Chapter 2 - Delineation and Characterization of the Boulder Creek Watershed and its Sub-Watersheds

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Abstract

The 1160-km^2 Boulder Creek Watershed was delineated from Digital Elevation Model data using automated techniques. The resulting watershed boundary compares favorably to previous watershed maps and contributing areas estimated for U.S. Geological Survey streamgaging stations. The automation of watershed delineation allows for easy replication.

The Boulder Creek Watershed was divided into eight sub-watersheds for a more detailed accounting of the watershed's topography, land cover, soils, and precipitation. The four steeper mountain sub-watersheds are primarily forested with shallow soils, while the four foothill/plains sub-watersheds have grassland, urban, and agricultural land cover with deeper soils. Topography, as measured by mean slope and topographic index, $\ln(a/\tan\beta)$, is more highly variable among foothills/plains sub-watersheds than among mountain sub-watersheds. Estimated precipitation varies from over 1000 mm near the Continental Divide to 330 mm near the watershed outlet.

INTRODUCTION

Purpose and Scope

In this chapter, the Boulder Creek Watershed is delineated from the surrounding landscape using a digital extraction method. This watershed delineation is fundamental in distinguishing between areas that contribute solutes and water to Boulder Creek and those that contribute constituents to neighboring drainages. Consequently, watershed boundaries are critical in understanding the development of water chemistry. Fundamental watershed properties such as basin area and relief are defined for Boulder Creek and each of its major tributaries.

The watershed boundaries are also used to characterize the topographic, soil, land cover, and precipitation for each Boulder Creek sub-watershed. These data can be used to interpret the chemical effects of non-point sources. They also could guide future sampling or experimental design by defining topographic, soil, and land use end-members.

Basics of Automated Watershed Delineation

Delineation of the Boulder Creek Watershed was completed with the computer program RiverTools^{TM} (Peckham, 1998; Rivix Limited Liability Co., 2001). The use of an automated method and readily-available topographic data allows the procedure to be easily replicated. RiverTools^{TM} uses Digital Elevation Model (DEM) data to predict water flow paths and determine the location of drainage basin boundaries. Digital Elevation Models are gridded representations of the earth's surface with each grid cell assigned an elevation, and have the advantage of being continuous, regular surfaces, so quantities like surface slope and aspect can be readily calculated. Digital Elevation Models are available at several scales; the DEM of the Boulder area displayed in figure 2.1 is a 1:24,000 scale grid with 900-m^2 cells. This is the finest resolution that is publicly available for both the Boulder Creek Watershed and the entire United States.

With a tunnel and canal transporting water into the Boulder Creek Watershed, the actual watershed contributing area extends beyond the topographic boundaries demarcated here. Defining the actual watershed would involve

