green stormwater management practices at the watershed, community, and individual lot level. While the manual was developed for Clear Creek County, the concepts, guidelines, and best management practices are applicable throughout the mountain regions of Colorado and surrounding states. We encourage other communities to adopt stormwater management practices that maintain predevelopment hydrology. It is designed to assist planners, developers, architects, landscape professionals, city and county community development and public works staff, and the public with the selection and design of practices and techniques that facilitate runoff reduction and infiltration. The manual provides guidance for practices and techniques applicable to achieve those objectives. Detailed information about best management practices design is beyond the scope of this manual. This manual is intended to complement existing regional, city and county regulatory design and best management practices (BMP) manuals. Users are referred to a wide range of publically available stormwater BMP design manuals for detailed engineering and application information.

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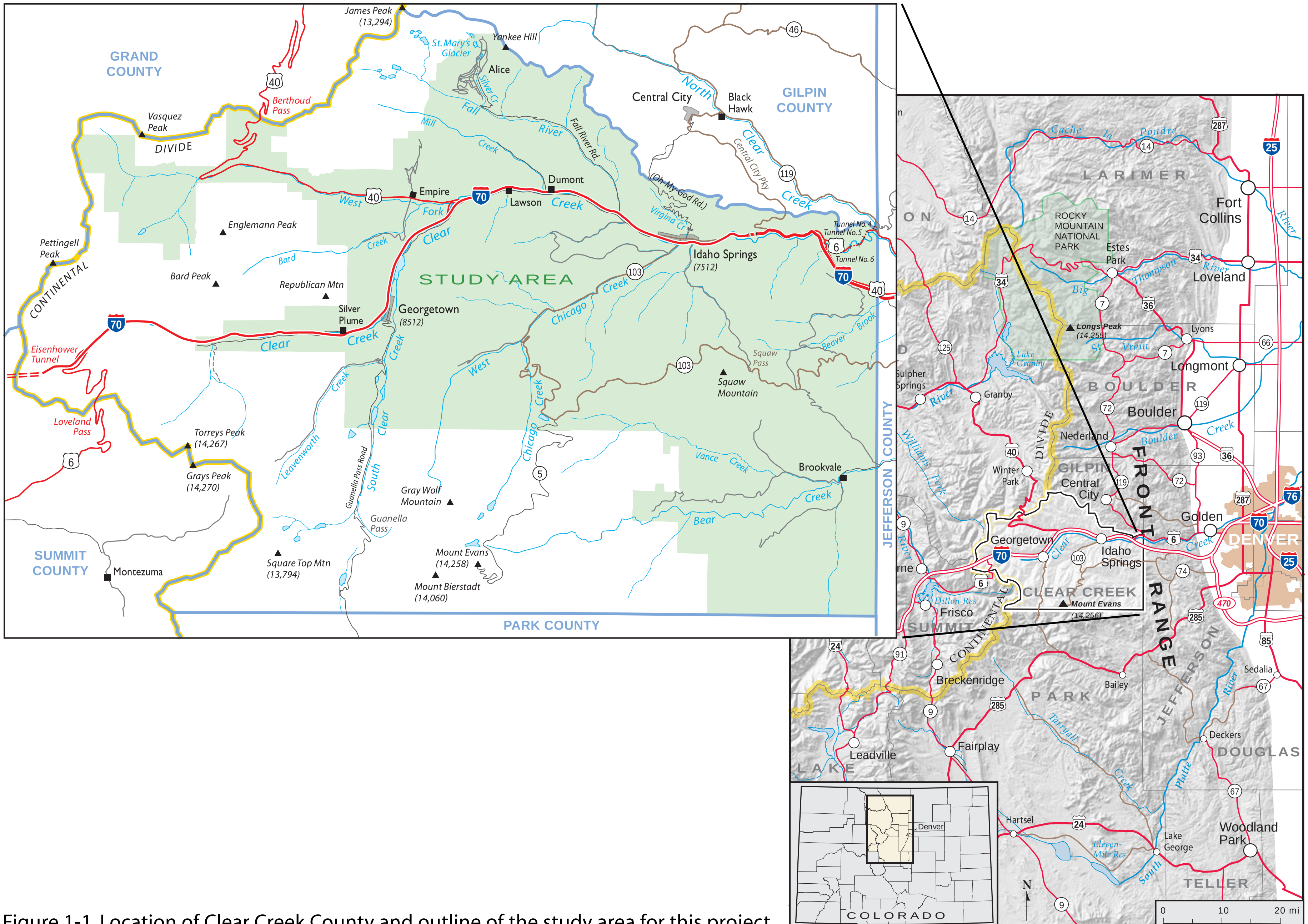


Figure 1-1. Location of Clear Creek County and outline of the study area for this project.

2. Water Resource Impacts of Development

Recharge concepts/definition

An area's suitability for habitation and prosperity is dependent upon its abundance of natural resources. In the arid west, even in mountainous terrain, water supply is perhaps the foremost natural resource challenge. That supply, whether from surface or groundwater, is entirely dependent upon the region's precipitation. While we can't create or guarantee the most favorable precipitation regime, we can use known planning, design, and construction techniques to support the continued viability of the resource. More specifically, developed land can be designed to manage stormwater in a manner that does not generate excess runoff. In other words, we can use land use planning tools, engineering design and construction techniques that help maintain predevelopment hydrology instead of emphasizing techniques that drain precipitation from the watershed. The focus of this manual is to identify passive absorption and infiltration best management practices that target the development induced runoff from frequent, smaller volume storms that would not have produced runoff in the native environment.

Even "sheet flow" drainage occurs in this undisturbed area and does not exhibit a concentrated flow path.

A gulch in the center of this photo indicates a concentrated flow path that can be created by previous land disturbance or a point discharge such as a road culvert.

In Colorado's semi-arid climate, most of the precipitation that falls on the land surface is lost to evapotranspiration. The remaining water is: 1) absorbed by the soil to increase soil moisture and when saturated infiltrates into the subsurface and/or 2) flows overland to become runoff. It is not until excess soil moisture conditions exist that water moves downward by gravity to reach the water table recharging the aquifer. *Natural recharge* occurs when precipitation percolates into the ground (infiltration) and reaches the water table. Natural recharge rates in Colorado are highly variable. In the mountainous regions of the Front Range it is estimated that only 6-8 percent of total precipitation contributes to recharge of long-term groundwater storage (Poeter and others, 2003). *Enhanced recharge* has historically consisted of vegetation management, where deep-rooted, hydrophilic or "water-loving" vegetation are replaced by shallow-rooted water-conserving vegetation or bare soil. Enhanced recharge can also be achieved by selective management of runoff.

Replacement of native vegetation by hardened or impervious surfaces as the landscape is developed affects the hydrologic budget with a shift from infiltration and evapotranspiration to surface runoff. Reduced infiltration causes a reduction of natural recharge that in combination with increased withdrawals through well pumping can cause a decline in water levels. Absent other sources of recharge, declining water levels also leads to a reduction of baseflow in streams.

Surface and subsurface infiltration

Infiltration implies flow into a material, while percolation means flow through a material. Infiltration occurs when falling rain or snowmelt enters a soil or rock, through pores or small openings. When the water moisture exceeds the material's pore pressure, the excess water percolates downward by gravity through the unsaturated zone to the water table thereby recharging groundwater. Engineered structures are used to compensate for some of the negative effects of added impervious area.

Engineered structural management designs that allow infiltration can be implemented on the surface or in the subsurface. Land use and permeability of near surface materials are the primary factors that determine infiltration potential. Surface infiltration is simply allowing water at the ground surface to soak into the underlying soil or rock material. Surface stormwater infiltration systems can be relatively simple to construct, but are highly dependent upon the existing surface conditions and typically require engineered media below the surface to allow infiltration. These systems can be implemented on flat land or take advantage of natural topography. They can coexist with other uses such as recreation and wildlife habitat, but compatibility with adjoining land use is an important consideration. Surface infiltration best management practices (BMP) include vegetated swales, porous landscape detention, infiltration basins or trenches, and permeable pavement systems.

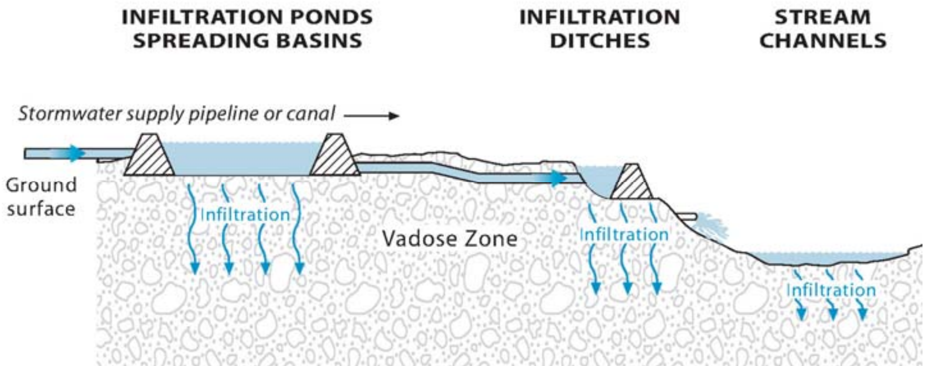


Figure 2- 1: Examples of surface infiltration

Subsurface infiltration is the application of water below ground surface for percolation into the underlying soil or rock. These systems may be more conducive to areas where surface conditions, such as impermeable soils or incompatible land uses preclude surface infiltration. For example, an infiltration gallery may be installed beneath parking lots. Subsurface infiltration systems in mountainous terrain are complicated by shallow bedrock conditions that may require extensive excavation or blasting. Subsurface infiltration BMPs include infiltration galleries, infiltration trenches, and dry wells.

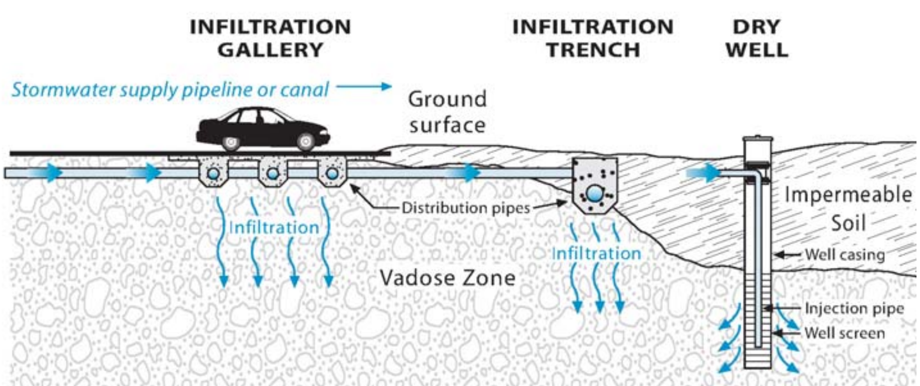


Figure 2- 2: Examples of subsurface infiltration

Why stormwater matters

When land is altered by development from a natural forested ecosystem to impervious or hardened surfaces such as rooftops, streets, and parking lots, the hydrology of the system is significantly altered. After development, rainfall that previously infiltrated into the soil and/or evapotranspired by vegetation is converted directly into surface runoff. As the percentage of the native landscape that is paved or compacted increases, the land area available for infiltration of precipitation is reduced and vegetation removal decreases evapotranspiration. Figure 2-3 illustrates the change in components of the hydrologic cycle as land cover changes from vegetated and undeveloped to increased urbanization. These changes in hydrology can have dramatic effects in arid and semi-arid regions of the country.

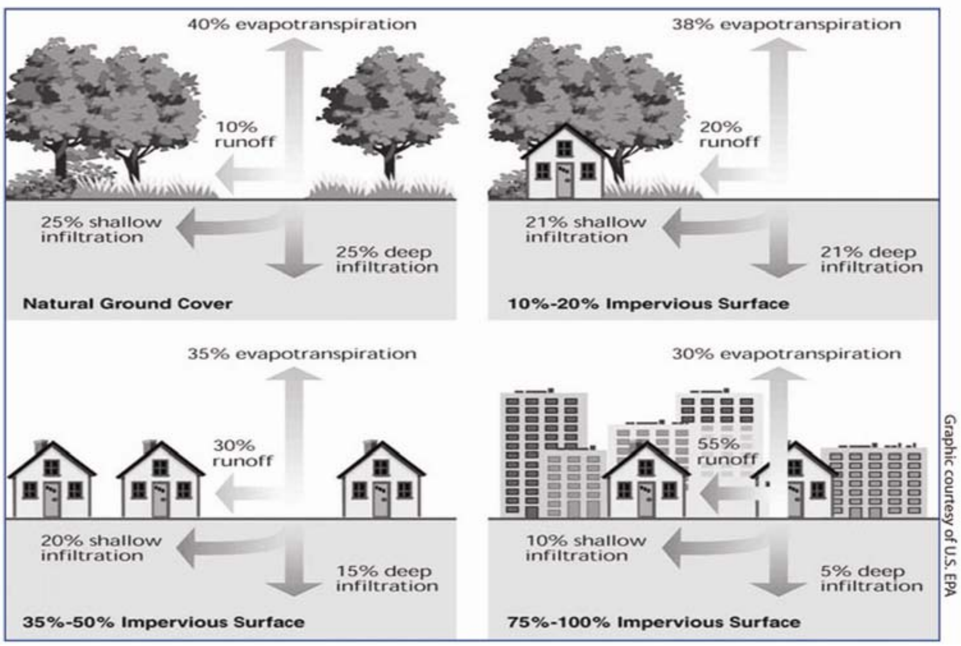


Figure 2-3. This graphic illustrates the effects of increased imperviousness on evapotranspiration, runoff, and infiltration. Percentage values vary by geography and are not representative of Colorado's mountainous regions.

On undeveloped land, a substantial portion of the annual precipitation that falls onto the native surface infiltrates to produce soil moisture. Excess moisture percolates downward to the water table, recharging aquifers and supplying baseflow to nearby rivers, wetlands, and lakes. Native land with no impervious surfaces typically has the capacity to absorb precipitation from small storm events and a significant portion of precipitation of large events prior to the generation of runoff. On the plains along the Denver Front Range, for example, undeveloped land has the ability to absorb the first inch of precipitation. Since most storms amount to less than an inch of precipitation with the mean storm amount about 0.5 inches of precipitation, there is, on average, less than one runoff event annually from undeveloped property. After development, however, there are between 20 and 30 runoff events each year (Urbonas and Wulliman, 2005). This is because the additional impervious surfaces and their inter-connectivity creates runoff events from small storms that previously did not produce runoff.

Most urban stormwater runoff is a product of human-made hydrologic changes that accompany land development. The addition of impervious surfaces, along with soil compaction, and vegetation removal, reduces interception, evapotranspiration, and infiltration, and converts precipitation to overland flow. The chart below illustrates the direct relationship between runoff and imperviousness. Prior to development, nearly all of the precipitation from a one-inch event (in two hours) in Denver is absorbed (Fig. 2-4). Water adsorption does not necessarily imply infiltration. An identical storm, on a property with 100% impervious area, generates approximately 0.9 inches of runoff (Urbonas and Wulliman, 2005).

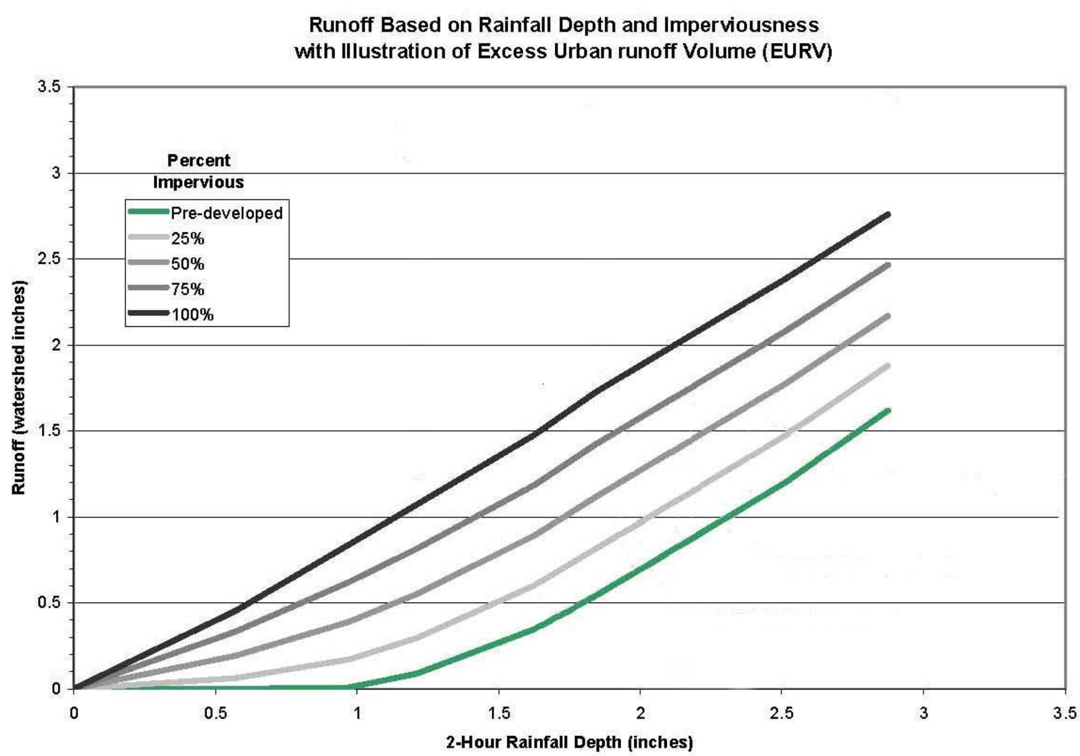


Figure 2-4. As the percentage of impervious cover increases, so does the quantity of runoff from any given storm event. (Urbonas and Wulliman, 2005).

Because of the increase in runoff rate and volume associated with increased impervious cover, stormwater management has traditionally meant drainage and flood control, i.e. moving water away from the impacted structures as fast as possible and completing channel projects to safely contain and convey the increased volume in the water channel instead of on developed property. Consequently, stormwater management programs focus on structural engineering solutions to manage the hydraulic consequences of increased runoff. These are largely conveyance storm sewer systems, end of the pipe control and treatment strategies such as detention basins aimed at regulating peak flow rates and suspended solids concentrations. However, conventional centralized control and treatment strategies fail to address the cumulative hydrologic modifications from frequent small precipitation events within the watershed that result in increased flow volumes and runoff rates and their resultant erosion and stream channel degradation impacts.

Managing stormwater to protect water resources

As discussed above, when land area is urbanized both shallow and deep infiltration decrease and runoff is increased. Traditional drainage-based stormwater management promotes the collection and conveyance of stormwater away from the site and typically out of the local watershed resulting in increased pollutant loading, sedimentation, increased flood flows, and a reduction of native groundwater recharge. Most of the public's concerns regarding stormwater center on flooding, the effects of which can be catastrophic causing damage to property and loss of life. Changes in stormwater runoff quality and quantity can have significant environmental impacts as well, affecting not only the aquatic ecosystem, but also the quality of life in a community by changes in the hydrologic budget.

Maintaining an area's predevelopment hydrology is particularly important to those rural mountain communities in Colorado which rely predominantly on groundwater for their water supplies. Managing stormwater is important because it is one element of the hydrologic budget over which communities have direct control. Stormwater infiltration and absorption techniques provide a way to maintain predevelopment hydrology and reduce the loss of water resources from the local watershed that occurs with land development and disturbance. Infiltration and absorption structures also provide water quality and channel protection benefits as they act as filters. Also, absorbing small storms onsite reduces the type of channel scour that occurs with repeated discharge of small storms, which did not previously flow off of the property, to waterways.

Socioeconomic Benefits

While there are numerous environmental reasons and benefits to develop land in a manner that maintain predevelopment hydrology, there are as many socioeconomic reasons to do so. From the perspective of residents who rely on well water for domestic supply and a functioning well to maintain property value, stormwater infiltration is crucial and a direct financial benefit. From the perspective of a developer, stormwater runoff reduction design can offer social, economic and environmental benefits. In the mountains and in other areas with high value land, the benefits of using the same area of land to serve multiple management functions, in an attractive manner, can be reflected in higher land values, reduced infrastructure costs, and longer economic life. Runoff reduction techniques also reduce offsite or externalized costs that the community bears. To state it directly, the more mitigation and prevention techniques that are included on the developed property to reduce excess runoff volume, the more cost savings are realized by the community from: mitigating pollutants in the waterway, stream bank destabilization, reduced flood risk, and maintaining stormwater infrastructure in the right-of-way. These are direct benefits for the developer, property owner and community.

3. Hydrogeology of Clear Creek County

Hydrogeology is the science that deals with groundwater and with related geologic aspects of surface waters. Groundwater in the mountainous terrain of Colorado is a limited resource constrained by climate, vegetation, geomorphology, and geology. As we are promoting infiltration BMPs to protect and sustain this limited water resource, we believe a more current understanding of the hydrogeology of the county will assist this manual's user in understanding the need for optimizing the management of stormwater runoff.

In 1976, Jan Krason prepared a hydrogeologic map of Clear Creek County with accompanying text based on an inventory of water resources and ancillary information available in published and unpublished reports. Other than Krason's work there are no public reports specific to the hydrogeology of the county. The available literature focuses on the geology, ore deposits, and mining activities of the area with some limited surface water quality data. Within the scope of this study, we focus on the source of water – climate and the geologic units that comprise the aquifers that store groundwater.

Clear Creek County occupies approximately 394 square miles in the central Front Range of the Colorado Rocky Mountains (Fig. 1-1). The county's topography is rugged with elevations ranging from mountain summits in excess of 14,200 feet (Mt. Evans, Grays and Torreys Peaks) to valley bottoms at about 7,000 feet (Clear Creek/Jefferson county line). The continental divide, at elevations from 12,000 to 14,000 feet, forms the county boundary to the west and northwest. The present topography is a product of multiple episodes of glacial erosion and river incision. That topography is expressed as over-steepened mountain sides, with unstable colluvium development, and relatively steep drainages at the valley bottoms.

Climate Considerations

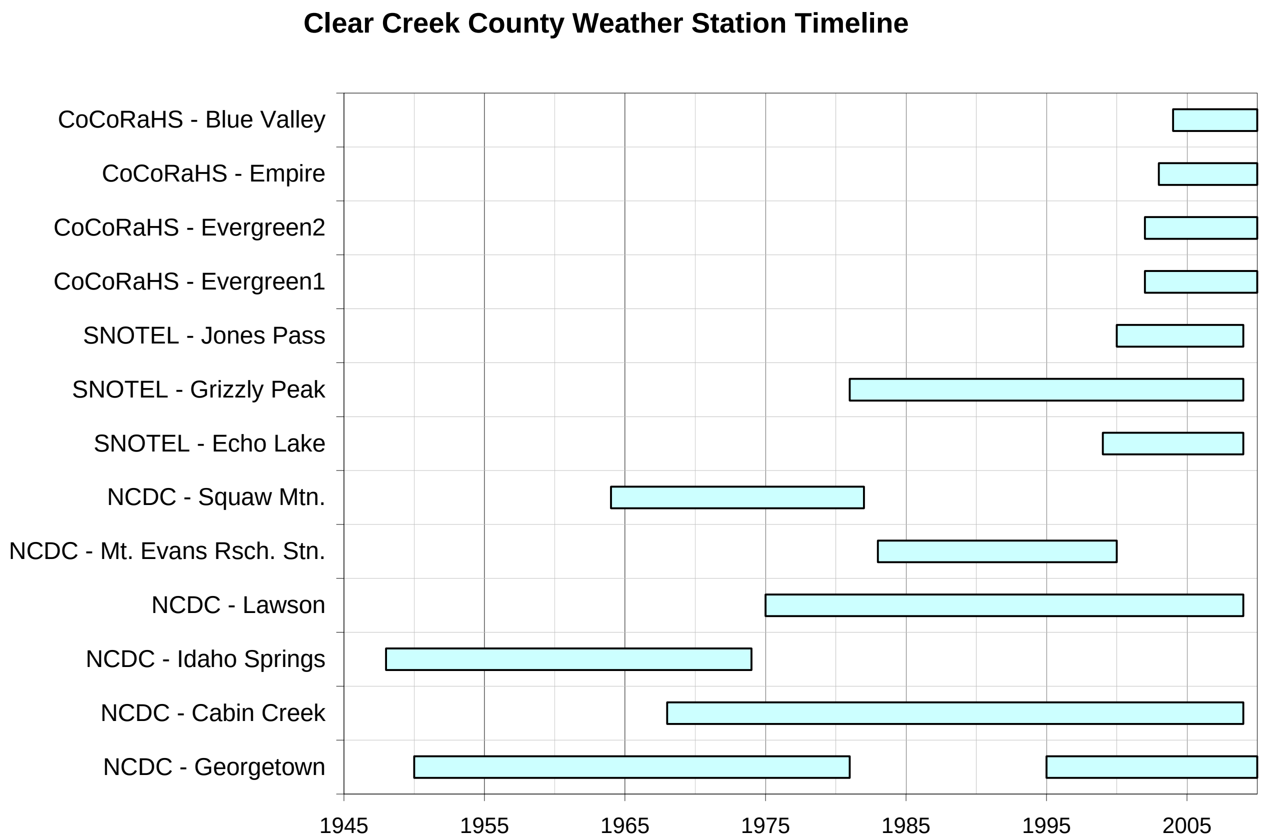
The mountainous regions of Colorado represent areas of net water gain as precipitation exceeds potential evapotranspiration. Precipitation is the dominant source of groundwater recharge through natural infiltration. It also produces the stormwater events that offer opportunities for infiltration management. The climate of Clear Creek County varies from semi-arid at lower altitudes to alpine at higher elevations. Differences in precipitation are caused by elevation changes and orographic effects of topography. Sparse groundwater recharge occurs in winter as the majority of precipitation falls as snow and frozen ground precludes infiltration. Groundwater levels recovery quickly, however, during the onset of spring snowmelt.

Climatic data in the county is collected by and available from three weather station networks – the National Climatic Data Center (NCDC), the SNOTEL Data Collection Network (SNOTEL), and the Community Collaborative Rain, Hail & Snow Network (CoCoRaHS) (Chart 1). The period of record and continuity of data varies greatly among networks and stations (Chart 2). Understanding the amount of precipitation an area may experience is critical in estimating the amount of runoff and infiltration. Climate is an important consideration is designing BMPs. To characterize the precipitation in Clear Creek County where large variations in elevation exist, stations were selected for analysis based on geographic and topographic variation across the nine watersheds within the county (Fig. 3-1).

Chart 1: Weather networks and sites selected for analysis in Clear Creek County

Network	Description	Weather Station Sites
NCDC	Administered by the National Oceanic and Atmospheric Administration, the NCDC contains the world's largest archive of weather data. Weather data is obtained from the National Weather Service, Military Services, Federal Aviation Administration, as well as data from voluntary cooperative observers.	Georgetown Cabin Creek Idaho Springs Lawson Mt. Evans Research Stn. Squaw Mtn.
SNOTEL	Administered by the Natural Resource Conservation Service, SNOTEL is an extensive automated system, designed to measure snowpack and precipitation, along with related climatic data at high-elevation sites throughout the Western United States.	Echo Lake Grizzly Peak Jones Pass
CoCoRaHS	A community-based network of volunteers working to measure and map precipitation across the United States.	Evergreen1 Evergreen2 Empire Blue Valley (Idaho Sprs)

Chart 2: Period of record and continuity of climatic data in Clear Creek County



Average Annual and Mean Monthly Precipitation

Weather station sites are distributed throughout six of the nine watersheds in the county, including: Upper Clear Creek, the mainstem of Clear Creek, Bear Creek, West Fork of Clear Creek, Chicago Creek, and Beaver Brook. Because of differences in topography, temperature, and air movement, weather stations are compared against those within common watersheds. As expected, annual precipitation and mean monthly precipitation are directly related to elevation. Chart 3 summarizes the annual and mean monthly precipitation data from the available stations. Precipitation values reported in Chart 3 represent rainfall equivalents, i.e. including snowfall.

Chart 3: Annual and mean monthly precipitation at weather stations in Clear Creek County

Weather Station Site	Watershed	Elevation (ft)	Average Annual (in)	Mean Monthly Range (in)
Georgetown	Upper Clear Creek	8,520	16.42	0.63 – 2.28
Cabin Creek	Upper Clear Creek	10,020	19.73	0.79 – 2.81
Grizzly Peak	Upper Clear Creek	11,100	32.47	1.68 – 3.96
Evergreen2	Bear Creek	7,789	20.31	0.72 – 2.89
Evergreen1	Bear Creek	8,097	22.83	0.83 – 3.25
Blue Valley	Bear Creek	9,800	25.21	0.99 – 3.95
Echo Lake	Bear Creek	10,600	28.02	1.28 – 4.06
Mt. Evans Rsch. Stn.	Chicago Creek	10,630	32.89	1.31 – 5.17
Idaho Springs	Clear Creek Main	7,566	15.52	0.47 – 2.44
Lawson	Clear Creek Main	8,100	16.06	0.41 – 2.09
Empire	West Fork of Clear Creek	8,684	15.70	0.58 – 2.09
Jones Pass	West Fork of Clear Creek	10,400	34.32	1.54 – 3.99
Squaw Mtn.	Beaver Brook	11,509	25.09	0.79 – 3.50

Average annual precipitation within the river valley bottoms represented by Idaho Springs, Lawson, Empire, and Georgetown are quite similar ranging from 15.5 inches on the eastern portion of the county to 16.4 inches on the western portion. Stations at higher elevations on or near the continental divide (Grizzly Peak and Jones Pass) receive average annual rainfall of 32.4-34.2 inches, approximately double that of the valley bottoms. The orographic effect of Mount Evans is obvious from the climate data with the Bear Creek watershed receiving higher average precipitation totals (20.3-28.0 inches) than equivalent elevation stations in other watersheds. Understanding the potential variability in the mean monthly range between watersheds and within a watershed is critical to designing flow capacity for best management practices.

Almost universally throughout the county, 68-69% of the total precipitation falls during the months of April through September (NRCS, 2003). This time frame coincides with the growing season for most crops. On average, winter conditions with at least one inch of snow on the ground range from 21 days on the eastern edge of the county to 101 days in the higher elevations west of Georgetown (NRCS, 2003).

Rainfall Frequency Spectrum

Over the course of a year, numerous precipitation events occur within Clear Creek County. Most of the events are quite small, but a few can produce more than half an inch in a day. A Rainfall Frequency Spectrum (RFS) was developed for the county that demonstrates the percentage of rainfall events that are less than or equal to a given amount. The RFS disregards all rain events under 0.1 inches, along with snow events that do not melt immediately. The spectrum is used as a tool by stormwater managers to provide the technical foundation for management criteria such as channel protection, runoff reduction, and water quality volume treatment. Based on the analysis conducted herein, we recommend that local jurisdictions promote infiltration of small storms and larger storms to the water quality volume represented by the 90th percentile of rainfall depth.

Rainfall Frequency Spectra were developed for Georgetown and Idaho Springs to evaluate the overlapping period of record from 1950–1973. Additionally, a second Rainfall Frequency Spectrum for Georgetown analyzes the most recent period of record, from 1994–2008 (Chart 4).

Chart 4: Rainfall Statistics and Frequency Spectrum for Georgetown and Idaho Springs

Station, Time Period	Precipitation[a]		Rainfall event: Depth in inches				
	Annual (inches)	Days[b]	50%	75%	90%[c]	95%	99%
Georgetown, 1950 – 1973	10.92	38	0.20	0.35	0.59	0.74	1.16
Georgetown, 1994 – 2008	10.80	36	0.22	0.37	0.59	0.76	1.12
Idaho Springs, 1950 – 1973	9.86	32	0.21	0.37	0.60	0.84	1.44

[a] Excludes rainfall depths of 0.1 inch or less and snow events that did not melt immediately.

[b] Average days per year with measurable precipitation.

[c] The 90% storm defines the water quality volume

For the period of record from 1950–1973, the rainfall frequency in Idaho Springs (Figure 3-2) and Georgetown (Figure 3-3) are quite similar with an average of 9.9-10.9 inches of precipitation falling as rain during an average of 32-38 precipitation days. Fifty percent of those days produced 0.22 inches of water or less and ninety percent produced 0.6 inches or less (Chart 4 and Figure 3-2). The maximum precipitation events of 3.95 inches in Georgetown and 4.10 inches in Idaho Springs are also quite similar.

