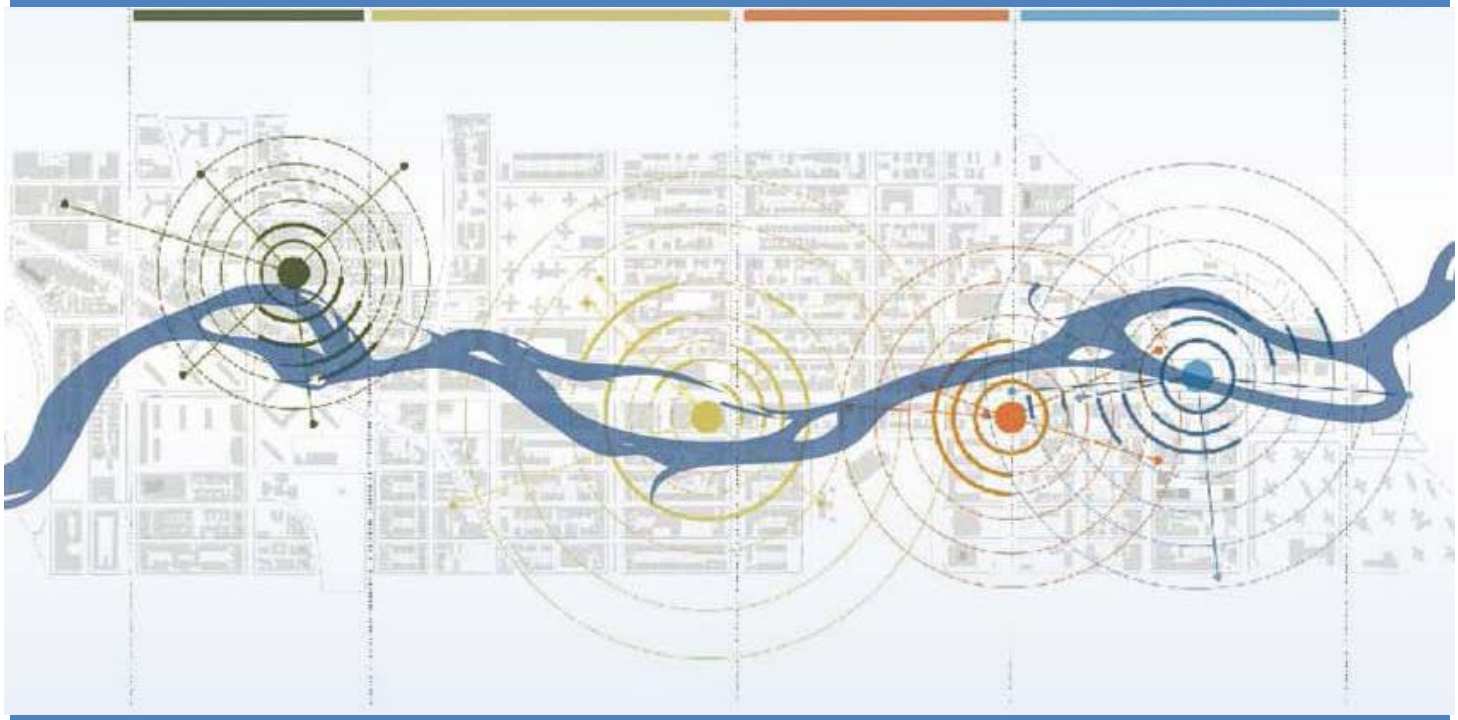
December 4th, 2017



South Platte Watershed Natural Capital Resource Assessment

Prepared by:

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South Platte Natural Capital Resource Assessment
Acknowledgements

This resource assessment is a collaborative stakeholder driven assessment of the natural capital of Colorado's South Platte River Watershed. The resulting resource and tools will guide future investments (conservation and/or restoration activities) undertaken by the South Platte River Urban Waters Partnership.

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Contents

Introduction

The South Platte Watershed encompasses 3.8 million acres from the mountains to the Denver Metro area and into the plains. In 2011, over 50 public and private stakeholders, under the leadership of US Forest Service and US EPA formed the South Platte River Urban Waters Partnership. The partnership area boundary includes the majority of the South Platte River Watershed. The primary goal of the partnership is to engage stakeholders in protecting and restoring lands and waters in the South Platte River watershed. In order to attain these progressive goals, and manage a highly diverse set of natural resources and interests, the Colorado State Forest Service secured funding from the US Forest Service and began building the South Platte Natural Capital Resource Assessment – From Mountains to Plains (South Platte Natural Capital Assessment).

The South Platte Natural Capital Assessment is a collaborative natural capital (also called green infrastructure) assessment undertaken by a diverse project team (Figure 1). Over the course of 20 months, this team: catalogued existing data sources, identified the most important natural assets in the watershed and then mapped the natural capital and valued the ecosystem services produced throughout the watershed. Finally, a decision-support tool was produced to assist stakeholders with prioritizing future investments in the watershed, whether for preservation or conservation. The South Platte River Urban Waters Partnership will use the resource assessment and decision support tool to prioritize future investments in either conservation or restoration throughout the watershed based on the natural capital of the region and the value of the ecosystem services that natural capital provides.

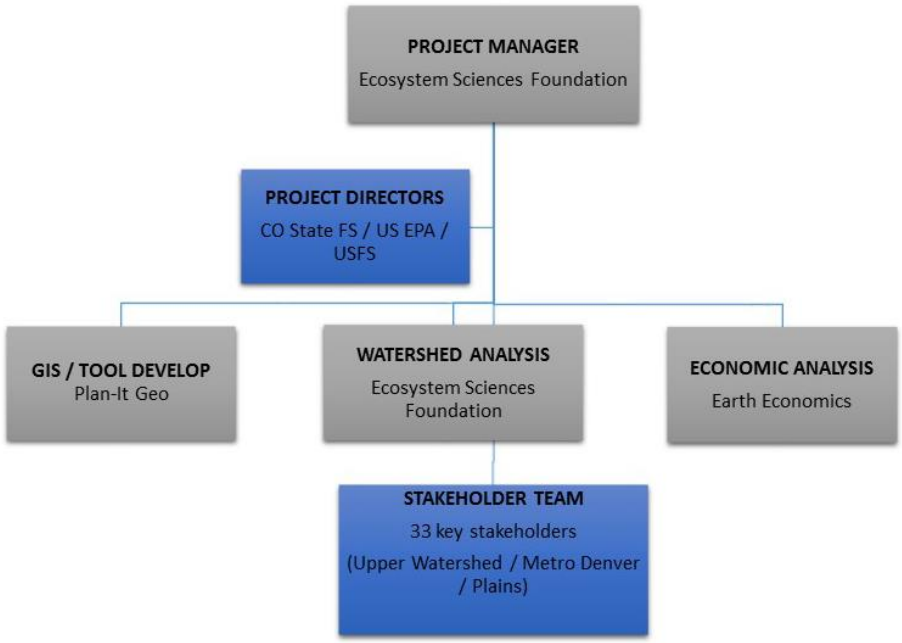


Figure 1. South Platte Natural Capital Project Team

Project Description

The Watershed

The South Platte River Watershed provides extensive value, approximately $7.4 billion per year in ecosystem services, to the economy and people of the watershed. The Natural Capital Asset Map and Ecosystem Services Valuation Maps produced through this assessment, provide a visual representation of the natural assets and ecosystem services provided by each of the 3 project areas (Upper Watershed, Denver Metro and Plains) and collectively by the entire watershed. By better understanding and communicating the network of natural assets and value they produce for the people of the watershed, the Urban Waters Partnership can better communicate with decision-makers and funders. Stakeholders can use the data and tools from this assessment to prioritize and invest in preservation and restoration activities that will increase the quality and value of natural capital in the watershed.

Project Delineation Area

The Natural Capital Resource Assessment delineated three distinct project areas within the 3.8 million acres of the watershed: Upper Watershed, Denver Metro, and Plains. The three project areas differ in size, with the Upper Watershed encompassing over 57% (>2.1 million acres) of the entire South Platte Watershed, while the Plains and Denver Metro project areas encompass roughly 28% (>1 million acres) and 15% (>550,000 acres), respectively (Figure 2 and Figure 3).

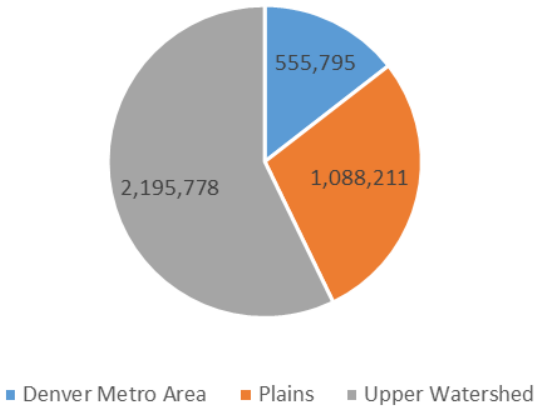


Figure 2. Acreage of the South Platte Watershed per Project Area

Each of these project areas has unique attributes and data sets that necessitate breaking the overall South Platte Project Area into three distinct areas. For example, the Denver Metro Project Area is a densely developed urban area characterized by large areas of impervious surface, which differs considerably from the two other project areas (Figure 4). Additional defining attributes between the three project areas include:

- The Denver Metro, based on NLCD 2011 data, consists of over 60% developed area, compared to only 8% in the Plains and less than 2% in the Upper Watershed (Figure 4).
- The Upper Watershed is dominated by evergreen forest (45%), while the two other project areas contain less than 5% of this land cover (Figure 4). The abundance of evergreen forest, including the natural capital that forests provide and the management of wildfire, necessitated delineating the Upper Watershed Project Area.
- The Plains is dominated by herbaceous (41%) and agriculture (34%) land cover types (Figure 4). Although the Upper Watershed encompasses over 30% herbaceous land, it is primarily located in the high elevation South Park area, which is a different herbaceous land type than found in the Plains. The Plains abundance of agriculture (34%) is a marked difference from the two other project areas, which is acknowledged in the Natural Asset mapping.

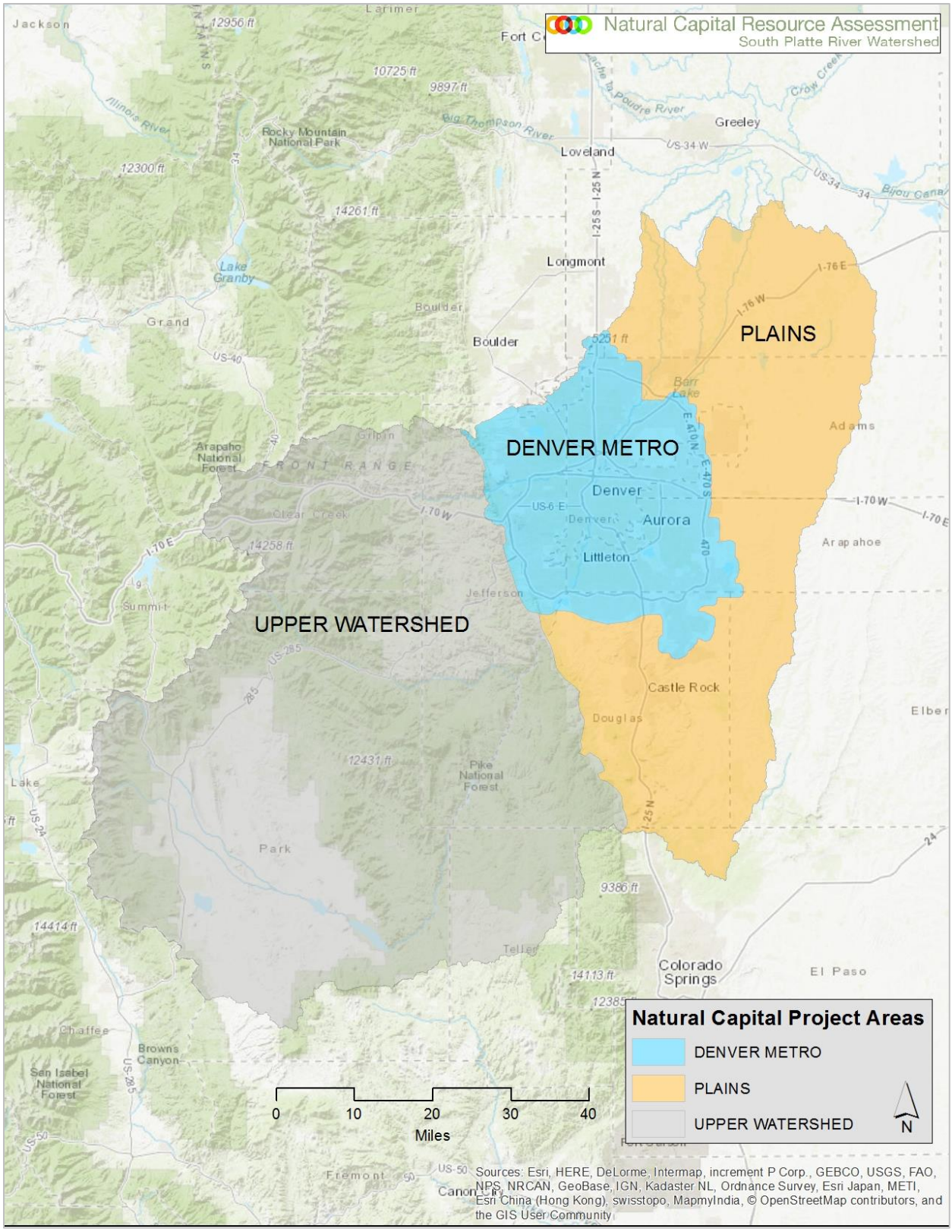


Figure 3. Project Areas of the South Platte Natural Capital Resource Assessment

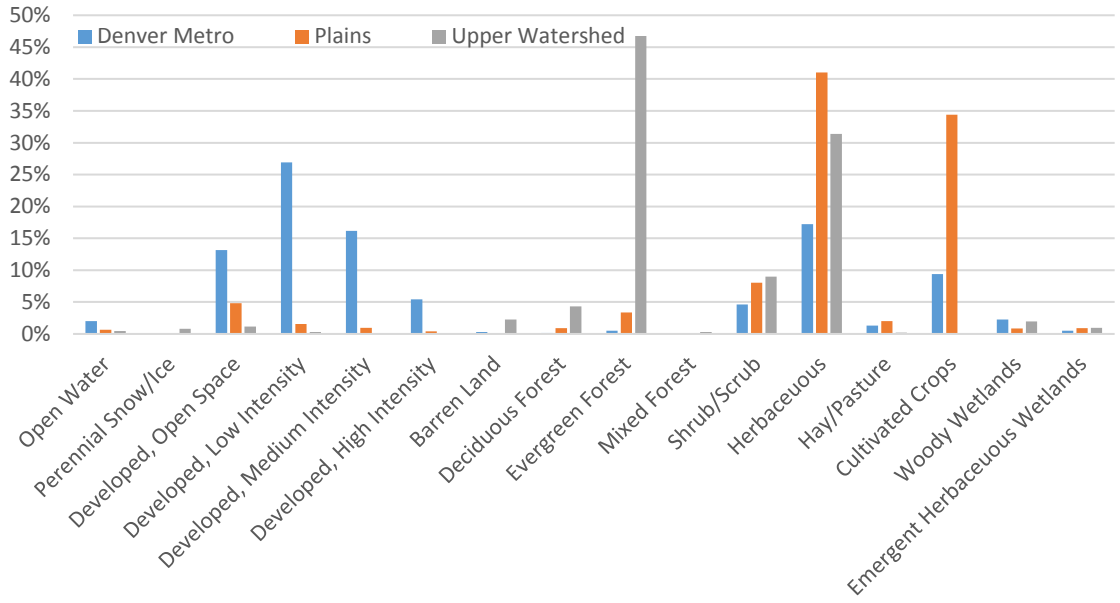


Figure 4. NLCD 2011percent land cover per project area

While there are important land cover attributes that differentiate the three project areas, just as important in the delineation process are the data sets available for each project area. Thus, previous work performed and data availability influenced the project area delineation process as much as, or more so, than the land cover attributes of each project area. A few key examples include:

- The Denver Metro Project Area coincides with 2013 Denver Metro UTC Study boundaries. There are some populated areas that were not included in the Denver Metro 2013 UTC study, but are included in the Denver Metro Project Area. These areas fall between the Upper Watershed and the Denver Metro project areas and were included in the Denver Metro Project Area due to their developed (urban) nature.
- The Upper Watershed Project Area corresponds to the mountainous areas to the west of Denver that are dominated by native forest. Much work has been done in these areas in an effort to mitigate wildfire risk and flooding. For example, two organizations, the Coalition for the Upper South Platte (CUSP) and the Upper South Platte Partnership (USP), have done considerable work in the Upper Watershed. Both organizations have prioritized several Upper Watershed HUC 12s for implementation of mitigation actions aimed at reducing risk of wildfire. Thus, the Upper Watershed Project Area includes these prioritized HUCs as well as adjacent forested mountainous areas, including portions of the Front Range and the Clear Creek drainage that were not included in the CUSP and USP work.
- Once the Denver Metro and Upper Watershed project areas were delineated, the remaining area of the South Platte Watershed was delineated as the Plains Project Area. The Plains Project Area corresponds to the low slope, generally herbaceous and agricultural dominated landscapes to the south and east of the Denver Metro Project Area.

The three project areas are organizational for data, methods and prioritization. The final Natural Capital Asset map, Ecosystem Services Valuation (ESV), and prioritization apply to the entire

project area and can be summarized by any boundary. Therefore, the project areas defined herein do not hinder summarizing the final data layers created through this project using any boundary (e.g. HUC, County, Municipality, etc.).

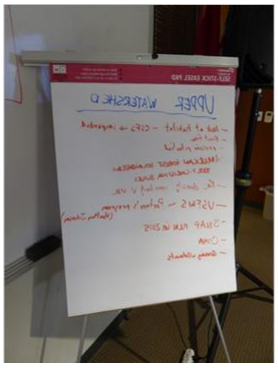
The People

Over 50 public, private and non-profit stakeholders are actively engaged in the South Platte River Urban Waters Partnership. Of these stakeholders, over 40 were active in collaborating on the stakeholder driven planning process of the South Platte Natural Capital Resource Assessment (Appendix C stakeholder list). Stakeholders represent all geographies of the South Platte watershed, from Mountains to Denver Metro to Plains; and are engaged in all facets of management, including urban infrastructure, outreach and education, water quality, wildland fire, water resources and more. Stakeholders provided over 40 key data sources that are the foundation for the natural capital and ecosystem services valuation products created for this project (reference meta-analysis).

In addition, stakeholders determined which natural assets were most important to the people and environment of the watershed (see Natural Assets of Importance section) and which prioritization categories (See Prioritization section) to analyze and incorporate into the project's decision-support tool. By directly informing all aspects of the project, the urban waters partners now have a valuable resource and decision-support tool that provides the data, information and prioritization tools to maximize future investments throughout the watershed.