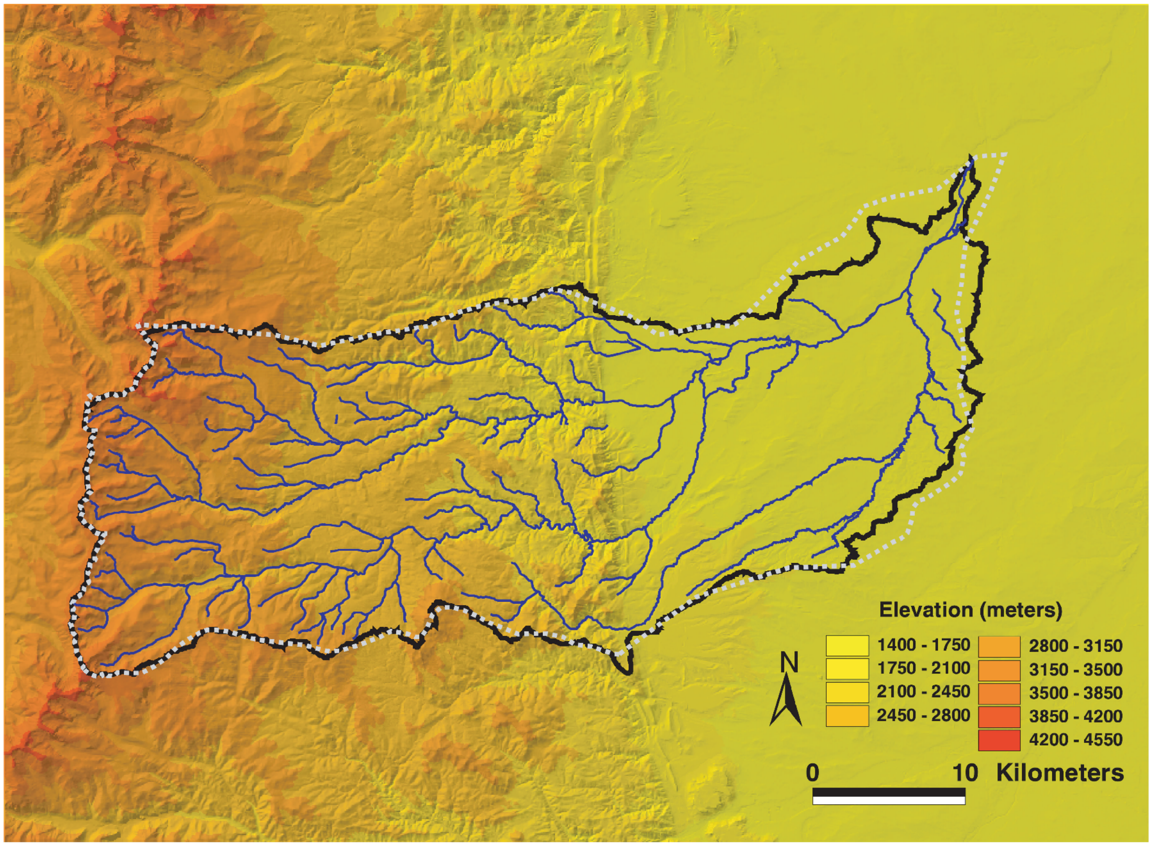


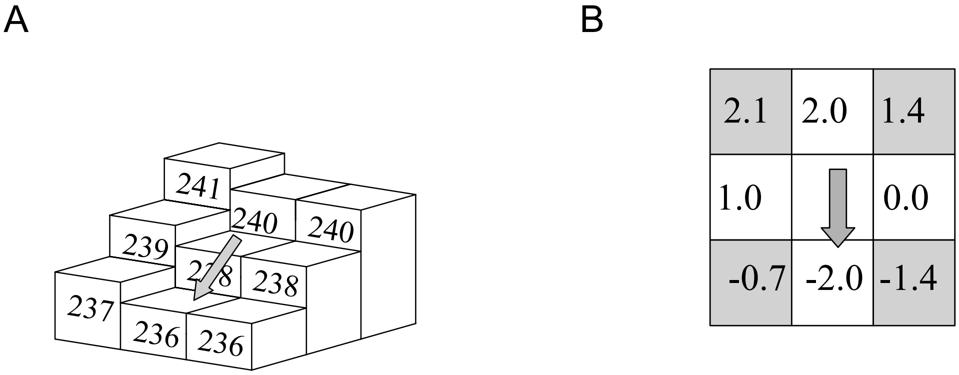
Figure 2.1. Digital elevation model of the Boulder Creek Watershed and surrounding area. (Watershed boundary determined by this study is shown by solid black line; boundary given by the Colorado Division of Water Resources, 2002, is shown by white dashed line; surface waters from U.S. Geological Survey, 2002)

defining the contributing areas for the imported waters and is beyond the scope of this study. This analysis is restricted to the natural topographic boundary of the watershed.

Defining watershed boundaries strictly by topography has disadvantages. Because the boundaries are based on the surficial expression of the landscape, groundwater flow paths or drainage ditches that are inconsistent with topography may be misrepresented. Further, in areas where topography is subtle, it may be difficult to calculate the direction of flow because of limited resolution in the DEM. The method of topographic extraction used in RiverTools^{TM} is most accurate in areas where the DEM properly resolves the topographic gradient, basically in regions where topography is steep.

The key assumption in using DEM data to extract the watershed boundary is that water falling as precipitation flows downhill, along the topographic gradient. The flow direction algorithm employed here checks the eight surrounding cells for the steepest slope between cell centers. As the flow direction is into only one of the surrounding cells, this algorithm is known as the single-direction or D-8 algorithm (Jenson and Domingue, 1988). Because of its simplicity and effectiveness, the D-8 algorithm is applied in most DEM analysis software packages.

Figure 2.2 shows how the D-8 algorithm works. The block diagram on the left of the figure shows the relative elevations of a theoretical nine-cell DEM neighborhood. The plan-view to the right shows the calculated slopes from the center cells, assuming that each DEM cell has an area of



2.1	2.0	1.4
1.0	↓	0.0
-0.7	-2.0	-1.4

Figure 2.2. Diagram showing the principle behind the single-direction or D-8 flow algorithm of Jenson and Domingue (1988): (A) Theoretical eight-cell neighborhood (numbers indicate elevation of cell); (B) Computed slopes between center cell and each of the surrounding eight cells. Water follows the largest negative (downhill) slope to the south.

1 m^2. As the highest negative (downhill) slope is in the south direction, water "flows" south.

The D-8 algorithm (fig. 2.2) assumes that there are elevation differences between adjacent cells. However, DEMs typically have flat regions (known as flats) where a neighborhood of cells has the identical elevation. For these situations, the imposed gradient method of Garbrecht and Martz (1997) was used. This method builds up artificial topography over flats that direct flow away from surrounding higher topography to the lowest cell adjacent to the flat region. The imposed gradient method tends to create a single channel centered in broad flat valleys. This algorithm has been implemented and improved upon in RiverTools^{TM} as the flat resolution method called "imposed gradient plus" (Rivix Limited Liability Co., 2001).

After the flow direction is defined for every cell in a DEM, the watershed outlet is selected. For Boulder Creek, this point has been defined as the confluence of Saint Vrain Creek and Boulder Creek. RiverTools^{TM} then determines all of the cells that "flow" into the outlet cell. This routine is continued recursively until all of the cells in a watershed have been identified. The watershed boundary is then defined as the interface between cells that are included in the watershed and adjacent cells that are not.

Characterization of Morphologic Parameters

Given a watershed boundary, a wide range of basin variables can be defined from topography. In the present case, three parameters of interest are slope, aspect, and the topographic index, $\ln(a/\tan\beta)$ (Beven and Kirkby, 1979; Wolock, 1993; Quinn and others, 1995).