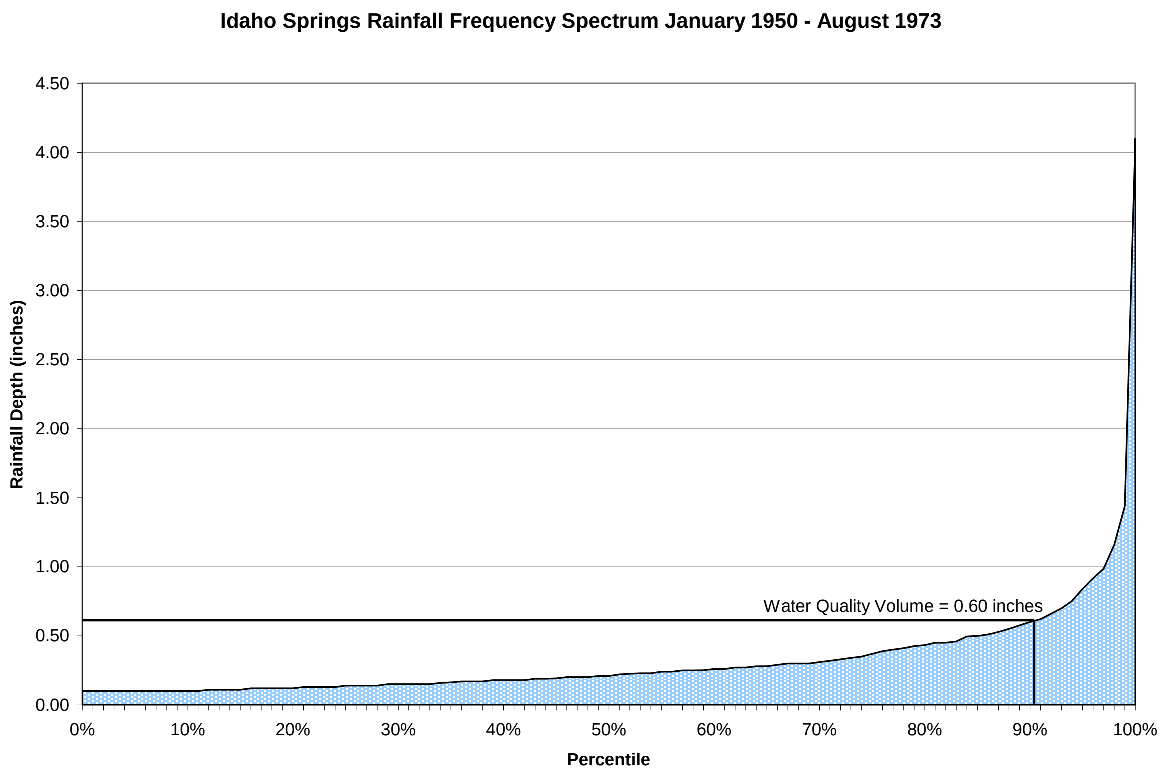
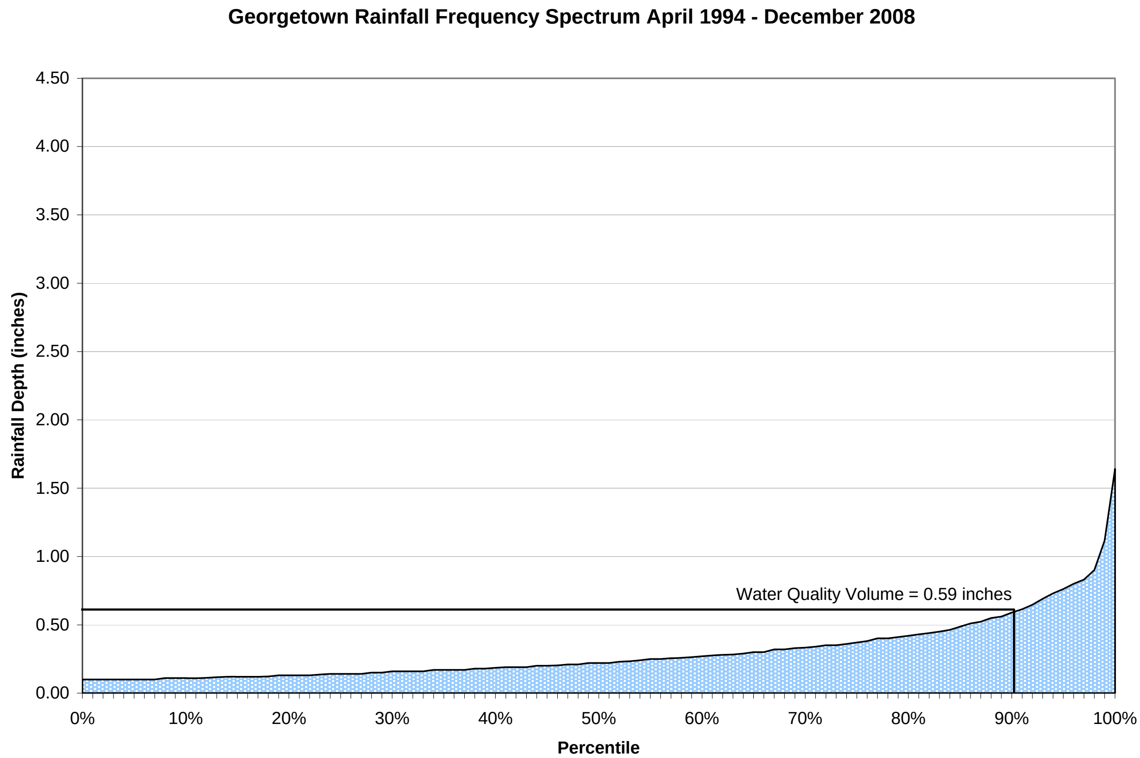


Figure 3-2: Rainfall frequency spectra for the NCDC Idaho Springs weather station.



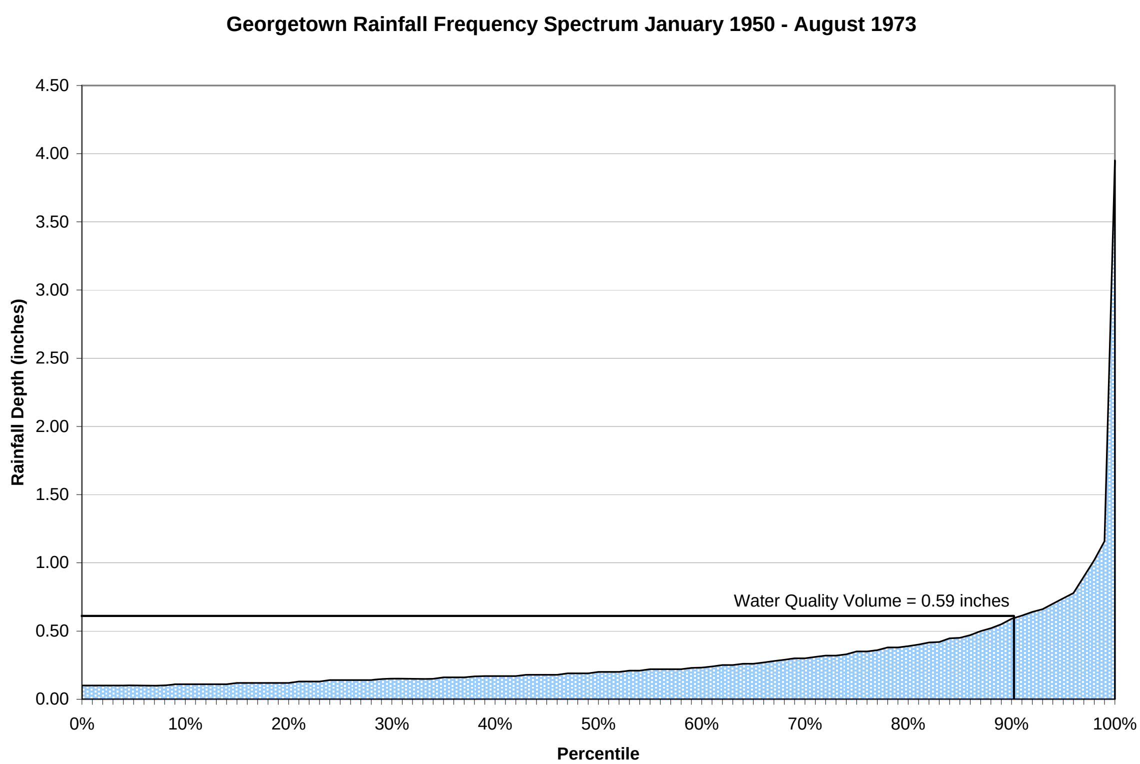


Figure 3-3: Rainfall frequency spectra for the NCDC Georgetown weather station.

Geology

The geologic units in the county consist of unconsolidated surficial deposits such as alluvium, colluvium and mass movement deposits, glacial deposits and bedrock units. The most recent and comprehensive geologic map that includes all of Clear Creek County was produced by Kellogg and others (2008). Figure3-4 is a generalization of their work to depict the geology of the county. The bedrock is composed primarily of metamorphic and igneous rocks, with the oldest metamorphic rocks being approximately 1.75 billion years ago (Selverstone and others, 1997). These rocks are light to medium gray in color and are often highly deformed, recrystallized, and partially melted. Often their foliation is still visible which reflects the original layering of the rocks. These old metamorphic rocks are well exposed in the vicinity of Idaho Springs.

The metamorphic rocks were then intruded by granitic rocks approximately 1.4 billion years ago (Kellogg and others, 2008). The granitic rocks are gray to pinkish-gray and medium to coarse grained. These granites do not have the "layered" structure that the older metamorphic rocks do, but instead have complex contacts composed of numerous dikes and irregular intrusive bodies. They are well exposed in the old mining areas immediately west of Silver Plume. These ancient rocks were then intruded by younger igneous rocks in various episodes from approximately 65 to 20 million years ago (Tweto, 1987; Widman and Miersemann, 2001). These younger igneous rocks are found as smaller bodies of rock that cross cut the older rocks and are more localized in areal extent.

The bedrock units are overprinted with a fairly extensive network of faults which tend to run in a northeasterly direction in the western portion of the county and in a northwesterly direction in the eastern portion of the county. Associated with these major faults are numerous fractures that trend in a variety of orientations. The igneous and metamorphic crystalline rocks represent the local bedrock aquifers, whose hydrologic properties are controlled by the faults and fractures and their relative density (number of fractures per unit volume or area). In addition to the regional fault and fracture system there is the northeast-southwest trending Idaho Springs-Ralston shear zone which is a band of highly strained and sheared rocks that dips steeply into the subsurface. Krason (1976) mapped an area of the crystalline-rock aquifer with higher productivity (inferred from well yields) along this shear zone.

The unconsolidated surficial deposits are often concentrated in valleys and along drainages. Glacial till deposits are located in the higher mountain valleys in the western portion of the county, and range in age from 10,000 to 170,000 years (Kellogg and others, 2008). Glacial tills consist of poorly sorted pebbles, cobbles, and boulders of the surrounding bedrock that was scraped off and transported by glaciers and eventually accumulated in large piles at the toe or along the sides of the glacier (morianes). Glacial till deposits tend to have moderate permeability. Examples of glacial deposits are well exposed along Highway 40 from Empire to Berthoud Falls.

Younger still are deposits of rock on hillsides that have been moved by gravity, typically in the form of rock falls or landslides (mass movement). These are the talus fields seen on many mountainsides in the area. The material comprising this colluvium typically ranges in size from small to very large with angular shapes. The permeability of these types of deposits is usually very high. Rocks and sediments that have been deposited by running water (alluvium) are the youngest of the unconsolidated deposits. Particle size varies from sand grains to medium sized boulders. These rocks will be well rounded, tend to be sorted by size to some degree and are found in valley bottoms. In steep, alpine areas such as Clear Creek County, alluvium also tends to be highly permeable.

Groundwater

Few publications exist that specifically address the hydrogeology of Clear Creek County. Publications on various aspects of geology and mining/ore deposits often contain ancillary hydrogeological information, but this information is usually local or site specific. Under contract with the county, Jan Krason (1976) produced a hydrogeologic map based on existing published and unpublished reports, maps, and water level data from the Office of the State Engineer. His study did not include specific field observations. Krason divided the aquifers in Clear Creek County into three categories: 1) groundwater in porous, loose or poorly compacted sedimentary rocks, 2) groundwater within fault zones within brecciated crystalline rocks, and 3) terrains with only local or limited quantities of water.

Precambrian age metamorphic and igneous crystalline bedrock dominates the surface and subsurface in the mountainous regions of Colorado. In Clear Creek County these rock types are represented by biotite gneiss and Silver Plume granite. These rocks are highly resistant, variably fractured, and complexly deformed. The productivity of a crystalline rock aquifer is very dependent upon the location and geometry of brittle fracture zones, which have higher fracture densities. The fracture porosity of these crystalline rocks is very low, typically less than one percent. Fractures provide the only significant porosity and flow conduits within these aquifers. Consequently, the water storage and yielding capacity of these fractured, crystalline rock aquifers limit the use of these aquifers to stock, domestic, or low demand commercial applications. Average well yields are typically 4-5 gallons per minute. Investigations by the U.S. Geological Survey in the Turkey Creek watershed of Jefferson County suggest that wells completed in metamorphic gneiss have a slightly higher yield than those completed in granite, but wells in fault zones produce significantly more water (Bossong and others, 2003).

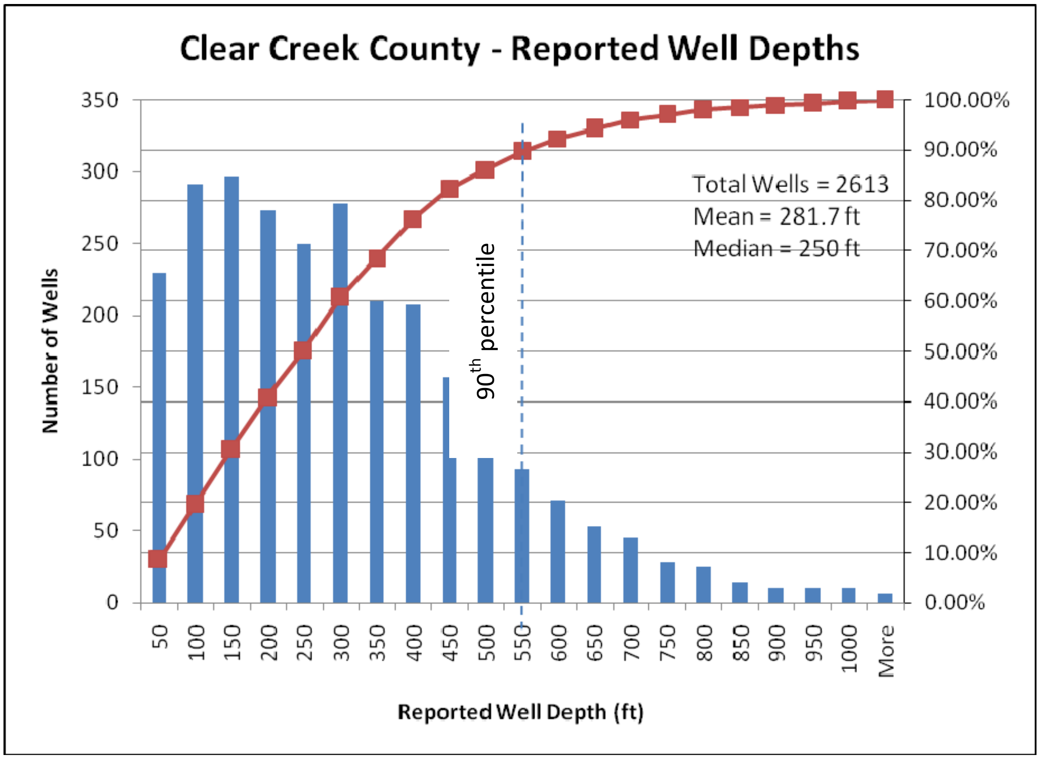
Based on the geologic map of the Denver West 30’ x 60’ quadrangle produced by Kellogg and others (2008), which we generalized as Figure 3-4, we also classify the aquifers within Clear Creek County in three distinct categories. These include: 1) fractured, crystalline bedrock, 2) alluvial aquifers associated with significant stream reaches, and 3) local colluvial aquifers largely consisting of mass movement and glacial deposits. We recognize the increased productivity of the fault zones, but the available resolution of the current mapping is insufficient to delineate distinct aquifer areas. A detailed discussion of the hydrologic characteristics of these aquifers is beyond the scope of this project.

We have analyzed the State Engineer’s database of permitted water wells to better understand the groundwater supply picture in Clear Creek County and impacts that development have had on this resource. In 1976, Krason reported 617 registered water wells in the county. Our query of water wells as of February 2009 produced 2,617 actual wells of record. Analysis of this database produced information on the distribution, depth, water level, and yield of these wells. The analysis was conducted without classifying these wells by aquifer or permitted use. The spatial distribution of these wells is shown in Figure 3-5. The majority of these wells are concentrated along the eastern edge of the county in the Bear Creek (930 wells) and Beaver Brook watersheds (665 wells).

Within the Clear Creek watershed, which includes all of the streams in the county except the North Fork of the South Platte River, reported well depths range from a few feet below ground to more than 1,000 feet. A frequency distribution graph of reported well depths is presented in Figure 3-6. This analysis shows the number of wells completed within specific 50-foot depth intervals. The mean well depth of this data set is approximately 282 feet, and 90 percent of the wells of record are completed at depths less than 550 feet. Reported water levels vary widely from near surface to greater than 600 feet below ground. Statistically, the water level data have a geospatial correlation (i.e. non-random) with generally shallower depths to water in the western portions of the county and deeper depths to water in the more developed eastern portions of the county. Figure 3-7 displays the wells of record by their reported depth to groundwater.

Well depth, water level, and well yield statistics for wells completed within the individual watersheds within the county are presented in Table 3-1. This table summarizes the number of wells within specific watersheds, minimum, maximum, and average values, and the 90th percentile value for well depth and well yield. A frequency distribution graph of reported well yields within the entire Clear Creek watershed is also presented in Figure 3-6. This analysis confirms the general low yield of wells within the fractured rock aquifers with a mean value of 7.6 gallons per minute (gpm). The well yield values are biased in part by the regulatory production limit on domestic and stock wells of 15 gpm. Consequently, the 90th percentile value for well yields within the county is 15 gpm.

a)



b)

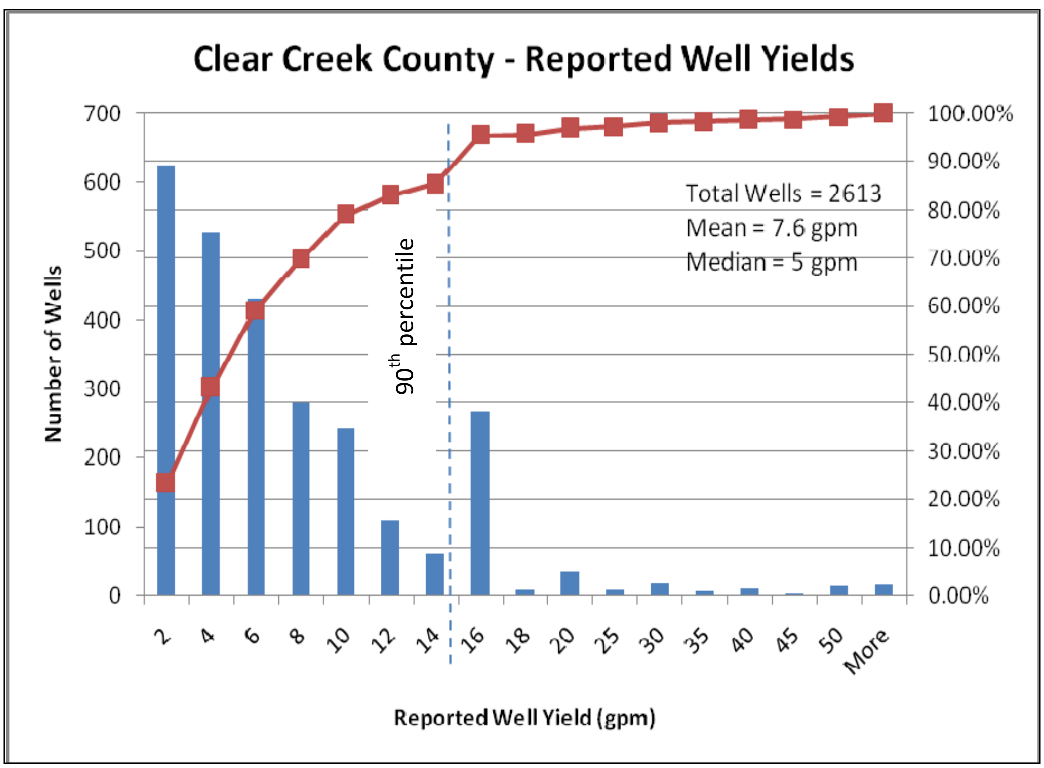


Figure 3-6: Frequency distribution of reported water supply a) well depths and b) well yields

Groundwater Recharge

Impacts to water resources as a result of development can pose challenges to mountain communities striving to protect their limited supplies. Development that uses land more efficiently or protects a greater percentage of native land helps a community to grow while still protecting its water resources. Areas that contribute most to natural recharge must be maintained to sustain the groundwater supply. These conservation design concepts are one of the key elements of low impact development.

The study area (Fig. 1-1) for the analysis presented herein is an approximation of the land suitable for potential development based on the county's zoning map layer. The CGS performed an analysis to identify specific areas that have the greatest potential for contributing to groundwater recharge. The natural recharge potential was evaluated through a series of matrices assembled and analyzed in ArcGIS. The process involved quantifying values for the main physical characteristics that affect the ability of water to infiltrate into the ground and eventually recharge the groundwater system. Four physical factors - geology, slope, soil type, and precipitation - were used to predict areas where groundwater recharge is likely to occur within the study area. Spatial data for each of the four matrix inputs was assembled in a GIS. All matrix inputs were converted to a GIS raster cell-based format at a minimum resolution of 30 meters. Each input was assigned rating values to be used in computing the groundwater recharge potential throughout the study area. Figure 3-8 shows the spatial distribution of these input characteristics within the study area. A more detailed discussion of input matrix classifications, rating values, and the sources of the input data are contained in Appendix A.

The geology input matrix was classified into three different geologic regimes: alluvial deposits and faults, non-alluvial deposits and fracture zones, and bedrock units. As shown in Figure 3-8, the county is dominated by bedrock units. The slope input classifications are also displayed in Figure 3-8 in 5 percent increments. Clear Creek County has identified a 30 percent slope threshold for development. The Natural Resources Conservation Service hydrologic soil group classification represents the third input in Figure 3-8. Hydrologic soil groups C and D are generally not suited to infiltration BMPs. It should be noted that exposed bedrock is classified as hydrologic soil group D, and its infiltration potential is influenced by the amount and density of fracturing. Precipitation forms the final input category for the groundwater recharge matrix. For this analysis, four precipitation ranges were used. The natural groundwater recharge potential was determined by multiplying the four input rank values for each raster cell within the study area and classifying the resultant values. In this conservative analysis, cells with any input value of zero (applicable for soil and slope) retain their low potential recharge ranking. The results of this analysis are shown in Figure 3-9. Low, moderate, and high potential groundwater recharge areas are delineated. This analysis is specific to Clear Creek County. That is, areas ranked for high recharge potential in Clear Creek County may rank much lower elsewhere in the state using the same criteria. Conversely, by the physiographic nature of Colorado mountainous regions even low or moderate recharge is as good as it gets. Therefore, areas with high natural groundwater recharge potential should be protected from extensive development to conserve the county's water resources. Conversely, existing developments within these areas are prime candidates for implementing infiltration stormwater management BMPs.

The natural potential recharge map (Fig. 3-9) suggests that the recharge potential is low over much of the county. This is largely due to the predominance of bedrock outcrops, limited soil cover, and steep slopes. The low potential recharge rating of these areas is relative as recharge still occurs, but to a lesser extent than in higher rated areas. Runoff reduction stormwater BMPs target the frequent, small storms of one inch or less. Though these small storms have a lower volumetric impact, it is these precipitation events that the native landsurface has the greatest opportunity to capture.

Cited References

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Kellogg, K.S., Shroba, R.R., Bryant, Bruce, and Premo, W.R., 2008, Geologic map of the Denver West 30' x 60' quadrangle, north-central Colorado: U.S. Geological Survey Scientific Investigations Map 3000, scale 1:100,000, 48p. pamphlet.

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Widman, Beth, L., Miersemann, Ulrike, 2001, Geologic map of the Georgetown Quadrangle, Clear Creek County, Colorado, Colorado Geological Survey Open-File Report 05-1, 22p., scale 1:24,000.

Table 3-1

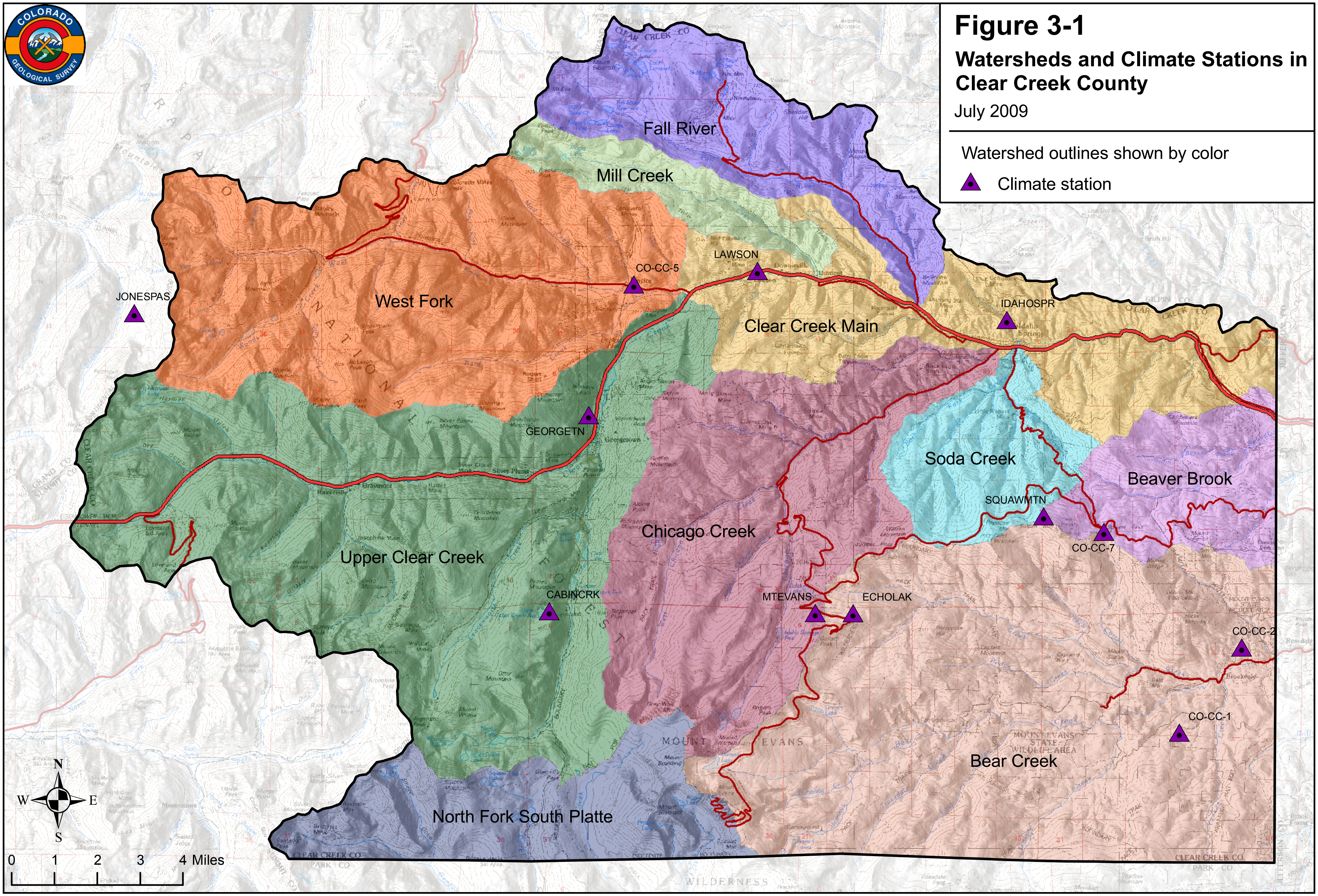
Summary of Water Well Statistics by Watershed

	Reported Well Depth (feet)					Reported Water Level (feet)				Reported Well Yield (gpm)				
Watershed	Number of Wells	Min	Max	Average	90%	Number of Wells	Min	Max	Average	Number of Wells	Min	Max	Average	90%
Upper Clear Creek	72	8	325	78.5	160	60	4	150	35.5	72	0.1	50	12.5	24
West Fork Clear Creek	88	8	642	151.5	380	75	1	293	44.4	73	0.8	60	10.4	15
Mill Creek	38	14	951	262.2	600	36	5	300	60.1	37	1	30	7.1	13
Fall River	163	22	952	293.3	550	157	1	404	70.3	156	0.75	68	8.2	15
Chicago Creek	92	3	951	295.75	600	81	4	460	102.7	84	0.4	40	7.8	15
Clear Creek Main	389	3	1100	278.4	600	363	1	847	106.3	374	0.1	45	9.0	15
Soda Creek	123	5	936	300.0	600	113	1	614	78.0	123	0.1	60	8.3	15
Bear Creek	930	4	1252	299.2	550	859	1	500	81.1	893	0.1	82	6.4	15
Beaver Brook	665	5	1050	307.9	550	614	1	600	91.5	639	0.25	70	6.6	15