The Planning Process

The South Platte Natural Capital planning process is founded on active stakeholder engagement facilitated by the project consultant team (Ecosystem Sciences Foundation, Plan-It Geo and Earth Economics) in collaboration with the project directors (Colorado State Forest Service, US Forest Service and US EPA); collectively the project team. Through all aspects of the planning process, data was gathered from stakeholders and project outputs were produced (natural capital asset map, ecosystem services valuation, etc.) based on extensive stakeholder guidance and input. The resulting resource assessment and outputs reflect the priorities of the managers and stakeholders within the watershed, ensuring they can be used to effectively inform management decisions for years to come (Figure 5).

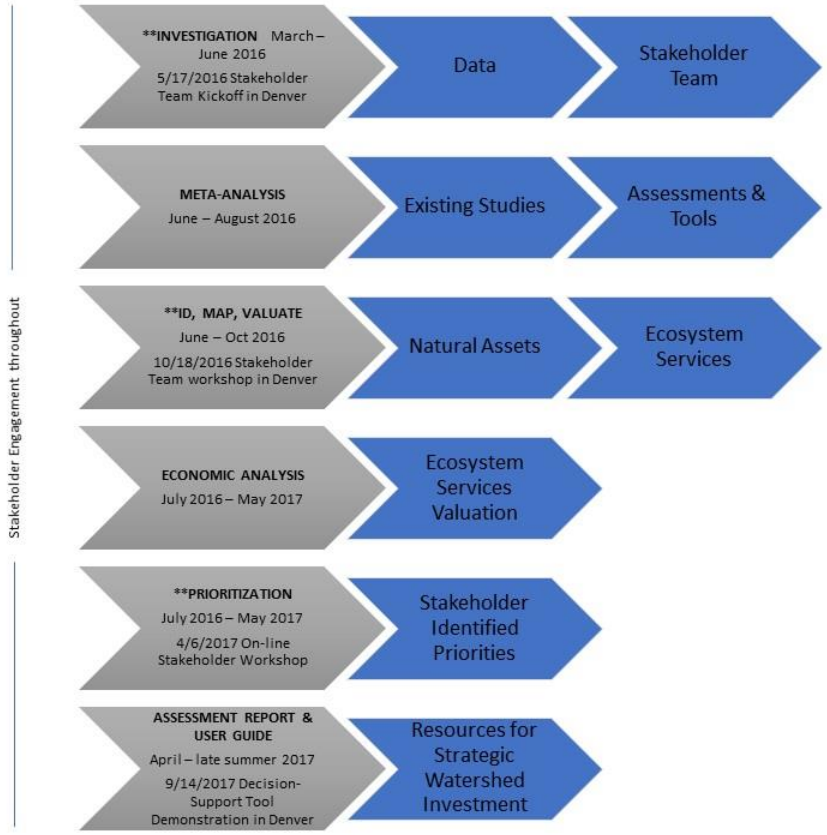



Figure 5. South Platte Natural Capital Project Process and Timeline

Methods

The project directors and stakeholders recommended over 40 datasets that informed and shaped the project (see Meta-analysis section). A subset of these datasets was used to create a Natural Capital Asset Map (i.e. Green Infrastructure [GI] map), inform the Ecosystem Services Valuation (ESV), and define the prioritization and case studies for this resource assessment.

Natural Assets of Importance (NAI)

Natural assets of importance and prioritization categories were identified by project directors and the stakeholder team and used to organize data sources and inform all aspects of the project. The resulting resource assessment and project outputs (Natural Capital Asset map and ESV) reflect the value of the watershed as identified by the stakeholders who live, work and play in the watershed. A total of seven natural assets of importance were identified by the stakeholder team as being valuable to the environment and people of the South Platte: native forest resources, productive agricultural resources, wildlife habitat, clean drinking water, healthy waterways, access to nature, and urban ecosystem resources and parks (Table 1). The Natural Capital Asset Map categorized and weighted all data sources according to these Natural Assets of Importance to ensure the resulting natural asset rank reflects the stakeholder identified values of the assets within the watershed.

Table 1. Natural Assets of Importance

Upper Watershed (6)	Denver Metro (6)	Plains (6)
Native Forest Resources	Urban Ecosystem Resources & Parks	Native Forest Resources
Productive Ag Resources	Productive Ag Resources	Productive Ag Resources
Wildlife Habitat	Wildlife Habitat	Wildlife Habitat
Clean Drinking Water	Clean Drinking Water	Clean Drinking Water
Healthy Waterways	Healthy Waterways	Healthy Waterways
Access to Nature	Access to Nature	Access to Nature

Natural Capital Asset Mapping

The Natural Capital Asset map was derived based on stakeholder identified datasets and Natural Assets of Importance, and weighted according to stakeholder identified criteria. The map provides the foundation for the Natural Capital Resource Assessment and all project outputs.

Creating the Natural Capital Asset map follows similar Green Infrastructure (GI) efforts such as Karen Firehock's Strategic Green Infrastructure Planning (2015) and ESRI's Green Infrastructure for the U.S. (http://www.esri.com/about-esri/greeninfrastructure). ESRI describes GI as "a strategically planned and managed network of open spaces, watersheds, wildlife habitats, parks, and other areas that deliver vital services and enrich local quality of life" (ESRI 2016). The Green Infrastructure Center defines GI as "the interconnected natural systems and ecological processes that provide clean water, air quality and wildlife habitat. Green infrastructure sustains a community's social, economic, and environmental health" (Firehock 2015). In short, mapping GI or natural capital entails identifying the natural components of a region that inhabitants value and creating of map of these components. The resulting Natural Capital Asset Map and Decision

Support Tool provide a valuable resource for stakeholders and managers to prioritize future investments throughout the watershed.

The South Platte Watershed's Natural Capital Asset Map (Green Infrastructure), is based on existing datasets provided by project stakeholders (see Meta-Analysis section), organized and ranked according to Natural Assets of Importance which were also identified by the stakeholders (Table 1). It must be acknowledged that the scale of the Natural Capital mapping differs per project area. For example, the available GIS data (e.g. Urban Tree Canopy) for the Denver Metro Project Area is of a higher resolution (1m vs. 30m) than the available data (NLCD) for the Upper Watershed and Plains project areas. Table 2 documents the datasets and Figure 6 details the weighting employed to create the Natural Capital Asset map. All mapping was performed in ArcGIS 10.5. The datasets in Table 2 were weighted and then combined in ArcGIS. Combining the 16 layers in ArcGIS resulted in a watershed wide layer consisting of 30m pixels, with each pixel given a score based on the weighting criteria in Figure 6. Scores ranged from a low of -3 to a high of 37. Because of differences in natural characteristics and datasets, the overall watershed wide Natural Capital dataset was broken into the three project areas. A natural break classification method was used to reclassify each project areas' natural capital score into 5 classes. Classes ranged from 0 to 4, with 0 indicating limited to no natural capital and 4 indicating high quality natural capital. The Natural Capital class (0-4) is indicative of the amount of natural assets of importance that each pixel supports. For example, a class value of 4 indicates that the pixel supports multiple natural assets of importance.

Table 2. Datasets and sources used for Natural Asset Mapping.

Dataset	Source
Wetlands	Colorado Wetland Inventory
Rivers	National Hydrography Dataset (NHD)
Lakes and Reservoirs	National Hydrography Dataset (NHD)
Parks and Open Space	DRCOG/COMAP
Elevation	National Elevation Data (NED)
Recreation Density	CSFS
Habitat for Imperiled Species	CSFS
Contiguous Area	NLCD 2011
Urban Forest	Denver Parks and Recreation 2013
Riparian	NLCD 2011
Agriculture	NLCD 2011
Forest Treatment Area	CSFS, USFS, BLM, Landfire
Trails	DRCOG/COMAP
Urban	NLCD 2011
Wildlifre	CSFS, USFS, BLM
Human Modification	CSFS

Additional information on the Natural Capital Asset Map can be found in the Natural Capital Asset Map Atlas output of the resource assessment (See Outputs Section).

Figure 6. Datasets and weighting employed to create Natural Capital Asset Map.

Ecosystem Services Valuation (ESV)

The goal of the Ecosystem Services Valuation (ESV) analysis is to provide ecosystem service values for natural assets of the South Platte River watershed. This section describes the steps taken in the valuation analysis. The first step is to assess the extent of natural capital in the study area. Next, values for ecosystem services are determined. Finally, these two datasets are combined to estimate the total value of economic benefits provided by the South Platte River watershed.

The ESV is based on existing land cover data, National Land Cover Database (NLCD) (USDA/NRCS 2011). In addition, the NLCD data was supplemented by other existing datasets per project area to further refine the value of ecosystem services based on the condition of the resource. For example, the Denver Metro Project Area relies on the 2013 UTC Assessment data, but is also cross-walked to the NLCD data. Additional data was used to supplement the NLCD and improve the accuracy and precision of the economic analysis.

The Ecosystem Services Valuation (ESV) was performed using the Benefit Transfer Method (BTM) and Earth Economics' online tool EVT. EVT is an online database of extensive ecosystem service valuation literature. BTM applies previously published ecosystem service values (based on land cover classifications) from comparable ecosystem types and transfers them to the South

Platte Watershed. This process is analogous to a home appraisal in which value and comparable features of neighboring homes are used to estimate the value of the home in question.

The ESV outputs (Table 8) are presented in a range (minimum, maximum, average) to highlight the range of variability of values for each natural asset of importance. The values provided include an array of different potential demand scenarios and states of the environment. By extracting values from a large pool of studies and contexts, the average illustrates a well-informed value approximation, while the minimum and maximum values display the variability and uncertainty in the data. These ESV outputs are also based off the best available data and, if anything, under-represent the total value of ecosystem services produced throughout the watershed. It is important to note that a gap in the ecosystem service valuation literature does not necessarily mean that the ecosystem does not produce that service or that the service is not valuable. Rather, it shows a lack of primary, peer-reviewed data for that service. For example, agricultural land provides many ecosystem services to people, such as food for human consumption, habitat for small prey species, and aesthetic beauty. Yet the valuation literature does not contain quality value estimates for food provisioning in this region. Hence, all of the values for ecosystems included in this analysis should be viewed as underestimates. Appendix B describes the ESV methods in more detail.

Ecosystem Service Framework

Natural Capital consists of the minerals, energy, plants, animals, and ecosystems found on Earth that provide a flow of natural goods and services. Ecosystems perform natural functions (such as intercepting rainfall and preventing soil erosion) and provide goods and services that humans need to survive (e.g., a clean water supply and reduction of downstream flooding). The benefits that humans receive from nature, many of which are generally taken for granted, are known as ecosystem goods and services.

In 2001, an international coalition of over 1,360 scientists and experts from the United Nations Environmental Program, the World Bank, and the World Resources Institute assessed the effects of ecosystem change on human well-being. A key goal of the assessment was to develop a better understanding of the interactions between ecological and social systems, and in turn to develop a knowledge base of concepts and methods that would improve our ability to "…assess options that can enhance the contribution of ecosystems to human well-being." This study produced the landmark Millennium Ecosystem Assessment, which classifies ecosystem services into four broad categories according to how they benefit humans (Figure 7). These categories are as follows:

- Provisioning goods and services provide physical materials and energy for society that varies according to the ecosystems in which they are found. Forests produce lumber, agricultural lands supply food, and rivers provide drinking water.
- Regulating services are benefits obtained from the natural control of ecosystem processes. Intact ecosystems keep disease organisms in check, maintain water quality, control soil erosion or accumulation, and regulate climate.
- Information services are functions that allow humans to interact meaningfully with nature. These services include providing spiritually significant species and natural areas, natural places for recreation, and opportunities for scientific research and education.

- Supporting services include providing shelter, promoting growth of species, and maintaining biological diversity. These services are the basis of the vast majority of food webs and life on the planet.

The ecosystem services valued for the South Platte Natural Capital Project are shown in Figure 8. The ecosystem services that were not valued in the South Platte Natural Capital Project are shown in Figure 9.

Figure 7. What Are Ecosystem Services

Figure 8. Ecosystem Services valued for the South Platte Natural Capital Project

Figure 9. Ecosystem Services not valued in the South Platt Natural Capital Project

ESV Methodology

We use Benefit Transfer Methodology (BTM) to value ecosystem services in the South Platte River watershed. BTM is a well-established methodology that indirectly estimates the value of ecological goods or services. Benefit transfer is broadly defined as "…the use of existing data or information in settings other than for what it was originally collected"(Rosenberger and Loomis 2003). BTM is frequently used because it can generate reasonable estimates quickly and at a fraction of the cost of conducting local, primary studies, which may be more than $100,000 per service/land cover combination. BTM is often the most practical option available to produce reasonable estimates, and continues to play a role in the field of ecosystem service valuation (Richardson et al. 2015).

The BTM process is similar to a home appraisal in which the value and features of comparable, neighboring homes (e.g. two bedrooms, garage, one acre, recently remodeled) are used to estimate the value of the home in question. In our analysis, the BTM process identifies previously published ecosystem service values from comparable ecosystems and transfers them to our study site, the South Platte River Watershed. As with home appraisals, the BTM results can be somewhat rough, but quickly yield values appropriate for policy work and analysis.

The process begins by finding primary studies with land cover classifications (wetland, forest, grassland, etc.) comparable to those within the study area. Any primary studies deemed to have incompatible assumptions or land cover types are excluded. Individual primary study values are

adjusted and standardized for units of measure, inflation, and land cover classification to generate an “apples-to-apples” comparison. However, transferring primary study values using a unit transfer approach assumes that supply and demand factors (such as those described above) between the primary study site and the study site of this report are the same, and this assumption can lead to under- or overestimates of the actual value of a service in the South Platte River Watershed. See Appendix B for more details.

Land Cover and Ecosystem Health

BTM results are applied to ecosystem types within the watershed. These ecosystem types are derived from the National Land Cover Database (NLCD) using GIS software. We constructed a set of indicators to better describe these land cover types in terms of location and health. These indicators include location-based spatial attributes such as being within a riparian zone, urban areas, or agricultural areas. Health-based indicators included whether or not forests had been treated, contiguous area of land cover types, level of human modification to ecosystems, recreation accessibility, location of important habitat for endangered species, density of canopy cover within the metro area, and history of wildfires. These attributes were combined into a health score, which was used to modify ecosystem service values. For example, more degraded ecosystems would have lower ecosystem service values.

Project Prioritization (Categories)

A total of ten prioritization categories were identified by the stakeholder team as important future investment opportunities in the South Platte: Wildland Fire, Water Quality/Quantity, Invasive Species/Insect & Disease, Development, Flooding, Biodiversity/Wildlife Habitat, Recreation, Connectivity, Urban Heat Island, and Demographic Factors (Environmental Justice & Public Health) (Table 3).

Table 3. Prioritization Categories

Upper Watershed (8)	Denver Metro (8)	Plains (8)
Wildland Fire	Urban Heat Island	Wildland Fire
Water Quality / Quantity	Water Quality / Quantity	Water Quality / Quantity
Invasive Species / Insect & Disease	Invasive Species / Insect & Disease	Invasive Species / Insect & Disease
Development	Development	Development
Flooding	Flooding	Flooding
Biodiversity / Wildlife Habitat	Biodiversity / Wildlife Habitat	Biodiversity / Wildlife Habitat
Recreation	Recreation	Recreation
Connectivity	Demographic Factors (Environmental Justice & Public Health)	Connectivity

Project prioritization is based on the Natural Capital Asset Map, Ecosystem Services Valuation (ESV), information from existing projects (e.g. CUSP and USP), and additional available data (e.g. FEMA Flood Zones). Project prioritization is similar to other Green Infrastructure analyses “risk assessment” process, described as “What natural assets are most at risk and what actions can be taken to minimize these risks” (ESRI 2016). CSFS, SPP and CUSP have all done work prioritizing areas for mitigation of risks (e.g. wildfire and flooding). All this data and information helps drive the prioritization portion of the resource assessment. Figure 10 (Meta-Analysis) lists data sets used to inform the prioritization portion of the Upper Watershed Project Area.

Prioritization categories, identified by the project stakeholders, differ for each project area, as the risks and needs of each project area are different. Stakeholders can use the project prioritization to either: (1) identify areas for restoration that are currently of low quality (based on the Natural Capital Asset Map) and value (based on the ESV); or (2) identify areas for conservation that are currently of high quality and value.

Additional details for project prioritization, including project case studies can be found in the prioritization output of the resource assessment (see Project Outputs section).

Natural Capital Asset Map and Decision-Support Tool

The Natural Capital Asset Map and Decision-Support Tool is a user-friendly on-line resource for stakeholders and members of the South Platte River Urban Waters Partnership to: (1) communicate the quality and ecosystem service value of the natural assets throughout the watershed; (2) prioritize investment in future projects to either restore landscapes of low quality and low value or conserve landscapes of high quality and high value.

Additional details for the decision-support tool can be found in the user guide output of the resource assessment (See Project Outputs section).

Project Outputs

The South Platte Natural Capital Project derived several outputs; Meta-analysis, Natural Capital Map atlas and layers (natural capital layer and ESV layer), and the Natural Capital Decision Support Tool.

Meta-Analysis

Over forty datasets were provided to the Consultant team by the Stakeholders and Project Directors. These datasets are the foundation of the Natural Capital project informing the Natural Capital Asset Mapping, Ecosystem Services Valuation (ESV), and the prioritization. The meta-analysis organizes the provided datasets into an easy to use format that informs future strategic investments of resources. Through the meta-analysis organization, the Natural Capital project becomes a foundation for the strategic investment of resources by apprising stakeholders on future project identification, prioritization and overall project related information gathering. The meta-analysis facilitates future project prioritization by identifying layers that can assist in a prioritization effort aimed at any prioritization category (e.g. Wildland Fire, Flooding etc.). Figure 10 lists all the datasets provided to the consultant team and how they inform the prioritization categories per project area.