The concept of $\ln(a/\tan\beta)$ is illustrated in figure 2.3, which it adapted from Wolock (1993). A represents the upslope area that contributes water to the calculation point. The calculation point is a specific grid cell. The contributing area, A, (in units of length^2) is divided by the grid cell contour length, c, to get a normalized area, a, which has units of length. For $\ln(a/\tan\beta)$ calculations using the D-8 algorithm, c can have one of two values. If water flows to a cell that is in a cardinal direction (north, south, east, or west), then the contour length is the length of the grid cell, or in the case of 900-m^2 cells, 30 m. If water flows diagonally, then the contour length is the length of the grid cell multiplied by the square root of two. This contour-length convention allows for topographic convergence due to diagonal flow to be represented in the index. Tanβ represents the local slope gradient. For a complete derivation of the $\ln(a/\tan\beta)$ index the reader is referred to Beven and Kirkby (1979) and Wolock (1993).

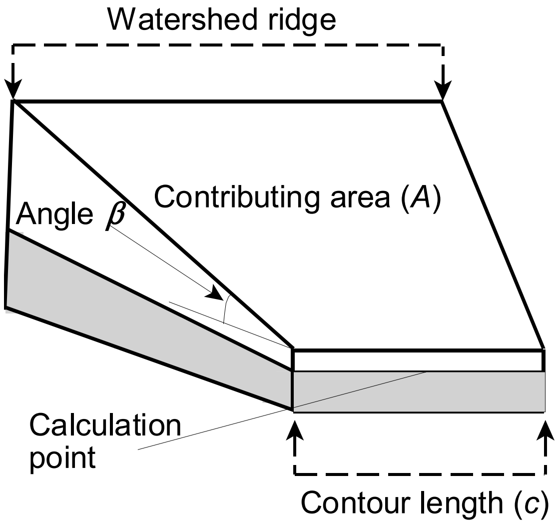


Figure 2.3. Diagram illustrating the concept of ln(a/tanβ), after Wolock (1993).

As the distance from a ridgeline increases, the source area increases in size, and there is more groundwater flowing through a given grid cell. If the slope is large, then water in the subsurface moves more rapidly. Conversely, areas that have a low slope serve as areas where flow is limited. If these two concepts are enjoined, the landscape is partitioned between areas near ridges with high gradients and low contributing areas (low ln(a/tanβ) regions) and areas in valleys with low gradients and high contributing areas (high ln(a/tanβ) regions). Given similar soil types throughout the landscape, high ln(a/tanβ) cells are likely to be inundated because there is a large volume of water moving through them at low velocities. Conversely, areas near ridges are often dry.

The topographic index is a relative measure of the proximity of the water table to the surface and has been used to predict the relative interaction of water with the shallow nutrient and mineral soil (Robson and others, 1992). The acid neutralizing capacity of watersheds also has been positively correlated with the mean value of ln(a/tanβ) in watersheds in the northeast United States (Wolock and others, 1989, 1990).

Other characteristics that may be important to chemical analysis include stream network properties such as drainage density, stream length, and stream order. Automatically defining these properties over an entire river basin requires channel DEM cells to be distinguished from other DEM cells in the watershed. One method for differentiating stream channels is to define a minimum contributing area for channel formation, and all cells with contributing areas greater than that threshold are labeled “stream” cells. In Boulder Creek, there is such diversity in lithology, climate, and soils that there are likely different thresholds for different regions of the watershed. Because the scope of this characterization is limited, there was no attempt to define channel network thresholds or examine stream network properties. Mapped channels from the 1:24,000 topographic maps and part of the U.S. Geological Survey (USGS) National Hydrography Dataset (USGS, 2002) are included in figure 2.1 for the reader’s benefit. These mapped channels represent larger perennial streams. Smaller-scale, ephemeral channels are often omitted from the mapped network.

Extracting Environmental Parameters

Three additional data sources were used to establish environmental conditions throughout the basin. For characterizing soil type, the States Geographic Soil Database (STATSGO) was queried. The STATSGO database is a digital summary of all of the U.S. Department of Agriculture (USDA) field soil surveys aggregated into soil association units. The STATSGO attributes that were queried are organic matter, calcium carbonate, and soil pH. A description of how to develop soil attribute maps from the STATSGO database is included in USDA (1994) and Bliss and Reybold (1989).

The second data source is the National Land Cover Data Set (NLCD; Vogelmann and others, 2001). This work summarizes the land use characterized by the LANDSAT satellite imagery. Land cover classes are defined by examining both winter (leaves-off) and summer (leaves-on) images. For Boulder County, the data set is based on satellite images over the period 1989-1994. These data provide a detailed (900-m^2 grid cell) analysis of land cover. Much of the basin, particularly the mountain regions, has similar land cover today to what is recorded in the NLCD. However, rampant growth and development east of the mountains make the data set less applicable in these areas.

The third data source is the PRISM (Parameter-elevation Regressions Independent Slopes Model) mean annual precipitation dataset that has been produced by the Oregon State Climate Center (Daly and others, 1994). This unique dataset interpolates between individual rain gages to create a gridded map of precipitation for the United States. One focus of PRISM is the estimation of rainfall variation in mountainous or hilly areas. This is achieved by using linear regression to interpolate between gages at different mountain elevations. These interpolations are done locally, so, for example, rainfall on the leeward and windward sides of a mountain range is distinguished.

These three data sets do not represent the only available data that could be used for analysis. Given a watershed boundary, other datasets produced by the USGS or other agencies or individuals could be queried and utilized to interpret chemical data. These datasets could include current and future land cover or higher-resolution soil coverages.