Figure 3-1

Watersheds and Climate Stations in Clear Creek County

July 2009



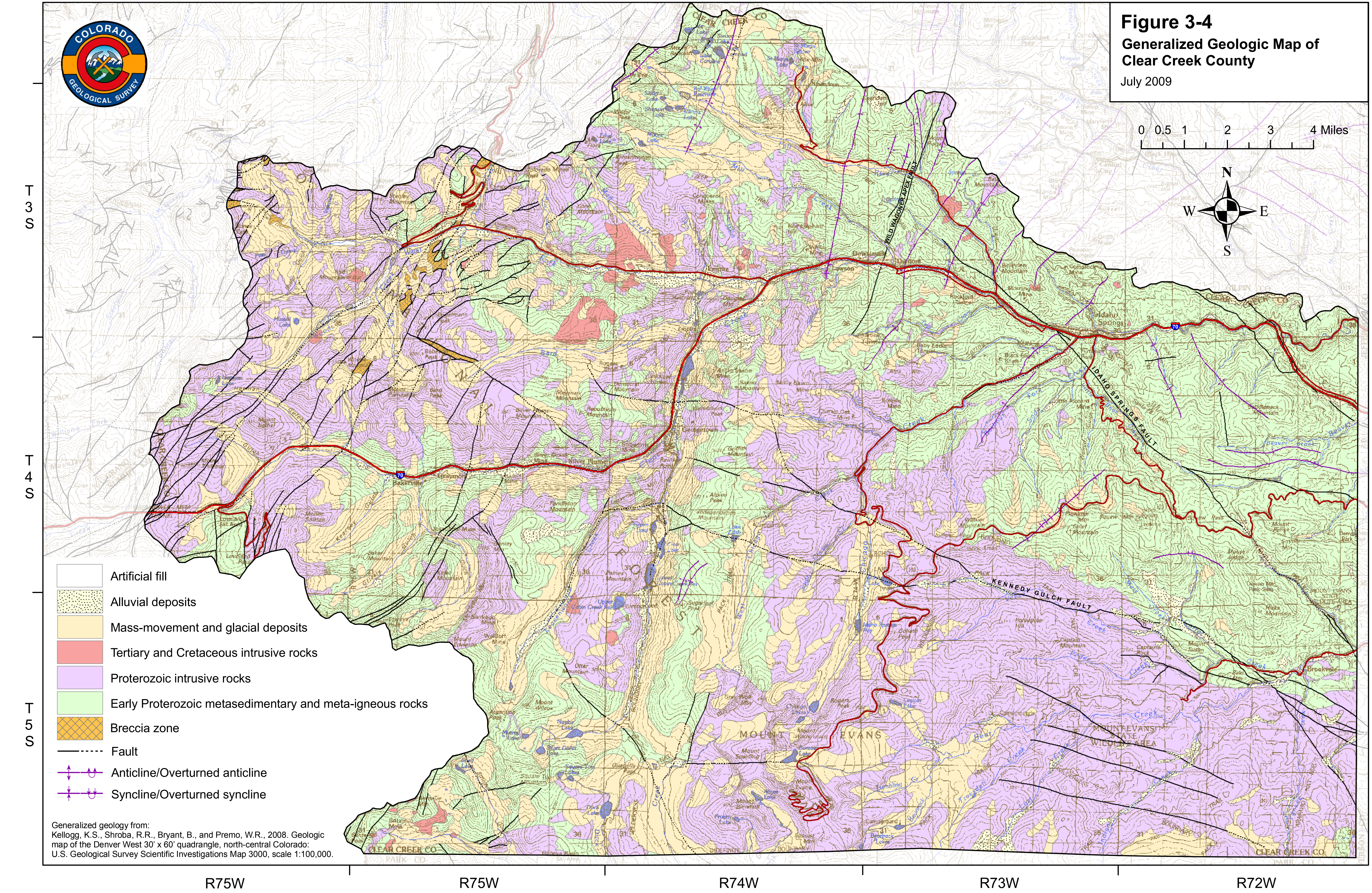


Figure 3-4
Generalized Geologic Map of Clear Creek County
July 2009

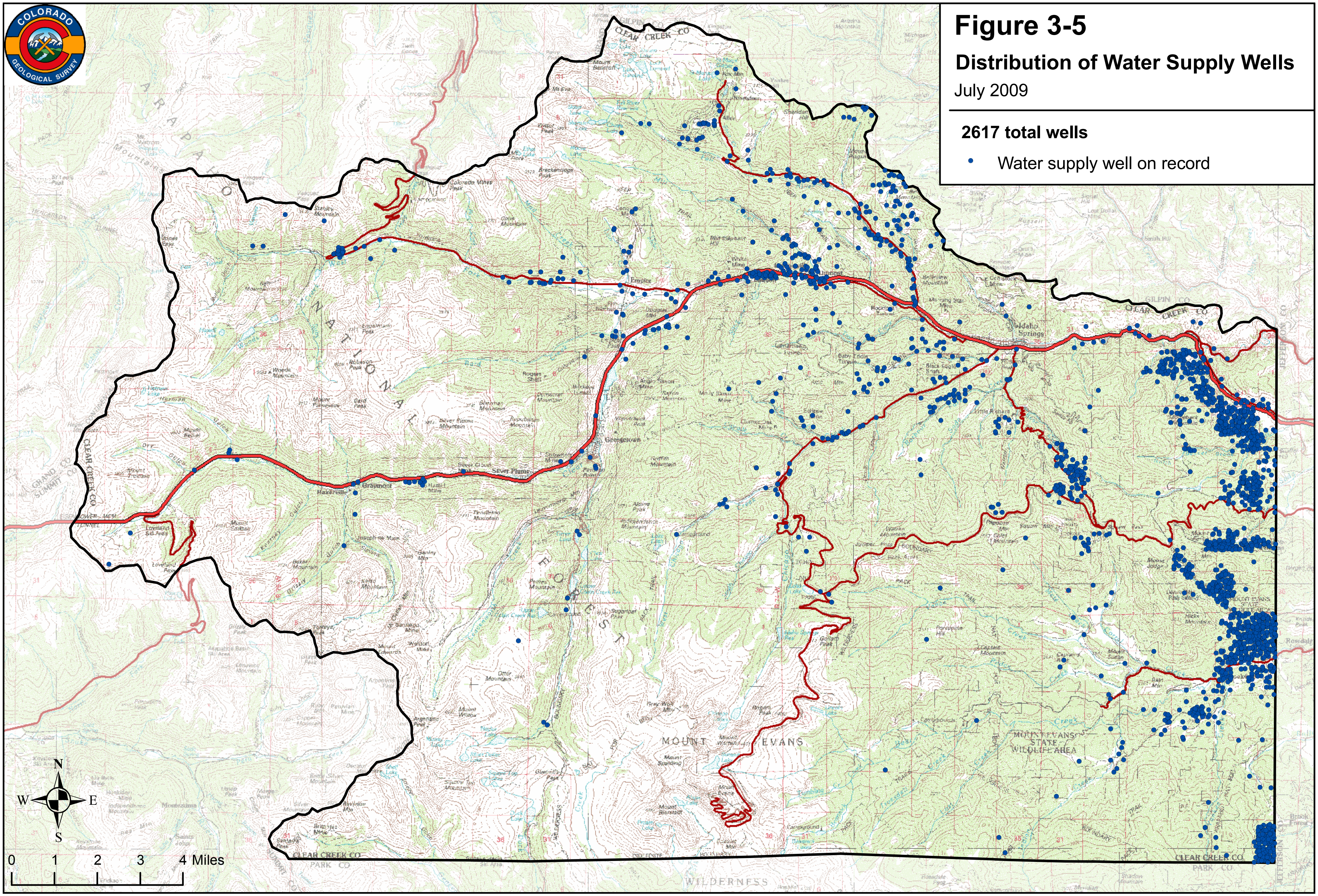


Figure 3-5

Distribution of Water Supply Wells

July 2009

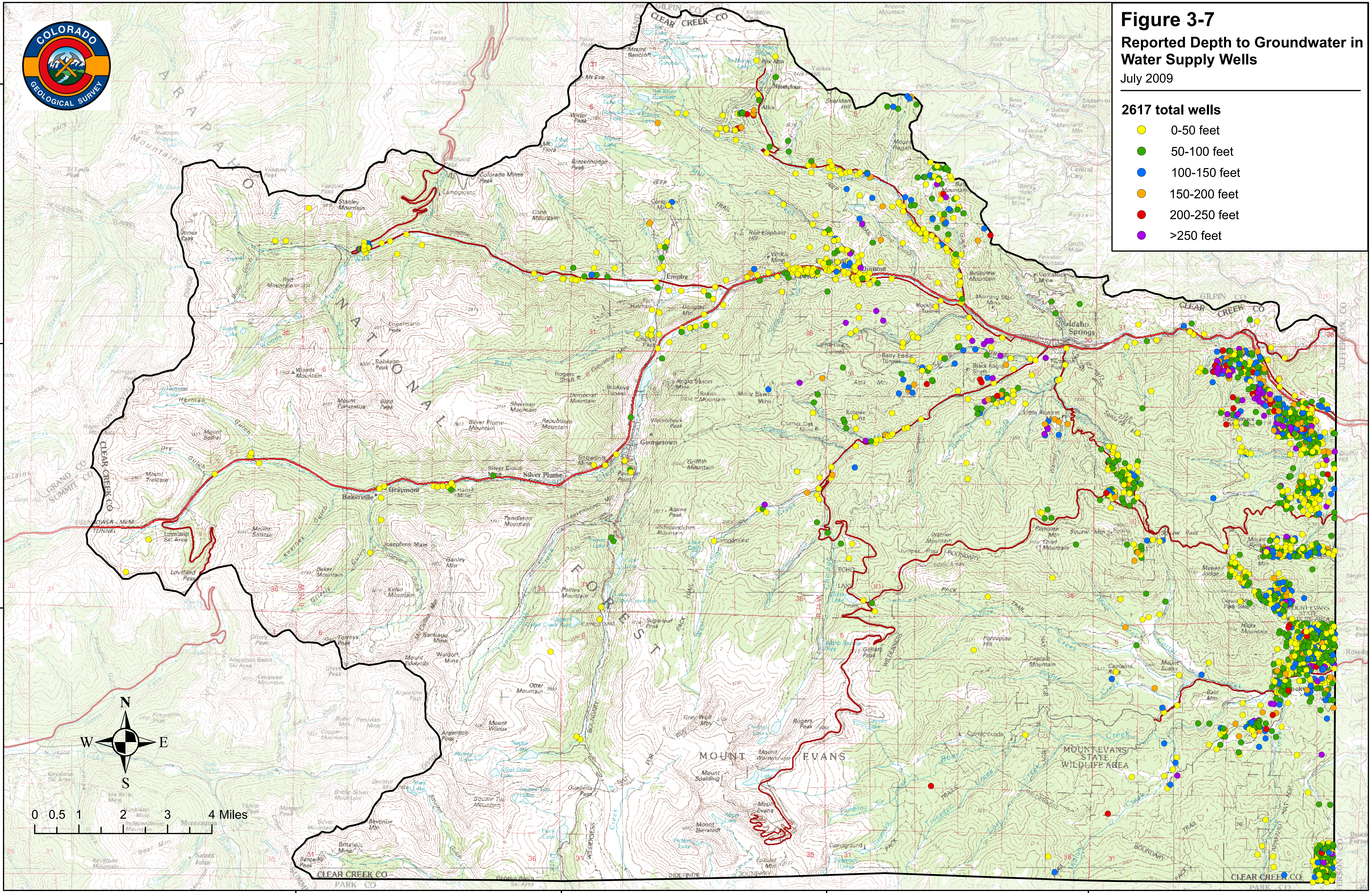


Figure 3-7
Reported Depth to Groundwater in Water Supply Wells
July 2009

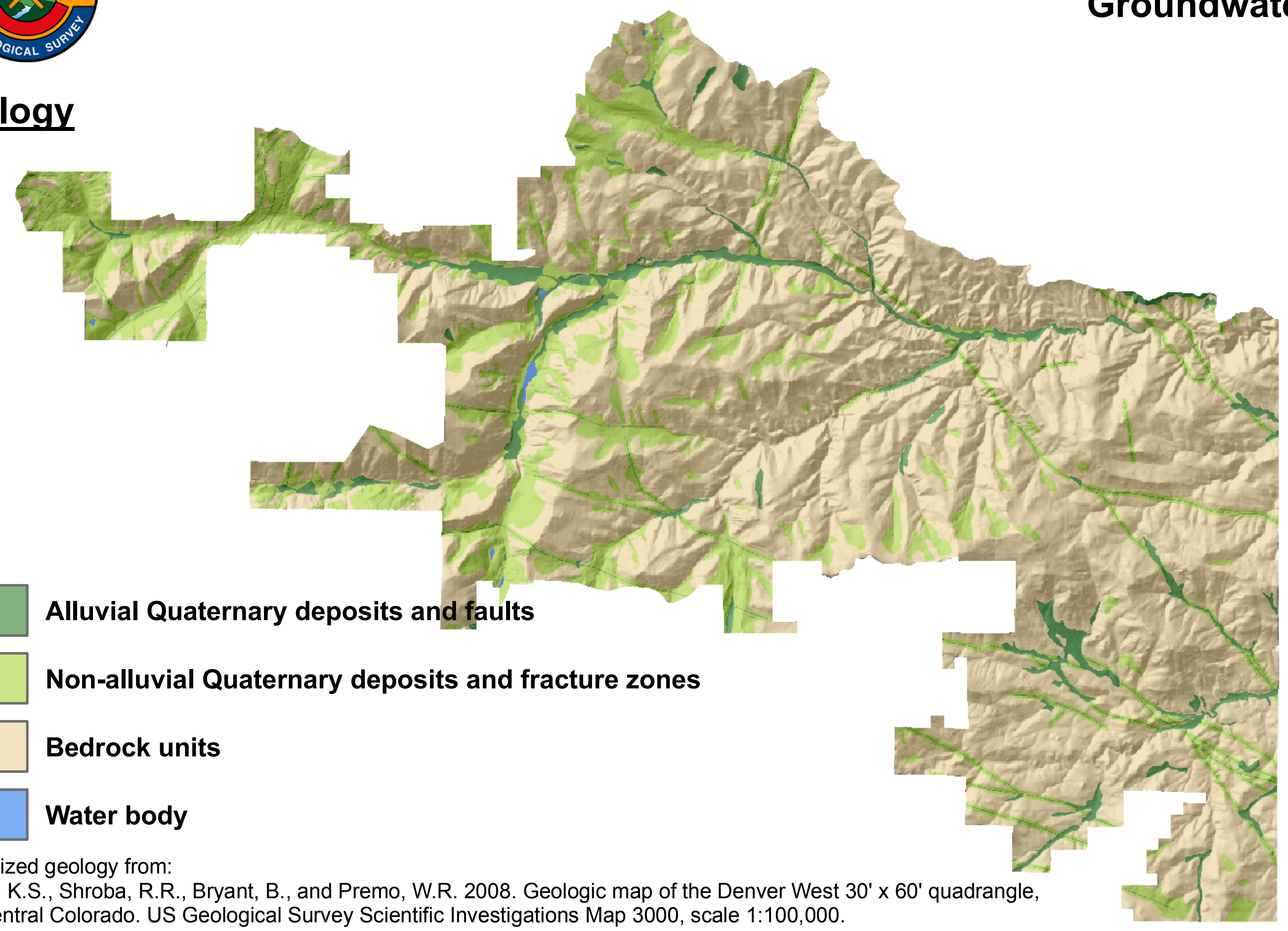
Clear Creek County Study Area

Groundwater Recharge Matrix

Figure 3-8
Input Parameters for Analysis of Groundwater Recharge Potential
July 2009

0 1 2 3 4 Miles

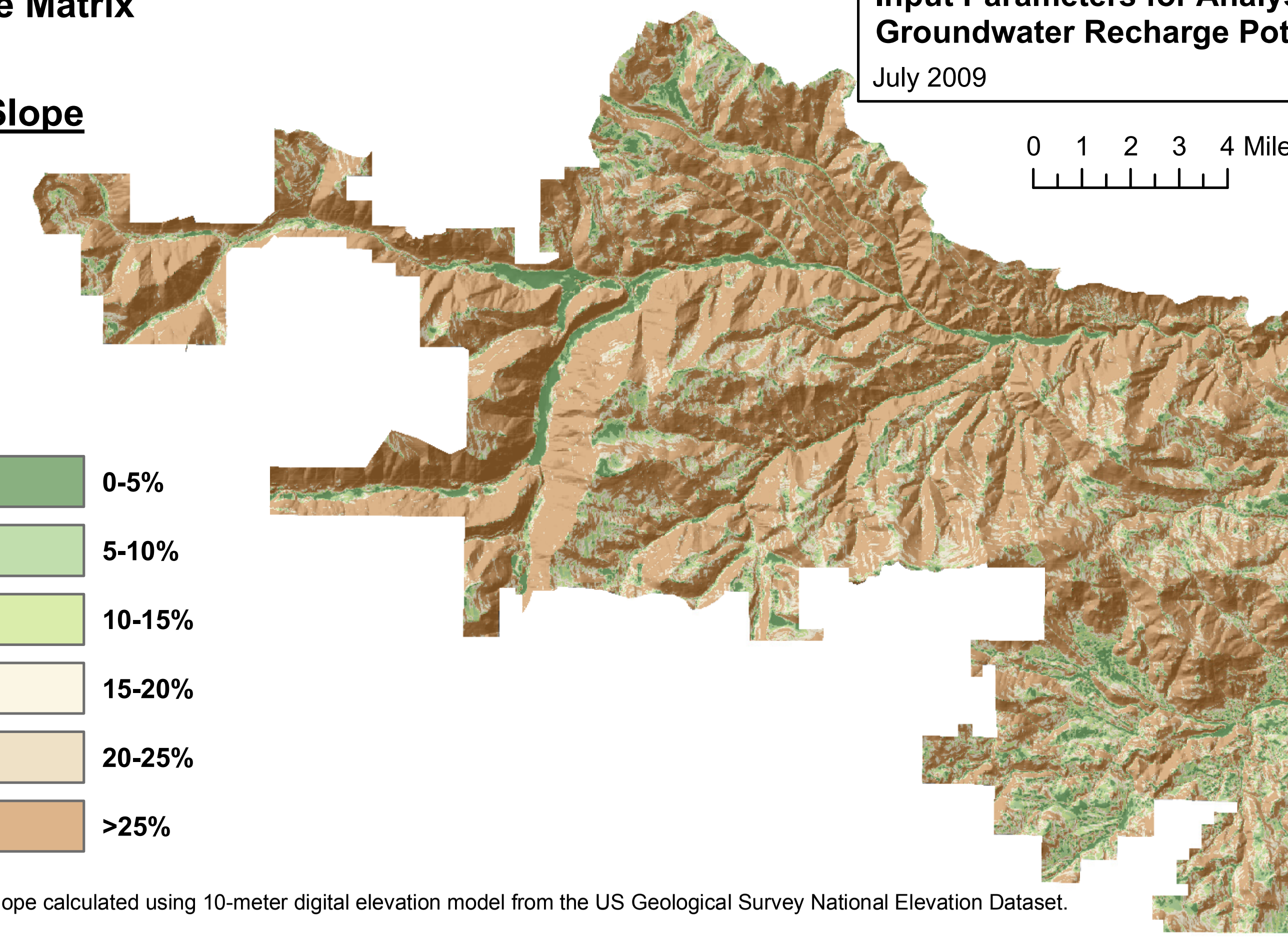
Geology



- Alluvial Quaternary deposits and faults
- Non-alluvial Quaternary deposits and fracture zones
- Bedrock units
- Water body

Generalized geology from:
Kellogg, K.S., Shroba, R.R., Bryant, B., and Premo, W.R. 2008. Geologic map of the Denver West 30' x 60' quadrangle, north-central Colorado. US Geological Survey Scientific Investigations Map 3000, scale 1:100,000.

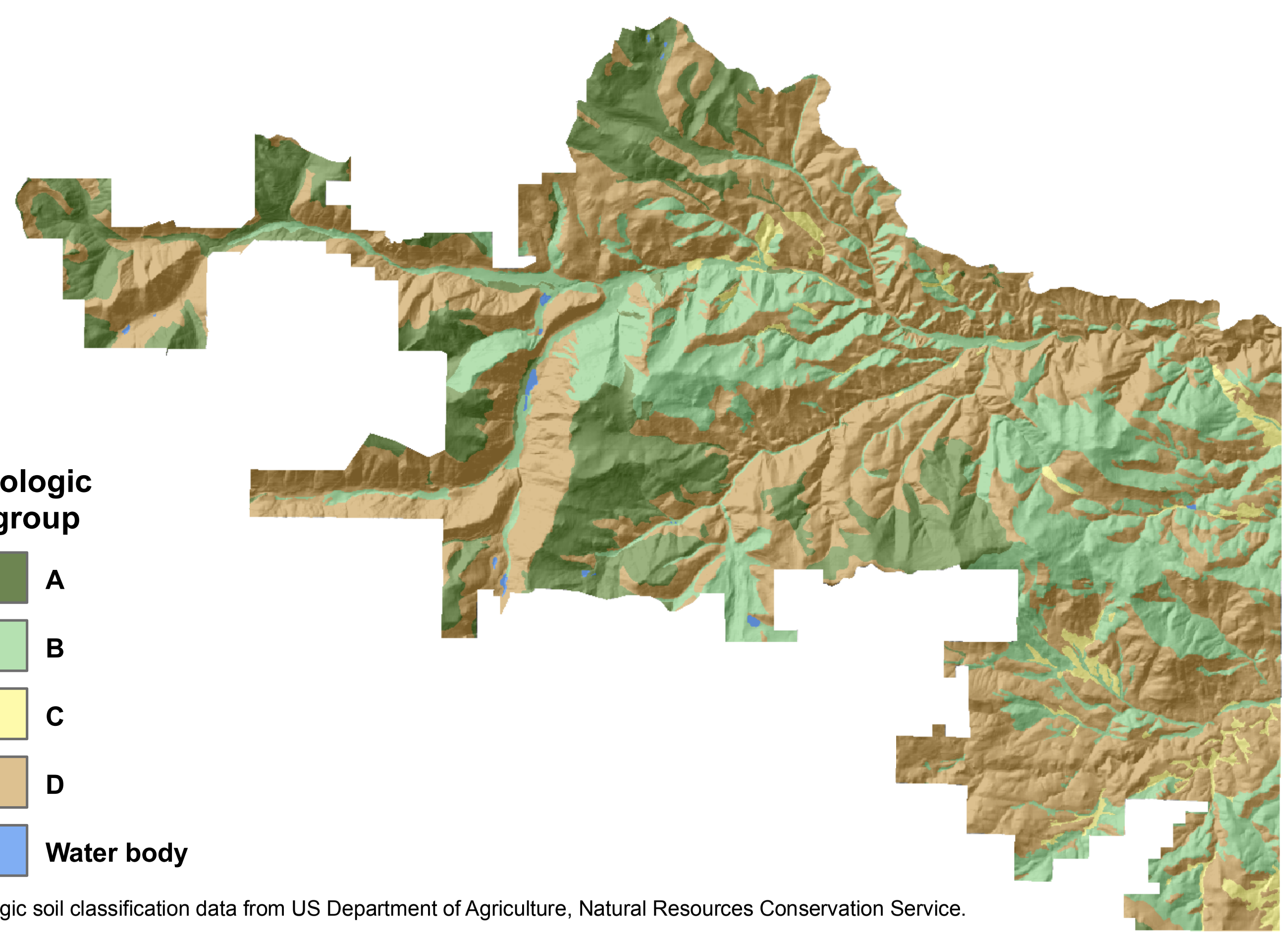
Slope



- 0-5%
- 5-10%
- 10-15%
- 15-20%
- 20-25%
- >25%

Slope calculated using 10-meter digital elevation model from the US Geological Survey National Elevation Dataset.

Soil

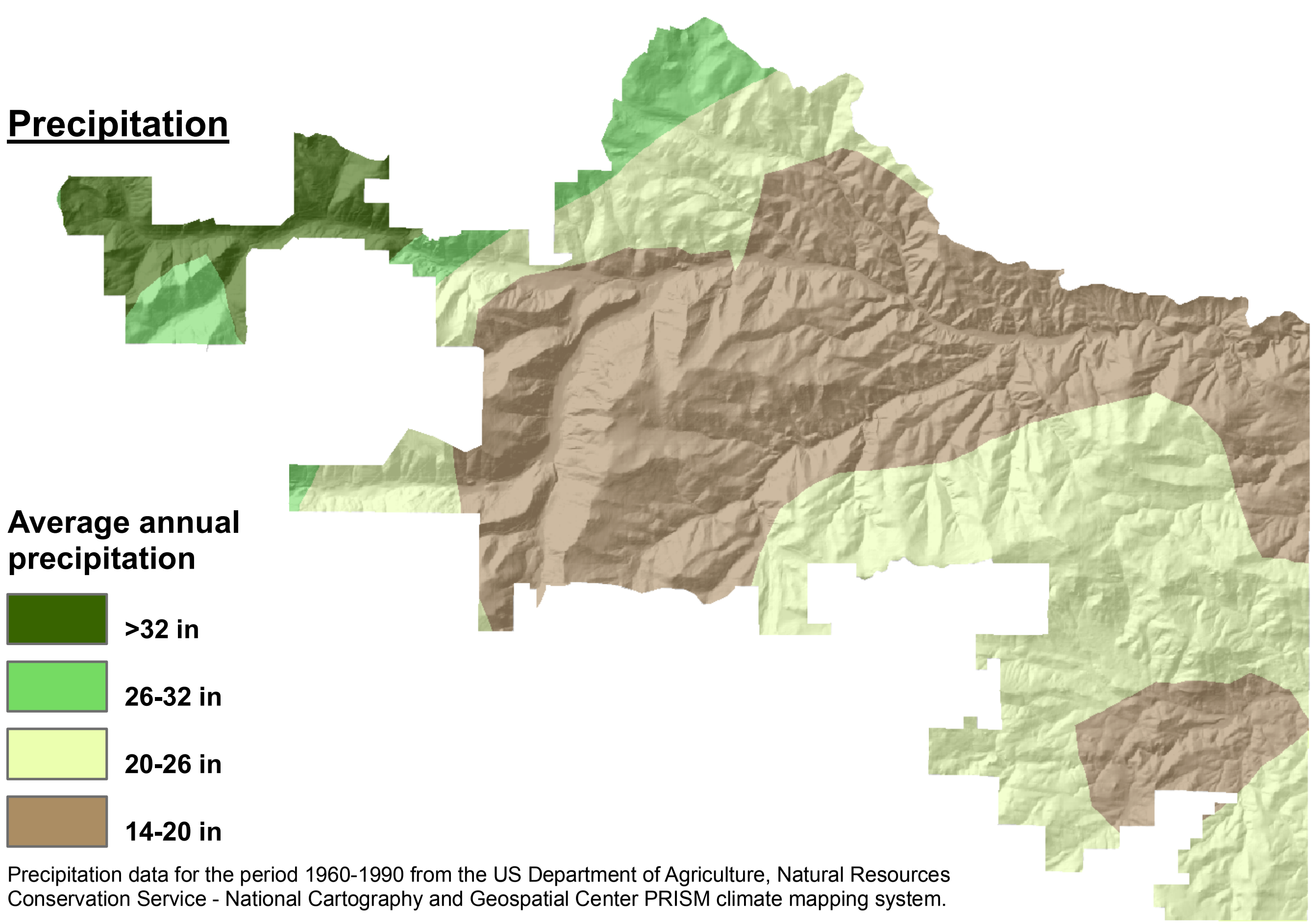


Hydrologic soil group

- A
- B
- C
- D
- Water body

Hydrologic soil classification data from US Department of Agriculture, Natural Resources Conservation Service.

Precipitation



Average annual precipitation

- >32 in
- 26-32 in
- 20-26 in
- 14-20 in

Precipitation data for the period 1960-1990 from the US Department of Agriculture, Natural Resources Conservation Service - National Cartography and Geospatial Center PRISM climate mapping system.

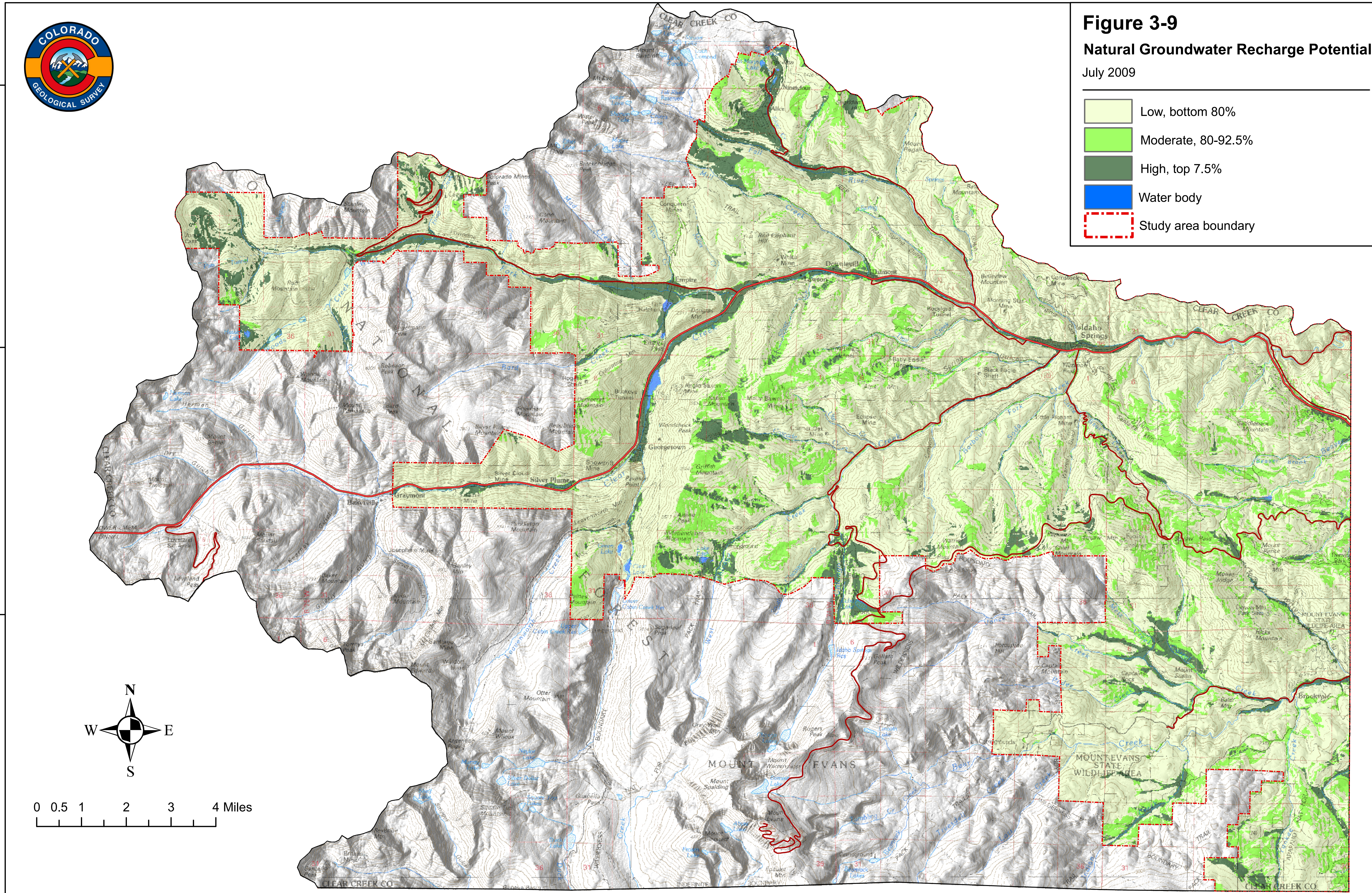


Figure 3-9
Natural Groundwater Recharge Potential
July 2009
Low, bottom 80%
Moderate, 80-92.5%
High, top 7.5%
Water body
Study area boundary
COLORADO GEOLOGICAL SURVEY
T 3 S
T 4 S
T 5 S
R76W
R75W
R74W
R73W
R72W
N
W
E
S
0 0.5 1 2 3 4 Miles
CLEAR CREEK CO
Idaho Springs
Georgetown
Silver Plume
Empire
Dumont
Downieville
MOUNT EVANS
MOUNT EVANS STATE WILDLIFE AREA
NATIONAL FOREST

4. The Regulatory Environment

The centerpiece legislation addressing stormwater discharge was the 1972 Clean Water Act (CWA) and its subsequent amendments. The purpose of that act is to ensure protection of the physical, biological, and chemical integrity of the nation's waters. Stormwater is defined in federal regulations as "storm water runoff, snow melt runoff, and surface runoff and drainage" [40 CFR §122.26(b)(13)]. The Clean Water Act is implemented by the U.S. Environmental Protection Agency. The 1987 amendments to the CWA established a framework for regulating municipal, industrial, and construction stormwater discharges under the National Pollutant Discharge Elimination System (NPDES) permit program. In addition to the existing federal stormwater management programs, there are regional, state, and local management programs in existence. Many of these programs include best management practices design or performance standards, site plan review and inspection, and technical assistance. In the following sections, we discuss the federal, state, and local regulations as well as potential ramifications of Colorado water law.

Federal (EPA)

The Water Quality Act of 1987 required comprehensive storm water regulation using a two-phased approach. Phase I, in place since 1990, requires operators of medium and large municipal separate storm sewer systems (MS4s) located in incorporated areas and counties with populations of more than 100,000, to obtain an NPDES permit to discharge storm water runoff. In October 1999, the EPA expanded the federal storm water program with the promulgation of the Phase II rule.

Phase II requires operators of small MS4s in "urbanized areas" to obtain an NPDES permit. NPDES permitting authorities are also required to assess, for potential designation, all other areas with a population of at least 10,000 and a population density of 1,000 per square mile. Colorado's permitting authority, the Colorado Department of Public Health and Environment, has not designated Clear Creek County as a small MS4 subject to Phase II requirements.

Construction Sites

EPA classifies storm water runoff from construction sites as discharge from an industrial activity. EPA's rulings mandate that pollutants associated with storm water discharges from construction sites be reduced by using best-available technology (BAT) and best conventional pollutant control technology practices (BCT).