		Project Area			Prioritization Categories										Local Data
Dataset	Source	UW	DM	PL	Wildland Fire	Water Quality Quantity	Invasive Species (I&D)	Developed	Flooding	Biodiversity - Wildlife Habitat	Recreation	Connectivity	Urban Heat Island	Demography (Env. Justice)	
"Sixth level" Priority Subwatersheds from Assessment	Upper South Platte Partnership														
BMW - Water Quality	Barr Lake Milton Reservoir														
Climate Change Vulnerable Communities	EPA														
Counties/Cities/Municipal Bounds	CDOT														
CUSP Priority HUCS	CUSP														
Demographic Data (census)	DRCOG														
Denver Green Infrastructure Mapping (in-progress)	City of Denver														
Denver Metro Trees	TreeKeeper														
Elevation	USGS NED														
FEMA National Flood Hazard Layer	FEMA														
Fluvial Instability and Restoration	ERAMS														
Forests to Faucets	USFS														
Habitat For Imperiled Species	CSFS														
Human Modification	CSFS														
Hydrology	USGS NHD														
Imperiled Habitat For Economic Important Species	CSFS														
Land Use	Denver Parks & Rec														
Metro Vision 2035	DRCOG														
National Land Cover Data Set	USGS NLCD														
Noxious Weeds	CDOT														
Ownership, Protected Areas, Conservation easements	COMap														
Parks and Open Space	DRCOG														
Pervious Surfaces (UTC Data)	Denver Parks & Rec														
Potential Conservation Areas	Colorado Wetland Inventory														
Priority Source Water Areas	Denver Water														
Recreation Density	CSFS														
Regional Trails	DRCOG														
TPL Climate Smart Cities (in-progress)	TPL														
TPL Denver Metro Greenspace Study Online Mapping	TPL														
Transportation	DRCOG														
Treatment Priorities	CSFS														
Urban Heat Island	Denver Parks & Rec														
Urban Tree Canopy	Denver Parks & Rec														
Urban Waterways Restoration Study	City and County of Denver														
USFS Data (Pike-San Isabel & Arapaho-Roosevelt NF)	USFS														
Water Quality Assessment	EPA (UWP)														
Water Quality Data	CDSN														
Watershed Priority Rating	CUSP														
Watershed Wildfire Protection Group (WWPG)	CSFS														
Watersheds	USGS NHD														
Wetlands	Colorado Wetland Inventory														
Wildfire Perimeters	CSFS, USFS, BLM														
Wildfire Risk	CSFS														
Wildland Urban Interface (WUI)	CSFS														
WQPondBasins	Denver Public Works														

Figure 10. Meta-Analysis of recommended datasets

Natural Capital Asset Map Atlas

The Natural Capital Asset Map Atlas is a compendium of maps that describe the Natural Capital and ESV outputs in visual form. Tables 4 through 7 and Figures 11 through 14, below, show Natural Capital by Natural Asset Class (rank) for the entire South Platte Watershed as well as the three project areas (Upper Watershed, Denver Metro, and Plains).

Table 4. South Platte Watershed Natural Asset (NA) Class by Percent

NA Rank	0	1	2	3	4
Percent	17%	27%	21%	19%	17%

Table 5. Upper Watershed Natural Asset Class by Percent

NA Rank	0	1	2	3	4
Percent	20%	23%	24%	17%	16%

Table 6. Denver Metro Natural Asset Class by Percent

NA Rank	0	1	2	3	4
Percent	28%	18%	19%	19%	16%

Table 7. Plains Natural Asset Class by Percent

NA Rank	0	1	2	3	4
Percent	4%	40%	16%	23%	18%



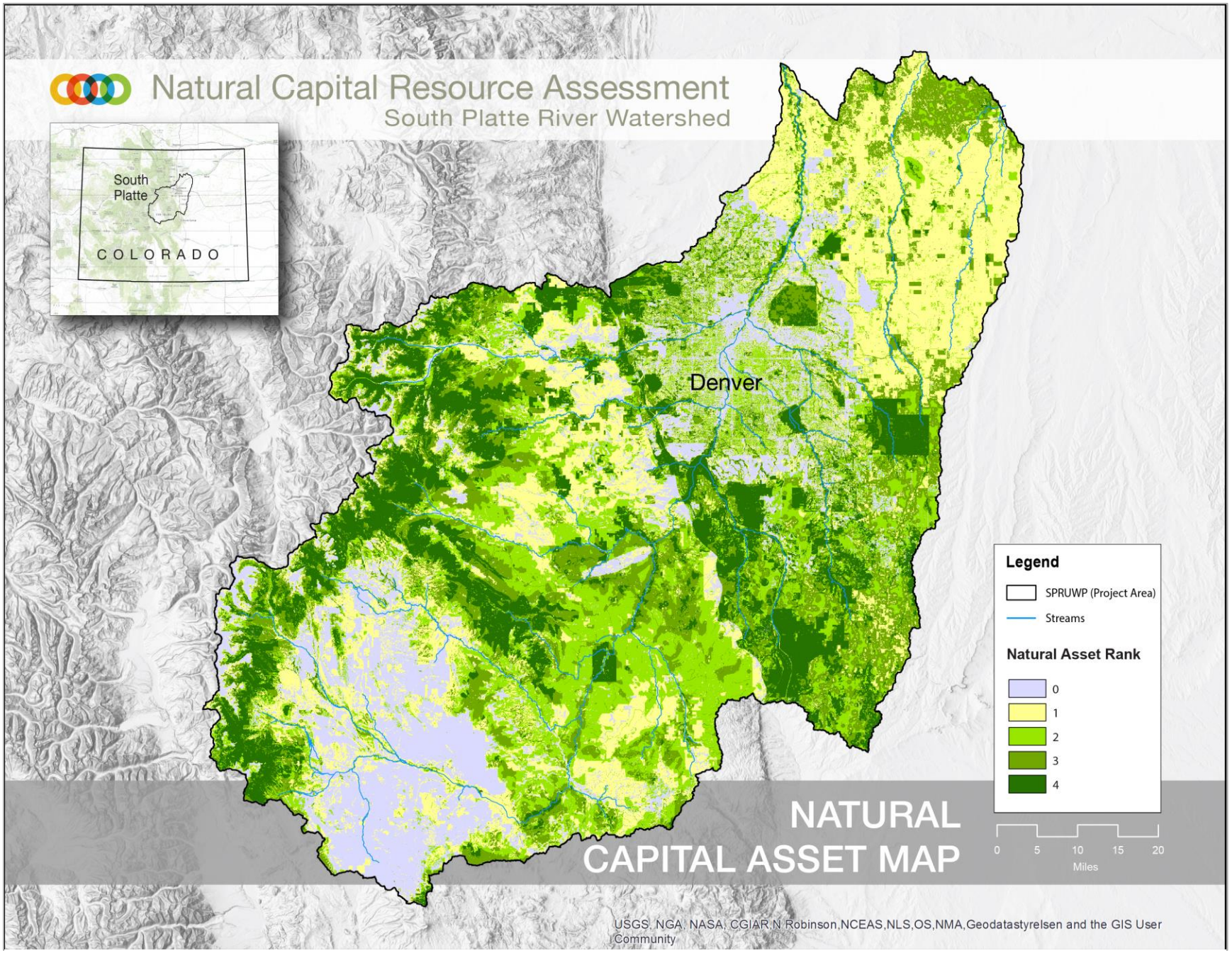


Figure 11. Natural Capital Asset Map of the Entire South Platte Watershed

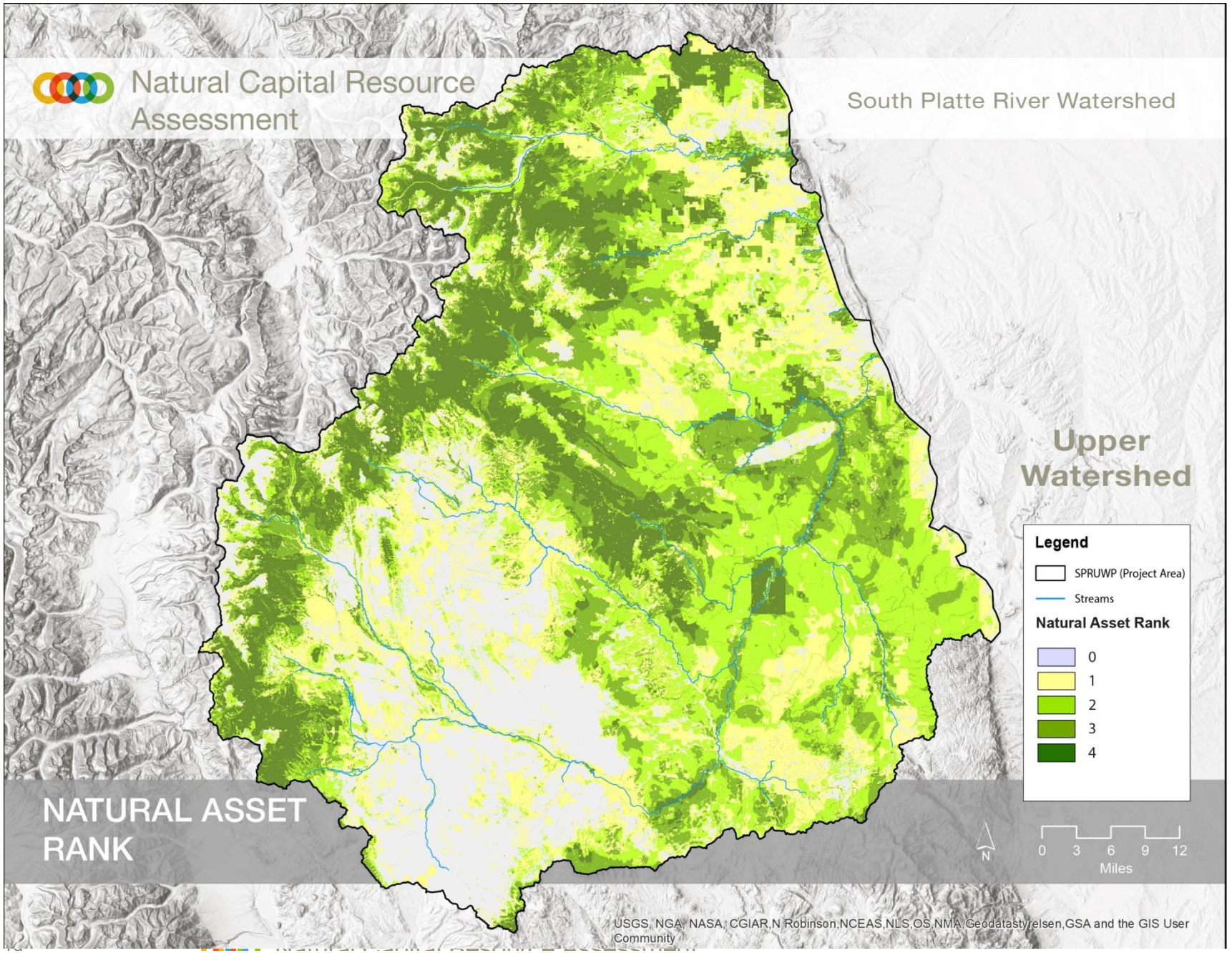


Figure 12. Upper Watershed Natural Capital Asset Map

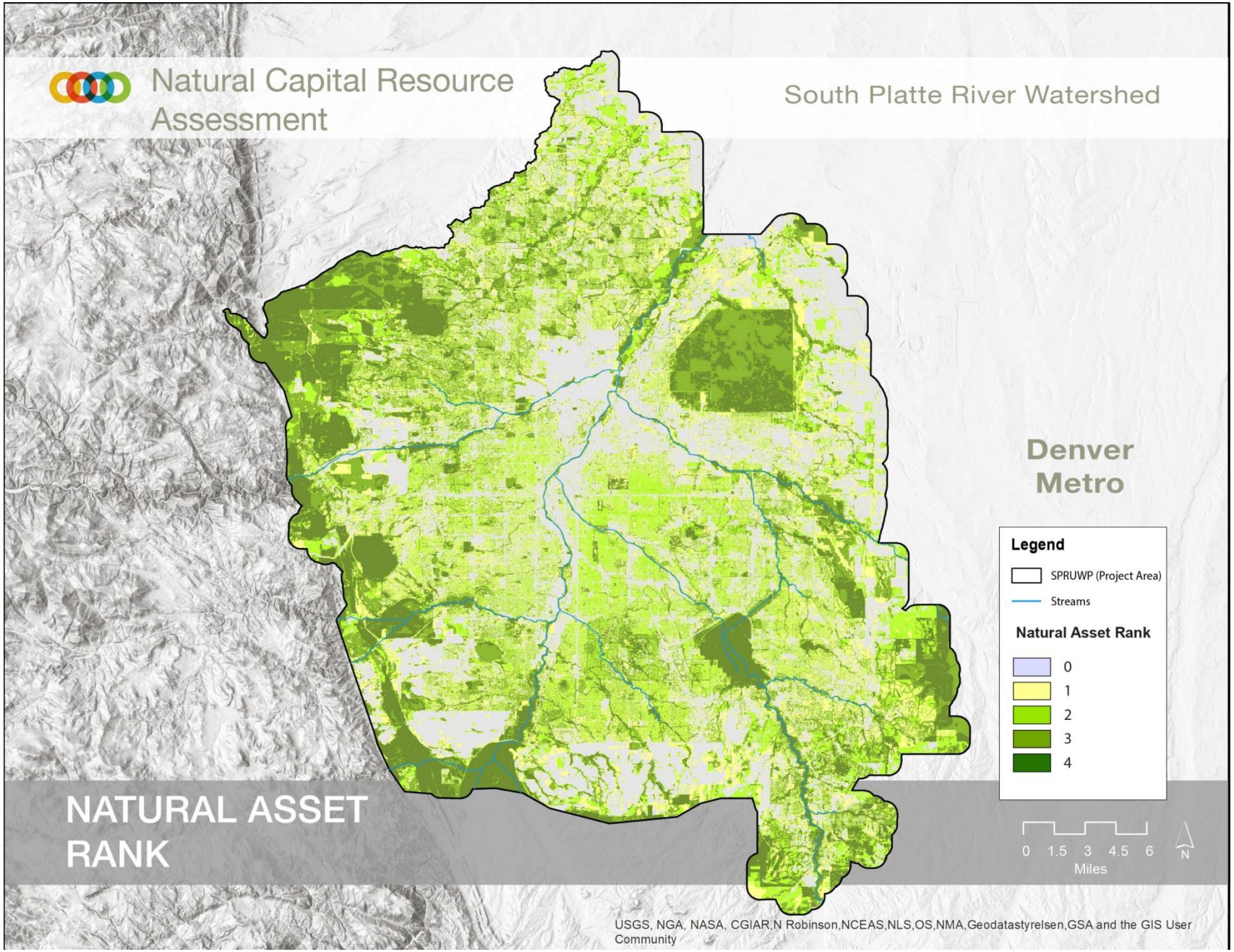


Figure 13. Denver Metro Natural Capital Asset Map

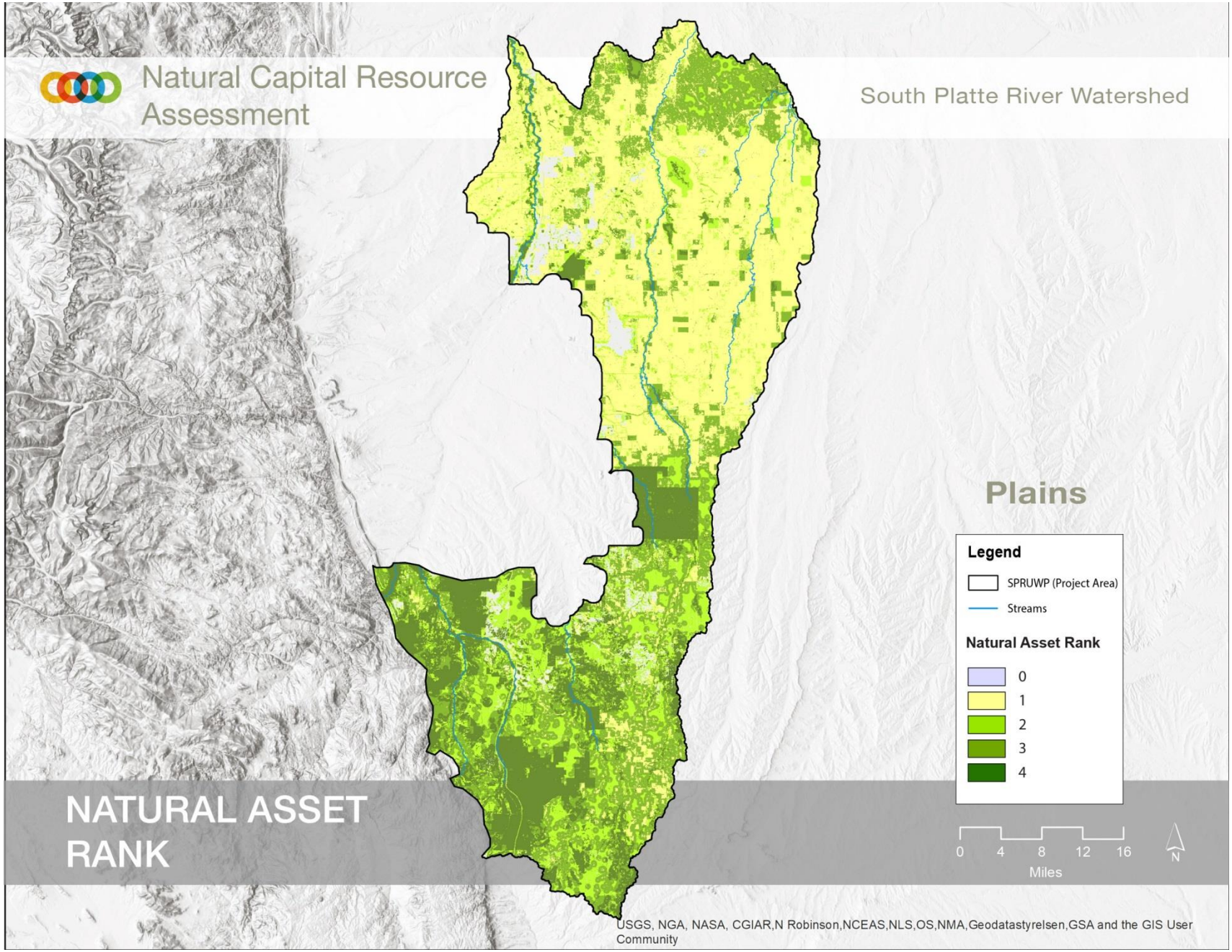


Figure 14. Plains Natural Capital Asset Map

Ecosystem Services Valuation Results

Table 8 below and the subsequent map set (ESV for the entire watershed and three project areas) details the ESV results. The ESV results are presented in a range of values (minimum, maximum and average) in order to appreciate their range and distribution. Values were constructed from 48 different studies and combined with local data to produce a well-informed approximation of the economic benefits produced by natural capital. Again, we reiterate that the data from these 48 studies represent a range of contexts under which ecosystem services occur. Showing a range in these values highlights the uncertainty and variability in the value of ecosystem services, while the average displays the central tendency of values based on relevant knowledge of these values. This approach, which is commonly found in policy applications and the benefit-cost analyses, is an accepted economic technique which represents the best available data for the South Platte River Watershed. However, these values should be viewed as underestimates. Many gaps occur in the valuation literature, so not every ecosystem service was valued for every land cover type. Therefore, comparisons across land cover types or ecosystem services must be made with caution. For example, one reason that the Upper Watershed has such a high value in terms of ecosystem services is because of the fact that the majority of the Upper Watershed is forested, which is very well represented in the valuation literature. The plains contain mostly grassland and agricultural land, which are not as well represented. This does not mean agriculture and grasslands are not valuable. Rather, it highlights a lack of primary, peer-reviewed data for that area.