METHODS

The first step in this analysis was to piece together the requisite DEMs to delineate the Boulder Creek Watershed. To make sure the Boulder Creek Watershed could be fully defined, twenty 7.5-minute, 30-m cell DEMs were joined (table 2.1). DEMs were read into the Geographic Information System (GIS) Arc-Info™ and merged. The key Arc-Info commands for joining the DEMs were "Merge" which joins the DEMs and "Nibble" which fills in gaps between the joined grids. Gaps between adjacent DEMs are fairly common at the 7.5-minute resolution. Nibble uses linear interpolation to fill in topography between joined DEM sheets.

Table 2.1. List of digital elevation models used in deriving figure 2.1

Quadrangles completely or partially in Boulder Creek Watershed	
Boulder	Longmont
Black Hawk	Louisville
Central City	Monarch Lake
East Portal	Nederland
Eldorado Springs	Niwot
Empire	Ralston Buttes
Erie	Tungsten
Gold Hill	Ward
Lafayette	
Additional quadrangles included in figure 2.1	
Allenspark	Gowanda
Arvada	Hygiene
Commerce City	Isolation Peak
Eastlake	Lyons
Golden	Raymond

The aggregate DEM was imported as a binary grid into RiverTools™ for basin delineation. RiverTools™ was selected because it offers several algorithms for flow direction calculation. After the flow directions were defined, the basin outlet was chosen at the confluence of Boulder Creek and Saint Vrain Creek and the automated watershed delineation tool was applied. Aspect, slope and $\ln(a/\tan\beta)$ were also computed using RiverTools™. The basin boundary was exported to Arc-Info™ to "clip" the soil, land cover, and precipitation grids. After the polygons representing the soils were truncated at the basin boundary, derivative maps were created.

To examine variability in watershed characteristics, nine sub-watersheds were delineated (fig. 2.4, table 2.2): South Boulder Creek above Gross Reservoir; Middle Boulder Creek; North Boulder Creek; Fourmile Creek; South Boulder Creek below and including Gross Reservoir; Boulder Creek between the North and Middle Boulder Creek confluence and Coal Creek; Coal Creek; Rock Creek; and Boulder

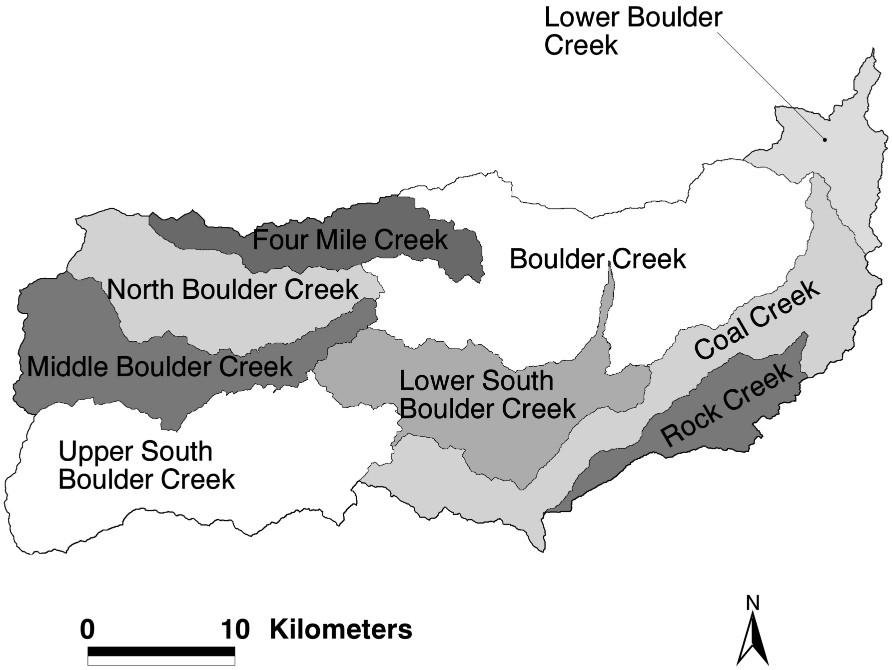


Figure 2.4. Map of sub-watersheds in the Boulder Creek Watershed.

Creek from its confluence with Coal Creek to the watershed outlet. The first four sub-watersheds listed are primarily mountain watersheds; the last five are foothills/plains watersheds. Because South Boulder Creek includes both mountain and plains areas, the watershed was divided to examine the differences between these two physiographic regions. All topographic and environmental data were clipped to these boundaries to determine the properties of different regions within the Boulder Creek Watershed.

RESULTS AND DISCUSSION

Basin Area and Relief

The Boulder Creek Watershed has a computed area of 1160 km^2 (447 mi^2) if the outlet point is defined at the confluence of Boulder Creek and Saint Vrain Creek (fig. 2.1). The watershed relief as measured from the highest point to the basin outlet is 2275 m. Thus, as one might expect with a mountain river basin, there is a dramatic change of relief over a relatively short river distance.