Initially, NPDES permits were required for the discharge of storm water from land disturbing activities of 2.0 or more hectares (5.0 ac). However, in 1992, a successful court challenge by the Natural Resources Defense Council remanded the exemption for construction sites of less than 2.0 ha to EPA for further rule making. EPA addressed this issue with its October 29, 1999 ruling on NPDES requirements for construction sites of 0.4 ha to 2.0 ha (1.0 ac. to 5.0 ac.).

State (CDPHE)

In Colorado, the construction site program is under the Colorado Department of Public Health & Environment, Water Quality Control Division (CDPHE). With some limited exceptions, construction sites that disturb one acre or greater, or are part of a larger common plan of development disturbing one acre or greater, must obtain a stormwater construction permit.

The Stormwater Construction Permit requires dischargers to control and eliminate the sources of pollutants in stormwater through the development and implementation of a Stormwater Management Plan (SWMP). The purpose of an SWMP is to identify possible pollutant sources that may contribute pollutants to stormwater, and identify Best Management Practices (BMPs) that, when implemented, will reduce or eliminate any possible water quality impacts.

For construction activities, the most common pollutant source is sediment. Other pollutant sources include fuels, fueling practices and chemicals/materials stored on site, concrete washout, etc. BMPs encompass a wide range of practices, both structural and non-structural in nature, and include the stormwater runoff reduction principles often called “low impact development”.

Local (Clear Creek Co.)

In Colorado, local governments have broad authority to plan for and regulate the use of land and protect the environment (C.R.S. § 29-20-101 through 108, from HB 74-1034) and counties may impose local requirements to control the discharge of pollutants from construction activities. Green infrastructure practices mimic natural environmental systems and processes to infiltrate, evapotranspirate (the return of water to the atmosphere either through evaporation or by plants), or slow runoff on the site where it is generated. Clear Creek County has adopted policies and regulations that promote this concept. Green Infrastructure concepts can be found in the County's comprehensive plan, zoning regulations, subdivision and site development standards.

Clear Creek County Comprehensive Plan

A comprehensive plan contains the hopes and goals of a community. It lays the groundwork and articulates a vision for all future development. It is a written document that identifies the goals, principles, guidelines, and strategies for directing and managing change. The plan is the foundation of all land-use decisions. Clear Creek County's comprehensive plan contains the following goals and objectives aimed at protecting the soil and water resources:

- Balance the County's personal, cultural, and environmental values with those values necessary for economic vitality.
- Encourage and promote the principles of environmental sustainability wherever growth is fostered.
- Preserve the County's mineral and natural resources for future generations.
- Preserve groundwater quality and quantity.
- Preserve water sheds.
- Recognize and respect natural geologic conditions.

Generally, comprehensive plan goals and objectives are incorporated into zoning and subdivision regulations.

Zoning Regulations

Through zoning, Clear Creek County controls building size, building density and the way land is used. Most of the county's zoning districts contain provisions regarding geologic conditions and conservation of natural resources. Some of the relevant zoning regulations include:

- Demonstration that the proposed development incorporates and utilizes to the extent practical, natural assets present on the site such as existing tree stands, watercourses, prominent peaks/ridgelines, and rock outcroppings.
- The development will maintain the quality of peripheral or downstream surface or subsurface water resources, if applicable.
- No significant alteration to existing drainage patterns or cause runoff or erosion that will have a significant adverse impact on the area.

- Must meet the standards of the County adopted Best Management Practices (BMP's) for control of stormwater runoff.
- The Landscaping Plan shall demonstrate water conservation by requiring xeriscaping concepts. The use of native species should be maximized so that native species continue to dominate the County's mountain environment.

The Subdivision Process

In Colorado, counties have regulations and development standards that control the creation of new subdivisions. In general planning terms, subdivision is the act of dividing property or property interests for resale to multiple owners. A residential subdivision usually consists of dividing a piece of vacant land into individual lots, constructing homes on each lot, and selling each lot to individual owners. The county's subdivision process involves three steps; sketch plan, preliminary plan and final plat which address protection of natural features, floodplain analysis, location and identification of natural and man-made hazards, and grading and drainage plans.

All subdivision applications must meet certain standards. The purpose of these standards is to ensure that new owners will have adequate public and private facilities, like roads, water, and sewer and the new subdivision does not create severe problems, such as sedimentation or flooding, for adjacent neighbors or a financial burden to the community. Overall design criteria incorporate protection of soil and water resources.

Other Policy and Design Reference Manuals

Clear Creek County has specifically addressed erosion control and environmental mitigation for road and driveway construction through specific manuals. The "Mountain Driveway Best Management Practices Manual" is such an example. The county has also recognized and adopted other publications as policy guides and design criteria references. Many of these references contain Green Infrastructure concepts and low impact development practices. Key references include:

- Urban Storm Drainage Criteria Manual, Colorado, Urban Drainage and Flood Control District, June 2001
- Fifield, Jerald S. Ph.D, Designing for Effective Sediment and Erosion Control on Construction Sites, California: Forester Press, 2001
- CDOT Design and Construction Specifications and Procedures

Ramifications of Colorado Water Law

The Colorado Division of Water Resources/State Engineer's Office administers the waters of the State guided by the prior appropriation doctrine, the regulations codified in the Colorado Revised Statutes, and case law. The State Engineer acknowledges that land in Colorado will be developed for residential, commercial, and other purposes, and that some state and local requirements as well as stormwater design practices will require that the developer manage runoff. When the only objective is to manage storm runoff to protect life and property from flooding, to minimize channel degradation and sedimentation, and to manage water quality; the Division has not intervened in stormwater runoff management design. The Division requires any consumption of water resulting from stormwater management design implementation to be minimal and incidental. The critical criterion is that stormwater can not be put to beneficial use nor can management design elements or practices consume water other than incidentally. A good example of incidental consumption would be the consumption from vegetation within a vegetated swale. The following advisory statement helps clarify the concerns of the Colorado Division of Water Resources:

> *"Any effort to manage the on-site hydrology in a way that purposefully, through a structure or an action, allows more infiltration or more consumption of water than historically occurred may constitute an "out-of-priority" diversion of precipitation. The county and/or developer should contact the Colorado Division of Water Resources for comment if any feature of stormwater management has potential to allow infiltration or consumption that is greater than existed before development."*

The objectives of green infrastructure or LID stormwater management practices are to address the runoff from small, frequent storm events through natural systems as close to the source as possible. Promotion of infiltration BMPs emulates the native environment since naturally vegetated ecosystems produce little to no runoff from the vast majority of precipitation events. Green infrastructure designs are not intended to include any reliance on the water for beneficial use, any effort to put the water to beneficial use, or improvement of the water supply for users other than to manage the quality, magnitude, and timing of storm runoff.

Historically, many people were surprised to learn that they were not entitled to the precipitation that falls on their homes and properties. In 2009, the Colorado legislature adopted a more holistic approach to precipitation management by passing Senate Bill 09-080. This legislation was predicated on the fact that the law associated with this bill would not allow additional use or consumption of tributary water. Senate Bill 09-080 was signed into law and is particularly pertinent to the mountain communities as it allows for limited precipitation capture from rooftops of homes that are served by exempt wells. Rural property owners can now use rainwater rooftop catchments on a small scale. Rooftop precipitation capture is limited to properties served by an exempt well, and the water thus collected is limited to those uses identified on the well permit, but not to exceed:

- Ordinary household purposes;
- Fire protection;
- The watering of poultry, domestic animals, and livestock on farms and ranches; or
- The irrigation of not more than one acre of gardens and lawns.

Rooftop precipitation capture or rainwater harvesting has a dual purpose, reducing water supply demand and reducing storm water runoff. Residents intending to use a system or method of rooftop precipitation capture need to obtain a permit or complete a new form as prescribed by the State Engineer.

5. Maintaining Pre-Development Hydrology – Nonstructural Controls

Impacts to water resources as a result of development can pose challenges to mountain communities in the arid west striving to protect their limited supplies. Development that uses land more efficiently or protects a greater percentage of native land helps a community to grow while still protecting its water resources. Because the flow of water is dramatically altered as land is developed, stormwater runoff has emerged as a community issue. In addition to intensified runoff, increased imperviousness accelerates erosion and subsequent sedimentation. Runoff reduction practices on developed land offer a solution to help protect water resources. Other terms for runoff reduction techniques include Low Impact Development (LID) and Green Infrastructure. Regardless of the terminilogy used, the intent is to manage stormwater runoff as close to its source as possible, with the ultimate goal to maintain or mimic the predevelopment hydrology of the site, which helps protect waterways, wildlife and aquatic habitat, baseflow, and groundwater recharge. These techniques promote the use of natural systems to reduce runoff volumes, pollutant loadings, and the negative impacts of development on the affected receiving waters. Employing techniques that reduce excess runoff volume on individual properties throughout the watershed will have a wider impact that may include flood control benefits in addition to water quality benefits. Runoff reduction designs typically incorporate more than one type of technique in an integrated cascading process to address runoff from a site.

Land Use Planning

Maintaining predevelopment hydrology with non-structural controls begins with land use planning. The planning process is the first step in developing water resources and stormwater best management practices. At the heart of this planning process is the establishment of three design goals:

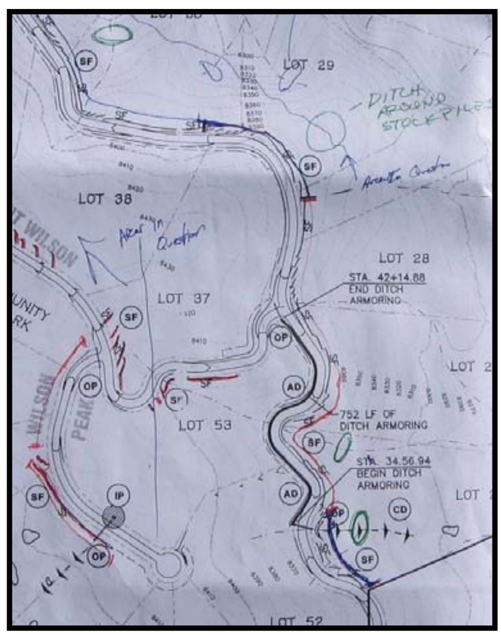
1. Create an informed project team and involve them in the design process.
   (Developer, property owner, civil engineers, landscape architects, geologists, planners, and staff.)
2. Maximize permeability and minimize offsite discharge.
   (Every added square foot of impervious area will generate greater stormwater volumes and flow rates.)
3. Use stormwater BMPs as a site design element
   (Infiltration systems that take advantage of the natural landscape can enhance the project.)

Logically, the first step would consist of reviewing land development requirements to determine the design standards such as parking requirements and road width. A reduction of impervious area may include administrative allowances such as removing parking requirements, reducing road widths, increasing building height/density to leave undisturbed recharge areas elsewhere.

Often, low impact development incorporates a series of practices and techniques in unison to develop a treatment train approach. For example, planners might include a bioretention area in each yard, disconnect downspouts from impervious driveways, reduce street widths and parking requirements, and include vegetated swales in common areas.

Once these design elements are agreed upon and the plan is developed, the cumulative runoff volume needs to be calculated based on the added impervious area.   This water management volume provides guidance to selection, sizing, and number of the BMPs required to handle the water quality volume (volume needed to capture and treat 90% of the average annual stormwater runoff) on-site. The structural techniques that allow stormwater absorption and infiltration such as rooftop collection, sunken landscape areas, permeable pavements can be then be discussed. These structures absorb the small storms and remove this amount of runoff from the volume that is created from a larger storm, which will be detained in a detention facility.

Mountain development plans should include infiltration BMPs to retain water resources from small storms and drainage infrastructure to convey the excess from large storms.   This may be an iterative process and plans may be altered, as shown, as runoff reduction BMPs are added.



Low Impact Development Strategies

Nationally, the Environmental Protection Agency has found that implementing well-chosen LID practices in an area's stormwater management plan results in significant savings for developers, property owners, and communities due to reduced costs for site grading and preparation, stormwater infrastructure, site paving, and landscaping. Specific structural BMPs often incorporated into LID designs will be discussed in Chapter 6. Conservation and landscape design elements should be incorporated into the planning process.

Conservation design seeks to minimize the generation of runoff by decreasing impervious areas and encouraging the protection of open spaces. By building around natural features – such as floodplains, wetlands, riparian areas, and porous soils – developers can preserve areas that provide valuable stormwater functions. Runoff from the built environment can be directed to protected natural features and open space for infiltration and evaporation.

Conservation Design

- Protect sensitive features
- Conserve and enhance riparian areas
- Minimize total disturbed area
- Cluster development
- Reduce pavement widths (streets, sidewalks)
- Shared driveways
- Reduced setbacks (shorter driveways)

Development that plans on the smallest possible area minimizes topsoil stripping and soil compaction from grading and construction equipment. Reducing disturbance and increasing the preservation of the natural vegetation translates into less stormwater runoff from the development parcel. Additionally, reducing impervious surfaces by decreasing driveway lengths, and limiting sidewalk and roadway decreases the volume of runoff that must be treated.

Simple design techniques are cost-effective methods of decreasing the necessity for more expensive structural stormwater controls. Additionally, developments that incorporate conservation design techniques have shown to positively affect land values because of increased access and proximity to open space and recreational opportunities (Pennsylvania, 2006).

Low impact landscaping practices can reduce impervious surfaces, improve infiltration potential, increase pollutant uptake, and improve aesthetics. The primary objective – covered by conservation design – is to minimize the need for landscaping and re-vegetation by minimizing disturbance. Where damage has occurred, native vegetation should be planted. Properly preparing the soil and selecting appropriate plant species for Clear Creek County greatly increases chances of plant establishment and growth. The county has an adopted revegetation policy to help control soil erosion, sedimentation, and slope stability. Often, compaction of soil is unavoidable where construction activity requires grading and filling. In these situations, soil amendments should be considered to restore permeability.

Low Impact Landscaping

- Re-vegetate/re-forest disturbed areas with native species
- Planting native, drought tolerant plants
- Converting turf areas to trees and shrubs
- Amending soil to improve infiltration

Clear Creek County has a long mining history and that industry is still a significant contributor to the county's economy. Unfortunately historic mining practices lacked today's more stringent reclamation requirements and left exposed tailings piles and mineralized spoils. The sulfate mineralization in these rocks produces an acid rock drainage condition when exposed to the environment (oxygen and water). County staff are familiar with the locations and characteristics of mine tailings and spoils, which are nearly impossible to revegetate without emplacement of a topsoil cap. A reclaimed mine site is best left undisturbed unless a major restoration is planned as construction activities could expose unweathered ore that has a greater potential of producing acid rock drainage.

Evaluation of Costs and Benefits

LID emphasizes lot-level and sub regional strategies that reduce the impacts of development and produce numerous environmental benefits. The ecosystem benefits provided by low impact development are well established: reduced flood risk, increased groundwater recharge, structural channel protection and improved water quality. The difficulty of monetizing the benefits of these practices often hinders equal consideration in the design and selection process. Both ECONorthwest (2007) and the U.S. EPA (2007) have documented economic evaluations of low impact development designs. The studies conclude that installation costs of LID practices compare favorably with conventional measures in areas with expensive real estate when the size of storm sewer systems and detention areas can be reduced. In other instances, the cost of infiltration and absorption BMPs may cost more to construct. However, the stormwater treatment capabilities are increased and offsite impacts are reduced. Developers tend to focus on construction costs and not life cycle costs or cost benefits, which include operation and maintenance costs, differences in effectiveness, and other environmental, social or economic benefits. The construction, operations and maintenance costs of a BMP should be compared to the externalized costs that result if the BMP is not implemented. In the 17 case study presented by the EPA (2007), the use of LID practices was found to be both fiscally and environmentally beneficial to communities. That study documented total capital cost savings ranging from 15-80%. Mary Catherine Hager (2003) concludes in the journal *Stormwater* that LID projects can be completed at a cost reduction of 25-30% over conventional projects. These percentages are representative of the average values cited in the EPA study.

One often cited economic advantage to developers implementing LID practices include increasing the number of developable lots and reducing costs associated with stormwater infrastructure. Eliminating or reducing stormwater detention volume by implementing LID controls increases a site's developable area. Construction costs associated with curbs, gutters, and stormwater pipes may be reduced with LID controls such as bioswales and permeable pavers.

The economics of the environmental and ancillary benefits are difficult to quantify as part of development projects, though their value is very real. The environmental value, land value, and social value such as quality of life benefits of LID practices include:

<u>Environmental</u>

- ***Water quality improvements and protection of downstream water resources:*** LID practices address both the volume of runoff and the pollutant loadings associated with it by reducing hydrologic impacts on receiving waters, reducing stream channel degradation from erosion and sedimentation, improving water quality, increasing water supply, and enhancing the recreational and aesthetic value of our natural resources (EPA, 2007).

- ***Groundwater recharge:*** Infiltration practices can be used to enhance natural groundwater recharge and increase stream baseflow (National Research Council, 2009). Groundwater recharge is a key water supply management strategy to protect a limited resource.
- ***Reduction of pollutants:*** LID practices reduce pollutant loadings to receiving waters through settling, filtration, adsorption, and biological uptake. Reduced pollutant loads decrease water treatment costs, improve aquatic habitat, and enhance recreational uses.

Land value and quality of life

- ***Reduced flooding and property damage:*** The benefits of managing stormwater through LID practices include reduced frequency, area, and impact of flooding events (ECONorthwest, 2007). While LID practices do not replace the need for a flood control program, widespread use of runoff reduction techniques can offer flood control benefits because small storms are kept out of the storm sewer system thereby keeping the storm sewer capacity available for large storms – as intended. On-site retention of stormwater reduces the need and expenditure for downstream flood control infrastructure and through reduction of peak flows reduces property damage.
- ***Enhanced aesthetics and property values:*** Natural features, open space and vegetative cover of LID can enhance an area's aesthetics and increase adjacent property values. Developers can take advantage of a "water" feature or other natural or recreational amenity to market the property. In addition to aesthetics increasing the inherent value of property, the economic benefit may also come from increased lease rates on commercial property or increased visitation and sales tax as well as reduced vacancy, which all contribute to a longer economic life.
- ***Quality of life and public participation:*** Involving homeowners and commercial property owners in stormwater management on individual lots and in their communities provides a mechanism to empower them in the planning process and enhances public awareness of water supply and quality issues.
- ***Maximizing lot yield:*** LID practices employed on individual lots and along subdivision roadsides frees up land that would normally be dedicated to stormwater structural control measures.

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6. Structural Control Measures/Best Management Practices

Structural BMPs are features requiring construction supported by engineering plans, and they become permanent features of the landscape. Structural stormwater BMPs that address runoff reduction involve absorption and infiltration. This specifically requires that stormwater infrastructure be designed in a manner that is the opposite of drainage. This is a substantially different way of managing stormwater and requires a paradigm shift. Typically, land development applications include "drainage plans". This type of paradigm produces a design that removes water resources from the watershed as rapidly as possible, without increasing downstream flood risk, after providing time for sediment to settle out in a rate-controlled detention facility. The new paradigm, which addresses quantity aspects of water resources, involves designing infrastructure that allows stormwater to be managed at the source through flow control, filtration, and infiltration. When planning and designing runoff reduction and infiltration BMPs, it is important to realize that runoff reduction or low impact development BMPs focus on small, more frequent storms and do not eliminate the need to accommodate large precipitation events with flood control and retention/detention BMPs.

Structural BMPs that serve these functions include vegetated buffers, swales, porous landscape detention, permeable pavements, and infiltration trenches and pits. BMPs are tailored to the site and are often combined in a treatment train approach. Instead of using ditches and pipes to convey stormwater to a single detention structure, the site is designed with several BMPs that manage the stormwater close to the source where it is generated. The general categories for water quality and runoff reduction techniques often include a flow control aspect to separate small storm flows from larger events to prevent scour or damage to the runoff reduction structure. This is important because, as explained previously, the target for runoff reduction and maintaining predevelopment hydrology is to absorb and infiltrate precipitation from small, frequent events, not the entire volume from large, infrequent events. Flow control examples include wiers, bypasses, split flow devices, level spreaders and other techniques to allow small storms to flow into the structure and large flow to bypass it, so that large storms don't flood or scour a BMP that is designed to accommodate small storms.

BMPs that reduce the volume of runoff not only reduce pollutant loads but help mitigate other concerns such as downstream channel erosion and reduced infiltration. This guidance manual is not intended to be a stormwater design manual that contains detailed construction standards and specifications. The developer, engineer, or designer are referred to numerous references in the appendices of this manual for specific design, construction, and implementation details. The most applicable regional and local guidance manuals being:

- *Urban Storm Drainage Criteria Manual by the Urban Drainage and Flood Control District*
- *Mountain Driveway Best Management Practices Manual by Clear Creek County*

Our focus is to promote the paradigm shift that favors runoff reduction and infiltration BMPs throughout the watershed. While specific infiltration BMPs are the primary tools to achieve this goal, infiltration-only practices cannot adequately address all aspects of stormwater runoff quality and quantity management. A combination of management practices, including flow control, filtration, and detention are required. To provide consistency with the available literature, structural BMPs presented in this publication are divided into four categories – filtration, infiltration, flow control, and retention/detention. The compilation of available BMPs presented herein is derived from numerous sources from across the country. Consequently, not all the BMPs presented may be practical or appropriate for specific locales. Fact sheets for individual BMPs are included as Appendices B-E. The BMPs in these appendices are common examples of various techniques, but do not represent the complete spectrum of available designs. The appendices are designed to provide a “first-stop” resource for information on various practices that have proven successful in other areas. The first page of each fact sheet is a synopsis of the specific BMP being presented and can be a stand-alone document. The descriptions should give the reader a basic idea of BMPs that may be appropriate in a specific situation, including general applicability, benefits, and limitations. Some comments are added regarding designs, along with some basic schematic diagrams.

The user should keep in mind that many BMPs may provide multiple functions. For example, porous pavement can be used for both infiltration and detention and a grass buffer can provide filtration and infiltration benefits depending on the infiltration capacity of the subgrade soils. Modifications such as substrate materials can further expand the functionality of a particular BMP.

Filtration

Filtration practices treat runoff by routing it through vegetation as a filter to reduce flow velocity, settle solids and capture pollutants. Vegetated filtration offers primarily water quality benefits through a straining function, yet can offer infiltration benefits and runoff reduction if the substrate media is designed for infiltration. Modification or replacement of the substrate materials can enhance the applicability and functions of the BMP, such as promoting infiltration. Filtration techniques through media involve using sand or organic materials to filter stormwater and have the additional advantage of enhanced pollutant removal.

Filtration Techniques

- Disconnect from storm sewer
- Bioretention
- Vegetated Swales
- Vegetated Filter Strips

Impervious roads and driveways contribute a considerable amount of contaminants and excess volume to stormwater runoff. LID filtration techniques focus on redirecting road and driveway runoff through vegetated swales, filter strips and bioretention areas with filtration media allowing pollutants to settle out.

The BMPs presented in this category depend upon vegetation or media to function as the filter. While filtering out particulate matter, the flow of the water is slowed, allowing for infiltration. These technologies include bioretention, sand/organic filters, vegetated filter strips and vegetated swales; they are widely applicable for stormwater treatment. Details can be found in Appendix B.

Photo from Colorado Stormwater Assoc.

Infiltration

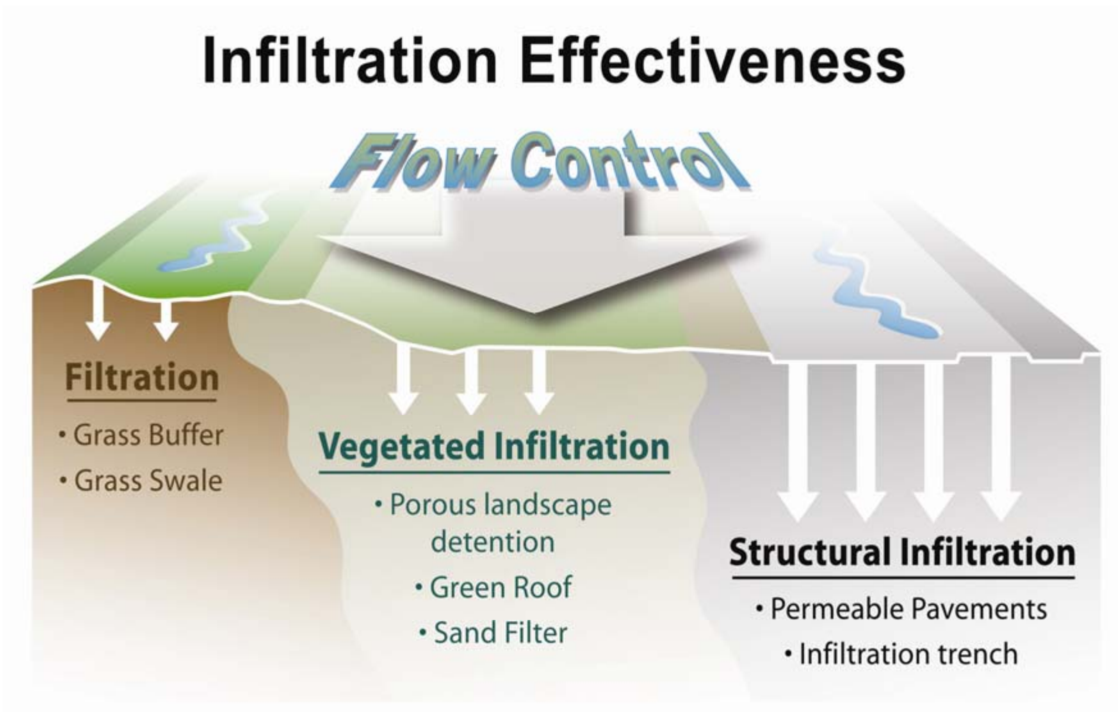
Infiltration BMPs are engineered control facilities that capture a volume of runoff and infiltrate it into the ground. Infiltration BMPs serve to reduce runoff volume from small events and allow for percolation of stormwater to the subsurface. Only infiltration and absorption techniques can reduce stormwater runoff volume. They can be designed to decrease peak flow from larger events. Applying infiltration techniques at the lot-level reduces the volume of runoff and decreases the need for and expense of community-wide control, conveyance and treatment structures. By simply disconnecting rooftop downspouts from conventional stormwater conveyance systems and encouraging developers to use pervious paving materials, runoff can be controlled and reduced on-site. Structural infiltration practices such as permeable paver systems allow communities the benefits of developed property while reducing offsite impacts to receiving waterways or other properties.

Infiltration Techniques

- Reduce street and parking imperviousness
- Rooftop downspout disconnection
- Infiltration basins/trenches
- Bioretention

Infiltration techniques return water to the subsurface, which is especially important in Clear Creek County where groundwater provides the dominant drinking water supply in unincorporated areas. The performance of infiltration BMPs is dependent upon the permeability of the soils or materials through which the water must flow, pollutant levels and loads, and the degree of maintenance. Filtration techniques are often combined with infiltration BMPs to reduce premature clogging of the system. Particulates, sediment, and pollutants are trapped in the filter media (e.g. vegetation). These BMPs must be maintained to restore infiltration capacity and continue their protective function. Dry wells, subsurface infiltration beds and infiltration trenches are examples of subsurface control features. Pervious or porous pavement systems allow runoff to infiltrate through a permeable layer of pavement or other stabilized permeable materials to prevent the full-area run-off of driveways and parking lots. These systems can include porous asphalt, porous concrete, perforated concrete block, and cobble or interlocking concrete pavers with permeable joints or gaps. Infiltration basins can generally

accept runoff from larger areas as they are designed to capture a stormwater runoff volume, hold the water, and infiltrate it into the ground over a period of days. Due to shallow bedrock conditions and the need for excavation and blasting, infiltration basins are generally not practical in mountainous terrain. The following illustration provides a graphical presentation of infiltration effectiveness associated with various BMPs. As discussed, many of these practices or structures are implemented in a treatment train approach with flow control features preceding infiltration BMPs. The details of infiltration BMPs can be found in Appendix C.



Detention

Stormwater detention provides for temporary storage of a runoff volume for subsequent release. Examples include detention basins, underground vaults, or chamber devices. Temporary detention functions are also found in areas such as parking lots, flat rooftops, and depressed grassy areas. Retention BMPs are designed to store the runoff from a storm event for a longer time period without subsequent release. For example, a wet pond is designed to maintain a permanent pool of water throughout the year. Retention of water is considered a beneficial use in Colorado and is administered per requirements of water law. Detention BMPs are rate control structures that provide temporary volume storage (limited to 72 hours) to reduce downstream flood risk from larger major storm events.

These features reduce the peak discharge of stormwater to limit downstream flooding and provide some degree of channel protection from large storm events. Constructed wetland systems also provide for quantity control by detaining a volume of water. Details for these BMPs are found in Appendix D.

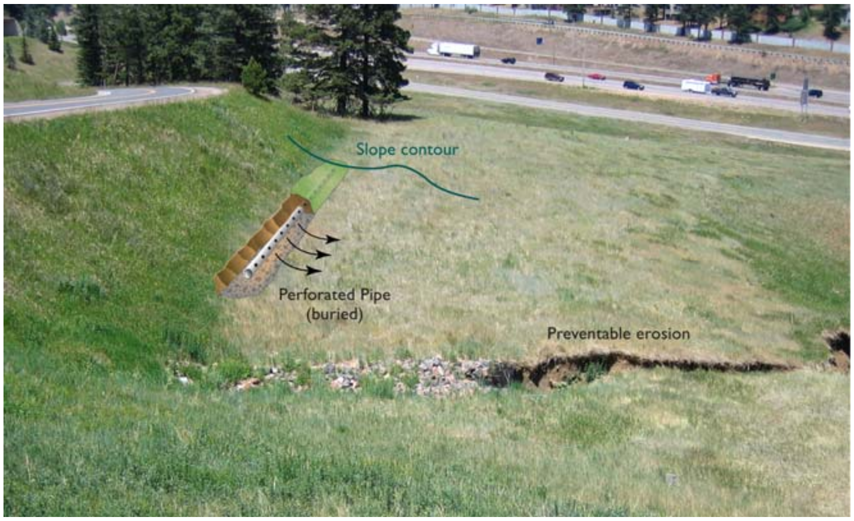
Flow Control

Flow control structures are implemented to reduce the runoff velocity and promote sheet flow over a larger area. Flow control BMPs such as an infiltration berm and the level spreader are examples of these types of structures. The infiltration berm is built along the contour of a hill to retain a small amount of water and allow its release as sheetflow as it overtops the berm. The level spreader can be any number of designs to develop sheetflow on water exiting a site (usually an impervious site) and prevent channelization. A relatively new technique, split-flow stormwater systems allow communities to meet both flood control and runoff reduction goals. Split-flow techniques divide the management of peak flow rates from specific design storms using a proportional stormwater flow splitter that handles the excess runoff created by development separately.

Flow Control Techniques

- Utilize natural flow pathways
- Create long flow paths over native surfaces
- Eliminate curbs and gutters
- Vegetated conveyance
- Roughen surfaces
- Create terraces and check dams

While small storms can be absorbed and infiltrated to maintain predevelopment hydrology, long storm events are too large to be fully infiltrated on-site. Naturally, large storm events are intended to create runoff. Infiltrating all of precipitation volume from a large storm is not a goal of low impact development. By identifying and utilizing natural flow paths, developers can reduce the need for engineered systems. In steep terrain, the creation of long flow paths is advantageous to limit runoff flow velocities. Natural vegetated drainage features are advantageous because they slow runoff, and thereby reduce peak discharge and improve water quality through filtration, infiltration and evaporation. LID conveyance techniques often include rough surfaces, check dams, and terraces to slow runoff and increase evaporation and the settling of solids. Additionally, LID conveyance techniques can perform similar functions to conventional curb and gutter systems by routing runoff to landscaped areas for filtration, infiltration, and evapotranspiration. Details of these BMPs are included in Appendix E.



Road embankments can be retrofitted with dirt berms contoured with the slope and containing perforated pipe to diffuse and control flows.