The Ecosystem Services Valuation (ESV) Map (Figures 15 through 18) is the product of extensive valuation of ecosystem services produced in the watershed. By using the foundation created by the natural capital asset map, the ESV map values the ecosystem services produced by the natural assets present at that location and produces a mean annual value ($/acre/year). We chose to only represent mean values in the map to simplify the results. Mean annual value within the ESV layer ranges from 0 to over $9,000 per acre per year. Table 8 below offers more detail on the values of the Natural Assets of Importance per project area.

Table 8. Total Ecosystem Service Values by Natural Asset of Importance

Location and NAI	Ecosystem Services Value (million USD per year)		
	Minimum	Maximum	Average
UPPER WATERSHED			
Native Forest Resources	152.7	500.4	317.4
Productive Ag Resources	0.1	0.2	0.1
Wildlife Habitat	485.2	935.5	710.3
Clean Drinking Water	2,223.8	3,020.6	2,622.2
Healthy Waterways	74.6	136.5	105.5
Access to Nature	328.4	4,215.1	2,271.8
Upper Watershed Total	***3,265***	***8,808***	***6,027***
DENVER METRO			
Productive Agricultural Resources	0.4	0.4	0.4

Wildlife Habitat	53.7	55.7	54.7
Healthy Waterways	73.2	75.9	74.5
Access to Nature	15.9	75.6	45.7
Urban Forest Resources & Parks	433.5	805.6	619.6
Denver Metro Total	***577***	***1,013***	***795***
PLAINS			
Native Forest Resources	47.8	85.6	66.7
Productive Ag Resources	5.8	5.8	5.8
Wildlife Habitat	31.6	55.7	43.7
Clean Drinking Water	251.8	400.0	325.9
Healthy Waterways	35.2	44.3	39.8
Access to Nature	16.7	140.5	78.6
Plains Total	***389***	***732***	***561***
South Platte Watershed Total	***4,231***	***10,553***	***7,383***

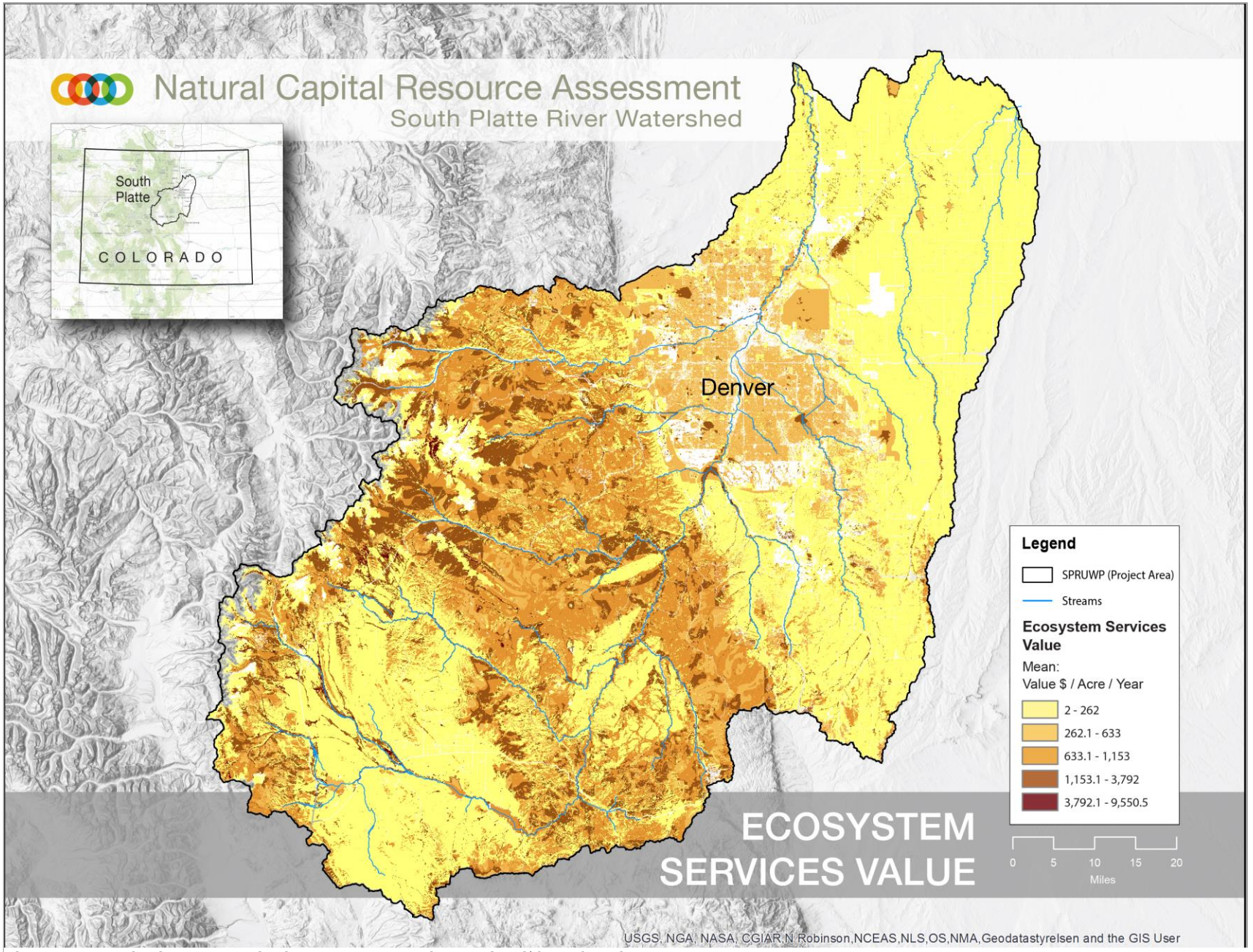


Figure 15. South Platte Watershed Ecosystem Services Value ($/Acre/year)

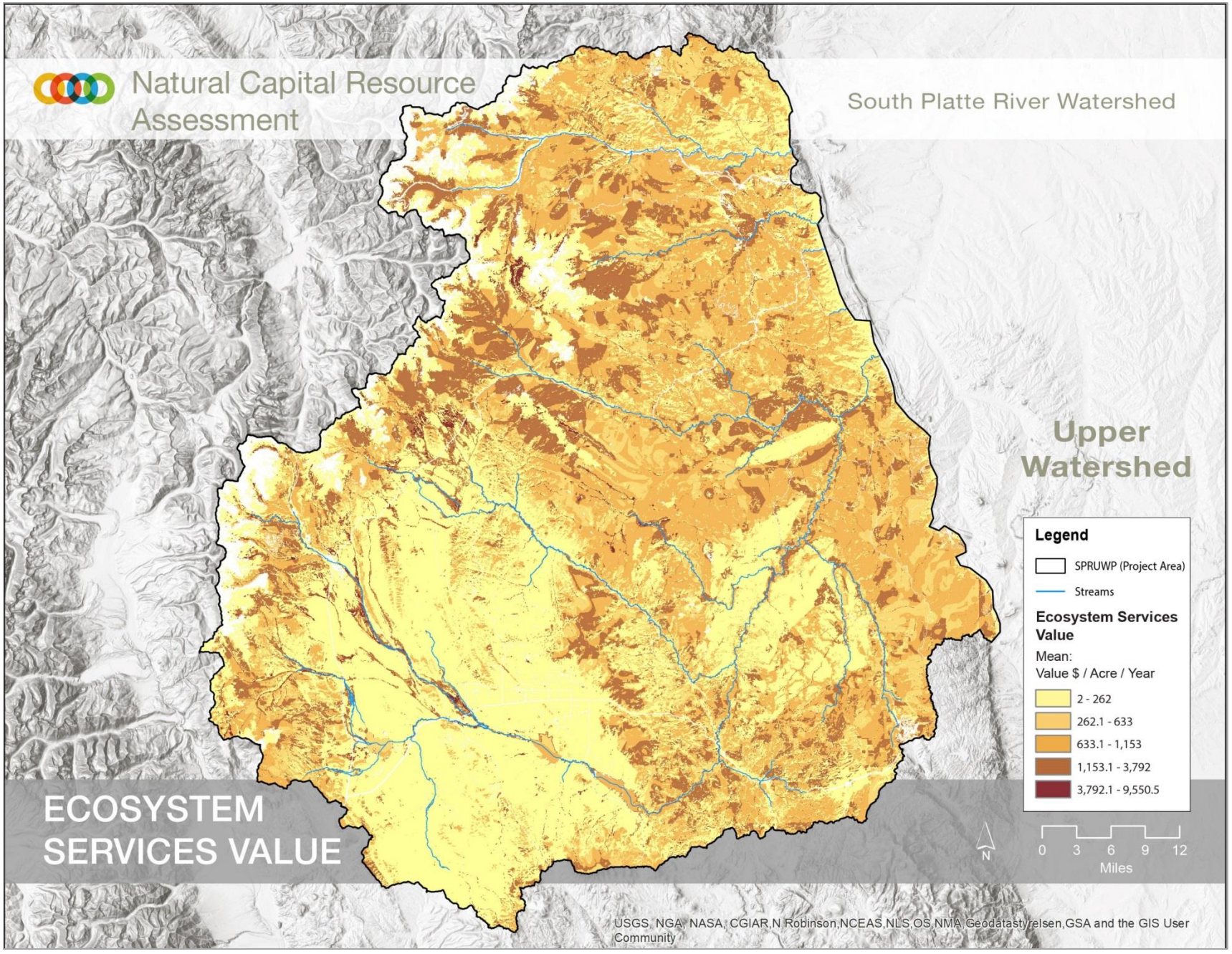


Figure 16. Ecosystem Services Value Upper Watershed ($/Acre/Year)

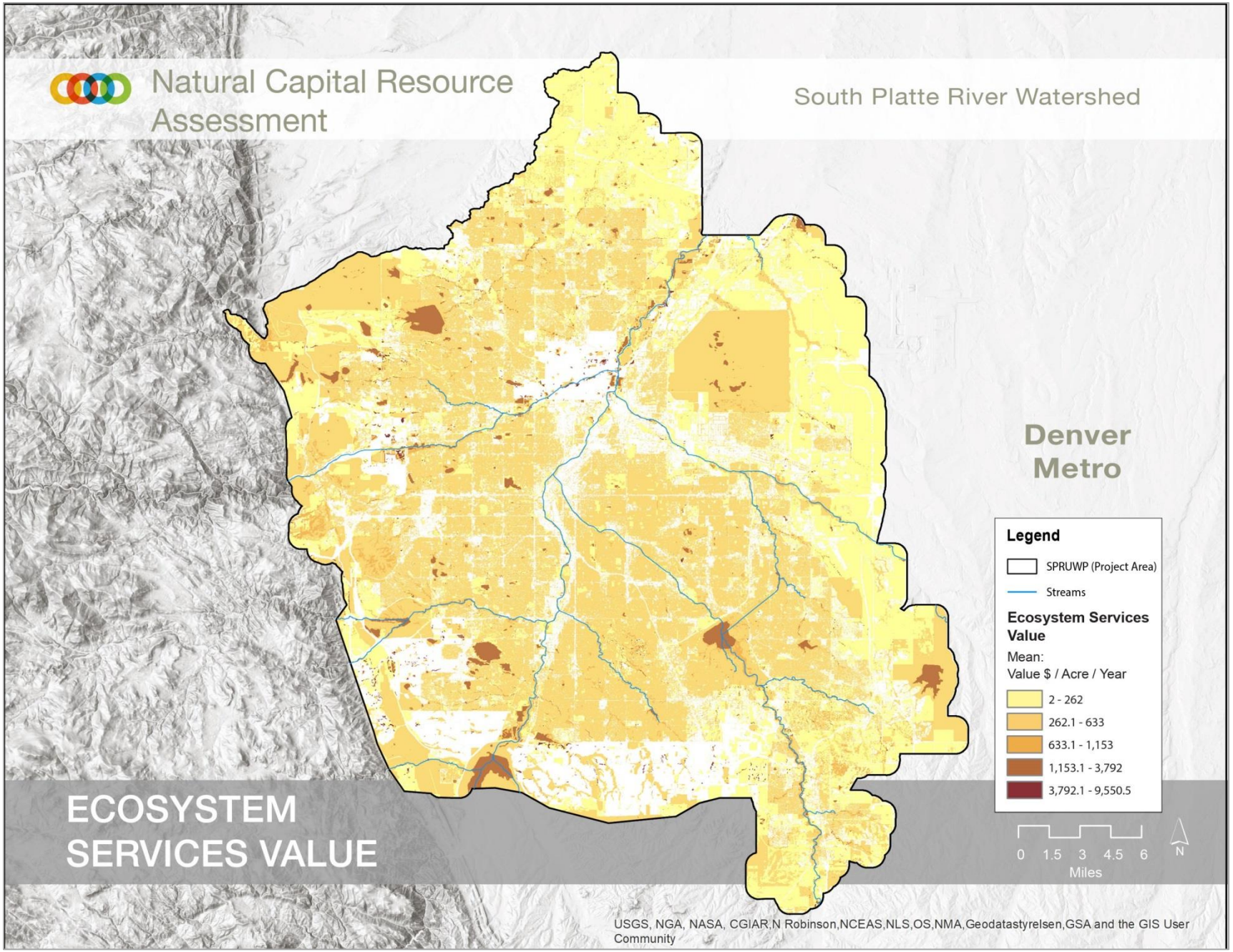


Figure 17. Ecosystem Services Value Denver Metro ($/Acre/Year)

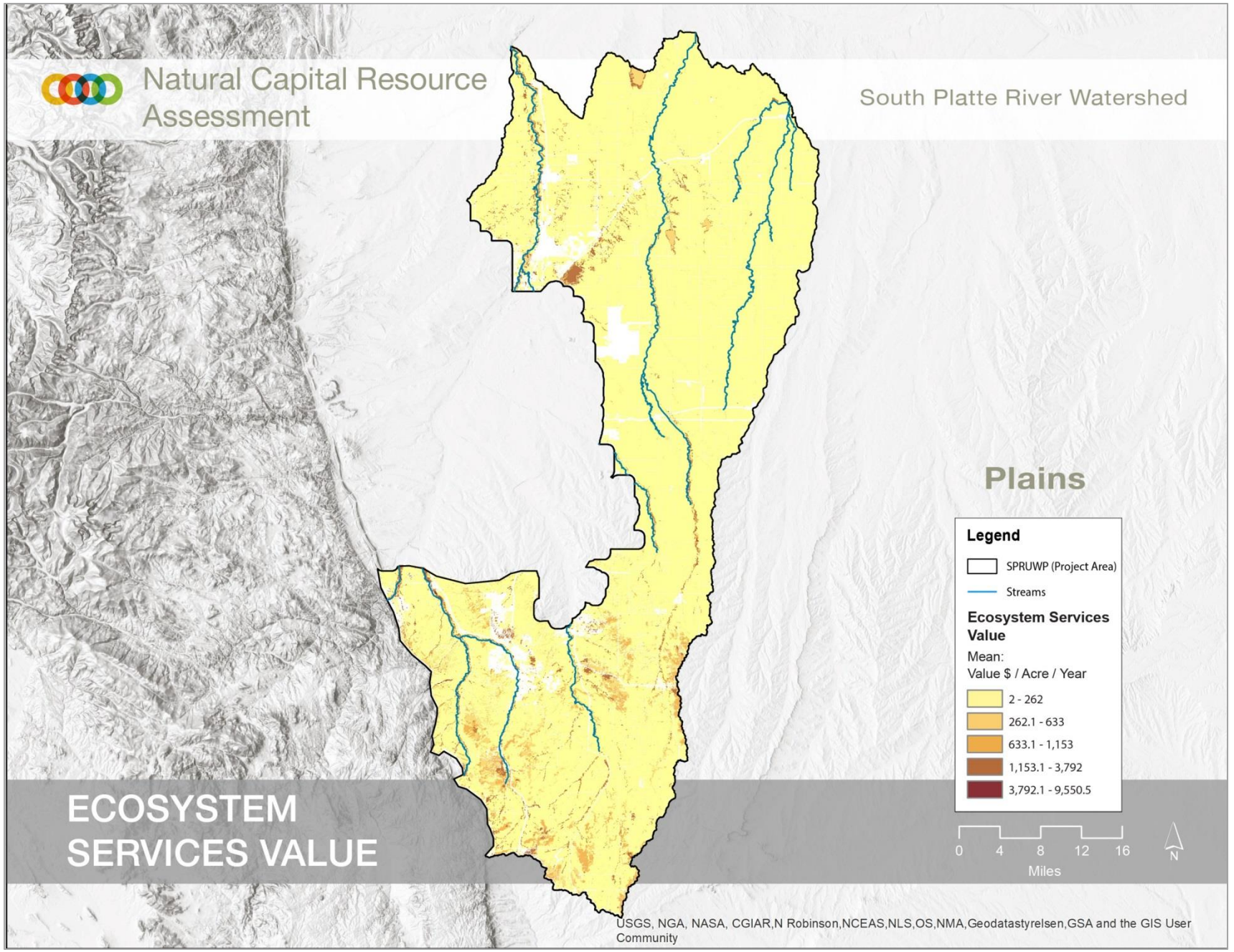


Figure 18. Ecosystem Services Value Plains ($/Acre/Year)

Prioritization

The South Platte Natural Capital Project produces project prioritization based on the Natural Capital and Ecosystem Services Valuation (ESV) data created through this project. The goal of the project prioritization is to develop and map priority areas for resource investment (restoration, forest health practices, green stormwater infrastructure, preservation and conservation etc.) within the priority categories outlined by the stakeholders (Table 9).

Table 9. Prioritization Categories

Upper Watershed (8)	Denver Metro (8)	Plains (8)
Wildland Fire	Urban Heat Island	Wildland Fire
Water Quality / Quantity	Water Quality / Quantity	Water Quality / Quantity
Invasive Species / Insect & Disease	Invasive Species / Insect & Disease	Invasive Species / Insect & Disease
Development	Development	Development
Flooding	Flooding	Flooding
Biodiversity / Wildlife Habitat	Biodiversity / Wildlife Habitat	Biodiversity / Wildlife Habitat
Recreation	Recreation	Recreation
Connectivity	Demographic Factors Environmental Justice & Public Health)	Connectivity

The project prioritization employs data from the Meta-Analysis (Figure 10). The datasets identified in the Meta-Analysis coupled with the ESV and Natural Capital layers provide additional resolution to each stakeholder's area of interest and prioritization needs. The prioritization briefs presented below document the prioritization layer employed from the Meta-Analysis and then summarizes the prioritization layer's geographic area for Natural Capital and ESV data. This action allows stakeholders to analyze their prioritization's geographic area and analyze high-value landscapes versus low-value landscapes (ESV layer), while simultaneously exploring the natural capital (high functioning landscapes v. low functioning landscapes).