Validation of the RiverTools$^{\text{TM}}$-derived watershed boundary is difficult because there is no definitive map of the Boulder Creek Watershed boundary. One indication that the map is relatively accurate is that the stream network from the National Hydrography Dataset shown in figure 2.1 does not cross any derived watershed boundaries. The derived boundary does appear similar to other boundaries displayed in earlier reports (Muller Engineering Company, 1983; Naropa Institute, 1996) and is similar to the boundary of Boulder Creek Basin (Water Division 1, District 6) given by the Colorado Division of Water Resources (2002), shown as a white dashed line in figure 2.1. The Water District 6 boundary was originally mapped at a scale of 1:2,000,000, and has a watershed area of 1190.4 km^2. The fact that the two boundaries were mapped at different scales likely accounts for the disparity in the boundary shape near the watershed outlet. Because topography is subtle near the outlet on the eastern boundary, errors are

Table 2.2. List of characteristics for sub-watersheds of the Boulder Creek Watershed

[km^2, square kilometers; km, kilometers; mm, millimeters; kg, kilograms; standard deviations are in parentheses; Confl., confluence; N., North; Cr., Creek; M., Middle; S., South; organic matter from U.S. Department of Agriculture, 1994]

Sub-watershed	Watershed outlet	Drainage area (km^2)	Relief (km)	Mean elevation (km)	Precipi -tation (mm)	Mean slope (degrees)	Mean ln(*a*/tan)	Percent north-facing aspect	Organic matter (kg)
Boulder Cr. (entire)	Basin outlet	1160	2.63	2.29 (0.63)	526.2 (153.0)	11.1 (10.0)	7.1 (2.3)	56.1	15.4 (1.4)
Fourmile Cr.	Confl. with Boulder Cr.	68	1.81	2.49 (0.39)	533.0 (116.3)	17.9 (8.7)	6.1 (1.9)	39.6	14.9 (1.3)
N. Boulder Cr.	Confl. with M. Boulder Cr.	112	1.99	2.99 (0.40)	682.5 (174.6)	15.2 (9.5)	6.5 (1.9)	44.8	13.8 (1.2)
M. Boulder Cr.	Confl. with N. Boulder Cr.	115	1.93	3.04 (0.39)	697.8 (152.8)	16.8 (9.6)	6.4 (1.9)	48.4	13.8 (1.3)
S. Boulder Cr.	Confl. with Boulder Cr.	338	2.47	2.62 (0.48)	582.9 (120.8)	14.2 (9.1)	6.5 (2.1)	57.0	15.0 (1.3)
Lower S. Boulder Cr.	Confl. with Boulder Cr.	130	0.64	2.15 (0.30)	494.0 (356.7)	13.9 (10.3)	6.6 (2.3)	55.7	16.1 (0.3)
Upper S. Boulder Cr.	Inlet of Gross Reservoir	208	1.83	2.92 (0.30)	637.9 (122.8)	14.4 (8.3)	6.5 (1.9)	57.9	14.3 (1.2)
Coal Cr. (entire)	Confl. with Boulder Cr.	208	1.69	1.83 (0.36)	419.5 (71.8)	6.3 (7.8)	7.8 (2.3)	60.0	16.4 (0.4)
Coal Cr. (except Rock Cr.)	Confl. with Boulder Cr.	151	1.69	1.89 (0.40)	431.8 (79.7)	7.3 (8.8)	7.6 (2.4)	57.7	16.3 (0.4)
Rock Cr.	Confl. with Coal Cr.	57	0.56	1.69 (0.09)	387.0 (236.4)	3.7 (3.4)	8.2 (2.3)	65.1	16.6 (0.1)
Lower Boulder Cr.	Basin outlet	320	1.24	1.72 (0.02)	423.5 (54.7)	6.7 (9.3)	8.0 (2.5)	64.3	16.5 (0.2)
Lower Boulder Cr. above Coal Cr.	Confl. with Coal Cr.	269	1.20	1.76 (0.25)	437.8 (47.8)	7.6 (9.8)	7.7 (2.5)	63.6	16.4 (0.2)
Lower Boulder Cr. below Coal Cr.	Basin outlet	51	0.14	1.52 (0.20)	348.1 (4.9)	1.2 (1.1)	9.0 (1.9)	67.9	16.6 (0.1)

Table 2.3. Contributing areas calculated by this study and reported by the U.S. Geological Survey (USGS) for streamgaging stations (USGS, 2002)

[ID#, identification number; km^2, square kilometers; percent difference is expressed as (Area$_{study}$-Area$_{USGS}$)/Area$_{study}$.].

Streamgaging station (station ID#)	Area- this study (km^2)	Area- USGS reported (km^2)	Percent difference
Boulder Creek at mouth near Longmont, CO (06730500)	1160	1137	2.0
Boulder Creek at N 75th St NR Boulder, CO (06730200)	799	787	1.5
South Boulder Creek near Eldorado Springs, CO (06729500)	288	282	2.0
Boulder Creek at Orodell, CO (06727000)	260	264	-1.5
South Boulder Creek at Pinecliffe, CO (06729300)	193	188	2.6
South Boulder Creek near Rollinsville, CO (06729000)	113	111	1.8
Middle Boulder Creek at Nederland, CO (06725500)	95	94	1.1
Coal Creek near Louisville, CO (06730400)	84	71	15
Fourmile Creek at Orodell, CO (06727500)	67	62	7.5
Coal Creek near Plainview, CO (06730300)	39	39	0
North Boulder Creek at Silver Lake, CO (06726000)	23	23	0

possible in this region; this area might merit further analysis.