7. Considerations for BMP selection in mountainous terrain

Colorado's mountain communities must consider snowpack hydrology as part of their stormwater management plans. Little infiltration or runoff occurs in the winter as precipitation falls as snow and the ground is frozen. On average, winter conditions with at least one inch of snow on the ground range from 21 days on the eastern edge of the county to 101 days in the higher elevations west of Georgetown (NRCS, 2003). Areas dominated by snow pack naturally deliver more runoff to drainage channels when the temperature warms up in the spring. New isotopic and geochemical analysis suggests that over 60% of spring runoff may actually be older groundwater (Liu and others, 2004). That is, groundwater discharge constitutes the majority of stream flow. Natural infiltration of spring snowmelt is evidenced in hydrographs from water wells in crystalline bedrock where groundwater levels may rise 50 feet or more. On undeveloped property, snowmelt percolates through the surface soil and weathered bedrock material (regolith) versus channelized flow on developed property down dirt road ditch lines carrying sediment and eroding embankments.

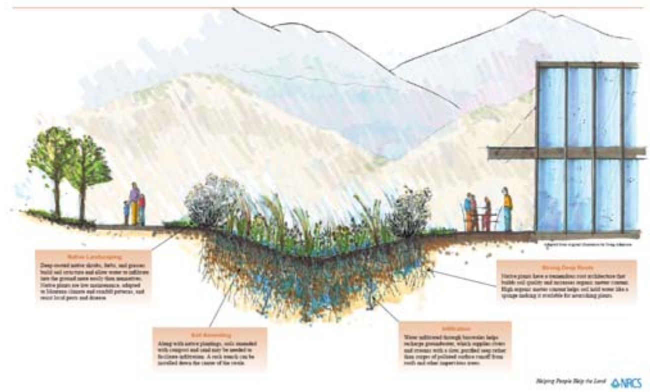
In mountainous terrain, the land surface naturally offers more drainage opportunities than in flatter terrain. However, individuals and communities in the mountains often rely on infiltration to recharge fractures in the bedrock for well supplies or to saturate the regolith and provide base flow to a surface stream that may provide the municipal supply. Planning and designing developed land to drain more than what would naturally occur, removes much needed water resources from the community. Additionally, increased drainage requires increased infrastructure, which creates added financial burdens on individuals and communities.

While the steeper mountainous terrain naturally facilitates drainage and snow pack hydrology creates large spring-time runoff events, there are best management practices that can be used on individual and commercial properties or in the right–of-way to reduce the excess runoff volume that a drainage-based design would create. To be specific, the goal is not to stop drainage. The focus is on reducing the excess runoff that is created when impervious area is added to the land or impervious areas are connected to convey drainage, such as when a roof drains to a driveway and the driveway drains to the street or storm sewer and discharges directly to the creek without treatment.

To understand what BMPs to use and in what combination, requires an understanding of both the site characteristics and BMP capabilities. Consideration must be given to increase in runoff rates and volumes from the impervious areas. Runoff reduction BMPs are used to interrupt connected impervious area and provide infiltration opportunities. Additionally, BMP selection may be an iterative process that comes from experience with mountain soils, bedrock fractures, vegetation, etc.

The process of choosing BMPs and arranging them on the site is determined by the stormwater management goals. These goals may generally include runoff reduction, however more specific needs may be addressed. For example, the type of development (residential, commercial, level of density), pollutant characteristics, sedimentation potential all help guide the selection , sizing and placement of BMPs. Roof or parking lot runoff from a commercial may flow to a porous landscape detention area that is sized for a certain storm and uses engineered media to produced desired water quality benefits, whereas roof runoff on a mountain residential lot may flow to a rock ring that allows ponding to reduce erosion on the property. A commercial parking lot that must comply with the Americans with Disability Act (ADA) requirements may include permeable pavement to not generate runoff in the first place. Residential driveways may have a gravel surface. A roadside ditch may have several check structures to create many ponding areas to reduce runoff volume and provide more convenient sediment removal access. The options are endless and require the property owner, design engineer, planner and local government staff to discuss the site goals and BMP functions at the beginning of the site design process. As discussed in Chapter 5, this is a different approach than what is typically used for land development projects.

It should be noted that there may be different structure names for similar BMPs. For example, rain garden, bioswale, bio retention areas, porous landscape detention are all names for a BMP that consists of a depression that accepts stormwater and contains engineered soil media and plants. The shape may vary and there may be design variations according to land use type (residential or commercial), drainage area size, storm size capacity, soils. Some installations may include a liner, gravel layer, collection and discharge pipe, as well.



It bears repeating that when planning and designing runoff reduction and infiltration BMPs, it is important to realize that low impact development BMPs do not eliminate the need for flood control BMPs. The filtration and infiltration BMPs are designed to maintain predevelopment hydrology, which targets the small storms. Reducing downstream flood risk will likely still need flood control and detention facilities. Runoff reduction BMPs are a complement to a flood control program and offer added water quality and channel protection benefits and some flood control benefits if implemented throughout the watershed.

Finally, the stormwater management practices and design guidance presented herein are an attempt to educate developers, engineers, and the end user on alternatives to conveyance style drainage designs. The information should not be used to supersede any local design guidance document. With specific local knowledge and experience, county staff are the best resource to discuss green infrastructure design opportunities.

APPENDIX A

GROUNDWATER RECHARGE POTENTIAL ANALYSIS

Groundwater Recharge Potential

The CGS performed an analysis to identify specific areas within the study area of Clear Creek County that have the greatest potential for contributing to groundwater recharge. The CGS assembled a "matrix" of physical characteristics that affect the ability of water to infiltrate into the ground and eventually recharge the groundwater system. Four physical factors - geology, slope, soil type, and precipitation - were used to predict areas where natural groundwater recharge is likely to occur. Spatial data for each of the four matrix inputs was assembled in a GIS. All matrix inputs were converted to a GIS raster cell-based format at a minimum resolution of 30 meters. Each input was assigned rating values according to the respective tables for each (shown below) to be used in computing the groundwater recharge potential throughout the study area. Figure 3-8 shows the spatial distribution of these input characteristics within the study area.

Geology

Geology data was generalized and classified from Kellogg and others (2008) based on the permeability of geologic units. Higher permeability units were assigned higher rating values because of their greater ability to convey water to the groundwater system. Similarly, areas within 10 meters of a mapped fault feature were considered to be part of the fault and therefore were grouped into the highest permeability category; areas within 100 meters of a mapped fault were considered fracture zones and were grouped into the second highest permeability category. Crystalline bedrock units were considered to be very low permeability and were assigned to the lowest rating value class.

Table 1

Geology	Rating value
Alluvial Quaternary deposits and faults	100
Non-alluvial Quaternary deposits and fracture zones	66
Bedrock units	10

Slope

Landform slope was generated from USGS National Elevation Dataset (NED) 10-meter resolution digital elevation models (DEM). Slope rating value is inversely proportionate to the steepness; water infiltration is generally highest on surfaces with low slopes and lowest on surfaces with high slopes.

Table 2

Slope (percent)	Rating value
0- 5	100
5-10	80
10-15	60
15-20	40
20-25	20
>25	0

Soil

Hydrologic soil type data was extracted from the USDA, Natural Resources Conservation Service (NRCS) soil survey data mart. The rating values for soil type were assigned based on hydrologic soil group and their infiltration capacity. Group A soils are soils with high infiltration rates, group B are soils with moderately high infiltration rates, group C are soils with moderately low infiltration rates, and group D are soils with very low infiltration rates.

Table 3

Soil (hydrologic soil group)	Rating value
A	100
B	66
C	33
D	0

Precipitation

Average annual precipitation was converted from the NRCS, National Cartography and Geospatial Center PRISM climate mapping system data provided in 2-inch precipitation intervals. Precipitation ranges were assigned rating values in proportion to annual precipitation amount.

Table 4

Precipitation (average annual, inches)	Rating value
14-20	20
20-26	40
26-32	60
>32	80

Analysis

With all of the data prepared in four separate raster layers with cell values representing the rating value for the respective input, a multiplicative computation of these four physical “matrix” inputs was performed in order to evaluate the natural groundwater recharge potential throughout the study area. In this analysis the four input rating values were multiplied together for a given cell area. Using a multiplicative approach, a cell area containing a rating value of zero for any of the inputs will have an output rating of zero for groundwater recharge potential regardless of whether other inputs are high or low. This methodology produces a conservative estimate of recharge potential.

In this study, the natural groundwater recharge potential ratings calculated using the multiplicative method were grouped into low, moderate, and high categories based on percentile of the result. The highest potential category represents calculated rating values in the top 7.5 percentile; the moderate potential category represents calculated ratings in the percentile range of 80 to 92.5; the lowest potential category represents calculated ratings below the 80th percentile of results. Figure 3-9 shows the natural groundwater recharge potential in the Clear Creek County study area as derived from this analysis.

APPENDIX B
FILTRATION BASED BEST MANAGEMENT PRACTICES

Note: The information provided in this appendix is compiled from numerous national sources. The general design considerations and guidance are intended to help the user, but should not be used to supersede any local design guidance document that is based on local conditions and site specific experience.

Vegetated Filter Strip

Image: CASFM

Description:

Vegetated filter strips are gently sloped areas designed to receive sheet flows. They are typically linear facilities that run parallel to an impervious surface and are used to receive the runoff from walkways and driveways. Filter strips are covered with vegetation, including grasses and groundcovers, that filter and reduce the velocity of the sheet flow. As the stormwater travels downhill, it infiltrates into the soils below. Vegetated filter strips are also known as grassed buffer strips, grassed filter strips, filter strips, and grassed filters.

Design Considerations

- Sheet flow across vegetated filter strip
- Filter strip length is a function of the slope, vegetative cover, and soil type
- Minimum recommended length of filter strip is 25 ft., however shorter lengths provide some water quality benefits as well.
- Maximum filter strip slope is also based on soil type and vegetated cover
- Filter strip slope should never exceed 8%. Slopes less than 5% are generally preferred
- Level spreader devices are recommended to provide uniform sheet flow at the interface of the filter strip and the adjacent land cover
- Maximum contributing drainage area slope is generally less than 5%, unless energy dissipation is provided
- Minimum filter strip width should equal the width of the contributing drainage area
- Construction of a filter strip should disturb as little existing vegetation at the site as possible

Potential Applications

Residential: Yes
Commercial: Yes
Ultra Urban: Limited
Industrial: Limited
Retrofit: Yes
Highway/Road: Yes

Stormwater Functions

Volume Reduction: Low/Med.
Recharge: Low/Med.
Peak Control: Low
Water Quality: High

Water Quality Functions

TSS: 30%
TP: 20%
NO3: 10%

Advantages:

- If weeds are controlled, the strip has the attractive appearance as a landscaped strip.
- Requires minimal maintenance (erosion control, weed control, mowing).

Limitations:

- Thick vegetative cover is necessary for proper functioning; this may be problem in Colorado's climate.
- Vegetated filter strips will not provide significant infiltration when volume and flow rate of runoff are high.

Variations:

- Roadside shoulders can function as buffer strips where slope and length are appropriate
- Effectiveness can be enhanced by the addition of a pervious berm at the toe of the slope. This practice will result in a shallow, temporarily ponded area that will enhance infiltration.
- Small check dams can be installed on filter strips with slopes exceeding 5%. These also encourage ponding and infiltration.
- A gravel-filled trench installed along the entire upgradient edge of the strip is an effective device for creating uniform sheet flow.
- Engineered media under vegetation can increase filtering and runoff reduction benefits.

Applications:

- Residential development lawn and housing areas,
- Roads and highways
- Parking lots
- Commercial light industrial facilities
- Part of riparian buffer

Design Considerations:

Performance

- Vegetated buffer strips tend to provide somewhat better treatment of stormwater runoff than swales, having less tendency for channelization or erosion.
- A good guideline is that the area ratio of the contributing drainage area to the strip should not exceed 6:1.
- Maximum lateral slope of the filter strip is 1%.

Siting Criteria

- Vegetated buffer strips can only be used on gently sloping areas with good vegetative cover.
- Filter strips are most applicable for catching runoff from roads, roof downspouts, small parking lots and pervious surfaces.

Additional Design Guidelines

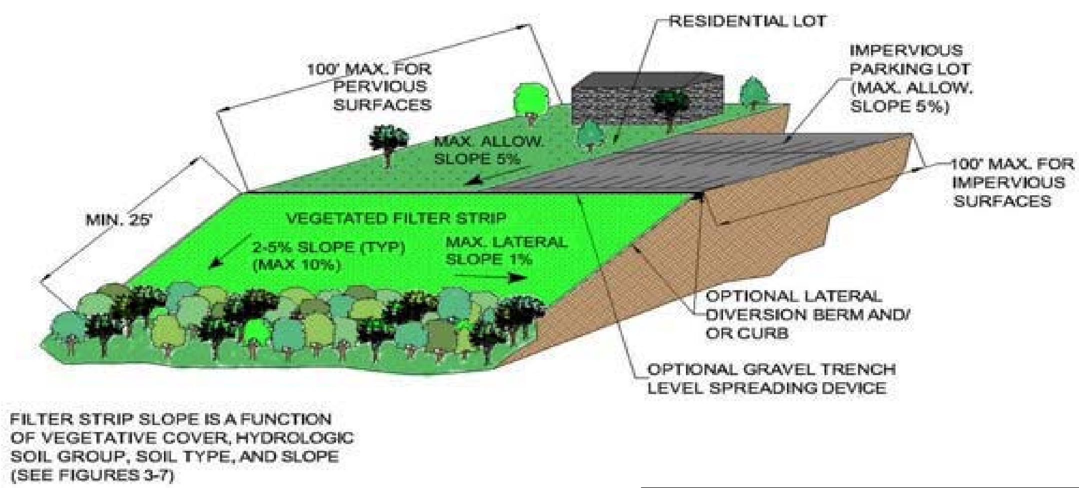
- Both the top and the toe of the slope should be as flat as possible to encourage sheet flow and prevent erosion the top of the strip should be installed 2-5 inches below the adjacent pavement so that vegetation and sediment accumulation at the edge of the strip does not prevent runoff from entering.

- An alternative or additional feature would be a porous or perforated pavement strip across the width of the top to serve as a flow spreader.
- Dense vegetation is needed to keep runoff flow at 1 foot-per-second velocity or less. A disadvantage may be the necessity of irrigating the vegetation during dry periods to maintain its effectiveness.
- If sod strips are used, the strips should be off-set to prevent water from running down seams and creating erosion problems.
- Effective use of filter strips to treat stormwater runoff is dependent on limiting the flow path to the filter. One of the main abuses of the past has been draining too much area through the filter strip. In most cases the sheet flow distance limitations will be the controlling factor.

Maintenance:

- This technology requires mainly vegetation management. The strips need to be maintained for litter removal and weed control.
- Sediment accumulating along the upper edge of the buffer strips and/or level spreaders should be collected and removed annually.

Schematic:



Pennsylvania Stormwater

Resources:

Pennsylvania stormwater best management practices manual, chapter 6 – Structural BMPs, 2006, retrieved February 12, 2009, from Pennsylvania Department of Environmental Protection, Bureau of Watershed Management Website: http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=|.

Catalog of stormwater BMPs for Idaho cities and counties, 2005, retrieved February 4, 2009, from Idaho Department of Environmental Quality Website: http://www.deq.state.id.us/water/data_reports/storm_water/catalog/index.cfm

Claytor, R.A., Schueler, T.R., 1996, Design of stormwater filtering systems, retrieved February 19, 2009, from Center for Watershed Protection Website: http://www.cwp.org/Resource_Library/Center_Docs/SW/design_swfiltering.pdf

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Kenney/Jenks Consultants, 2007, The Truckee Meadows regional stormwater quality management program low impact development handbook, retrieved February 9, 2009, from http://www.cityofreno.com/index.aspx?page=366.

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United States Environmental Protection Agency, 1999, Preliminary Data Summary of Urban Stormwater Best Management Practices, retrieved February 4, 2009, from United States Environmental Protection Agency, Effluent Limitation Guidelines Website: http://www.epa.gov/guide/stormwater/.

National Menu of Stormwater Best Management Practices, retrieved February 9, 2009, from United States Environmental Protection Agency, Stormwater Program Website: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm.

Colorado Association of Stormwater and Floodplain Managers, Low Impact Development Database, retrieved February 12, 2009, from CASFM Stormwater Quality Committee Website: http://www.casfm.org/.

Vegetated Swale

Image: CASFM

Description: Vegetated swales are typically long, narrow, gently sloping landscape depressions that collect and convey stormwater runoff. As the stormwater flows along the length of the swale, the vegetation and check dams slow the stormwater down, filter it, and allow it to infiltrate into the ground. Where soils do not drain well, swales can overflow to discharge points such as a drywell or sump. Vegetated swales can serve as part of a stormwater drainage system and can replace curbs, gutters and storm sewer systems.

Design Considerations

- Plant dense, low-growing native vegetation that is water-resistant, drought and salt tolerant, providing substantial pollutant removal capabilities
- Longitudinal slopes range from 1% to 6%
- Side slopes range from 3:1 to 5:1
- Check-dams can provide limited detention storage, as well as enhanced volume control through infiltration. Care must be taken to prevent erosion around the dam
- Convey the 10-year storm event with a minimum of 6 inches of freeboard
- Design for non-erosive velocities up to the 10-year storm event
- Design to aesthetically fit into the landscape, where possible
- Significantly slows the rate of runoff conveyance compared to pipes

Potential Applications

Residential: Yes
Commercial: Yes
Ultra Urban: Limited
Industrial: Yes
Retrofit: Yes
Highway/Road: Yes

Stormwater Functions

Volume Reduction: Low/Med.
Recharge: Low/Med.
Peak Control: Med./High
Water Quality: Med./High

Water Quality Functions

TSS: 50%
TP: 50%
NO3: 20%

Advantages:

- If properly designed, vegetated, and operated, swales can serve as an aesthetic, potentially inexpensive urban development or roadway drainage conveyance measure with significant collateral water quality benefits.
- Roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible.
- Reduces peak flows.
- Lowers capital costs.
- Promotes infiltration.
- Can add a high value, attractive amenity to a commercial property

Limitations:

- Can be difficult to avoid channelization.
- May not be appropriate for industrial sites or locations where spills may occur.
- Grassed swales cannot treat a very large drainage area. Large areas may be divided and treated using multiple swales.
- They are impractical in areas with steep topography.
- Swales are impractical in areas with erosive soil and where vegetation is difficult to maintain.
- They are not effective and may even erode when flow velocities are high, or if the vegetative cover is not properly maintained
- Swales can be more susceptible to failure than other treatment BMPs if not properly maintained

Variations:

- Xeriscape swales can be planted with low water-use plants interspersed among rocks.
- Dry swales are similar to bioretention areas, with fabricated soil bed incorporated into the design. Native soil is replaced by a sand/soil mix that meets minimum permeability requirements.
- A wet swale intersects groundwater and behaves similarly to a linear wetland cell.

Applications:

- An on-line vegetated swale should be sized as a treatment facility and as a conveyance system to pass the peak hydraulic flows of the 10- and 100-year design storm while allowing infiltration.
- Natural drainage courses should be regarded as significant local resources that are generally to be kept in use for stormwater management. Roadside ditches should be regarded as significant potential infiltration sites; road design standards and ditch maintenance programs should be developed to maximize their usefulness in infiltration.

Design Considerations:

Performance

- Flow rate based design determined by local requirements or sized so that 85% of the annual runoff volume is discharged at less than the design rainfall intensity.
- Swale should be designed so that the water level does not exceed 2/3rds the height of the grass or 4 inches, whichever is less, at the design treatment rate.
- Longitudinal slopes should not exceed 2.5%
- Trapezoidal channels are normally recommended but other configurations, such as parabolic, can also provide substantial water quality improvement and may be easier to mow than designs with sharp breaks in slope.
- Swales constructed in cut are preferred, or in fill areas that are far enough from an adjacent slope to minimize the potential for gopher damage
- A diverse selection of low growing, plants that thrive under the specific site, climatic, and watering conditions should be specified. Vegetation whose growing season corresponds to the wet season is preferred. Drought tolerant vegetation should be considered especially for swales that are not part of a regularly irrigated landscaped area.
- The effectiveness of vegetated swales can be enhanced by adding check dams at approximately 17 meter (50 foot) increments along their length (See Figure 1). These dams maximize the retention time within the swale, decrease flow velocities, and promote particulate settling.

Siting Criteria

- A swale is set below adjacent ground level with runoff entering over grassy banks or rundowns.
- Swales are best used in areas treating less than 10 acres, with slopes no greater than 5%.

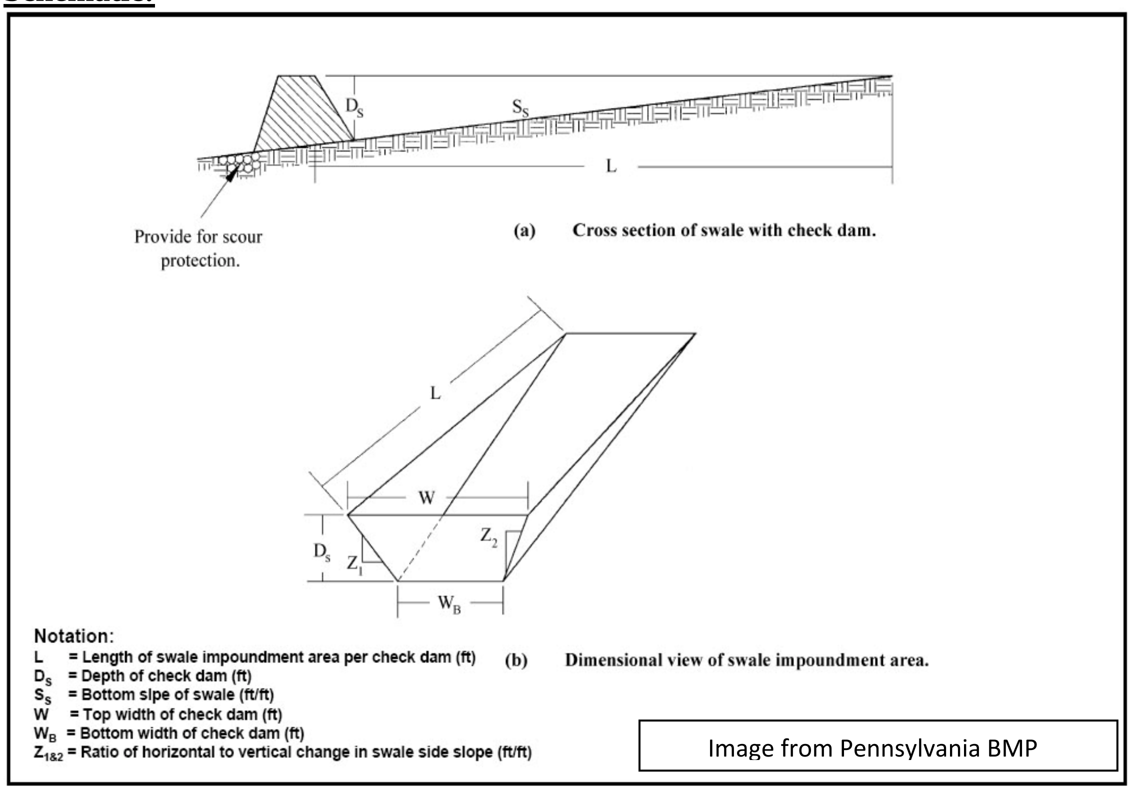
Additional Design Guidelines

- The maximum bottom width should not exceed 10 feet unless a dividing berm is provided. The depth of flow should not exceed 2/3rds the height of the grass at the peak of the water quality design storm intensity. The channel slope should not exceed 2.5%.
- A design grass height of 6 inches is recommended. At grass heights over 6 inches, the grass tends to flatten when water flows over it, thus limiting its effectiveness.
- Regardless of the recommended detention time, the swale should be not less than 100 feet in length.
- The swale can be sized as both a treatment facility for the design storm and as a conveyance system to pass the peak hydraulic flows of the 100-year storm if it is located "on-line." The side slopes should be no steeper than 3:1 (H:V).
- Roadside ditches should be regarded as significant potential swale/buffer strip sites and should be utilized for this purpose whenever possible. If flow is to be introduced through curb cuts, place pavement slightly above the elevation of the vegetated areas.
- Curb cuts above swales should be at least 12 inches wide to prevent clogging.
- Swales must be vegetated in order to provide adequate treatment of runoff. It is important to maximize water contact with vegetation and the soil surface. For general purposes, select fine, close-growing, water-resistant grasses. If possible, divert runoff (other than

necessary irrigation) during the period of vegetation establishment. Where runoff diversion is not possible, cover graded and seeded areas with suitable erosion control materials.
- Regardless of what vegetation is selected and planted, the species may take advantage of the real hydrology that develops. This is acceptable and does not necessarily indicate the structure is failing.

Maintenance:
- Regular inspections (twice annually) for erosion, vegetation damage, sediment/debris accumulation.
- Litter can be a big problem, especially in areas of heavy traffic.
- Regular mowing should maintain optimum grass height.

Schematic:



Resources:

Pennsylvania stormwater best management practices manual, chapter 6 – Structural BMPs, 2006, retrieved February 12, 2009, from Pennsylvania Department of Environmental Protection, Bureau of Watershed Management Website: http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=|

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Urban Drainage & Flood Control District, 2008, Urban storm drainage criteria manual volume 3, retrieved February 4, 2008, from http://www.udfcd.org/downloads/down_critmanual.htm.

Bioretention (Rain Garden)

Image: Truckee Meadows

Description: The bioretention best management practice (BMP) functions as a soil and plant-based filtration device that removes pollutants and allows ponded water to infiltrate. These facilities normally consist of a grass buffer strip, sand bed, ponding area, organic layer or mulch layer, planting soil, and plants. The runoff velocity is reduced by passing over or through a buffer strip and distributing evenly along a ponding area. Exfiltration of the stored water in the bioretention area planting soil into the underlying soils occurs over a period of days. Bioretention systems are also known as landscape detention, rain gardens, tree box filters, and storm water planters.

Design Considerations

- Flexible in terms of size and infiltration
- Ponding depths generally limited to 12 inches or less for aesthetics, safety, and rapid draw down. Certain situations may allow deeper ponding depths
- Deep rooted perennials and trees encouraged
- Native vegetation that is tolerant of hydrologic variability, salts and environmental stress
- Modify soil with compost
- Stable inflow/outflow conditions
- Provide positive overflow
- Maintenance required to ensure long-term functionality

Potential Applications

Residential: Yes
Commercial: Yes
Ultra Urban: Yes
Industrial: Yes
Retrofit: Yes
Highway/Road: Yes

Stormwater Functions

Volume Reduction: Medium
Recharge: Med./High
Peak Control: Low/Med.
Water Quality: Med./High

Water Quality Functions

TSS: 85%
TP: 85%
NO3: 30%

Advantages:

- Stormwater is temporarily stored and released over a period of days, enhancing the quality of the water released and allowing for infiltration.
- The vegetation provides addition benefits, including shade, windbreaks, noise absorption and visual enhancement.
- Can become a complete ecological habitat.

Limitations:

- Not recommended for slopes >20%.
- Not recommended where mature trees would be removed.
- Runoff with high sediment loads result in clogging and require maintenance
- Not recommended where water table is within 6 feet of ground surface or where soil stratum is unstable.
- Bioretention BMPs have potential to create attractive habitats for breeding mosquitoes and other insects by providing heavily vegetated habitat with shallow water.
- In cold weather, soil may freeze, preventing infiltration of runoff.

Variations:

- A bioinfiltration swale (BI swale) is a variation whereby a depression is created by excavation, berms or small dams and placed in a channel to infiltrate the design storm runoff from impervious surfaces through a grass or vegetative root zone. They represent a cross between a biodetention basin and a vegetated swale and are designed for conveyance as well as infiltration.
- A bioinfiltration basin is a larger feature designed to accommodate larger volumes of water in a larger area. This will be treated more fully in the “Infiltration Basin” section.
- Bioretention can also be used for roadways where adequate space is available for off-line implementation.

Applications:

- Sites with loamy soils are suitable because the excavated soil can be backfilled and used as planting soil, thus eliminating the cost of importing planting soil.
- Suitable for
    - parking lot islands,
    - parking lot perimeters,
    - tree wells within rights-of-way along roads,
    - street median strips,
    - driveway perimeters,
    - cul-de-sacs,
    - swales,
    - landscaped areas in commercial, residential, and industrial areas.

Design Considerations:

Performance

- Design should include the following elements:
    1. Optional pretreatment through a vegetated buffer strip of similar feature.
    2. A flow entrance for features treating something other than sheet flow; these can include curb cuts, roof leaders, or trench drains.
    3. A ponding area provides the temporary surface storage as it infiltrates.
    4. Plant material.
    5. An organic mulch layer serves as a surface filter to assist plant growth and health and to prevent clogging of infiltration.
    6. The planting volume provides growth medium and a sufficiently permeable bed to allow for infiltration
- The bioremediation structure allows runoff to pond and infiltrate gradually. A typical bioretention system design includes a depressed ponding area (at a grade below adjacent impervious surfaces).
- In Colorado, the bioretention area should be vegetated with appropriate native species that do well in sandy soils.
- Bioretention systems should generally be designed off-line to prevent erosion of the system by large run-off storm events.

Siting Criteria

- Suitable for parking lot islands and perimeters, tree wells within rights-of-way along roads, street median strips, driveway perimeters, cul-de-sacs, landscaped areas in commercial, residential, and industrial areas.
- Considerable savings can be recognized if a site is suitable for infiltration (underlain by NRCS soil types A, B, or C). Used to treat stormwater from impervious surfaces in commercial, residential and industrial areas
- Good site is upland from inlets receiving sheet flow from graded areas or areas planned for excavation
- To minimize sediment loading to the treatment area, bioretention should be used only in stabilized drainage areas.
- Bioretention may not be feasible on unstable soils, soils with high clay content (>25%), slopes >20% and/or sites already populated with mature trees that would have to be removed.

Additional Design Guidelines

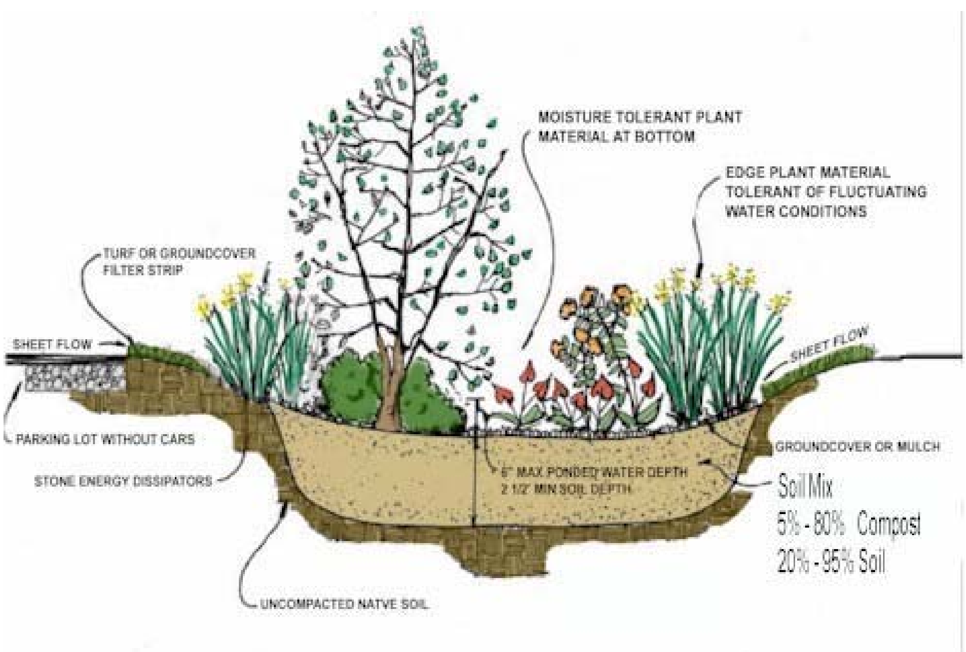
- The soil should have infiltration rates greater than 0.5 inches (1.25 centimeters) per hour, typical of sandy loams and loamy sands and loams, The pH of the soil should range between 5.5 and 6.5, where pollutants such as organic nitrogen and phosphorous can be adsorbed by the soil and microbial activity can flourish.
- Denver Urban Drainage recommends sandy soil to enhance infiltration.
- Planting soil should have 1.5 to 3 percent organic content and no more than 500 ppm soluble salts.