Additionally, provided prior to the prioritization briefs is the "Prioritization Processing Steps." These are step-by-step instructions for how to create one's own prioritization using any data layer from the Meta-Analysis or new data.

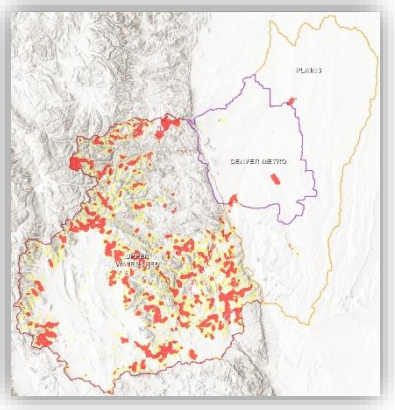


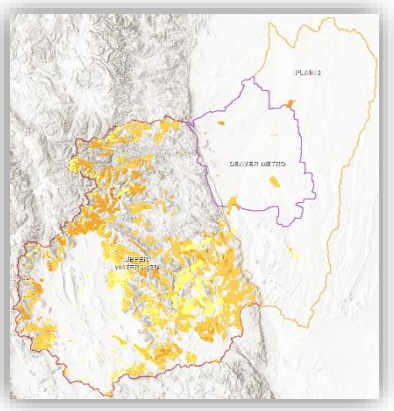
Prioritization Processing Steps

The final prioritization is based on the project area's Natural Asset map, the economic analysis and information from existing projects (e.g. CUSP and USP), and data (e.g. FEMA Flood Zones). A total of seven Natural Assets of Importance were identified by the stakeholder team as being valuable to the environment and people of the South Platte: native forest resources, productive agricultural resources, wildlife habitat, clean drinking water, healthy waterways, access to nature, and urban ecosystem resources and parks. The following geo-processing steps were taken to achieve the desired results:

1. Reclassify source data

Source datasets were reclassified to limit analysis to only the areas of highest concern. For the recreation prioritization category, the high (3) and very high (4) categories were selected.



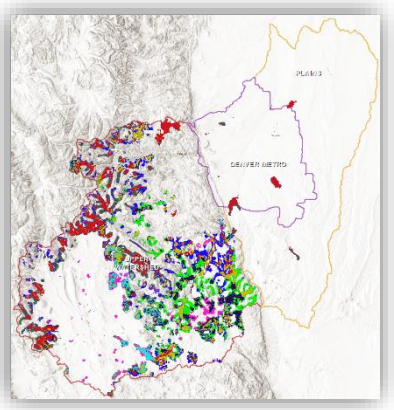


2. Combine

Using the Combine tool in ArcGIS, the reclassified data was combined with the Natural Asset map. This tool creates an intersection of raster layers and outputs all the unique combinations or overlaps between multiple datasets. For the recreation prioritization category, this step shows where recreation density is highest as well as the natural asset ranking at that location.

3. Lookup

Using the Lookup tool in ArcGIS, a new layer was created to show Ecosystem Services Valuation (ESV) for each 30 x 30-meter pixel across the project area. ESV depicts the mean annual value ($/acre/year) that each pixel provides in ecosystem services.



4. Zonal Statistics

Using the Zonal Statistics tool in ArcGIS, the mean ESV value for each area of interest was calculated. For the recreation prioritization category, the final output shows the recreation density score, the Natural Asset rank, and the ESV value.

Wildfire Risk

This prioritization focuses on wildfire, which is a major disturbance agent in the South Platte Watershed. The high and very high-risk categories were analyzed for prioritization.

Data Layer/s:
Colorado State Forest Service, Colorado Wildfire Risk Assessment Project, 2012

Data Layer Description:
A composite layer of the possibility of loss or harm from a wildfire created by combining the probability of a wildfire occurring with the potential impacts, if a wildfire did occur

Natural Capital and ESV Results:

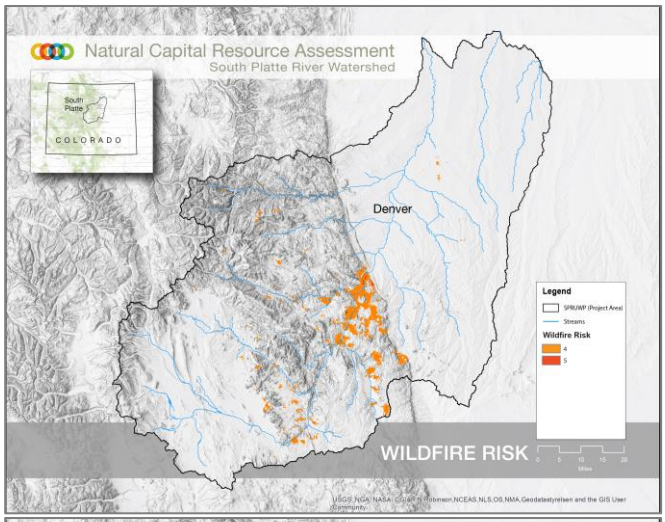
High Wildfire Risk Areas (Cat. 4)

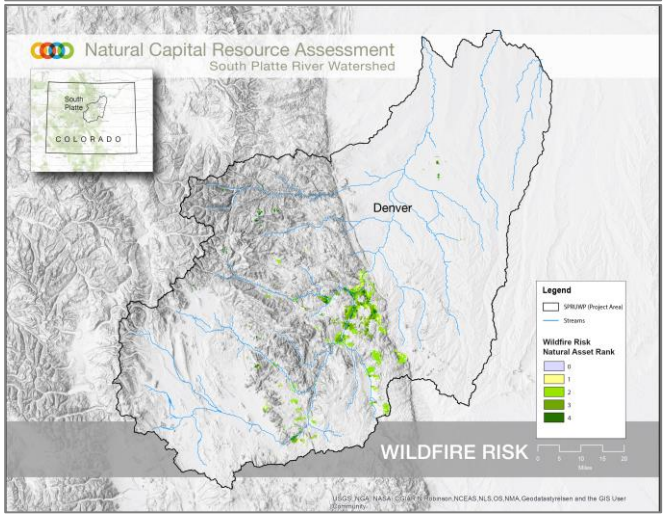
NA Rank	Acres	% NA	ESV Sum	% ESV
0	3949.7	5.4%	3,923,423	1.5%
1	9101.3	12.4%	22,442,915	8.5%
2	27551.8	37.6%	96,806,702	36.8%
3	23810.0	32.5%	99,961,476	38.0%
4	8934.7	12.2%	39,944,451	15.2%
Total	**73347.6**	**100.0%**	**263,078,968**	**100.0%**

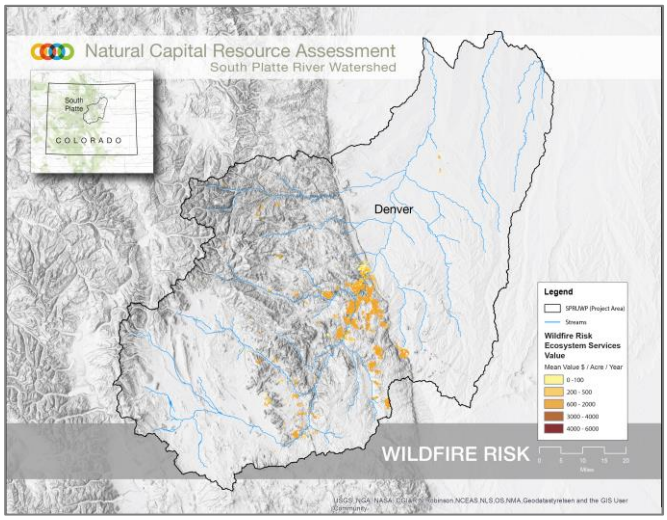
Very High Wildfire Risk Areas (Cat. 5)

NA Rank	Acres	% NA	ESV Sum	% ESV
0	206.6	35.9%	163,359	21.1%
1	191.5	33.3%	205,151	26.5%
2	109.2	19.0%	152,863	19.7%
3	38.3	6.7%	153,174	19.8%
4	29.4	5.1%	99,697	12.9%
Total	**574.9**	**100.0%**	**774,244**	**100.0%**

Project Areas:
Upper Watershed and Plains







Wildlife Habitat (Biodiversity)

This prioritization focuses on important wildlife habitats in the South Platte Watershed. The high and very high categories were analyzed for prioritization.

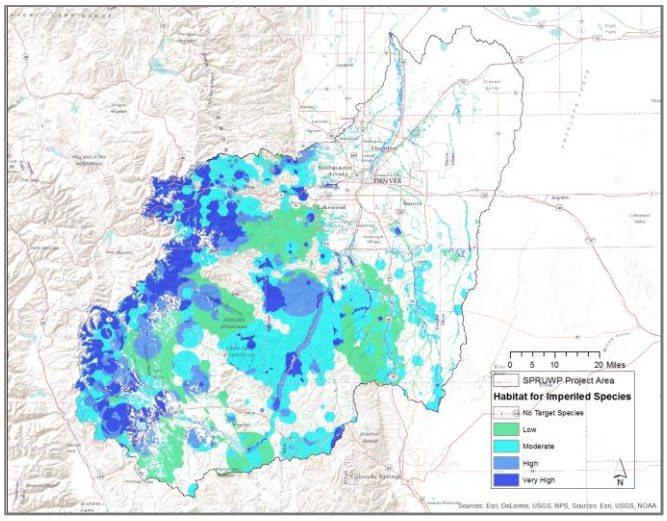
Data Layer/s:
Colorado State Forest Service, Important Habitat for Imperiled Species, 2008.

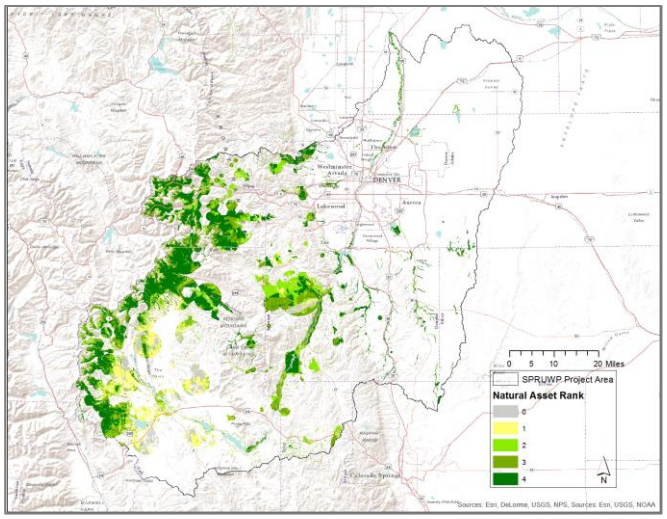
Data Layer Description:
The wildlife habitat layer identifies landscapes that represent or significantly contribute to viable habitats for focal conservation species (e.g., Threatened and Endangered species, state species of concern or keystone species that are representative of a healthy ecosystem).

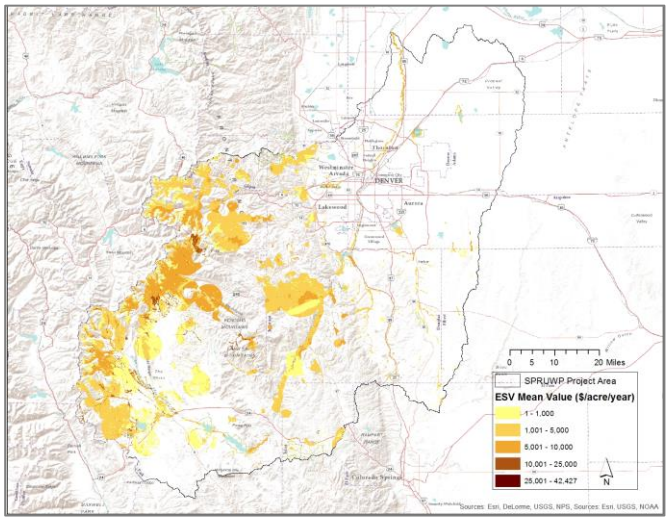
Natural Capital and ESV Results:
High and Very High Habitat for Imperiled Species

NA Rank	Acres	% NA	ESV Sum	% ESV
0	42,403	6%	29,346,039	1%
1	98,202	14%	126,434,963	6%
2	119,153	18%	391,022,456	17%
3	158,492	23%	538,740,675	23%
4	261,546	39%	1,232,649,193	53%
Total	**679,795**	**100.0%**	**2,318,193,374**	**100.0%**

Project Areas:
Portions of All







Urban Heat Island

This prioritization focuses on Urban Heart Island issues within the Denver Metro Region. The hot category was analyzed for this prioritization

Data Layer/s:
City and County of Denver - Denver Parks and Recreation / Office of the City Forester, and The University of California Davis - The Department of Land, Air, and Water Resources, and USDA Forest Service, Pacific Southwest Research Station, Urban Ecosystems and Social Dynamics

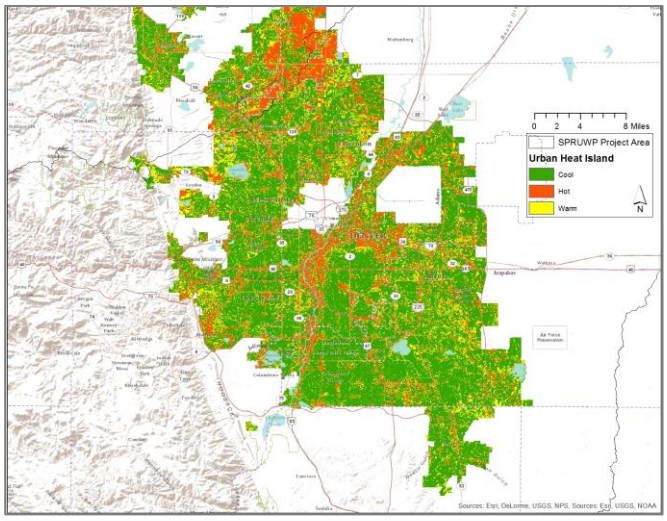
Data Layer Description:
Identifies urban heat island (UHI) using land surface temperatures (LST)

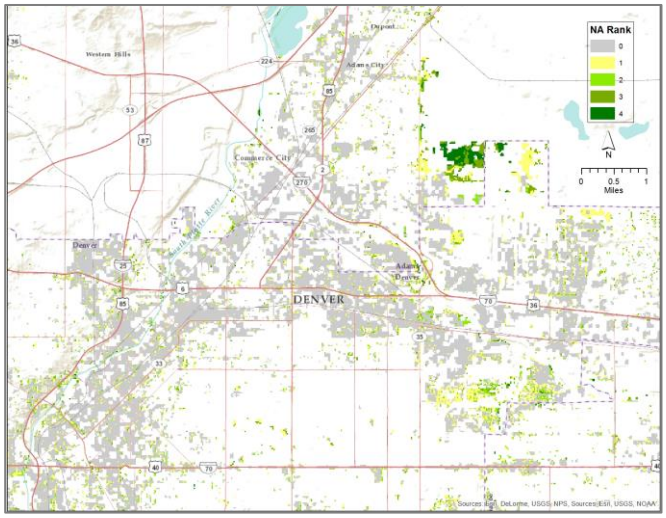
Natural Capital and ESV Results:
Urban Heat Island Hot Category

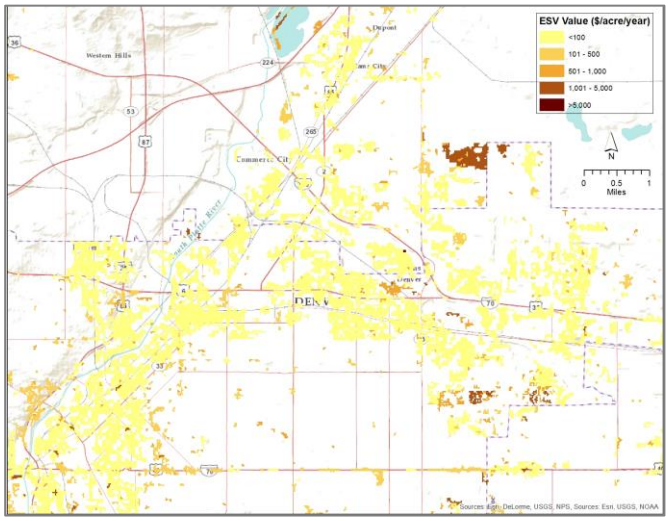
NA Rank	Acres	% NA	ESV Sum	% ESV
0	32,458	53%	2,195,016	18%
1	12,276	20%	1,606,740	13%
2	7,983	13%	1,410,091	12%
3	5,553	9%	2,145,526	18%
4	3,393	6%	4,883,478	40%
Total	**61,664**	**100.0%**	**12,240,478**	**100.0%**

**Natural Asset and ESV maps are zoomed in so that the detail of each layer is visible.

Project Areas:
Denver Metro Area







Flooding

This prioritization concentrates on FEMA's Flood Hazard Layer which maps floodplains and likely inundation zones.

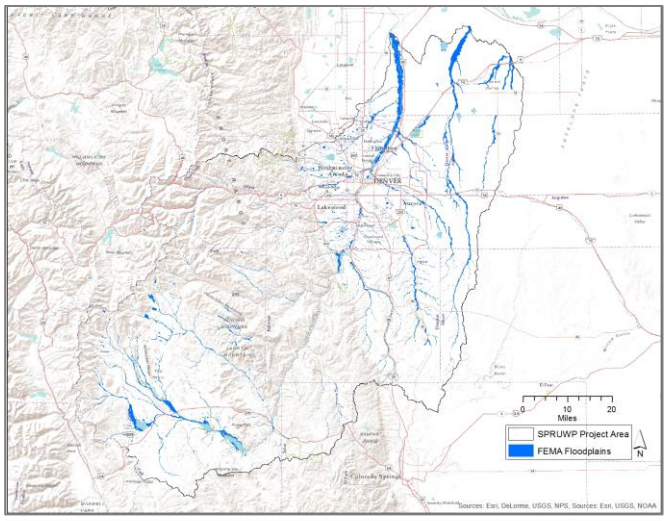
Data Layer/s:
FEMA Flood Hazard Zones. Accessed March 2017, via: https://fema.maps.arcgis.com/home/index.html

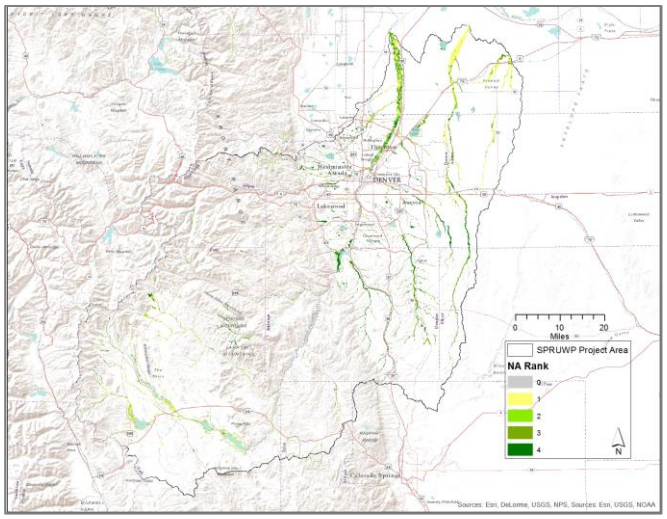
Data Layer Description:
The National Flood Hazard Layer (NFHL) is a digital database that contains flood hazard mapping data from FEMA's National Flood Insurance Program (NFIP). This map data is derived from Flood Insurance Rate Map (FIRM) databases and Letters of Map Revision (LOMRs).