A second method for validating the method is comparing RiverTools^{TM}-derived area estimates to the contributing areas reported for USGS streamgaging stations. The USGS calculated contributing areas by measuring the areas directly from river basin maps of Colorado (Crowfoot and others, 2000). To compare the RiverTools^{TM}-derived areas with these values, we used coordinates provided by the USGS (USGS, 2002) to locate streamgaging station locations on the Boulder Creek Watershed DEM. The streamgage locations did not always lie exactly on the DEM-derived streams. In that case, the nearest stream point was selected as the streamgage location.

A comparison of derived and reported contributing areas for streamgaging stations is given in table 2.3. Most of the errors are below 3 percent, but two locations, Fourmile Creek at Orodell and Coal Creek at Louisville, have larger errors (7.5 and 15 percent, respectively). To examine whether our method or the USGS historical method was responsible for the discrepancy, we examined topographic maps of the watersheds. It appears that that the boundaries of these two watersheds derived from the DEM follow ridges on 1:24,000 topographic maps, indicating that the DEM-derived estimates are reliable.

The comparison between areas derived by DEM analysis and through other methods provides some verification of the DEM analysis algorithms. However, errors in the DEM-derived estimates are not necessarily due to algorithm choice but could be due to DEM construction. Mixon (2002) identified two types of DEM errors in the 1:24,000 DEMs, which he labeled “granularity” and “seams.” Seams are created when adjacent DEMs are joined and there are vertical discontinuities at the boundaries between the two DEMs. Granularity occurs when visible, east-west bands occur in the DEM data. Both types of errors occur in the DEM shown in figure 2.1. They do not appear to affect the position of the watershed boundary, but these errors may cause subtle differences in watershed delineation.

Variability in Topographic Parameters

Slope decreases markedly with the transition from mountains to plains. This decrease in slope is manifested as an increase in $\ln(a/\tan\beta)$. The lower-elevation sub-watersheds have larger variability in $\ln(a/\tan\beta)$ (table 2.2). This occurs because the lower sub-watersheds, with the exception of Rock Creek, straddle topographically distinct foothills and plains. These sub-watersheds have terrace features (for example, Table Mesa and Rocky Flats) which are extremely flat but have steep slopes at their boundaries.

Another important observation can be made by comparing the mean and standard deviations of $\ln(a/\tan\beta)$ for three mountain sub-watersheds: North Boulder Creek, South Boulder Creek above Gross Reservoir, and Middle Boulder Creek. The mean value is approximately 6.5 m with a standard deviation of approximately 1.9 m. As $\ln(a/\tan\beta)$ is a good measure of the landscape structure (Woods and Sivapalan, 1997), this correlation indicates that the topography in these three sub-watersheds is remarkably similar.

There is variability in the percentage of north-facing (slopes with an aspect of 270 to 90 degrees) and south-facing slopes in the various sub-watersheds in the Boulder Creek Watershed. Generally, sub-watersheds in the south are bending north and therefore have up to 65 percent north-facing slopes. Sub-watersheds in the north are bending slightly south and therefore have less than 50 percent north-facing slopes. These differences in aspect may affect the soil moisture status of the sub-watersheds, as north-facing slopes tend to remain moister because they receive less solar radiation. Aspect also influences the local composition of the vegetation community.

Variability in Land Cover, Soil Chemistry and Mean Precipitation

Land cover varies with topography (table 2.4, fig. 2.5a). The land cover of the mountain sub-watersheds typically consists of ice, evergreen forests, and shrubs (vegetation below 1.8 m feet tall). Foothills/plains sub-watersheds have a high percentage of grasslands. Superimposed on the natural grassland vegetation are the anthropogenic land covers: agriculture and urban development. Due to rapid urban development, especially on Rock Creek, anthropogenic land uses in the lower-elevation sub-watersheds may already be outdated from when it was mapped in the early 1990s. An updated land cover characterization, which is imminent, will likely show the differences in land cover between the early 1990s and the present.

A map of soil organic matter (fig. 2.5b) indicates that there is higher soil organic matter associated with the grassland and agricultural ecosystems of the plains than the mountain ecosystems. Total organic matter has been calculated by examining 1-m wide, 1-m long columns of soil with variable depths. The organic matter mass is calculated for each soil horizon and then summed over the entire soil column (table 2.2). Much of the difference in organic matter inventories on the plains is due to deeper soils in this area.

Additional soil attributes (soil pH and calcim carbonate content) were queried in STATSGO, but showed little variability within the Boulder Creek Watershed and therefore are not reported. This lack of variability is not consistent with field observations of soil profile chemistry in the watershed, which shows considerable variability in pH and calcium carbonate content along an altitudinal gradient (P.M. Birkeland, University of Colorado, written commun., 2002). Therefore, STATSGO data may not provide an accurate picture of soil chemistry for the watershed. A finer-scale soil map might contribute to a greater understanding of this variability. Digital county-level soil maps are currently only available for the region of the Boulder Creek Watershed east of the foothills.

Using the PRISM dataset, the elevation-weighted mean annual precipitation in the Boulder Creek watershed is 526 mm/yr (20.7 in/yr). There is tremendous variability within individual sub-watersheds and also among the various sub-watersheds (table 2.2, fig. 2.6). Mean precipitation in sub-watersheds that border the Continental Divide (North, South and Middle Boulder Creeks) exceeds 600 mm/yr. Foothills and plains sub-watersheds generally have mean precipitation values below 450 mm/yr.