- Underdrains should be provided in areas where native soil permeability is less than 0.5 in/hour. Underdrain design references A,B,C, and D soil groups to determine applicability.
- Recommended minimum dimensions are 15 x 40 feet, with preferred with of 25 feet. Excavated depth should be 4 feet.
- Recommended planting density is 1 tree or shrub per 50 ft^2 of retention area.
- Runoff from paved areas can be designed to divert directly into the bioretention area or convey into the site by a curb or gutter collection system.
- Treatment effectiveness can be maximized if the site is graded to minimize sheet flow conveyed to the treatment area.
- Erosion control/energy dissipation features should be provided where runoff enters bioretention systems (e.g. cobbles or riprap beneath a curb cut opening or a splash block beneath a roof drain downspout).
- The optimum drainage area should be between 0.25 to 1.0 acres (0.1 and 0.4 hectares.) Larger drainage areas may require multiple bioretention features. Further considerations are the rainfall intensity and runoff rate. Stabilized areas may erode with velocities greater than 5 feet per second (1.5 meters per second). The design size of the bioretention area should be appropriate for the water volume anticipated.
- A grass channel entryway is valuable for pretreatment, by filtering out fine particulate matter that could clog the infiltration system of the bioretention facility.

Maintenance:

- Maintenance generally involves the routine maintenance required of any landscaped area.
- Mulch should be checked periodically and possibly replaced to prevent clogging.

Schematic:



Source: Pennsylvania BMP Fact Sheet.

Resources:

Pennsylvania stormwater best management practices manual, chapter 6 – Structural BMPs, 2006, retrieved February 12, 2009, from Pennsylvania Department of Environmental Protection, Bureau of Watershed Management Website: http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=|.

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The Truckee Meadows regional stormwater quality management program construction site best management practices handbook, 2008, retrieved February 9, 2009, from http://www.cityofreno.com/index.aspx?page=366.

National Menu of Stormwater Best Management Practices, retrieved February 9, 2009, from United States Environmental Protection Agency, Stormwater Program Website: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm.

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United States Environmental Protection Agency, 1999, Preliminary Data Summary of Urban Stormwater Best Management Practices, retrieved February 4, 2009, from United States Environmental Protection Agency, Effluent Limitation Guidelines Website: http://www.epa.gov/guide/stormwater/.

Sand/Organic Filter

Image: Denver Urban Drainage

Description: Sand/organic filters, similar to bioretention, are structural landscaped reservoirs used to collect, filter, and infiltrate stormwater, allowing pollutants to settle and filter out as the water percolates through the layer of sand, compost, organic material, peat, or other filter media. They can be constructed above, at, or below grade. Depending on site conditions, sand/organic filters can be designed to completely infiltrate all the stormwater they receive or designed as flow-through facilities where only a portion of the flow is infiltrated, and overflow is directed to an approved discharge point.

<table>
<tr>
<td rowspan="3">
Design Considerations

Follow Infiltration Systems Guidelines
Minimum permeability of filtration medium required
Minimum depth of filtering medium = 12”
Perforated pipes in stone, as required
May be designed to collect and convey filtered runoff down-gradient
May be designed to infiltrate
Pretreatement for debris and sediment may be necessary
Should be sized for drainage area
Regular inspection and maintenance required for continued functioning
Positive overflow is needed

</td>
<td>
Potential Applications

Residential: Limited
Commercial: Yes
Ultra Urban: Yes
Industrial: Yes
Retrofit: Yes
Highway/Road: Yes
</td>
</tr>
<tr>
<td>
Stormwater Functions

Volume Reduction: Low-High*
Recharge: Low-High*
Peak Control: Low-High*
Water Quality: High

* Depends on if infiltration is used
</td>
</tr>
<tr>
<td>
Water Quality Functions

TSS: 85%
TP: 85%
NO3: 30%
</td>
</tr>
</table>

Advantages:

Sand filters take up little space and can be used on highly developed sites and sites with steep slopes.

Limitations:

- Organic filter media such as peat or compost may hold water, freeze and become impervious in the winter.
- This BMP is not recommended where high sediment loads are anticipated or where runoff contains high concentrations of pollutants.
- Sand/organic filters can be expensive to construct and maintain.
- High solid loads can cause clogging and require more frequent maintenance.

Variations:

- Plants may be used to help fulfill a site's required landscaping area requirement and should be integrated into the overall site design.
- Surface may be covered in sand, peat, gravel, river stone, or similar material.

Applications:

Filters are commonly used in urbanized areas and are good for limited spaces. Filters may be used for water quality treatment. Typical uses include:

- Parking lots
- Roadways and highways
- Light industrial sites
- Transportation facilities
- Fast food and shopping areas
- Urban streetscapes

Design Considerations:

Performance

- If the tested infiltration rate is greater than or equal to 2 inches per hour, the sandfilter should overflow to a subsurface infiltration facility.
- If the tested infiltration rate is less than 2 inches per hour, the sand filter should be designed as a partial infiltration or flow-through facility, with an overflow to an approved discharge point.
- Pretreatment is recommended for debris and coarser particulate material.
- Should be sized for drainage area.
- Entering velocity should be controlled by use of a level spreader.
- The filter medium may be a variety of materials and in most cases should have a minimum depth of 12 inches and a maximum depth of 30 inches (although variations may be acceptable for local conditions.)

Siting Criteria

- Local regulations should be checked for set-back requirements on filter structures.
- Sand filters are best applied on relatively small sites or multiple structures for large sites.

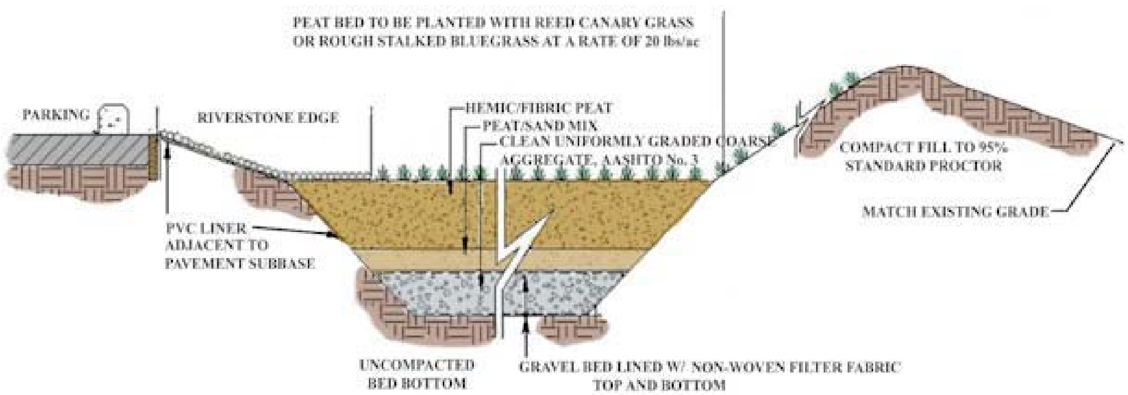
Additional Design Guidelines

- Locating sand filtration systems off-line from a primary conveyance/detention system can improve its long-term effectiveness.
- A maintenance ramp should be included in the design to facilitate access to the filter basin for maintenance.

Maintenance:

- Filters require regular inspection and maintenance as studies show that effectiveness diminishes through time as sediment accumulates in the filter medium. Odors have been reported as a common problem.
- Standing water indicates the filter is not functioning optimally.
- Film or discoloration of surface filter material indicates that organics or debris have clogged the filter.
- Maintenance practices include removal of trash and debris, scraping silt with rakes, tilling and aeration of the filter area and replacing filter medium if scraping and removal has reduced the depth of the medium.

Schematic:



PARKING LOT VEGETATED PEAT FILTER EXAMPLE (CA)

Image from Pennsylvania BMP Manual

Resources:

Urban Drainage & Flood Control District, 2008, Urban storm drainage criteria manual volume 3, retrieved February 4, 2008, from http://www.udfcd.org/downloads/down_critmanual.htm.

California Stormwater Quality Association, 2003, New development and redevelopment handbook, retrieved February 4, 2009, from the California Stormwater Best Management Practice Handbooks Website: http://www.cabmphandbooks.com/Development.asp.

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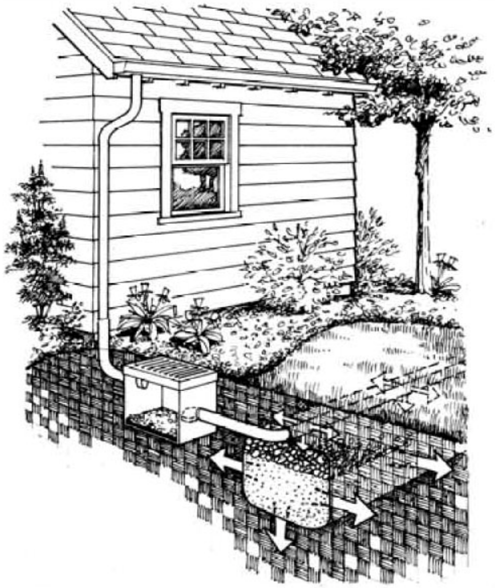
APPENDIX C

INFILTRATION BASED BEST MANAGEMENT PRACTICES

Note: The information provided in this appendix is compiled from numerous national sources. The general design considerations and guidance are intended to help the user, but should not be used to supersede any local design guidance document that is based on local conditions and site specific experience.

Advisory: Any effort to manage the on-site hydrology in a way that purposefully, through a structure or an action, allows more infiltration or more consumption of water than historically occurred may constitute an "out-of-priority" diversion of precipitation. The county and/or developer should contact the Colorado Division of Water Resources for comment if any feature of stormwater management has potential to allow infiltration or consumption that is greater than existed before development.

Dry well (seepage pit)



Description: A Dry well is a variation on an Infiltration system that is designed to temporarily store and infiltrate rooftop runoff. A dry well is constructed by excavating a hole in the ground and filling it with an open graded aggregate, and allowing the water to fill the dry well and infiltrate after the storm event. An underground connection from the downspout conveys water into the dry well, allowing it to be stored in the voids.

Image: City of Portland

Design Considerations

- **Follow infiltration system guidelines**
- Maintain minimum distance from building foundation.
- Provide adequate overflow outlet for large storms
- At least one observation well; clean out is recommended
- Wrap aggregate with nonwoven geotextile.
- Maintenance will require removal of sediment and leaves from sumps and cleanouts
- Provide pretreatment in some situations

Potential Applications

Residential: Yes
Commercial: Yes
Ultra Urban: Yes
Industrial: Limited
Retrofit: Yes
Highway/Road: No

Stormwater Functions

Volume Reduction: High
Recharge: High
Peak Control: Medium
Water Quality: Medium

Water Quality Functions

TSS: 85%
TP: 85%
NO3: 30%

Advantages:

- By capturing runoff at the source, Dry wells can dramatically reduce the increased volume of stormwater generated by the roofs of structures
- While roofs are generally not a significant source of runoff pollution, they are one of the most important sources of new or increased runoff volume from developed areas. By decreasing the volume of stormwater runoff, Dry wells can reduce runoff rates and improve water quality.

Limitations:

- Similar to other infiltration practices, Dry wells may not be appropriate for pollution “hot spots” or other areas where high pollutant or sediment loading is expected without additional design considerations.
- Dry wells are not recommended within a specified distance to structures or subsurface sewage disposal systems.

Variations :

Intermediate “Sump” Box – Water can flow through an intermediate box with an outflow higher to allow the sediments to settle out. Water would then flow through a mesh screen and into the dry well

Drain Without Gutters – for structures without gutters or downspouts, runoff is designed to sheetflow off a pitched roof surface and onto a stabilized ground cover (surface aggregate, pavement, or other means). Runoff is then directed toward a Dry well via stormwater pipes or swales.

Prefabricated Dry well – There are a variety of prefabricated, predominantly plastic subsurface storage chambers one the market today that can replace aggregate Dry wells. Since these systems have significantly greater storage capacity than aggregate, space requirements are reduced and associated costs may be defrayed. Provided the following design guidelines are followed and infiltration is still encouraged, prefabricated chambers can prove just as effective as standard Dry wells.

Applications :

Dry wells are a suitable BMP for any roof or impervious area with relatively low sediment loading. In practice, dry wells receiving runoff from single roof downspouts have been successful over long periods of time because they contain very little sediment. They must be sized according to the amount of rooftop runoff received, but are typically 4 to 5 square feet, and 2 to 3 feet deep, with a minimum of 1-foot soil cover over the top (maximum depth to 10 feet)

Design Considerations:

- Dry wells are sized to temporarily retain and infiltrate stormwater runoff from roofs of structures. A dry well usually provides stormwater management for a limited roof area.

Care should be taken not to hydraulically overload a dry well based on bottom area and drainage area.

- Dry wells typically consist of 18 to 48 inches of clean washed, uniformly graded aggregate with 40% void capacity. Dry well aggregate is wrapped in a nonwoven geotextile, which provides separation between the aggregate and the surrounding soil. At least 12 inches of soil is then placed over the Dry well.
- The design depth of a Dry well should take into account frost depth to prevent frost heave.
- A removable filter with a screened bottom should be installed in the roof leader below the surcharge pipe in order to screen out leaves and other debris.
- Adequate inspection and maintenance access to the well should be provided. Observation wells not only provide the necessary access to the well, but they also provide a conduit through which pumping of stored runoff can be accomplished in case of slowed infiltration.
- Though roofs are generally not a significant source of runoff pollution, they can still be source of particulates and organic matter, as well as sediment and debris during construction. Measures such as roof gutter guards, roof leader clean-out with sump, or an intermediate sump box can provide pretreatment for Dry wells by minimizing the amount of sediment and other a particulates that may enter it.
- Dry wells are not recommended when their installation would create a significant risk for basement seepage or flooding. In general, 10 feet of separation is recommended between Dry wells and building foundations. However, this distance may be shortened at the discretion of the designer. Shorter separation distances may warrant an impermeable liner to be installed on the building side of the Dry well.
- All Dry wells should be able to convey system overflows to downstream drainage systems. System overflows can be incorporated either as surcharge (or overflow) pipes extending from roof leaders or via connections to more substantial infiltration areas.

Maintenance:

As with all infiltration practices, Dry wells require regular and effective maintenance to ensure prolonged functioning. The following represent the minimum maintenance requirements for dry wells:

- Inspect dry wells at least four times a year, as well as after every storm exceeding 1 inch
- Evaluate the drain-down time of the dry well to ensure the maximum time of 72 hours is not being exceeded. If drain-down times are exceeding the maximum, drain the Dry well via pumping and clean out perforated piping, if included. If slow drainage persists, the system may need replacing.
- Regularly clean out gutters and ensure proper connections to facilitate the effectiveness of the dry well.
- If and intermediate sump box exists, clean it out at least once per year.

Schematic

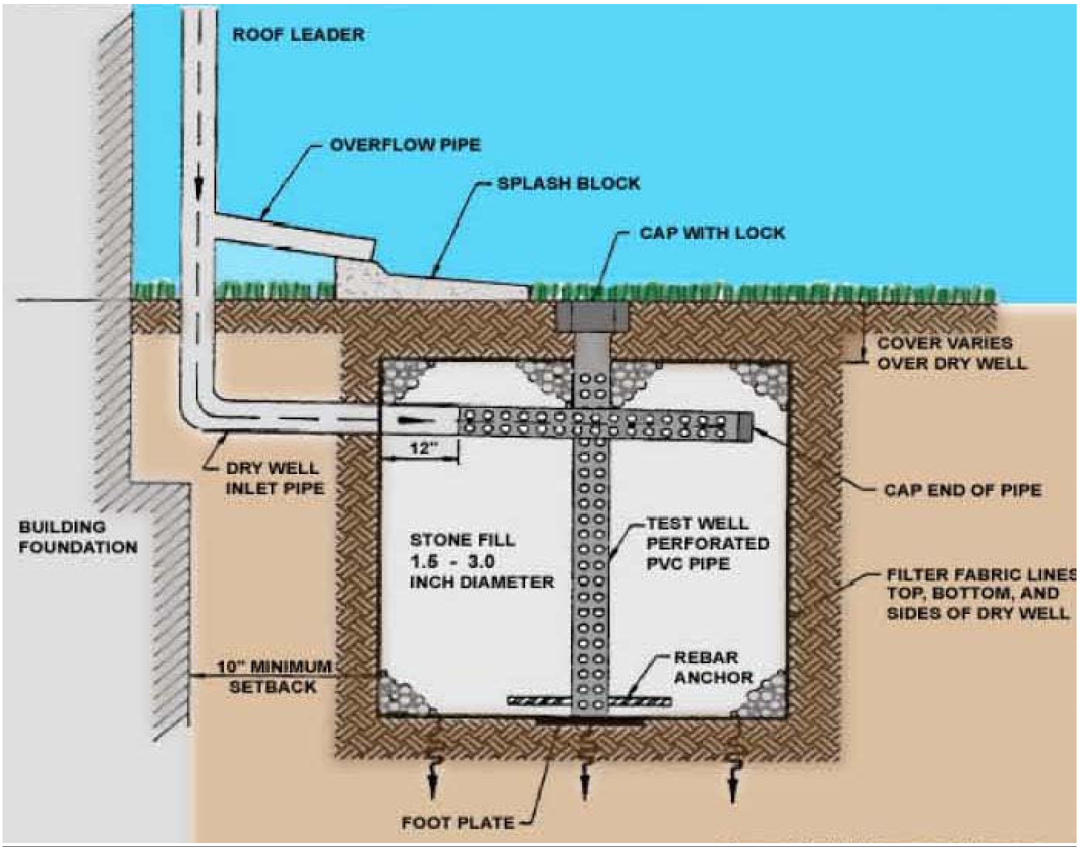


Image: Pennsylvania stormwater best management practices manual

Resources

Pennsylvania stormwater best management practices manual, chapter 6 – Structural BMPs, 2006, retrieved February 12, 2009, from Pennsylvania Department of Environmental Protection, Bureau of Watershed Management Website: http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=|.

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City of Portland, 2008, Stormwater Management Manual, retrieved February 10, 2009, from Portland Bureau of Environmental Services Website: http://www.portlandonline.com/BES/index.cfm?c=47952&.

Infiltration Basin

Description: An infiltration basin is a shallow impoundment that is designed to infiltrate stormwater. Infiltration basins use the natural filtering ability of the soil to remove pollutants in

stormwater runoff. Infiltration facilities store runoff until it gradually exfiltrates through the soil and eventually into the water table. This practice has high pollutant removal efficiency and can also help recharge groundwater, thus helping to maintain low flows in stream systems. Infiltration basins can be challenging to apply on many sites, however, because of soils requirements. In addition, some studies have shown relatively high failure rates compared with other management practices.

Design Considerations

- **Follow infiltration system guidelines**
- Maintain a minimum 2-foot separation to bedrock and seasonally high water table.
- Provide distributed infiltration area (5:1 impervious area to infiltration area – maximum).
- Uncompacted sub-grade is important.
- Preserve existing vegetation, if possible
- Design to hold/infiltrate volume difference in 2-year storm or 1.5’’ storm
- Provide positive stormwater overflow through engineered outlet structure.
- Do not install on recently placed fill (<5 years).
- Allow 2 foot buffer between bed bottom and seasonal high groundwater table and 2 foot buffer for rock

Potential Applications

Residential: Yes
Commercial: Yes
Ultra Urban: Limited
Industrial: Yes*
Retrofit: Yes
Highway/Road: Limited

*Applicable with specific considerations to design

Stormwater Functions

Volume Reduction: High
Recharge: High
Peak Control: Medium/High
Water Quality: High

Water Quality Functions

TSS: 85%
TP: 85%
NO3: 30%

Advantages:

- Provides 100% reduction in the load discharged to surface waters.
- The principal benefit of infiltration basins is the approximation of pre-development hydrology during which a significant portion of the average annual rainfall runoff is infiltrated and evaporated rather than flushed directly to creeks.
- If the water quality volume is adequately sized, infiltration basins can be useful for providing control of channel forming (erosion) and high frequency (generally less than the 2-year) flood events.

Limitations:

- May not be appropriate for industrial sites or locations where spills may occur.
- Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with Hydrologic Soil Types C and D.
- If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully treated prior to infiltration to protect groundwater quality.
- Not suitable on fill sites or steep slopes.
- Risk of groundwater contamination in very coarse soils.
- Upstream drainage area must be completely stabilized before construction.
- Difficult to restore functioning of infiltration basins once clogged.

Variations:

Re-Vegetation: For existing unvegetated areas or for infiltration basins that require excavation, vegetation may be added. Planting in the infiltration area will improve water quality, encourage infiltration, and promote evapotranspiration. This vegetation may range from a meadow mix to more substantial woodland species.

Usable Surface: An Infiltration Basin can be used for recreation (usually informal) in dry periods. Heavy machinery and/or vehicular traffic of any type should be avoided so as not to compact the infiltration area.

Soils with Poor Infiltration Rates: A layer of sand (6”) or gravel can be placed on the bottom of the Infiltration Basin, or the soil can be amended to increase the surface permeability of the basin.

Applications:

- **New Development:** Infiltration Basins can be incorporated into new development. Ideally, existing vegetation can be preserved and utilized as the infiltration area. Runoff from adjacent buildings and impervious surfaces can be directed into this area, which will “water” the vegetation, thereby increasing evapotranspiration in addition to encouraging infiltration.
- **Retrofitting existing “lawns” and “open space”:** Existing grassed areas can be converted to infiltration basins. If the soil and infiltration capacity is determined to be sufficient, the area can be enclosed through creation of a berm and runoff can be directed to it without excavation. Otherwise, excavation can be performed as described below.
- **Other Applications:** Other applications of Infiltration Basins may be determined by the Design Professional as appropriate.

Design Considerations:

- Water quality volume determined by local requirements or sized so that 85% of the annual runoff volume is captured.
- Basin sized so that the entire water quality volume is infiltrated within 48 hours.
- Vegetation establishment on the basin floor may help reduce the clogging rate.
- Determine soil type (consider RCS soil type ‘A, B or C’ only) from mapping and consult USDA soil survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil should not have more than 30% clay or more than 40% of clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.
- Groundwater separation should be at least 3 m from the basin invert to the measured ground water elevation. There is concern at the state and regional levels of the impact on groundwater quality from infiltrated runoff, especially when the separation between groundwater and the surface is small.
- Location away from buildings, slopes and highway pavement (greater than 6 m) and wells and bridge structures (greater than 30 m). Sites constructed of fill, having a base flow or with a slope greater than 15% should not be considered.
- Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.

Additional Design Guidelines

- Basin Sizing - The required water quality volume is determined by local regulations or sufficient to capture 85% of the annual runoff.
- Provide pretreatment if sediment loading is a maintenance concern for the basin.
- Include energy dissipation in the inlet design for the basins. Avoid designs that include a permanent pool to reduce opportunity for standing water and associated vector problems.

Maintenance:

Regular maintenance is critical to the successful operation of infiltration basins. Historically, infiltration basins have had a poor track record. In one study conducted in Prince George's County, Maryland (Galli, 1992), all of the infiltration basins investigated clogged within 2 years. This trend may not be the same in soils with high infiltration rates. A study of 23 infiltration basins in the Pacific Northwest showed better long-term performance in an area with highly permeable soils (Hilding, 1996). In this study, few of the infiltration basins had failed after 10 years.

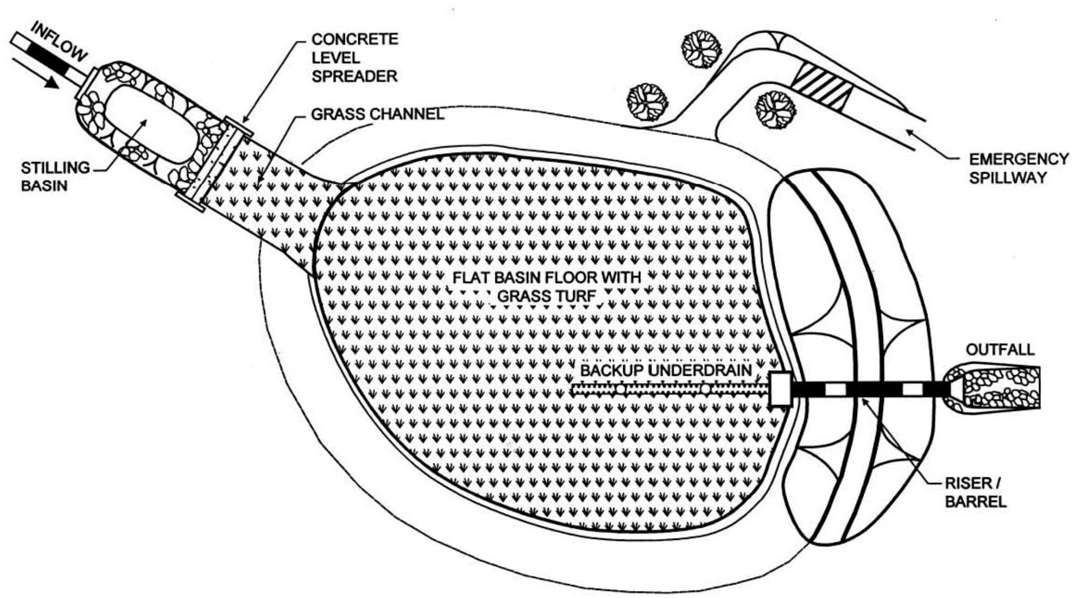
Maintenance Requirements

- Inspections and maintenance to ensure that water infiltrates into the subsurface completely (recommended infiltration rate of 72 hours or less) and that vegetation is carefully managed to prevent creating mosquito and other vector habitats.

- Observe drain time for the design storm after completion or modification of the facility to confirm that the desired drain time has been obtained.

- Schedule semiannual inspections for beginning and end of the wet season to identify potential problems such as erosion of the basin side slopes and invert, standing water, trash and debris, and sediment accumulation.
- Remove accumulated trash and debris in the basin at the start and end of the wet season.
- Inspect for standing water at the end of the wet season.
- Trim vegetation at the beginning and end of the wet season to prevent establishment of woody vegetation and for aesthetic and vector reasons.
- Remove accumulated sediment and regrade when the accumulated sediment volume exceeds 10% of the basin.
- If erosion is occurring within the basin, revegetate immediately and stabilize with an erosion control mulch or mat until vegetation cover is established.
- To avoid reversing soil development, scarification or other disturbance should only be performed when there are actual signs of clogging, rather than on a routine basis. Always remove deposited sediments before scarification, and use a hand-guided rotary tiller, if possible, or a disc harrow pulled by a very light tractor.

Schematic: Infiltration Basin:



PLAN VIEW

Resources

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Infiltration Trench

Description: An infiltration trench is a long, narrow, rock-filled trench with no outlet that receives stormwater runoff and is more appropriate in mountainous terrain than an infiltration basin. Runoff is stored in the void space between the stones and infiltrates through the bottom and into the soil matrix. Infiltration trenches perform well for removal of fine sediment and associated pollutants. Pretreatment using buffer strips, swales, or detention basins is important for limiting amounts of coarse sediment entering the trench which can clog and render the trench ineffective.

Image: CABMPhandbook

Design Considerations	**Potential Applications**
• **Follow infiltration system guidelines** • Continuously perforated pipe set at a minimum slope in a stone filled, level bottomed trench • Limited in width (3 to 8 feet) and depth of stone (6 feet max, recommended) • Trench is wrapped in nonwoven geotextile (top, sides, and bottom) • Placed on uncompacted soils	Residential: Yes Commercial: Yes Ultra Urban: Yes Industrial: Yes Retrofit: Yes Highway/Road: Yes
	Stormwater Functions Volume Reduction: Medium Recharge: High Peak Control: Medium
	Water Quality Functions TSS: 85% TP: 85% NO3: 30%

Advantages:

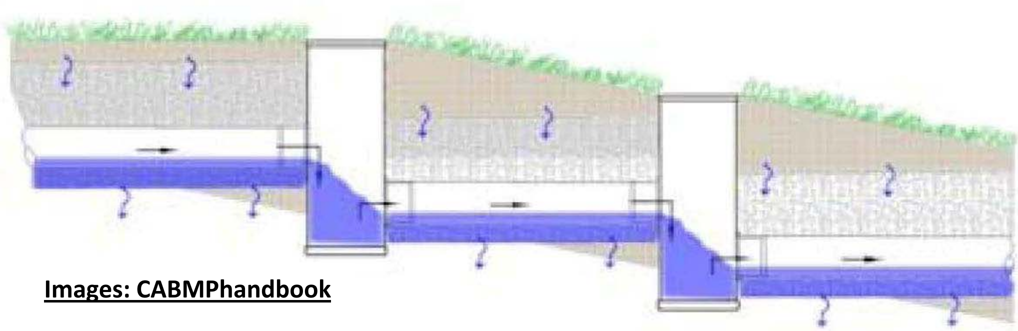
- Provides 100% reduction in the load discharged to surface waters.
- An important benefit of infiltration trenches is the approximation of pre-development hydrology during which a significant portion of the average annual rainfall runoff is infiltrated rather than flushed directly to creeks.
- If the water quality volume is adequately sized, infiltration trenches can be useful for providing control of channel forming (erosion) and high frequency (generally less than the 2-year) flood events.
- As an underground BMP, trenches are unobtrusive and have little impact of site aesthetics.

Limitations:

- This BMP has a high failure rate if soil and subsurface conditions are not suitable.
- May not be appropriate for industrial sites or locations where spills may occur.
- The maximum contributing area to an individual infiltration practice should generally be less than 5 acres.
- Infiltration basins require a minimum soil infiltration rate of 0.5 inches/hour, not appropriate at sites with Hydrologic Soil Types C and D.
- If infiltration rates exceed 2.4 inches/hour, then the runoff should be fully treated prior to infiltration to protect groundwater quality.
- Not suitable on fill sites or steep slopes.
- Risk of groundwater contamination in very coarse soils.
- Upstream drainage area must be completely stabilized before construction.
- Difficult to restore functioning of infiltration trenches once clogged.

Variations:

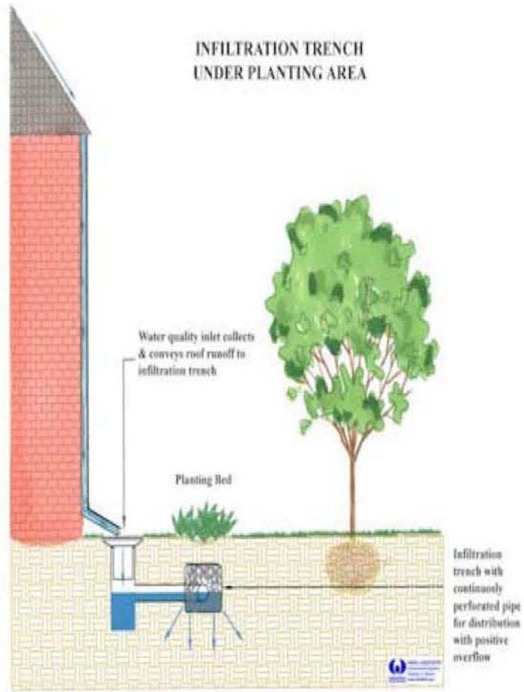
- Infiltration trenches generally have a vegetated (grassed) or gravel surface. Infiltration trenches also may be located alongside or adjacent to roadways or impervious paved areas with proper design. The subsurface drainage direction should be to the downhill side (away from subbase of pavement), or located lower than the impervious subbase layer. Proper measures should be taken to prevent water infiltrating into the subbase of impervious pavement.
- Infiltration trenches may also be located down a mild slope by "stepping" the sections between control structures as shown in the Figure below. A level or nearly level bottom is recommended for even distribution.



Images: CABMPhandbook

Applications:

- **Connection of Roof Leaders:** Roof leaders may be connected to infiltration trenches. Roof runoff generally has lower sediment levels and often is ideally suited for discharge through an infiltration trench. A cleanout with sediment sump should be provided between the building and infiltration trench.



- **Connection of Inlets:** Catch basins, inlets and area drains may be connected to infiltration trenches, however sediment and debris removal should be addressed. Structures should include a sediment trap area below the invert of the pipe for solids and debris. In areas of high traffic or areas where excessive sediment, litter, and other similar materials may be generated, a water quality insert or other pretreatment device is needed.

- **In Combination with Vegetative Filters:** An infiltration trench may be preceded by or used in combination with a vegetative filter, grassed swale, or other vegetative element used to reduce sediment levels from areas such as high traffic roadways. Design should ensure proper functioning of vegetative system.