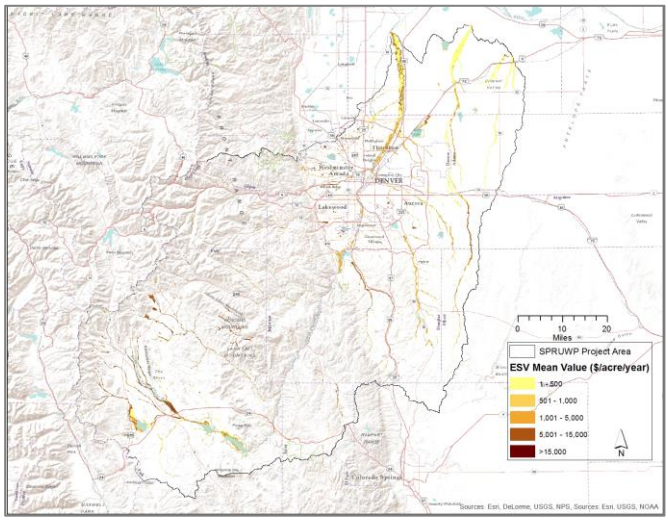
Natural Capital and ESV Results:
FEMA Flood Hazard Layer

NA Rank	Acres	% NA	ESV Sum	% ESV
0	17,915	12%	35,524,158	6%
1	47,427	31%	117,539,823	23%
2	25,229	16%	95,160,756	18%
3	23,412	15%	85,409,036	16%
4	40,715	26%	188,754,899	36%
Total	**154,698**	**100.0%**	**519,385,672**	**100.0%**

Project Areas:
Portions of All







Development

This prioritization focuses on areas of the South Platte Watershed that are highly modified due to human development.

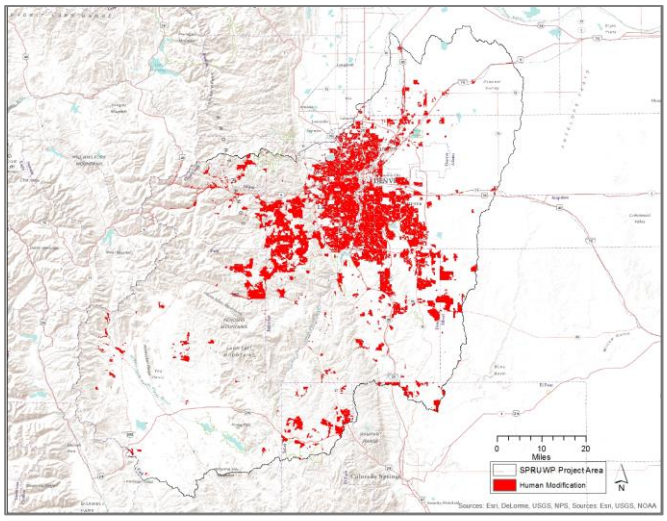
Data Layer/s:
Colorado State Forest service, Degree of Human Modification 2008.

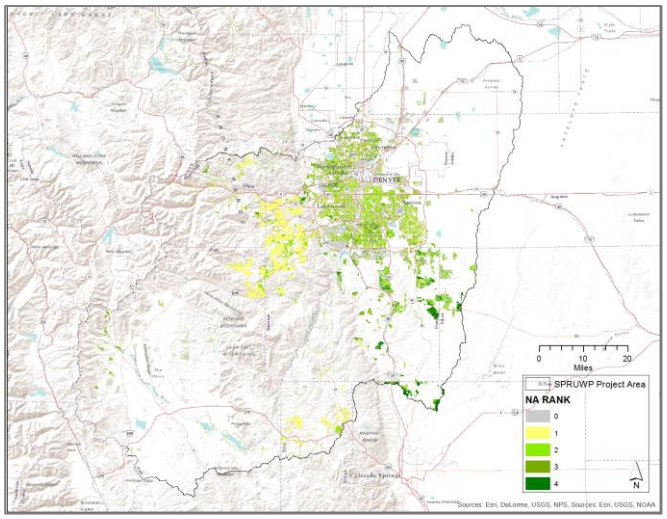
Data Layer Description:
This layer captures the estimated amount of modification of habitat due to human development.

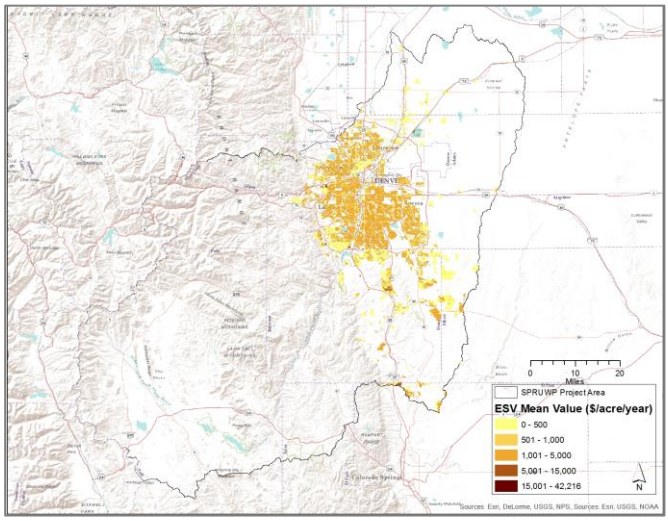
Natural Capital and ESV Results:
Highly Modified Due to Development

NA Rank	Acres	% NA	ESV Sum	% ESV
0	120,060	29%	36,471,070	9%
1	133,732	32%	77,320,347	19%
2	93,862	22%	138,107,216	34%
3	48,869	12%	89,688,759	22%
4	23,878	6%	61,482,808	15%
Total	**420,401**	**100.0%**	**403,070,200**	**100.0%**

Project Areas:
Portions of All







Water Quality/Quantity

This prioritization focuses important drinking water source areas of the South Platte Watershed. The highest drinking water importance category (10) was used to determine the prioritization area.

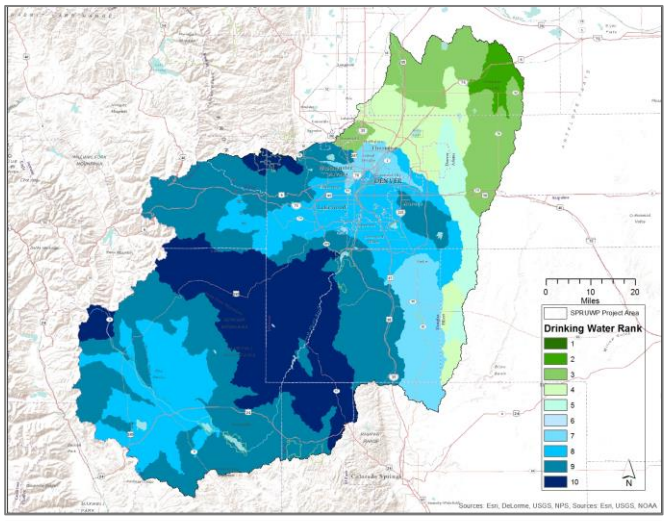
Data Layer/s:
Colorado State Forest Service, Colorado Wildfire Risk Assessment Project 2012, USFS, West Wide Wildfire Risk Assessment

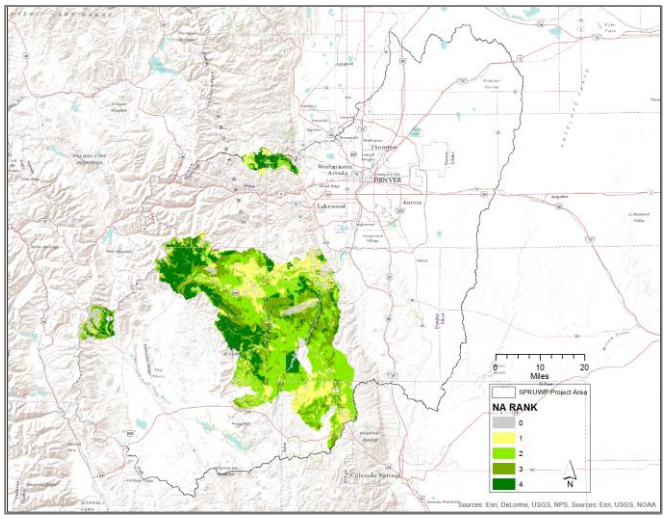
Data Layer Description:
A measure of quality and quantity of public surface drinking water categorized by watershed. Similar to the USFS Forests to Faucets data, but tailored to Colorado.

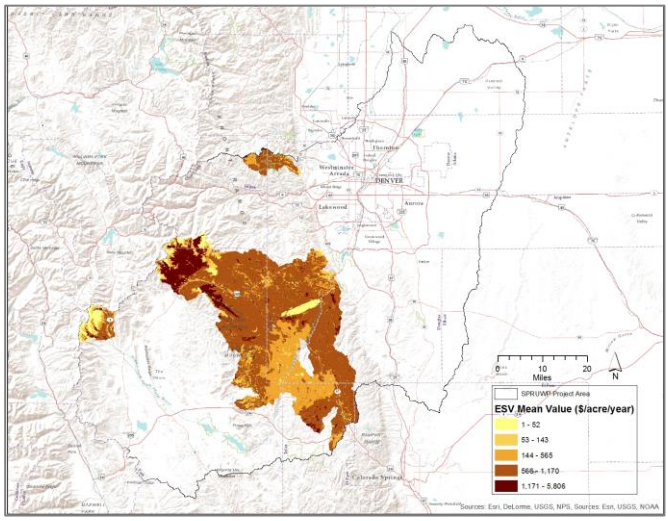
Natural Capital and ESV Results:
Important Drinking Water Sources

NA Rank	Acres	% NA	ESV Sum	% ESV
0	48,975	6.6%	2,675,071	9%
1	140,995	18.9%	5,043,125	16%
2	255,548	34.3%	8,075,596	26%
3	161,456	21.7%	9,000,311	29%
4	138,316	18.6%	6,521,429	21%
Total	**745,291**	**100%**	**31,315,533**	**100%**

Project Areas:
Upper Watershed







Recreation

This prioritization centers on high use recreation areas within the South Platte Watershed.

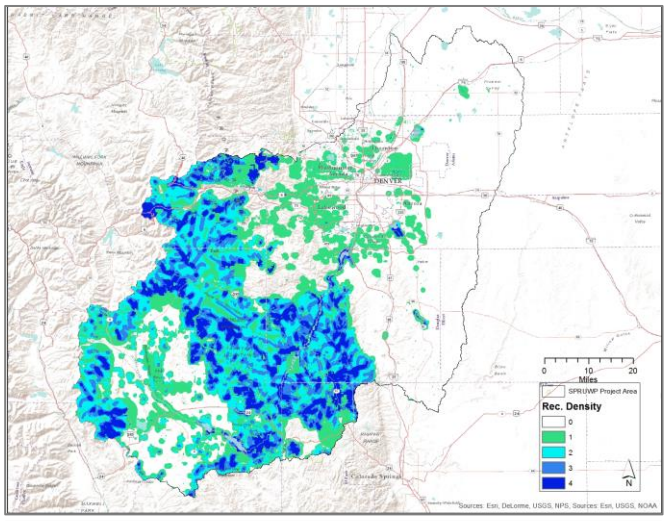
Data Layer/s:
Colorado State Forest Service, Density of Recreation Opportunities, 2008.

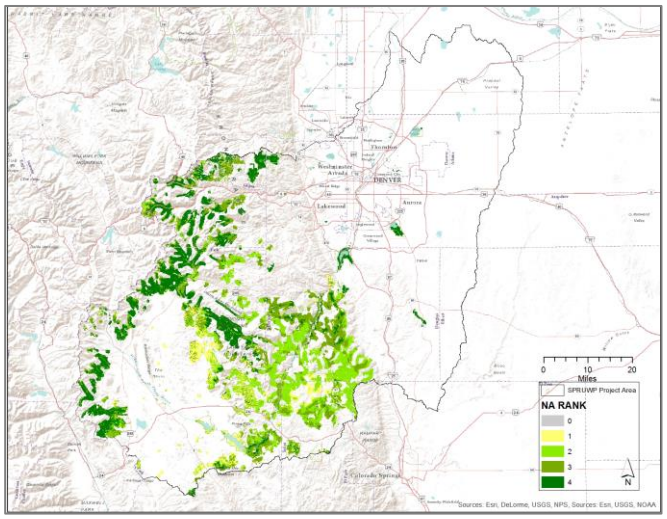
Data Layer Description:
The recreation density layer shows where the greatest density of forest-based recreation opportunities exists within the South Platte Watershed. The prioritization focuses on the high (3) and very high category (4).

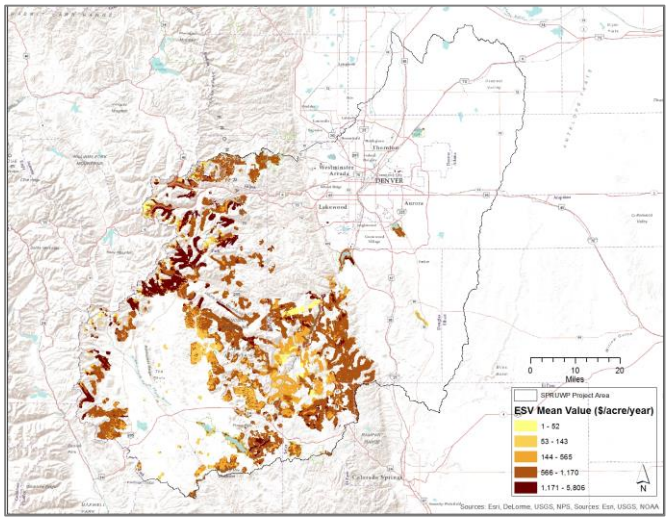
Natural Capital and ESV Results:
Very High Recreation Density Areas

NA Rank	Acres	% NA	ESV Sum	% ESV
0	9,960	1.5%	537,574	1%
1	81,250	12.1%	4,460,329	12%
2	187,735	28.0%	8,388,707	23%
3	189,195	28.2%	13,473,363	37%
4	201,809	30.1%	9,223,859	26%
Total	**669,948**	**100%**	**36,083,832**	**100%**

Project Areas:
Portions of All







Invasive Species/Insects & Disease

This prioritization addresses the problems that insects & disease cause in the South Platte Watershed. This analysis centers on the “at-risk” category in the insect and disease layer.

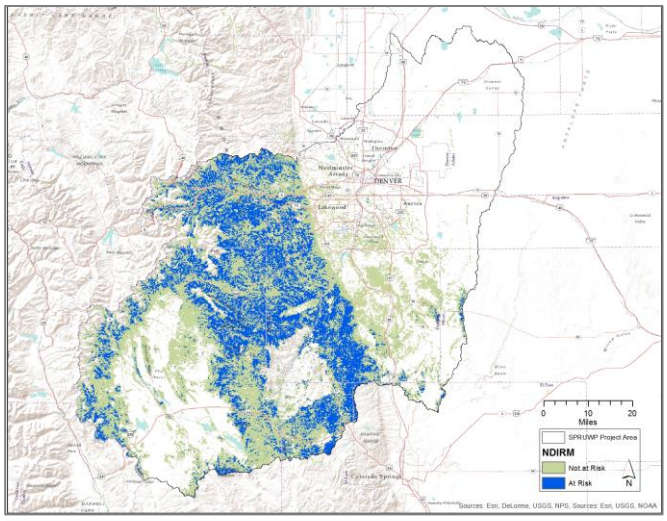
Data Layer/s:
USDA. 2012 National Insect and Disease Risk Map (NIDRM) project.

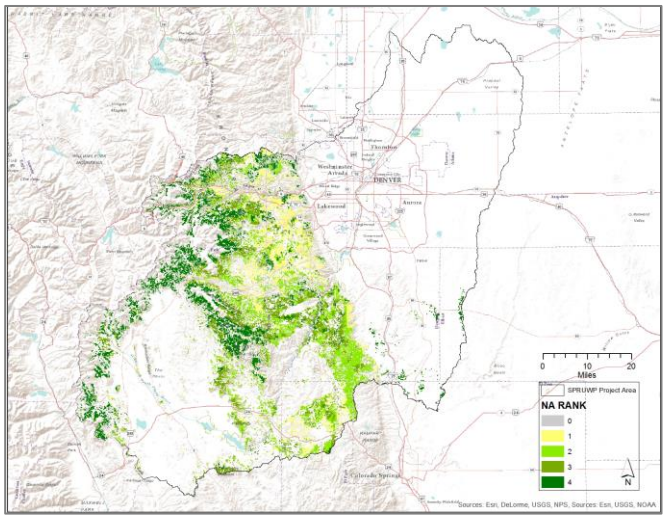
Data Layer Description:
The primary goal of the 2012 National Insect and Disease Risk Map (NIDRM) is to provide policy makers, USDA officials, and federal and state land managers with a periodic strategic assessment for risk of tree mortality due to major insects and diseases.

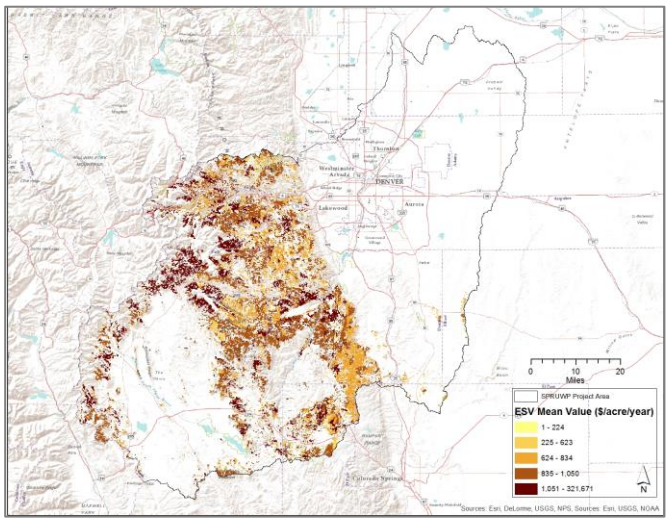
Natural Capital and ESV Results:
Insect and Disease At-Risk areas

NA Rank	Acres	% NA	ESV Sum	% ESV
0	9,004	1.5%	1,526,074	7%
1	100,481	16.7%	3,454,771	16%
2	172,939	28.8%	5,510,800	26%
3	150,487	25.0%	5,464,989	26%
4	168,468	28.0%	5,053,791	24%
Total	**601,378**	**100%**	**21,010,425**	**100%**

Project Areas:
Upper Watershed & Plains







Environmental Justice

This prioritization focuses on the social vulnerability of Environmental Justice (EJ). This EJ analysis centers on EJSCREEN's (EPA) indicator for vulnerable communities that is based on six demographic factors (Percent low-income, percent minority, education, linguistic isolation, individuals less than 5 and over 64).