Table 2.4. Land cover in the Boulder Creek Watershed and sub-watersheds

[Data from Vogelmann and others (2001) for period 1989 to 1994; km^2, square kilometers; water, exposed surface of water, reservoirs and wide streams; ice, perennial ice or snow; developed, high- and low-intensity residential (30-100 percent construction) and urban area; grass, herbaceous grasslands; deciduous, over 75 percent deciduous plants; evergreen, over 75 percent evergreen plants; shrub, 25-100 percent of cover less than 1.8 m tall; agriculture, includes pasture, row crop, small grain crops and fallow land; barren, rock outcrop or quarried land; Cr., Creek; N., North; M., Middle, S. South]

Stream	Area (km^2)	Percent								
		water	ice	developed	grass	deciduous	evergreen	shrub	agriculture	barren
Boulder Cr. (entire)	1160	1.9	1.5	6.5	18.4	7.3	36.5	12.4	15.5	0.0
Fourmile Cr.	68	0.2	0.1	0.4	2.1	7.7	65.1	24.3	0.1	0.0
N. Boulder Cr.	112	1.1	5.8	0.7	8.3	12.7	45.0	26.3	0.0	0.1
M. Boulder Cr.	115	1.1	7.2	1.0	8.2	15.0	41.1	26.3	0.0	0.1
S. Boulder Cr.	338	1.6	1.2	1.0	11.3	11.0	57.7	15.2	1.0	0.0
Lower S. Boulder Cr.	130	3.1	0.0	1.7	22.4	7.8	47.4	14.9	2.7	0.0
Upper S. Boulder Cr.	208	0.7	2.0	0.4	4.3	13.0	64.2	15.4	0.0	0.0
Coal Cr. (entire)	208	0.9	0.0	10.2	41.6	3.3	13.4	2.3	28.3	0.0
Coal Cr. (except Rock Cr.)	151	0.9	0.0	11.8	35.6	4.5	18.4	3.1	25.7	0.0
Rock Cr.	57	0.9	0.0	5.7	57.8	0.0	0.0	0.1	35.5	0.0
Lower Boulder Cr.	320	3.9	0.0	14.0	21.8	2.1	17.4	3.5	37.3	0.0
Lower Boulder Cr. above Coal Cr.	269	3.6	0.0	16.4	22.4	2.5	20.7	4.2	30.2	0.0
Lower Boulder Cr. below Coal Cr.	51	5.5	0.0	1.5	18.3	0.0	0.0	0.0	74.7	0.0