Design Considerations:

Performance

Infiltration trenches eliminate the discharge of the water quality volume to surface receiving waters and consequently can be considered to have 100% removal of all pollutants within this volume. Transport of some of these constituents to groundwater is likely, although the attenuation in the soil and subsurface layers will be substantial for many constituents.

The stone aggregate should be washed to remove dirt and fines before placement in the trench. The addition of organic material and loam to the trench subsoil may enhance metals removal through adsorption.

Siting Criteria

The use of infiltration trenches may be limited by a number of factors, including type of native soils, climate, and location of groundwater table. Site characteristics, such as excessive slope of the drainage area, fine-grained soil types, and proximate location of the water table and bedrock, may preclude the use of infiltration trenches. Generally, infiltration trenches are not suitable for areas with relatively impermeable soils containing clay and silt or in areas with fill.

As with any infiltration BMP, the potential for groundwater contamination must be carefully considered. The infiltration trench is not suitable for sites that use or store chemicals or hazardous materials unless hazardous and toxic materials are prevented from entering the trench. In these areas, other BMPs that do not allow interaction with the groundwater should be considered. Extensive site investigation must be undertaken early in the site planning process to establish site suitability for an infiltration trench.

Longevity can be increased by careful geotechnical evaluation prior to construction and by designing and implementing an inspection and maintenance plan. Soil infiltration rates and the water table depth should be evaluated to ensure that conditions are satisfactory for proper operation of an infiltration trench. Pretreatment structures, such as a vegetated buffer strip or water quality inlet, can increase longevity by removing sediments, hydrocarbons, and other materials that may clog the trench. Regular maintenance, including the replacement of clogged aggregate, will also increase the effectiveness and life of the trench.

Evaluation of the viability of a particular site is the same as for infiltration basins and includes:

- Determine soil type (consider RCS soil type ‘A, B or C’ only) from mapping and consult USDA soil survey tables to review other parameters such as the amount of silt and clay, presence of a restrictive layer or seasonal high water table, and estimated permeability. The soil should not have more than 30 percent clay or more than 40 percent of clay and silt combined. Eliminate sites that are clearly unsuitable for infiltration.
- Groundwater separation should be at least 3 m from the basin invert to the measured ground water elevation. There is concern at the state and regional levels of the impact on groundwater quality from infiltrated runoff, especially when the separation between groundwater and the surface is small.
- Location away from buildings, slopes and highway pavement (greater than 6 m) and wells and bridge structures (greater than 30 m). Sites constructed of fill, having a base flow or with a slope greater than 15 percent should not be considered.
- Ensure that adequate head is available to operate flow splitter structures (to allow the basin to be offline) without ponding in the splitter structure or creating backwater upstream of the splitter.
- Base flow should not be present in the tributary watershed.

Maintenance:

- Catch basins and inlets should be inspected and maintained to retain efficiency.
- The vegetation along the surface of the infiltration trench should be maintained in good condition, and any bare spots revegetated as soon as possible.
- Vehicles should not be parked or driven on a vegetated infiltration trench, and care should be taken to avoid excessive compaction by mowers.

Schematic: Infiltration Trench

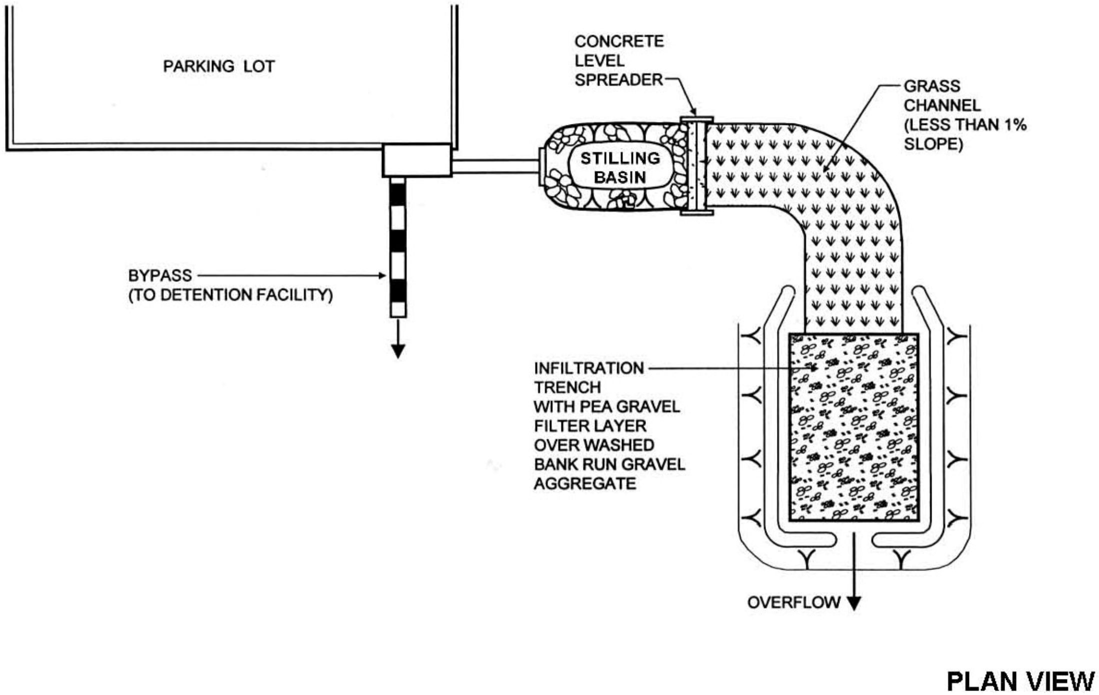


Image: CABMPhandbook.

Resources

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Catalog of stormwater BMPs for Idaho cities and counties, 2005, retrieved February 4, 2009, from Idaho Department of Environmental Quality Website: http://www.deq.state.id.us/water/data_reports/storm_water/catalog/index.cfm

Permeable Pavement Systems

Description:
Permeable paving systems allow infiltration of stormwater while providing void spaces to provide infiltration of runoff into their underlying engineered porous material and then into native soils. Permeable paving systems can preserve natural drainage patterns, enhance groundwater recharge and soil moisture, and can help establish and maintain roadside vegetation.

Image: Colorado Stormwater Assoc.

Design Considerations	**Potential Applications**
• Provide peak rate and volume control • Water quality and quantity are not always addressed • Short duration storage; rapid restoration of primary uses • Minimize safety risks, potential property damage, and user inconvenience • Emergency overflows • Maximum ponding depths • Flow control structures • Adequate surface slope to outlet	Residential: Limited Commercial: Yes Ultra Urban: Yes Industrial: Yes Retrofit: Yes Highway/Road: Limited **Stormwater Functions** Volume Reduction: Medium Recharge: Medium Peak Control: Medium Water Quality: Medium **Water Quality Functions** TSS: 85% TP: 85% NO3: 30%

Advantages:

- Permeable pavements reduce runoff volume while providing treatment.
- They are unobtrusive resulting in a high level of acceptability
- They provide retention, maximize infiltration by minimizing impervious land coverage.

Limitations:

- Permeable pavement can become clogged when not installed or maintained properly. However, this is countered by the ease with which small areas of paving can be cleaned or replaced.
- Permeable surfaces are currently not considered suitable for roads with high traffic speeds and heavy axle loads because of the risks associated with failure.
- When using unlined, infiltration systems, there is some risk of contaminating groundwater, depending on soil conditions and aquifer susceptibility. However, this risk is likely to be small because the areas drained tend to have inherently low pollutant loadings.
- The use of permeable pavement is restricted to gentle slopes.
- Porous block paving has a higher risk of abrasion and damage than solid blocks.

Variations:

Porous Asphalt, Colorado Stormater Assoc.

Pervious Paver, Colorado Stormater Assoc.

Pervious Concrete and Asphalt: Similar to conventional asphalt and concrete in structure and form, except that the fines (sand and finer material) have been removed. The top lifts are thicker than traditional pavements to provide the required stability and typically installed over layers of open graded aggregate.

Permeable pavers are modular systems with pervious joint space openings that allow water to seep through. Runoff permeated through is either detained in an underlying open graded aggregate bed, infiltrated into the underlying soil, or both.

Permeable Interlocking Concrete Pavers

Applications:

Pervious concrete and porous asphalt are ideal for light to medium duty applications such as residential access roads, residential street parking lanes, parking lot stalls, overflow parking areas, utility access, sidewalks, bike paths, maintenance walkways/trails, residential driveways, stopping lanes on divided highways, and patios.

Permeable pavers are designed to bear heavy loads and are well suited for industrial and commercial parking lots, utility access, residential access roads, driveways, and walkways.

Design Considerations:

- Avoid installing in high traffic or high speed areas
- Slopes should be flat or very gentle (less than 5 percent)
- Use a single size grading to provide open spaces in the gravel sub-base
- Erosion and sediment introduction from surrounding areas must be strictly controlled during and after construction to prevent clogging of void spaces in base material and permeable surface
- Install porous asphalt and pervious concrete towards the end of construction activities to minimize sediment problems
- Permeable pavers should be the last element installed during construction or redevelpment
- During construction, do not allow construction or heavy vehicles to cross excavated recharge areas of completed pervious pavement
- Consult local sources for specific mix design and installation guidance.
- Consult local quarries for screened and washed fractured aggregate that meets “filter criteria”.

Maintenance:

- Prevention is the best maintenance.
- The overall maintenance goal is to avoid clogging of the void spaces.
- Inspect pervious pavements several times during the first few storms to insure proper infiltration and drainage. After the first year, inspect only once a year
- Clean with a vacuum-type street cleaner a minimum of twice a year (before and after winter)
- Hand held pressure washer can be effective for cleaning the void spaces of small areas
- Joints between pavers may require occasional weed suppression.
- Pavers can be individually removed and replaced when utility work is needed.
- Replace aggregate material in grid systems as needed

Schematic:

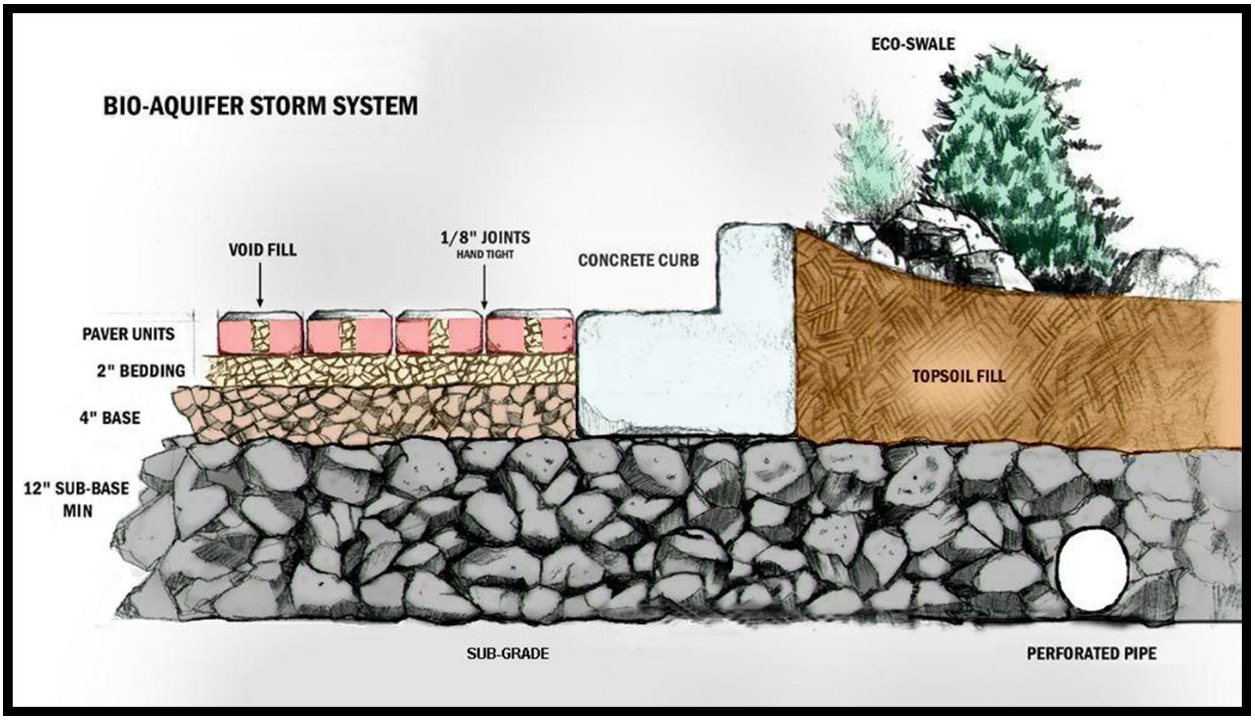

Image: Advanced Pavement Technologies

Resources

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Subsurface Infiltration Bed

Image: Pennsylvania stormwater

Description: A subsurface infiltration bed generally consists of a vegetated, highly pervious soil media underlain by a uniformly graded aggregate bed for infiltration of stormwater runoff. Subsurface infiltration beds are ideally suited for expansive, generally flat open spaces, such as lawns, meadows and playfields, located downhill from nearby impervious areas. Subsurface infiltration beds can be stepped or terraced down sloping terrain provided that the base of the bed remains level. Stormwater runoff from nearby impervious areas (including rooftops, parking lots, roads, walkways, etc.) can be conveyed to the subsurface storage media, where it is then distributed via a network of perforated piping or chambered systems.

Design Considerations • Maintain a minimum 2-foot separation to bedrock and seasonally high water table, provide distributed infiltration area (5:1 impervious area to infiltration area – maximum), site on natural, uncompacted soils with acceptable infiltration capacity • Beds filled with stone (or alternative) as needed to increase void space • Wrapped in nonwoven geotextile • Level or nearly level bed bottoms • Provide positive stormwater overflow from beds • Protect from sedimentation during construction • Provide perforated pipe network along bed bottom for distribution as necessary • Open-graded, clean stone with minimum 40% void space • Do not place bed bottom on compacted fill • Allow 2 ft. buffer between bed bottom and seasonal high groundwater table and 2 ft. for bedrock	**Potential Applications** Residential: Yes Commercial: Yes Ultra Urban: Yes Industrial: Yes Retrofit: Yes Highway/Road: Limited **Stormwater Functions** Volume Reduction: High Recharge: High Peak Control: Med./High Water Quality: High **Water Quality Functions** TSS: 85% TP: 85% NO3: 30%

Advantages:

- Subsurface infiltration features can stand-alone as significant stormwater runoff volume, rate, and quality control practices.
- Systems can maintain aquifer recharge, while preserving or creating valuable open space and habitat areas.
- Have the added benefit of functioning year-round, given that the infiltration surface is typically below the frost line.
- Eliminate the possibilities of mud, mosquitoes and safety hazards sometimes perceived to be associated with ephemeral surface drainage.

Limitations:

Subsurface infiltration beds have a high failure rate if soil and subsurface conditions are not suitable.

Variations:

Subsurface infiltration is generally employed for temporary storage and infiltration of runoff in subsurface storage media. However, in some cases, runoff may be temporarily stored on the surface (to depths less than 6 inches) to enhance volume capacity of the system.

Applications:

- **Connection of Roof Leaders:** Runoff from nearby roofs may be directly conveyed to subsurface beds via roof leader connections to perforated piping. Roof runoff generally has relatively low sediment levels, making it ideally suited for connection to an infiltration bed. However, cleanout with a sediment sump are still recommended between the building and infiltration bed.

- **Connection of Inlets:** Catch basins, inlets, and area drains may be connected to subsurface infiltration beds. However, sediment and debris removal should be provided. Storm structures should therefore include sediment trap areas below the inverts of discharge pipes to trap solids and debris. In areas of high traffic or excessive generation of sediment, litter, and other similar materials, a water quality insert or other pretreatment devices may be needed.

- **Under Recreational Fields:** Subsurface infiltration is very well suited below playfields and other recreational areas. Special consideration should be given to the engineered soil mix in those cases.

- **Under Open Spaces:** Subsurface infiltration is also appropriate in either existing or proposed open space areas. Ideally, these areas are vegetated with native grasses or vegetation to enhance side aesthetics and landscaping. Aside from occasional clean-outs or outlet structures, subsurface infiltration systems are essentially hidden stromwater management features making them ideal for open space locations. Deep-restricted open spaces are especially desirable because such locations minimize the chance that subsurface infiltration systems will be disturbed or disrupted accidentally in the future.

Design Considerations:

Performance

- Soil investigation and infiltration testing is needed.
- Guidelines for infiltration systems should be met

Siting Criteria

- The overall site should be evaluated for potential subsurface infiltration areas early in the design process, as effective design required consideration of existing site characteristics (topography, natural features/drainage ways, soils geology, etc.)

Maintenance:

Subsurface infiltration is generally less maintenance intensive than other practices of it type. Generally speaking, vegetation associated with subsurface infiltration practices are less substantial practices such as vegetated swale and bioretention and therefore require less maintenance. Maintenance activities required for the subsurface bed are similar to those of any infiltration system and focus on regular sediment and debris removal.

Maintenance Requirements

- All catch basin inlets should be inspected and cleaned at least 2 times per year
- The overlying vegetation of subsurface infiltration areas should be maintained in good condition, and any bare spots revegetated as soon as possible.
- Vehicular access on subsurface infiltration areas should be prohibited, and care should be taken to avoid excessive compaction by mowers. If access is needed, use of permeable, turf reinforcement should be considered.

Schematic:

Image: Pennsylvania

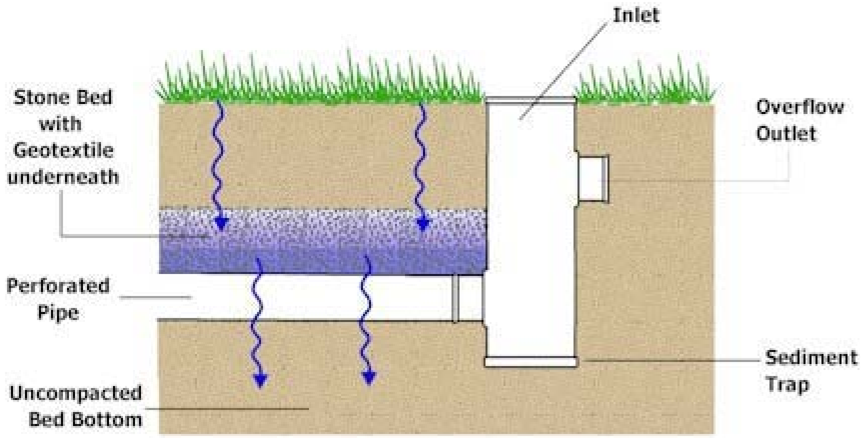

Image: Pennsylvania BMP Manual

Resources:

Pennsylvania stormwater best management practices manual, chapter 6 – Structural BMPs, 2006, retrieved February 12, 2009, from Pennsylvania Department of Environmental Protection, Bureau of Watershed Management Website: http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=|.

California Stormwater Quality Association, 2003, New development and redevelopment handbook, retrieved February 4, 2009, from the California Stormwater Best Management Practice Handbooks Website: http://www.cabmphandbooks.com/Development.asp.

APPENDIX D

DETENTION BASED BEST MANAGEMENT PRACTICES

Note: The information provided in this appendix is compiled from numerous national sources. The general design considerations and guidance are intended to help the user, but should not be used to supersede any local design guidance document that is based on local conditions and site specific experience.

Stormwater Wetland

Description: Stormwater wetlands or constructed wetlands are structural practices similar to wet ponds that incorporate wetland plants into the design. As stormwater runoff flows through the wetland, pollutant removal is achieved through settling and biological uptake within the practice. Wetlands are among the most effective stormwater practices in terms of pollutant removal and they also offer aesthetic and habitat value. Although natural wetlands can sometimes be used to treat stormwater runoff that has been properly pretreated, stormwater wetlands are fundamentally different from natural wetland systems in that they are designed specifically for the purpose of treating stormwater runoff, and typically have less biodiversity than natural wetlands in terms of both plant and animal life (National Menu of Stormwater BMPs).

Image: Urban Drainage and Flood

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Design Considerations

- Adequate drainage area (usually 5 to 10 acres minimum) or proof of sustained base flow
- Will require an investigation of water supply to ensure a sustained baseflow to maintain the wetland
- Maintenance of permanent water surface
- Multiple vegetative growth zones through varying depths
- Robust and diverse vegetation
- Sediment collection and removal
- Adjustable permanent pool and dewatering mechanism
- Maintenance – periodic sediment removal from the forebay and vegetation maintenance

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Potential Applications

Residential: Yes
Commercial: Yes
Ultra Urban: Limited
Industrial: Yes
Retrofit: Yes
Highway/Road: Yes

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Stormwater Functions

Volume Reduction: Low
Recharge: Low
Peak Control: High
Water Quality: High

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Water Quality Functions

TSS: 85%
TP: 85%
NO3: 30%

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Advantages:

- If properly designed, constructed and maintained, wet basins can provide substantial wildlife and wetlands habitat.
- Due to the presence of the permanent wet pool, properly designed and maintained wet
- basins can provide significant water quality improvement while retaining stormwater for infiltration.
- Widespread application with sufficient capture volume can provide significant control of channel erosion and enlargement from the increase of impervious cover in a watershed.

Limitations:

- There may be some aesthetic concerns about a facility that looks "swampy."
- Some concern about safety when constructed where there is public access.
- Mosquito breeding is likely to occur in wetlands, but can be kept below nuisance levels with natural predators favoring this habitat.
- Cannot be placed on steep unstable slopes.
- Require a relatively large footprint.
- Water temperature within the wetland may lead to warming downstream.
- Principle limitation in mountain communities is the ability to site where baseflow is available. In many cases, this may require consultation with the US Army Corps of Engineers and State regulators before any activities are initiated.

Variations:

- Constructed wetlands can be designed as either online or offline facilities.
- Can be used in series with other BMPs.
- A pond/wetland system combines a wet pond and a constructed wetland.
- A "pocket wetland" is a smaller feature serving smaller drainage areas provided there is baseflow to the wetland.

Applications:

A constructed wetland can provide multiple benefits. Beyond retention of stormwater by slowing runoff and allowing for enhanced infiltration, the feature can provide aesthetic, pollution control, and wildlife habitat.

Design Considerations:

Performance

- Adequate drainage area (usually 5 to 10 acres minimum) or proof of sustained base flow - will require investigation of water supply to ensure a sustained baseflow to maintain the wetland
- Goal should be maintenance of permanent water surface.
- Multiple vegetative growth zones through varying depths important so soil is important.
- Provides robust and diverse vegetation.
- Requires sediment collection and removal.
- Requires adjustable permanent pool and dewatering mechanism.
- The area required is generally 3 to 5 percent of the drainage area.

Siting Criteria

- In mountain communities, should be sited where baseflow can contribute to permanent or semi-permanent pool level.
- Loamy soils are required for plant establishment.
- A longitudinal slope of near zero is also required.

Additional Design Guidelines

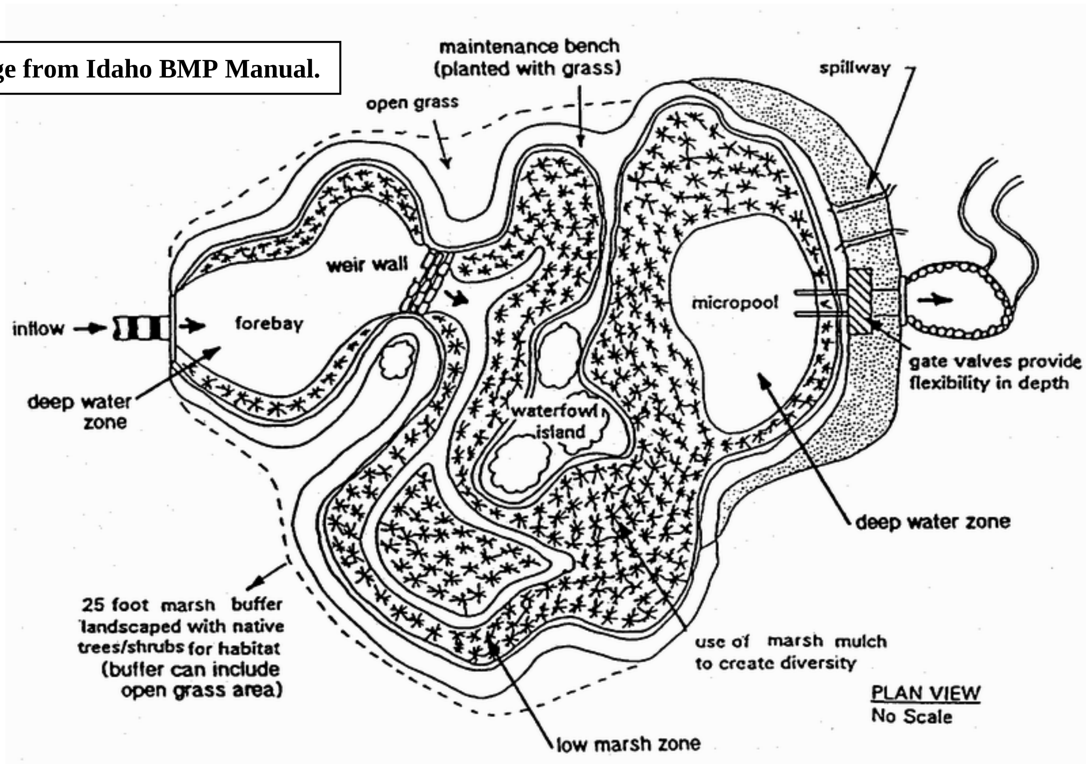
- Preferable length to width ratio of 3:1; flow pathway should be maximized.
- Constructed wetlands should feature a forebay at all major inflow points to capture coarse sediment, preventing excessive sediment accumulation in the larger wetland and minizing erosion by inflow.
- General guideline is that the vegetation zones should be half high marsh (up to 6 inches deep) and the other half low marsh (6 to 18 inches deep), as varying depth zones ijmprove plant diversity and health. The open water zone should be about 35 to 40 percent of the area.
- Outlet control devices should be in open water 4-6 feet deep and generally consist of multistage structures with pipes, orifices, or weirs for flow control.
- All areas deeper than 4 feet should have two safety benches, each 4-6 feet wide, 1-1.5 and 2 – 2.5 feet below the water surface.

Maintenance:

Vegetation should be inspected and maintained. Once established, constructed wetlands require little maintenance.

Schematic:

Image from Idaho BMP Manual.



Resources:

Urban Drainage & Flood Control District, 2008, Urban storm drainage criteria manual volume 3, retrieved February 4, 2008, from http://www.udfcd.org/downloads/down_critmanual.htm.

California Stormwater Quality Association, 2003, New development and redevelopment handbook, retrieved February 4, 2009, from the California Stormwater Best Management Practice Handbooks Website: http://www.cabmphandbooks.com/Development.asp.

Catalog of stormwater BMPs for Idaho cities and counties, 2005, retrieved February 4, 2009, from Idaho Department of Environmental Quality Website: http://www.deq.state.id.us/water/data_reports/storm_water/catalog/index.cfm

United States Environmental Protection Agency, 1999, Preliminary Data Summary of Urban Stormwater Best Management Practices, retrieved February 4, 2009, from United States Environmental Protection Agency, Effluent Limitation Guidelines Website: http://www.epa.gov/guide/stormwater/.

National Menu of Stormwater Best Management Practices, retrieved February 9, 2009, from United States Environmental Protection Agency, Stormwater Program Website: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm.

Dry Extended Detention Basin

Description:
Extended detention basins are also known as dry ponds or sedimentation basins. They are designed to detain the volume of storm water runoff produced by frequently-occurring storm events. The outlet structure is specifically designed to detain the water quality volume for a minimum of 48 hours to allow fine-grained sediments and associated pollutants to settle. Storm water is slowly released by the outlet structure and pollutants are primarily removed through physical settling as the water stands in the basin. Infiltration into underlying soils can substantially improve pollutant removal effectiveness. Extended detention basins are typically unlined and unless sited in clayey soils, at least some infiltration also typically occurs. Between storm events, the basin is typically dry. Extended detention basins can also be used for flood control by including additional flood detention storage.

Image: CASFM

Design Considerations	Potential Applications
• Evaluation of the device chosen should be balanced with cost • Hydraulic capacity controls effectiveness • Ideal in combination with other BMPs • Regular maintenance is necessary including periodic sediment removal • Detention basins are relatively easy and inexpensive to construct and operate	Residential: Yes Commercial: Yes Ultra Urban: Yes Industrial: Yes Retrofit: Yes Highway/Road: Yes **Stormwater Functions** Volume Reduction: Low Recharge: None Peak Control: High Water Quality: Low **Water Quality Functions** TSS: 60% TP: 40% NO3: 20%

Advantages:
- Extended detention basins are relatively easy and inexpensive to construct and operate.
- Basins can be incorporated into other land uses.
- Basins can accommodate large drainage areas – up to 50 acres.

Limitations:
- Construction in mountainous terrain likely requires excavation with conveyance to the feature reducing use of land for higher values.
- Because of the large in-put volumes involved, the risk of contamination to groundwater, while small, is real.
- Periodic immersion of vegetation in the basin requires careful selection of species.
- Geotechnical report should indicate permeable soils beneath the basin.
- Designs must take into consideration the possibility of overflows.
- If not landscaped and maintained properly, dry basins can detract from the value of surrounding homes

Applications:
Suitable for large areas - can be used in areas of
- Low density residential development
- Industrial development
- Commercial development
- Urban areas.

Design Considerations:
Performance
- Should be able to predict flow volumes and design of an outlet structure to drain slowly enough to provide infiltration but rapidly enough to empty for the next storm.
- The facility's drawdown time should be regulated by an orifice or weir. In general, the outflow structure should have a trash rack or other acceptable means of preventing clogging at the entrance to the outflow pipes.
- Length to width ration should be at least 2:1 where feasible while 3:1 is preferable. In general, the distance between inlets and outlets should be maximized to facilitate infiltration.
- Basin depths optimally range from 2 to 5 feet.
- Inlet design should include energy dissipation to reduce resuspension of accumulated sediment.
- A maintenance ramp and perimeter access should be included in the design to facilitate access to the basin for maintenance.

Siting Criteria
- The basin can be designed to accommodate other uses, such as passive recreation and wildlife habitat. The area will not be well suited for active recreation, such as picnic areas and playing fields.
- Generally used on sites draining a minimum area of 5 acres.
- Can be used with almost all soils and geology.

Additional Design Guidelines

- Facility should be designed to treat 85% of the runoff volume of the basin.
- Side slopes should be 3:1 or flatter for grass slopes.
- The State Engineer's regulatory requirements for larger dam embankments and storage volumes must be followed whenever regulatory height and/or volume thresholds are exceeded.

Maintenance:

- Sediment and trash removal, vegetation management and routine mowing are required.
- Basins accessible to populated areas should incorporate all possible safety precautions, including shallow side slopes and warning signs.