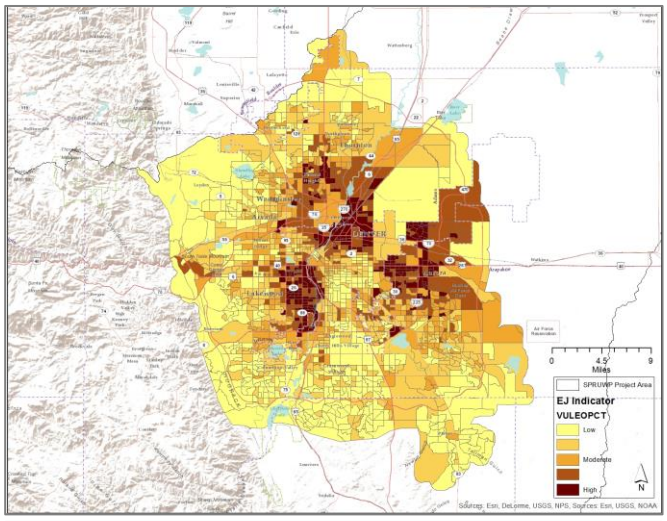
Data Layer/s:
U.S. Environmental Protection Agency (EPA), 2016. EJSCREEN Technical Documentation.

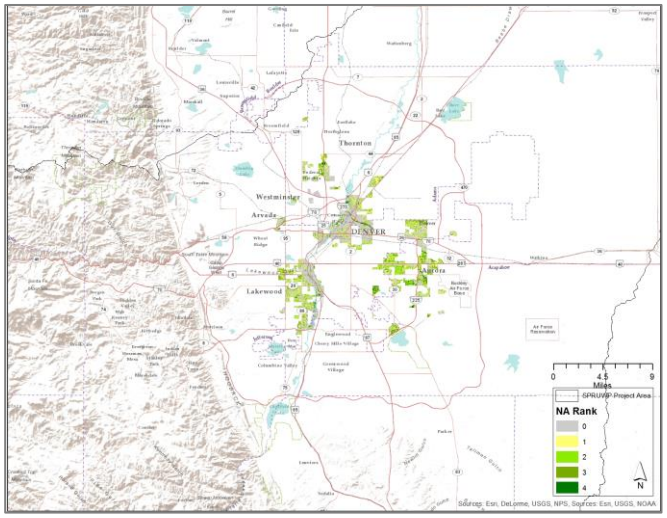
Data Layer Description:
EJ mapping and screening tools combine environmental and demographic indicators to highlight geographic areas at risk of elevated pollution levels and exposure to deleterious environmental conditions.

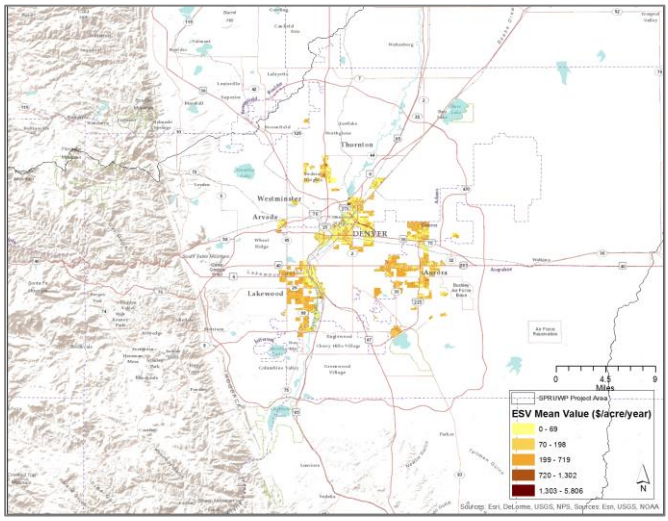
Natural Capital and ESV Results:
EJScreen Indicator (6 demographic factors)

NA Rank	Acres	% NA	ESV Sum	% ESV
0	15,053	49.1%	556,649	5%
1	6,322	20.6%	3,405,787	31%
2	4,789	15.6%	3,504,282	32%
3	3,436	11.2%	2,638,747	24%
4	1,070	3.5%	832,646	8%
Total	30,670	100%	10,938,111	100%

Project Areas:
Denver Metro Area







Environmental Justice

This prioritization focuses on the demographics of an "at-risk" population. This EJ analysis centers on EJSCREEN's (EPA) Respiratory Hazard Index (RESP field). This analysis highlights the most at-risk areas of the South Platte Watershed for respiratory health issues.

Data Layer/s:

U.S. Environmental Protection Agency (EPA), 2016. EJSCREEN Technical Documentation.

Data Layer Description:

EJ mapping and screening tools combine environmental and demographic indicators to highlight geographic areas at risk of elevated pollution levels and exposure to deleterious environmental conditions.

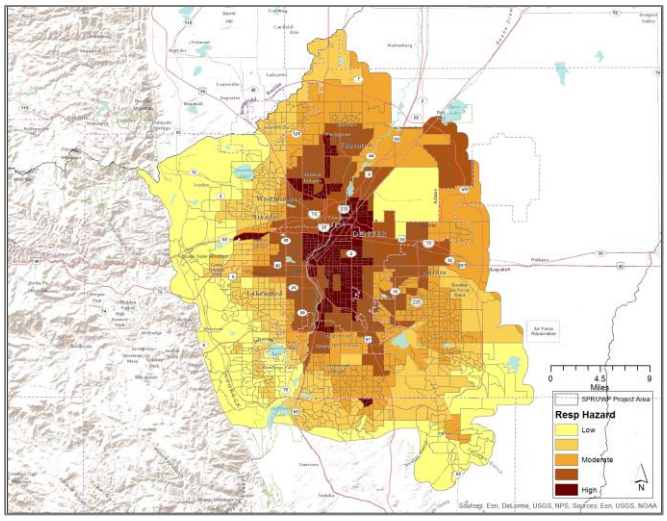
Natural Capital and ESV Results:

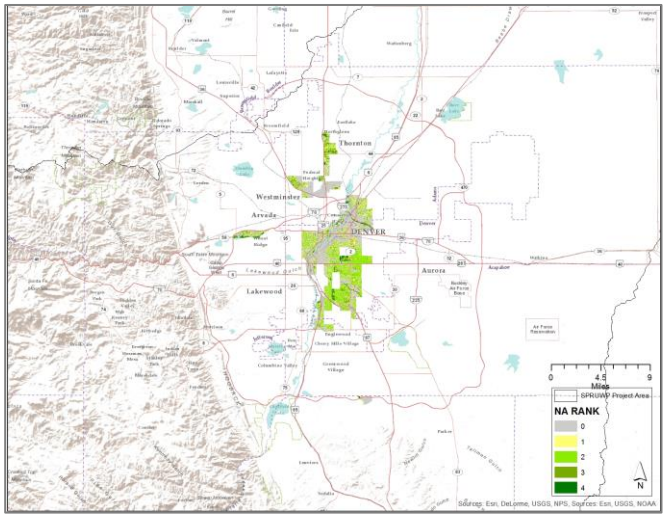
Respiratory Hazard Index

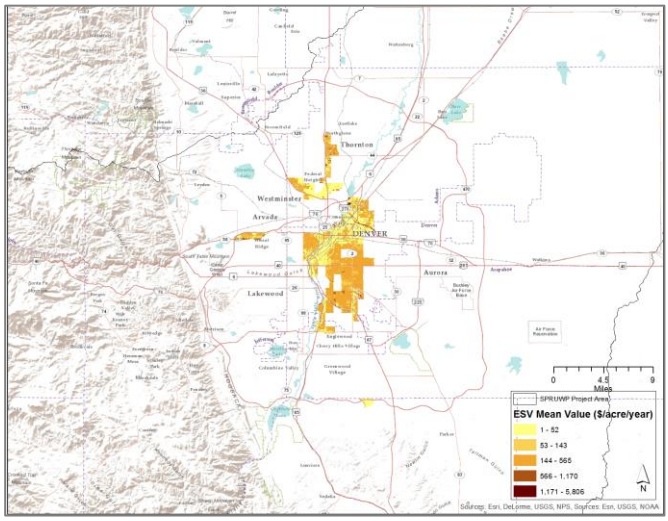
NA Rank	Acres	% NA	ESV Sum	% ESV
0	16,069	47.8%	809,322	8%
1	5,709	17.0%	3,890,896	37%
2	7,915	23.5%	2,861,966	28%
3	2,872	8.5%	2,198,014	21%
4	1,046	3.1%	620,268	6%
Total	**33,611**	**100%**	**10,380,465**	**100%**

Project Areas:

Denver Metro Area







Connectivity

This prioritization focuses on connectivity in the Denver Metro Area and Plains. The connectivity analysis relies on trails, river preservation areas, and parks and open space. This analysis looks at areas that can improve connectivity between green spaces in the two project areas.

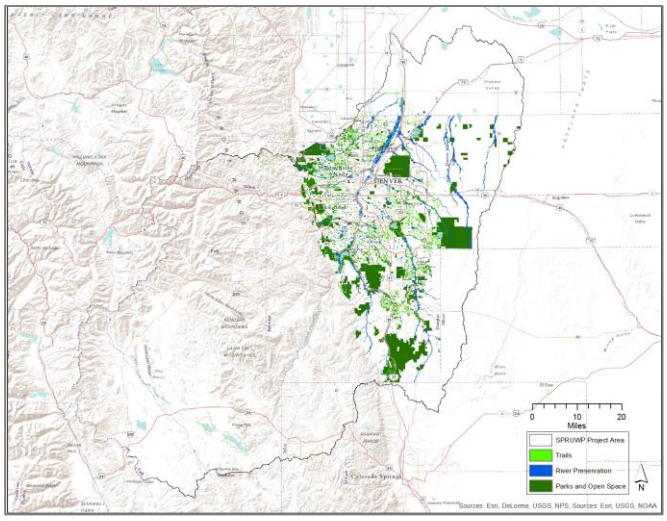
Data Layer/s:
Greenprint Regional Trails, CoMAP Parks and Open Space, and River Preservation Areas

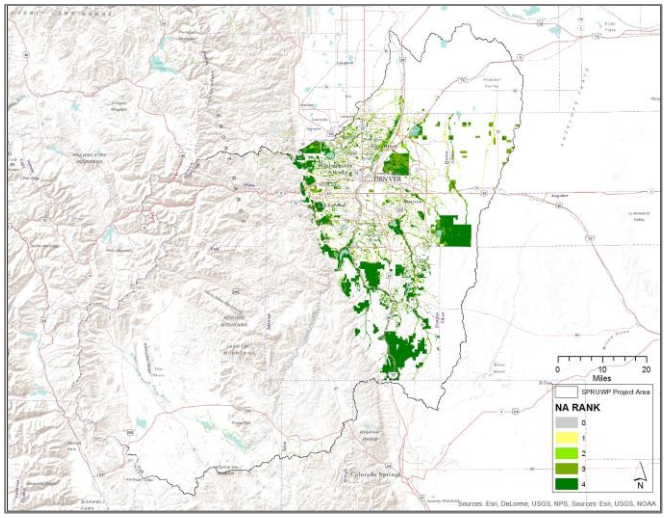
Data Layer Description:
A composite layer was created by combining the Greenprint Regional Trails, CoMAP Parks and Open Space and River Preservation Areas layers.

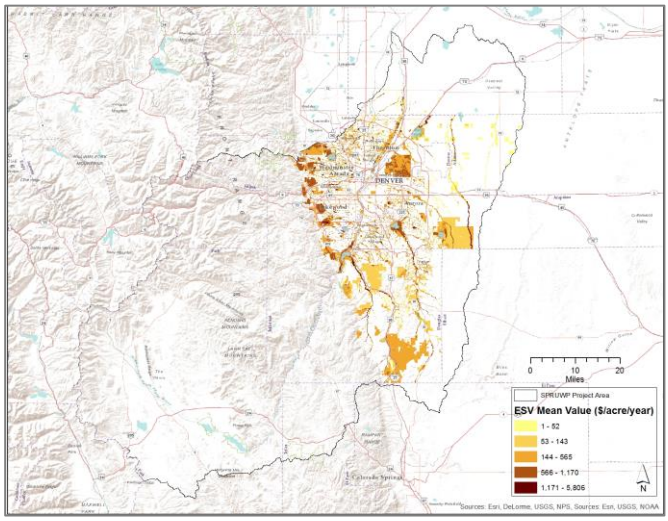
Natural Capital and ESV Results:
Connectivity

NA Rank	Acres	% NA	ESV Sum	% ESV
0	10,504	3.2%	771,265	1%
1	25,386	7.7%	5,348,721	10%
2	30,706	9.3%	9,856,728	18%
3	68,828	20.9%	18,643,278	35%
4	193,304	58.8%	18,906,661	35%
Total	**328,728**	**100%**	**53,526,653**	**100%**

Project Areas:
Denver Metro Area and Plains







South Platte Natural Capital Project – Prioritization Case Studies

The following prioritization case studies were developed using input from Project Directors and the Stakeholder Team. Each case study demonstrates how the Natural Capital outputs and tools can be used to prioritize future investments in high priority natural assets for the South Platte Watershed. The Case Studies, presented below, build off the overall project prioritization by combining multiple individual prioritizations into one single prioritization. In this effort, several datasets are combined to create a more refined prioritization that meets multiple adjectives.

Case studies, like the prioritization, examine where to invest resources for achieving two broad goals; **conserving high value natural assets and restoring low value natural assets**:

- The broad goal of "conserving high value natural assets" involves such things as placing high value landscapes into a conservation easement, reducing fire threat adjacent to high value timber areas, reducing recreation caused damage (e.g. trail maintenance) through important wildlife habitat, or preserving a high value agricultural area threatened by development. Overall, "conserving high value natural assets" centers on keeping valuable areas intact so that they continue to provide ecosystem services to the population within the South Platte River Watershed.
- The goal of "restoring low value natural assets" examines projects that focus on improving conditions, or increasing the functionality, of natural systems such as: restoring riparian vegetation along a stream or river to reduce erosion, thinning a dense forest that has a high fire risk, increasing tree canopy in an urban area to improve livability, or investing in urban trails to improve connectivity and safety for commuters and recreationists.

Water Quality / Quantity (WQ/WQ)

The WQ/WQ case study centers on improving overall watershed condition to improve water quality and reduce flooding risk to Chatfield Reservoir. Chatfield reservoir is an important reservoir in Denver Water's South Platte Reservoir System (Table 10). Not only does Chatfield provide drinking water to the Denver metro area, but it also serves as flood protection for the residents downstream.

Table 10. Denver Water South Platte System Reservoirs

Denver Water South Platte Reservoirs	Capacity (acre-feet)
Eleven Mile	97,779
Cheesman Lake	79,064
Strontia Springs	7,863
Chatfield	27,076

*https://www.denverwater.org/your-water/water-supply-and-planning/reservoir-levels

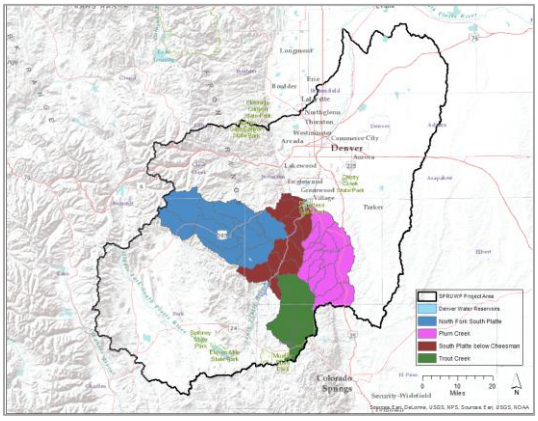
The WQ/WQ case study explores how to employ the Natural Capital Asset layer and ESV data to identify potential project locations and the values (ESV) associated with such projects. These projects will improve watershed condition to combat water quality issues and flooding in watersheds draining to Chatfield Reservoir.

Project Area: All (primarily Upper Watershed and Denver Metro)

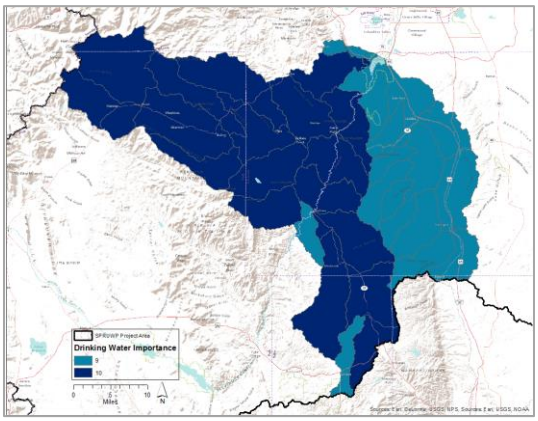
Datasets: Natural Capital Asset Layer, ESV Layer, FEMA Floodplains, USGS Hydrologic Units (HUC 12), CSFS Drinking Water Importance and National Hydrography Dataset (NHD) water bodies (reservoirs).

The case study identifies the Hydrologic Units that drain to Chatfield Reservoir (WQ/WQ 1), and why they are important (Drinking Water) (WQ/WQ 2).

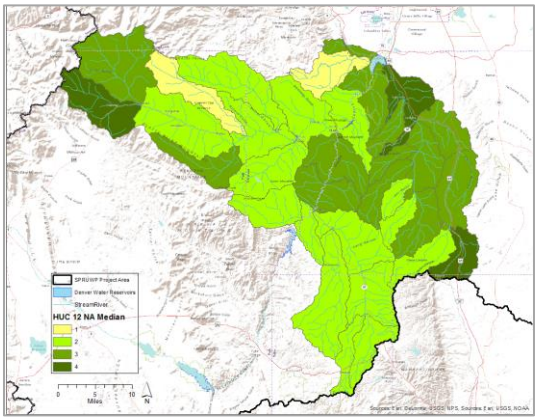
The Natural Capital Asset layer was then used to summarize the median Natural Asset rank per HUC to determine which HUCs had the lowest Natural Asset Rank (WQ/WQ 3).