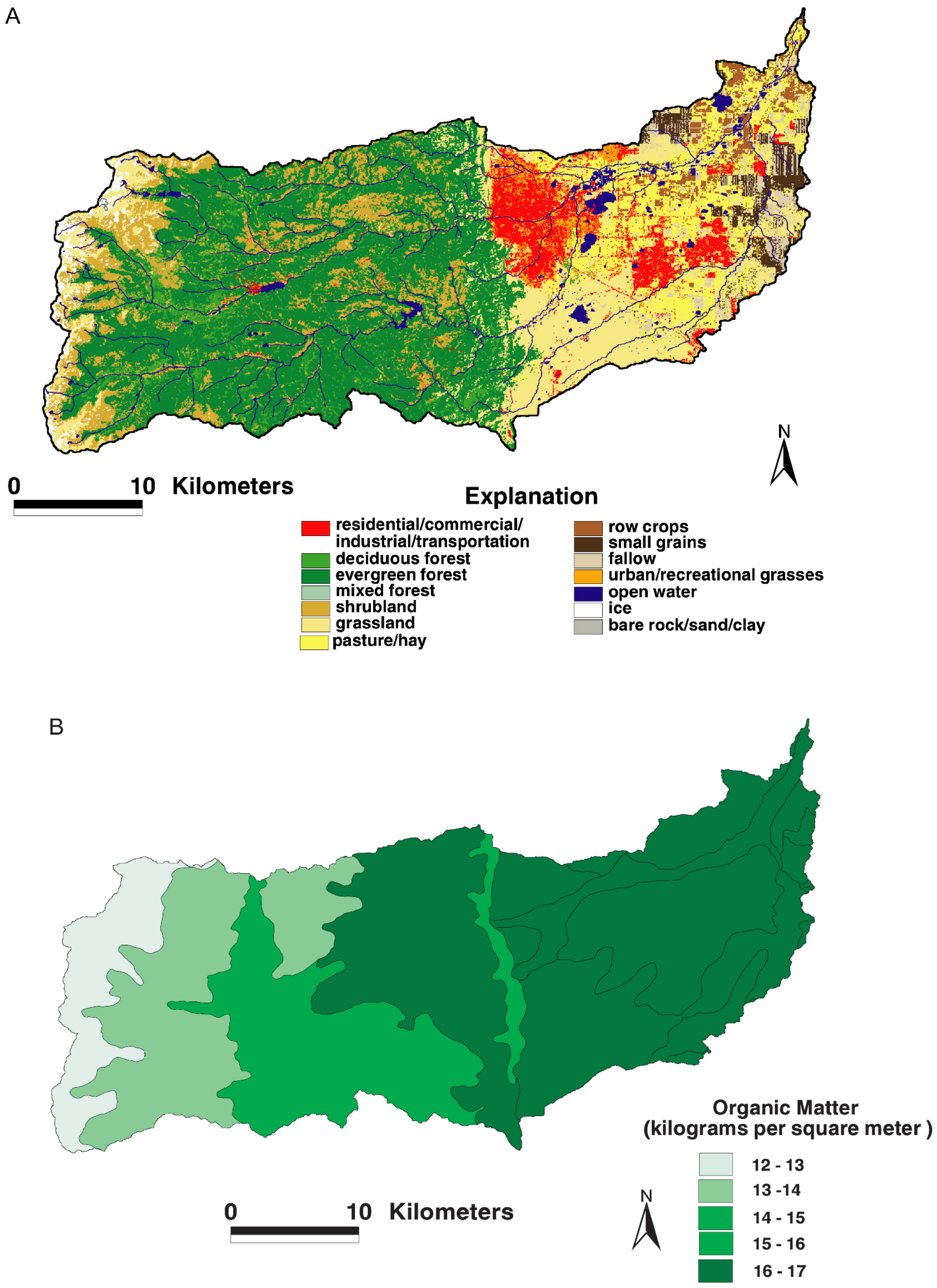


Figure 2.5. Maps showing (A) land cover (using National Land Cover Data Set of Vogelmann and others, 2001) and (B) soil organic matter (using STATSGO database of U.S. Department of Agriculture, 1994) in the Boulder Creek Watershed.

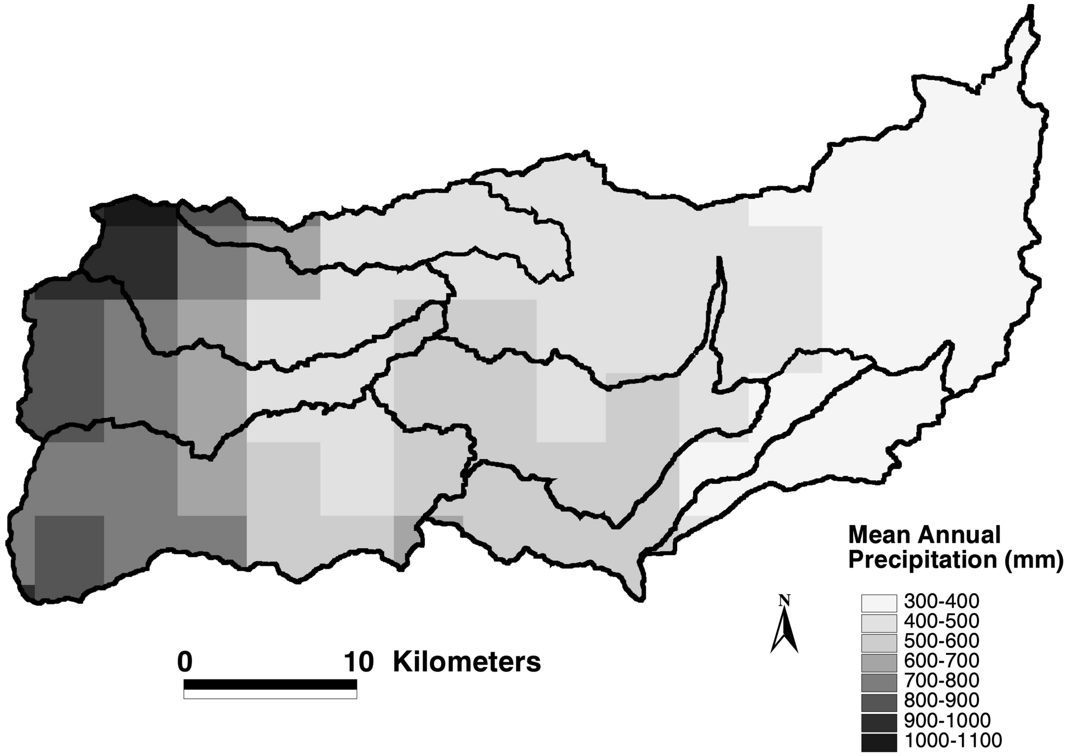


Figure 2.6. Map of precipitation in the Boulder Creek Watershed derived from the PRISM precipitation dataset (Daly and others, 1994).

SUMMARY

This work delineates and synthesizes landscape properties for the 1160-km^2 Boulder Creek Watershed. The boundary was computed with an automated procedure using digital data and represents an estimate of the watershed boundary determined with the best available Digital Elevation Model (DEM)-analysis algorithms. When the DEM-derived watershed areas are compared with USGS-reported contributing areas for streamgaging stations, most agreed within 3 percent error. The sub-watersheds with the largest discrepancies, Fourmile Creek and Coal Creek, appear to be correctly delineated on a topographic map. The location of the Boulder Creek Watershed boundary may change in flat regions near the Boulder Creek and Saint Vrain Creek confluence with the development of better flat-resolution algorithms or finer-resolution DEM data.

Not surprisingly, the variables identified-topography, land cover, soils and precipitation-are not independent, but can be easily grouped into environmental-physiographic regions. From the sub-watershed analysis, there are clear topographic and land cover differences between mountain and foothills/plains sub-watersheds.

This work is only the first step in providing a Geographic Information System (GIS) framework for studying chemical variability in Boulder Creek. The environmental data sets described here were used for illustrative purposes, and this comparison was not exhaustive. A GIS framework, like the one exhibited here, provides an efficient method for integrating diverse data sources into a single framework. Finer resolution soil and updated land cover data may be necessary to aid in the interpretation of variability.

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