Schematic:

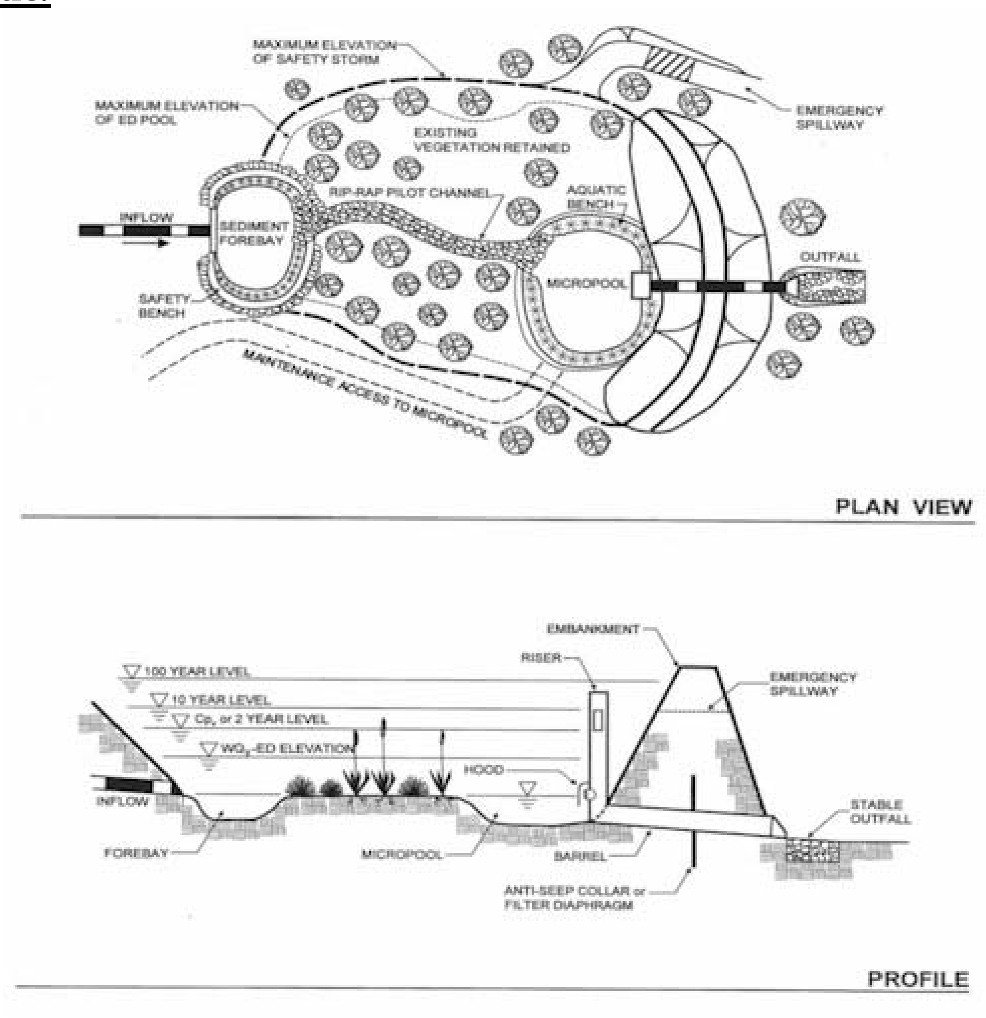


Image: Pennsylvania BMP Manual

Resources:

Brown, W. and T. Schueler, 1997, The Economics of Stormwater BMPs in the Mid-Atlantic Region; Chesapeake Research Consortium, Edgewater MD, Center for Watershed Protection.

Catalog of stormwater BMPs for Idaho cities and counties, 2005, retrieved February 4, 2009, from Idaho Department of Environmental Quality Website: http://www.deq.state.id.us/water/data_reports/storm_water/catalog/index.cfm

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Urban Drainage & Flood Control District, 2008, Urban storm drainage criteria manual volume 3, retrieved February 4, 2008, from http://www.udfcd.org/downloads/down_critmanual.htm.

Kenney/Jenks Consultants, 2007, The Truckee Meadows regional stormwater quality management program low impact development handbook, retrieved February 9, 2009, from http://www.cityofreno.com/index.aspx?page=366.

City of Portland, 2008, Stormwater Management Manual, retrieved February 10, 2009, from Portland Bureau of Environmental Services Website: http://www.portlandonline.com/BES/index.cfm?c=47952&.

United States Environmental Protection Agency, 1999, Preliminary Data Summary of Urban Stormwater Best Management Practices, retrieved February 4, 2009, from United States Environmental Protection Agency, Effluent Limitation Guidelines Website: http://www.epa.gov/guide/stormwater/.

Wet Pond

Description: Wet ponds (a.k.a. stormwater ponds, retention ponds, wet extended detention ponds) are constructed basins that have a permanent pool of water throughout the year (or at least throughout the wet season) and differ from constructed wetlands primarily in having a greater average depth. Ponds treat incoming stormwater runoff by settling and biological uptake. Infiltration of stormwater runoff is enhanced by residence time. Wet ponds are among the most widely used stormwater practices but may require base flow in an arid to semi-arid environment such as Colorado.

Image: California Stormwater BMPs

Design Considerations	**Potential Applications**
• Adequate drainage area (usually 5 to 10 acres minimum) or proof of sustained baseflow • Natural high groundwater table • Maintenance of permanent water surface • Should have at least 2:1 length to width ratio • Robust and diverse vegetation surrounding wet pond • Forebay for sediment collection and removal • Dewatering mechanism	Residential: Yes Commercial: Yes Ultra Urban: Yes Industrial: Yes Retrofit: Yes Highway/Road: Yes **Stormwater Functions** Volume Reduction: Low Recharge: Low Peak Control: High Water Quality: Medium **Water Quality Functions** TSS: 70% TP: 60% NO3: 30%

Advantages:

- If properly designed, constructed and maintained, wet basins can provide substantial
- wildlife and wetlands habitat.
- Due to the presence of the permanent wet pool, properly designed and maintained wet
- basins can provide significant water quality improvement while retaining stormwater for infiltration.
- Ponds are often viewed as a public amenity when integrated into the landscape or a park setting.

Limitations:

- Same siting and land utilization concerns as extended detention basins.
- Some concern about safety when constructed where there is public access.
- Need for base flow or supplemental water if water level is to be maintained.
- Principle limitation in mountain communities is the ability to site where baseflow is available. In many cases, this may require consultation with the US Army Corps of Engineers and State regulators before any activities are initiated.
- Effluent water may raise the temperature of cold-water streams below.

Variations:

- The wet extended detention pond combines the dry extended detention pond and the wet pond. During storm events, water is detained above the permanent pool.
- The water reuse pond is one used for irrigation water.

Applications:

Wet ponds are widely applicable except in very arid areas.

Design Considerations:

Performance

- Wet Ponds should be able to receive and retain enough flow from rain, runoff, and groundwater to ensure long-term viability. A permanent water surface in the deeper areas of the WP should be maintained during all but the driest periods. In Colorado, this almost certainly will require base flow.
- Organic soils should be used for shallow areas within Wet Ponds. Organic soils can serve as a sink for pollutants and generally have high water holding capacities. They will also facilitate plant growth and propagation and may hinder invasion of undesirable species.
- The area required for a WP is generally 1 to 3 percent of its drainage area.
- Constructed wet ponds should feature a forebay at all major inflow points to capture coarse sediment, prevent excessive sediment accumulation in the pond and to minimize erosion by inflow.
- Outlet control devices should be in open water 4-6 feet deep and generally consist of multistage structures with pipes, orifices, or weirs for flow control.
- Capture volume should be determined by local conditions.]
- To facilitate maintenance, road access should be provided along the edge of the pond.

Siting Criteria
A high water table is important.

Additional Design Guidelines

- To enhance habitat value, visual aesthetics, water temperature and pond health, a buffer (recommended 25 feet) should be added from the maximum water surface elevation. The buffer should be planted with trees, shrubs, and native ground covers. Existing trees within the buffer should be preserved.
- Permanent access should be provided to the forebay, outlet and embankment areas.
- A non-clogging outlet such as the reverse-slope pipe or a weir outlet with a trash rack should be installed in the pond.
- Local and state regulations should be consulted on pond sizing, as the pond should contain the permanent pool plus runoff from storm events without overtopping or eroding and creating a threat to health and safety.

Maintenance:

- Sediments should be removed from the forebay every five years or so.
- Sediments should be removed from the pond every 5 to 10 years, depending on sedimentation regime.

Schematic:

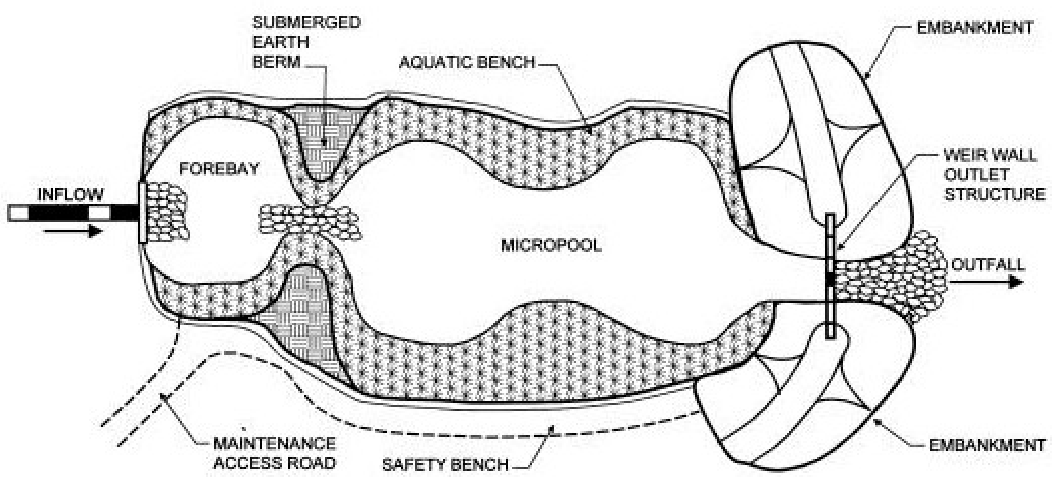


Image: Pennsylvania BMP Manual

Resources:

Brown, W. and T. Schueler, 1997, The Economics of Stormwater BMPs in the Mid-Atlantic Region; Chesapeake Research Consortium, Edgewater MD, Center for Watershed Protection.

Catalog of stormwater BMPs for Idaho cities and counties, 2005, retrieved February 4, 2009, from Idaho Department of Environmental Quality Website: http://www.deq.state.id.us/water/data_reports/storm_water/catalog/index.cfm

California Stormwater Quality Association, 2003, New development and redevelopment handbook, retrieved February 4, 2009, from the California Stormwater Best Management Practice Handbooks Website: http://www.cabmphandbooks.com/Development.asp.

Urban Drainage & Flood Control District, 2008, Urban storm drainage criteria manual volume 3, retrieved February 4, 2008, from http://www.udfcd.org/downloads/down_critmanual.htm.

Kenney/Jenks Consultants, 2007, The Truckee Meadows regional stormwater quality management program low impact development handbook, retrieved February 9, 2009, from http://www.cityofreno.com/index.aspx?page=366.

City of Portland, 2008, Stormwater Management Manual, retrieved February 10, 2009, from Portland Bureau of Environmental Services Website: http://www.portlandonline.com/BES/index.cfm?c=47952&.

National Menu of Stormwater Best Management Practices, retrieved February 9, 2009, from United States Environmental Protection Agency, Stormwater Program Website: http://cfpub.epa.gov/npdes/stormwater/menuofbmps/index.cfm.

United States Environmental Protection Agency, 1999, Preliminary Data Summary of Urban Stormwater Best Management Practices, retrieved February 4, 2009, from United States Environmental Protection Agency, Effluent Limitation Guidelines Website: http://www.epa.gov/guide/stormwater/.

APPENDIX E

FLOW CONTROL BASED BEST MANAGEMENT PRACTICE

Note: The information provided in this appendix is compiled from numerous national sources. The general design considerations and guidance are intended to help the user, but should not be used to supersede any local design guidance document that is based on local conditions and site specific experience.

Level Spreader

Description: A level spreader receives concentrated flow from channels, outlet structures, or other conveyance structures and converts them to sheet flow. Although a level spreader by itself is not considered an infiltration device, it improves the efficiency of other structures and facilities, such as vegetated swales, filter strips, and other infiltration devices, which are dependent on sheet flow to operate properly.

Design Considerations	Potential Applications
• Level spreaders must be level. • Specific site conditions must be considered prior to design; level spreaders are not usable in areas with easily erodible soils and/or little vegetation. • Level spreaders should safely diffuse at least the 10-year storm peak rate; bypassed flows should be stabilized in an effective manner. • Length of level spreaders is dependent upon influent flow rate, pipe diameter (if applicable) and downhill cover type. • It is always easier to keep flow distributed than to redistribute it after it is concentrated; multiple outfalls/level spreaders are preferable to a single one.	Residential: Yes Commercial: Yes Ultra Urban: Limited Industrial: Yes Retrofit: Yes Highway/Road: Yes **Stormwater Functions** Volume Reduction: Low Recharge: Low Peak Control: Low Water Quality: Low **Water Quality Functions** TSS: 20% TP: 10% NO3: 5% (ref: PA Manual)

Advantages:

- Level spreaders reduce the erosive energy of concentrated flows by distributing runoff as sheet flow to stabilized vegetative surfaces.
- Level spreaders promote infiltration and improved water quality.

Limitations:

- Provides no drainage or flood control.
- Level spreaders can't be used in areas with easily erodible soils and/or little vegetation.

Variations:

- One type of level spreader is design to evenly distribute flow entering another BMP, such as a filter strip, infiltration basin, or vegetated swale. These include concrete sills or lips, curbs, or earthen berms.
- A second type of level spreader – the outflow type – is intended to reduce the erosive force of low to moderate flows while enhancing natural infiltration opportunities. These include a level perforated pipe in a shallow aggregate trench (similar to an infiltration trench), and earthen berms.

Applications:

- Level spreaders are used in wide, level areas where concentrated runoff occurs.
- The site should be undisturbed soil stabilized by vegetation.
- Disturbed soil is subject to more erosion and may settle.
- If the spreader is not absolutely level, flows will concentrate at the low point and may produce erosion channels.
- Flows to the spreader should be relatively free of sediment or the spreader will be quickly overwhelmed by sediment and lose its effectiveness.

Design Considerations:

Performance

- The spreader should be constructed absolutely level.
- Height of the spreader is based on depth of design flow, allowing for sediment and debris deposition.
- Specific site conditions, such as topography, vegetative cover, soil, and geologic conditions must be considered prior to design.
- Level spreaders should safely diffuse at least the 10-year storm peak rate; bypassed flows should be stabilized in an appropriate manner.
- Length of level spreader is dependent on influent flow rate and downhill cover type.
- Multiple outfalls/level spreaders are preferable to a single outfall/level spreader, as it is always easier to keep flow distributed than to redistribute it after it is concentrated.

Siting Criteria

Level spreaders should not be located in constructed fill.

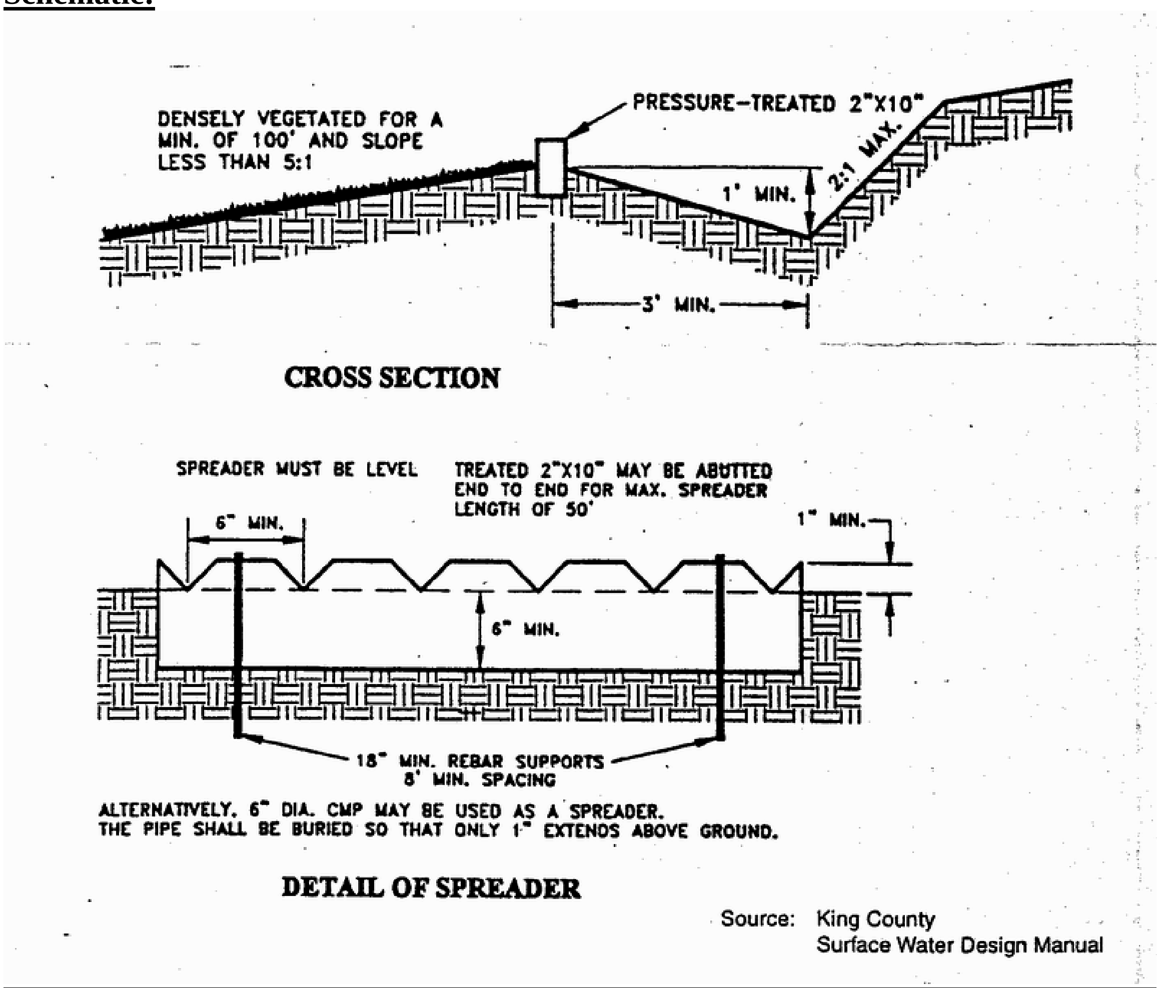
Additional Design Guidelines

- The slope leading to the level spreader should be less than 1% for at least 20 feet immediately upstream in order to keep velocities less than 2 feet per
- second at the spreader during the 10-year storm event.
- Slope of the outlet from the spreader should be 6% or less.

Maintenance:

- The level spreader should be regularly inspected, including after large rainfall events. Inspection should note and repair any erosion and low spots in spreader.
- Sediment should be removed from behind spreader.
- The receiving land area should be immediately restored to design conditions after any disturbance. Vegetated areas should be seeded and blanketed.

Schematic:



Resources:

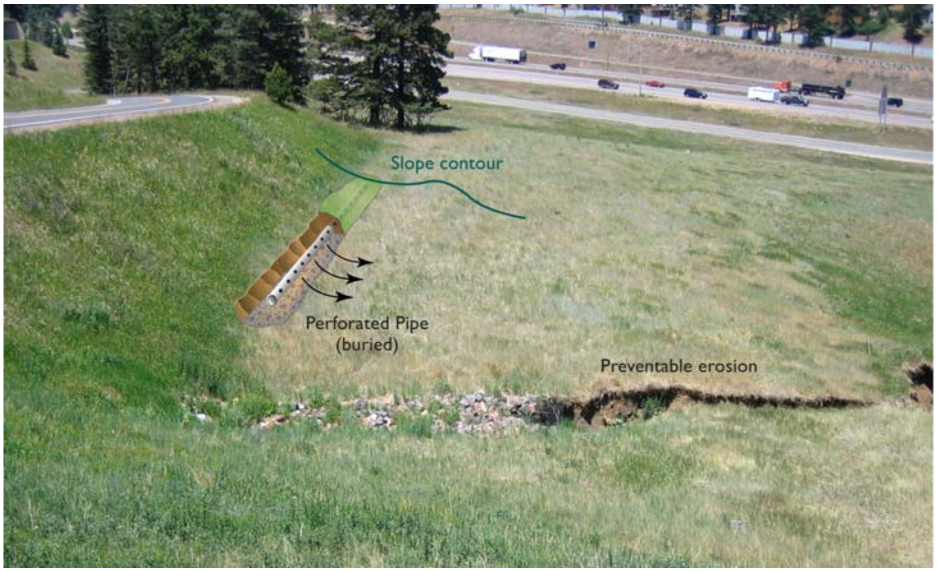
Catalog of stormwater BMPs for Idaho cities and counties, 2005, retrieved February 4, 2009, from Idaho Department of Environmental Quality Website: http://www.deq.state.id.us/water/data_reports/storm_water/catalog/index.cfm

Pennsylvania Pennsylvania stormwater best management practices manual, chapter 6 – Structural BMPs, 2006, retrieved May 22, 2009, from Pennsylvania Department of Environmental Protection, Bureau of Watershed Management Website: : http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=|.

Urban Waterways, Level Spreaders: Ovewrview, Design, and Mainenance; North Carolina State University Cooperative Extension Service, retrieved 22 May 2009, Website: http://www.bae.ncsu.edu/stormwater/PublicationFiles/LevelSpreaders2006.pdf

Infiltration Berm

Description: An infiltration berm is a mound of earth composed of soil and stone placed along the contour of a relatively gentle slope. The practice may be constructed by excavating upslope material to create a depression and storage area above a berm or earth dike. Stormwater flowing downslope to the drpressed area filters through the berm to maintain sheetflow. Infiltration berms should be used in conjunction with practices requiring sheetflow (e.g. sheetflow to buffers) or in a series on steeper slopes to prevent flow concentration. Also referred to as "retentive grading."



Design Considerations	**Potential Applications**
• Maintain minimum 2-foot separation to bedrock and seasonally high water table, provide distributed infiltration area (5:1 inpervious area to infiltration area • Site on natural uncompacted soils with good infiltration capacity • Berms should be less than 2 ft height • Thick turf grass or meadow vegetation should be used • Grass should not be mowed low	Residential: Yes Commercial: Yes Ultra Urban: Limited Industrial: Yes Retrofit: Yes Highway/Road: Yes **Stormwater Functions** Volume Reduction: Med/Low Recharge: Low Peak Control: Medium Water Quality: Med/High **Water Quality Functions** TSS: 60% TP: 50% NO3: 40%

Advantages:

- Wide application in mountain terrain along roadways and on residential lots.
- Berms are utilized to create noise or wind barriers, separate land uses, screen undesirable views or enhance or emphasize landscape designs. They are often used in conjunction with recreational features, such as pathways through woodlands.
- Infiltration berms can provide runoff rate and volume control, depending upon design variations such as height, on soil permeability rates, vegetative cover and slope.
- Infiltration berms are ideal for mitigating runoff from relatively small impervious areas with limited adjacent open space (such as roads or small parking lots).

Limitations:

- **Space:** The presence of large trees may limit the use of infiltration berms along a hillside. Berms may be threaded carefully along the contour of wooded slopes in order to avoid disturbing existing vegetation.

- **Topography:** Infiltration berms are not recommended on slopes greater than 10% to prevent erosion at the upstream toe of the berm.

- **Soils:** Infiltration berms shall not be installed on slopes where soils have low shear strength (or identified as "slope prone" or "landslide prone").

- **Drainage Area:** The drainage area should be small enough to prevent flow concentration upslope of the berm.

Variations:

- Meadow/woodland infiltration berms utilize vegetative covers, with meadow or woodland vegetation reducing maintenance requirements. Chare should be taken during construction to ensure minimum disturbance to existing vegetation, especially tree roots.
- Diversion berms consisting of compacted earth ridges are usually constructed across a slope in series to intercept runoff, providing greater opportunity for infiltration.
- Berms can be used within constructed wetland systems to create elongated flow pathways with a variety of water depths.

Applications:

- Infiltration berms may be used on gently sloping areas in residential, commercial, open space, or wooded land use conditions. They must be installed along the contour in order to perform effectively. The purpose of this practice is to augment natural stormwater drainage functions in the landscape by promoting sheetflow and dissipating runoff velocities.
- Diversion berms can be used to help protect steeply sloping areas from erosion, diverting concentrated discharge from a developed area away from the sloped

area. Berms may be installed in series down the slope to retain flow and to spread it out along multiple level berms to discourage concentrated flow.

<u>Design Considerations:</u>

Performance

- Stormwater runoff from impervious areas is intercepted by infiltration berms that are placed on the contour to prevent erosive, concentrated runoff patterns. Runoff flows to a depressed area immediately above the berm where velocities are reduced, stormwater flows through the berm, and sheetflows downslope. Stormwater discharges greater than the two-year, 24 hour design storm should flow over the crest of the berm at non-erosive velocities.

- Subsurface soils shall be uncompacted and may need to be scarified in order to encourage infiltration. A good topsoil should be used. To reduce cost, the top foot should be a high quality topsoil with well-drained soil making up the remainder of the berm. Gravel is not recommended in the layers directly beneath the topsoil because of the tendency of the soil to wash through the gravel.

- Berms should be planted with native meadow vegetation, shrubs, and trees.

Siting Criteria

- Infiltration berms may be used on gently sloping areas in residential, commercial, open space, or wooded land use conditions. They must be installed along the contour in order to perform effectively. The purpose of this practice is to augment natural stormwater drainage functions in the landscape by promoting sheetflow and dissipating runoff velocities.

Additional Design Guidelines

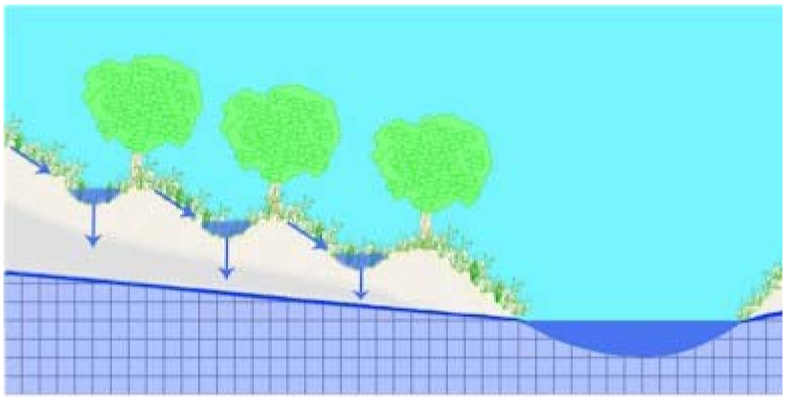
- A maximum berm height of 24 inches is recommended to prevent excessive ponding.
- Side slopes should be shallow; a ratio of 3:1 is recommended for mowed berms.
- When used in series along a slope, the elevation at the downstream toe of each berm should be the same elevation as the crest of the next berm downslope.
- The berm should be graded so that a concave shape is provided at the upgradient toe.
- The crest of the berm should be asymmetric in shape and should be two feet wide.
- Velocities for the two-year, 24-hour storm event should be non-erosive.

<u>Maintenance:</u>

- Berms should be inspected regularly to ensure ponding water does not create nuisance conditions.
- Signs of concentrated flow and other surface erosion should be repaired to promote sheetflow.

- A dense mat of vegetation should be present at all times. Vegetation should be replaced as needed.
- When infiltration berms are incorporated in a system with other practices, the Maintenance Criteria for that practice should be used.

Schematic:



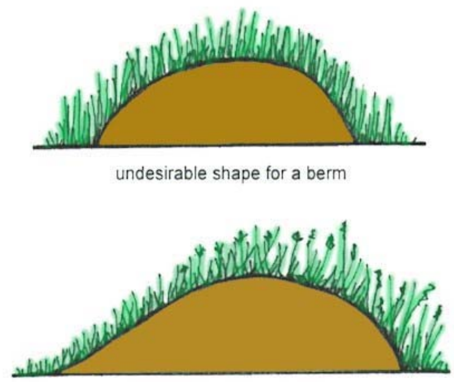


Image from Pennsylvania BMP Manual

Resources:

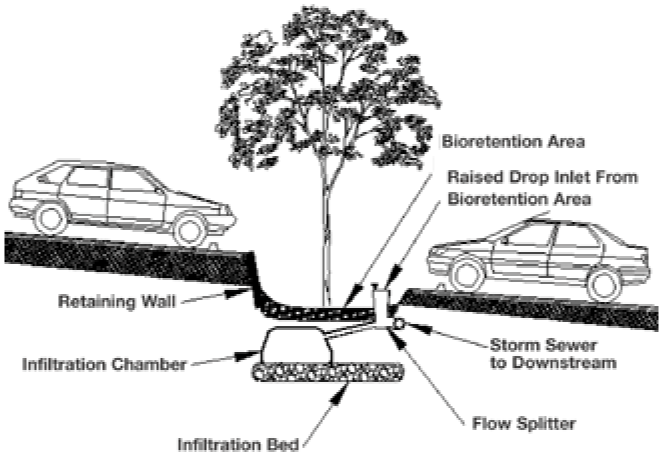
Catalog of stormwater BMPs for Idaho cities and counties, 2005, retrieved February 4, 2009, from Idaho Department of Environmental Quality Website: http://www.deq.state.id.us/water/data_reports/storm_water/catalog/index.cfm

Pennsylvania Pennsylvania stormwater best management practices manual, chapter 6 – Structural BMPs, 2006, retrieved May 22, 2009, from Pennsylvania Department of Environmental Protection, Bureau of Watershed Management Website: : http://www.depweb.state.pa.us/watershedmgmt/cwp/view.asp?a=1437&q=529063&watershedmgmtNav=|.

Split Flow Systems

Description:

The split-flow concept is a relatively new technique designed to achieve predevelopment stormwater flow rates, quality, and volumes that are not met by other detention methods.



standard BMPs fail to adequately address stormwater peak flow rates during precipitation events because those flow rates must be incorporated into the design of each individual structural BMP. As described in the name, the flow is divided with part of the structure address smaller flow volumes and the remainder accommodating larger storm flows.

Illustration: from Stuart Echols, Stormwater, 2002

Design Considerations	**Potential Applications**
• **Rainfall is divided into three separate portions – one for evapotranspiration, one for infiltration, and one for "natural" runoff.** • **Flow is apportioned - "split" - into bioretention, recharge and discharge.** • **Individual impervious features can have a split-flow facility to treat that run-off.**	Residential: Yes Commercial: Yes Ultra Urban: Yes Industrial: Yes Retrofit: Yes Highway/Road: Yes
	Stormwater Functions Volume Reduction: High Recharge: Med. Peak Control: Med. Water Quality: Med./High
	Water Quality Functions TSS: TP: NO3: No figures available.

Advantages:

- Flood reduction.
- Reduced costs.
- Reduced peak storm flow durations.
- Enhanced infiltration to groundwater.
- Avoids safety issues created by detention basins.
- The "first flush," generally the most polluted portion, is treated.

Limitations:

- Alternative sediment and erosion control methods are needed during construction since temporary sediment basins will not later be converted to detention basins.
- Split-flow systems should not be activated until a site is completely stabilized.

Variations:

None noted at this stage.

Applications:

- Sites using split-flow should incorporate open space immediately down slope from impervious areas.
- Works with other infiltration BMPs, such as pervious pavement, dry wells,infiltration trenches.

Design Considerations:

Performance

- Hydrologic calculations must be performed to size the system for pre-development peak flow.
- Individual small flow splitters should be installed for each paved surface to distribute runoff.
- Runoff is first directed into a bioretention facility where the "first flush" is retained by mulch, soil and plant material.
- Excess runoff is filtered through the bioretention facility, then through proportional splitters and divided into separate volumes for diversion and bypass depending upon desired infiltration and runoff rates.

Siting Criteria

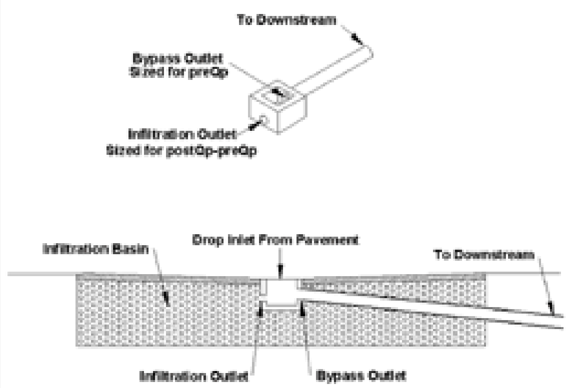
Split-flow systems have been shown to work on sites with impervious coverage up to 80%.

Additional Design Guidelines

- Individual proportional flow splitter should be designed according to the runoff of the impervious area it treats.
- In a development, runoff from each impervious feature – building, parking lot, etc, - can be directed to an individually designed split-flow facility.

Maintenance:
Maintenance requirements are the same as for the individual components of the system.

Schematic:



Drawing from Stuart Echols, Stormwater, 2002

Resources:

Echols, S.P. 2002. Split-flow method: Introduction of a new stormwater strategy. *Stormwater -The Journal for Surface Water Quality Professionals*, 3(5): 16-32.

Echols, S. P., 2003, Developing Split-Flow Stormwater Systems; retrieved 28 May 2009; www.epa.gov/nps/natlstormwater03/11Echols.pdf