WQ/WQ 1



WQ/WQ 2



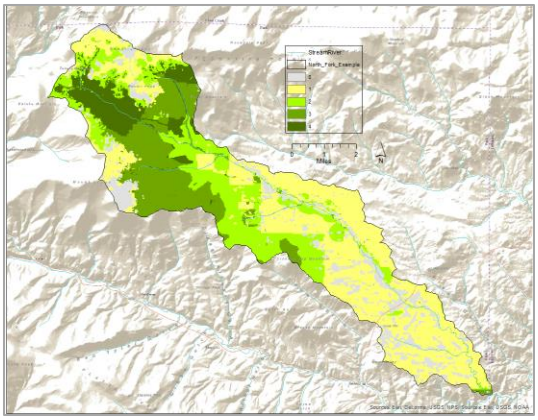
WQ/WQ 3

Deer Creek Watershed, a tributary to the North Fork of the South Platte River, was identified as a watershed with limited (median Natural Asset rank is 1) Natural Capital. Therefore, Deer Creek Watershed was selected to view at a greater resolution to determine where to invest resources.

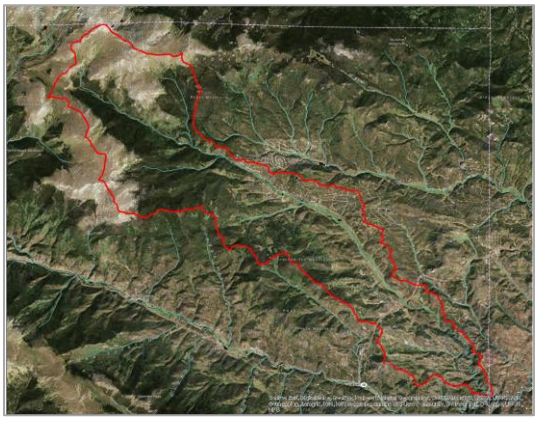
As seen in map WQ/WQ 4, much of the Deer Creek Watershed natural asset rank is 1 or below. Roads are apparent throughout the watershed (WQ/WQ 5). Roads often contribute sediment to local streams. Therefore, these areas need resource investment to improve the functionality of the local systems aimed at removing potential sediment from the Deer Creek Watershed.

ESV values for the Deer Creek Watershed (WQ/WQ 6) are generally low, which is to be expected for an area with such limited natural capital.

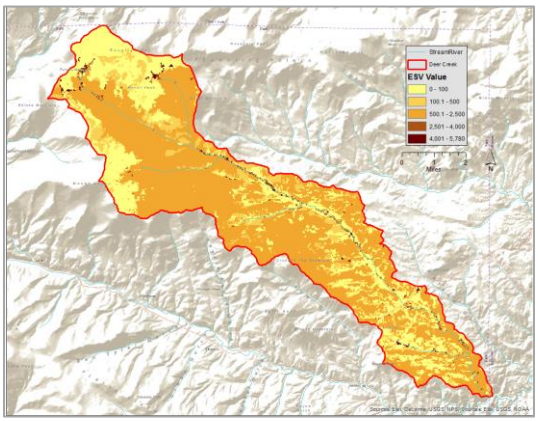
Further resource investment within the Deer Creek Watershed could occur in the form of floodplain restoration. WQ/WQ 7 depicts a zoomed in portion of Deer Creek's floodplain. Areas along the floodplain that have zero Natural Asset Rank would benefit from some intervention such as riparian plantings and streambank stabilization. Such projects would reduce sediment entering the stream and therefore improve water quality of the water that flows to Chatfield Reservoir.



WQ/WQ 4



WQ/WQ 5



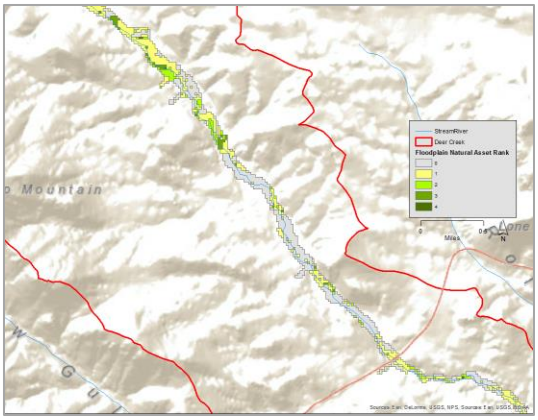
WQ/WQ 6

Much of the floodplain retains values in the 0 - $100 category, which is especially low considering the amount of Ecosystem Services that floodplains provide (e.g. flood retention, connectivity, water quality, habitat etc.). With restoration and resource investment, the floodplains within the Deer Creek Watershed could be providing greater than $2,000 per acre rather than less than $100 per acre.

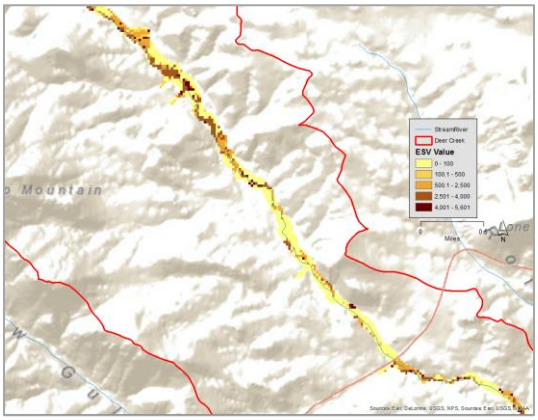
Below is a list of potential projects that could improve the functioning of the natural systems within the Deer Creek Watershed.

Potential Projects:

1. Road decommissions
2. Road improvements
3. Culvert upgrades
4. Riparian restoration
5. Streambank stabilization
6. Grazing management (if applicable)
7. Conservation easements protecting high ranked (>2) natural assets.



WQ/WQ 7



WQ/WQ 8

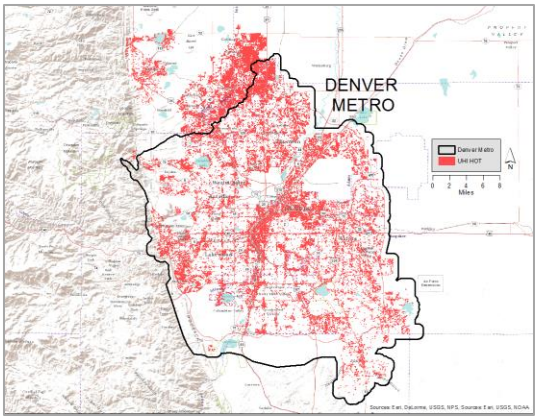
Respiratory Hazard and Urban Heat Island

The Respiratory Hazard and Urban Heat Island Case Study focuses on enhancing urban natural capital to improve air quality especially in areas that have a high risk of respiratory illness. The case study employs the 2013 UTC assessment's Urban Heat Island layer (City and County of Denver parks and Recreation 2013) (RESP 1), and the Environmental Protection Agency's (EPA) Environmental Justice Screening and Mapping Tool's (ESCREEN) Air Toxics Respiratory Hazard Index 's high category (RESP 2). The EJSCREEN data depicts the Respiratory Hazard Index per Census block.

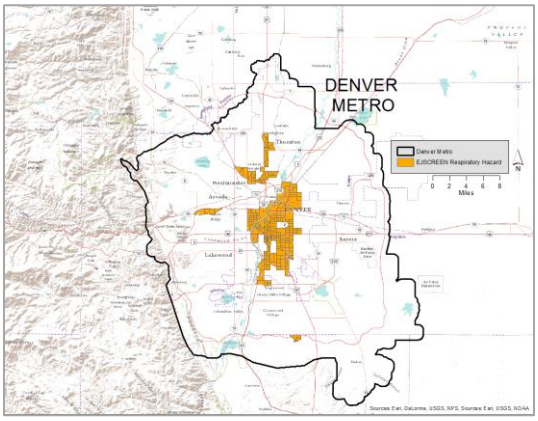
Project Area:
Denver Metro

Datasets:
Natural Capital Asset Layer, ESV Layer, 2013 UTC assessment Urban Heat Island Layer (Hot Areas), EPA's EJSCREEN Air Toxics Respiratory Hazard index (NATA Respiratory HI).

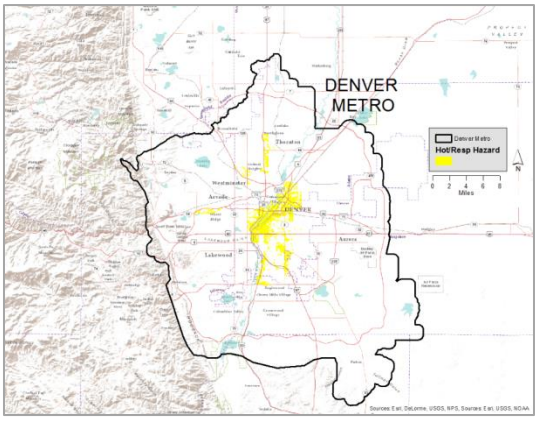
This case study explores how to employ the Natural Capital Asset layer to identify potential project locations and the values (ESV) associated with such projects. The aim is to reduce the deleterious effects of Urban Heat Island and improve air quality in areas prone to high air toxins. The "project area" for this case study is the intersection of "hot Areas" from the 2013 UTC assessment and the EJSCREEN's high category from the Respiratory Hazard Index (RESP 3).



RESP 1



RESP 2



RESP 3

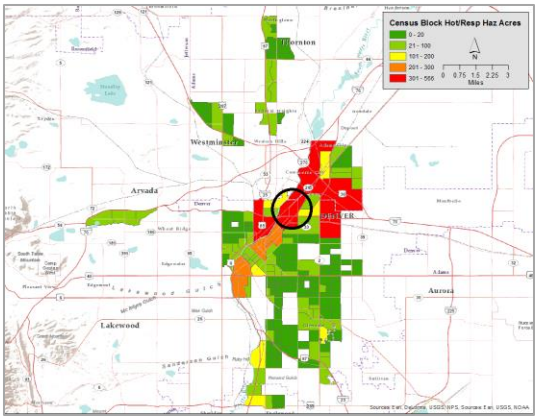
Further refinement of the project area was accomplished by summarizing the acreage of "hot area" per census block (RESP 4). This step determined the acreage of "hot area" per census blocks that have a High Respiratory Hazard Index.

In map RESP 4 census blocks with a high acreage of “hot area” are depicted in red. These areas have an abundance of area to invest in reducing the deleterious cumulative effects of Heat Island and Respiratory Hazard. Please note that the black circle in RESP 4 map, subsequent maps are zoomed in to this area.

Map RESP 5 depicts the Natural Capital found within the zoomed in area. Not surprisingly, the area supports very little Natural Capital as the area is dominated by impervious surfaces, highways and industrial areas. This mix of land use is prime for poor air quality and hot temperatures, which is a deadly mix for people suffering from respiratory illness.

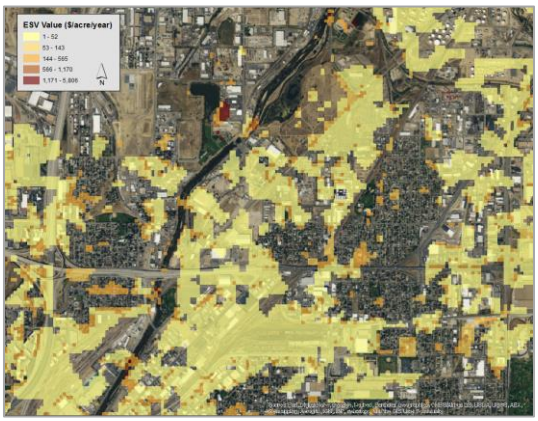
With such minimal Natural Capital within the area it is also not surprising that the area offers little value in terms of Ecosystem Services, with most of the area only providing less than $52 per acre per year (RESP 6).

In the next column is a list of potential projects that could improve the functioning of the natural systems within the Denver Metro Area. These projects aim to increase vegetation and pervious area within the census blocks identified in the analysis. Studies have shown that reducing impervious area and increasing vegetative area (trees and parks) reduces the deleterious effects of Urban Heat Island and improves air quality. For example, trees along roads have been shown to reduce the concentrations of PM10 in urban areas (McDonald et al. 2007).



RESP 4

RESP 5



RESP 6

Potential Projects:

1. Tree Plantings
2. Reduce impervious surfaces
3. Increase pervious areas (add parks or greenspace)
4. Vegetative strips along roads
5. Traffic calming installations

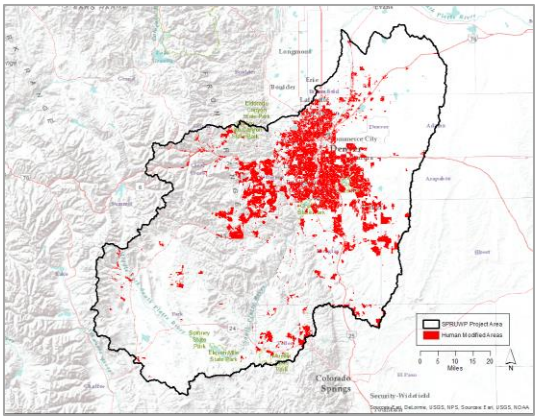
Connectivity in Developed Landscape

The Connectivity in a Developed Landscape Case Study focuses on enhancing natural capital to improve connectivity, safety along commuter corridors, and improving urban aesthetics. The case study employs the CSFS Degree of Human Modification layer (CONNECT 1). The highest value of Human Modification was used for this case study. To examine connectivity, a composite layer was created. The composite layer consists of the intersection of three individual layers; Greenprint Trails, CoMAP's Parks and Open Space and River Preservation Areas from MetroVision 2035 (CONNECT 2). The composite layer merges several layers to describe how people move through developed areas using non-motorized transportation.

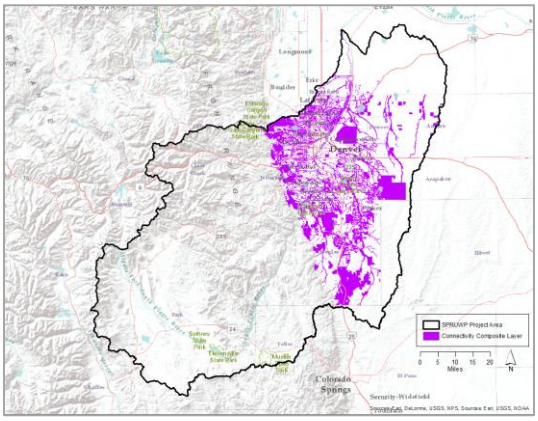
The intersection of the human modification layer and the composite connectivity layer describes the project area for this case study (CONNECT 3). This intersection identifies trails or commuter routes that are in a significantly modified (urban) landscape.

<u>Project Area:</u>
Denver Metro and Plains

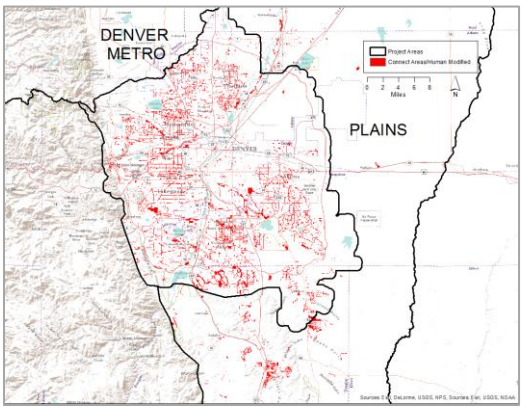
<u>Datasets:</u>
Natural Capital Asset Layer, ESV Layer, CSFS Degree of Human Modification (High Category), Composite Layer describing connectivity in Denver Metro and Plains consisting of: Greenprint trails, CoMAP parks and Open Space layer, and River Preservation Areas layer (Metro Vision 2035).



CONNECT 1



CONNECT 2



CONNECT 3

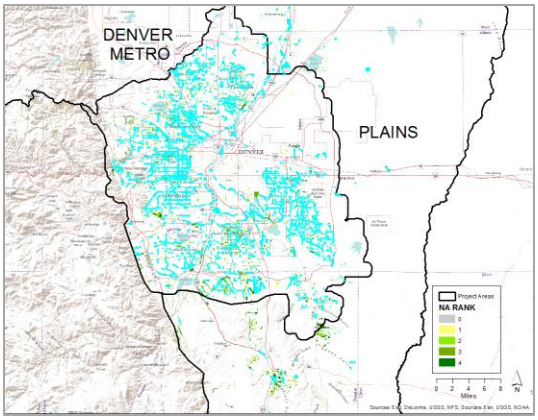
The goals of this case study are to identify project areas for resource investment. At the scale of map CONNECT 3, identifying project areas is daunting, as it looks like all trails in the Denver Metro and Plains are in a developed landscape. One simple way to determine project areas is to look for

areas that have a low (0 or 1) Natural Asset Rank.

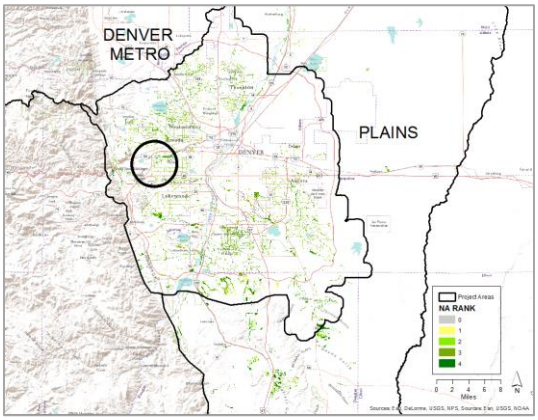
Map CONNECT 4 depicts all areas with a Natural Asset Rank of 0 in the Metro and Plains Project Areas. This amount of potential project area is still daunting, and so the remainder of this case study will focus on the appropriate scale of intervention, which for this project would be at the neighborhood level. The black circle in Map CONNECT 5 depicts the "neighborhood" scale in which the types of interventions needed to meet the goals of this case study should be employed.

At the neighborhood scale it is apparent where resource investments should occur. Map CONNECT 6 depicts the neighborhood scale and the three red circles delineate trail or commuter corridors that lack Natural Capital. These areas are prime candidates for projects and resource investments. The three circles show areas in which natural capital projects could be invested in that would meet the goals of this case study. Trees planted along these routes would not only increase safety for commuters but also beautify the areas making them more livable for the local inhabitants.

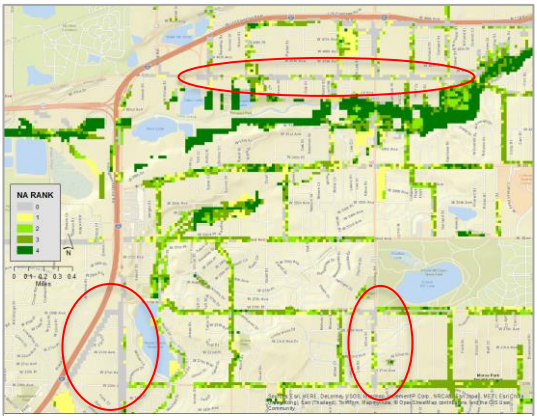
This case study demonstrates the value of natural capital in a developed landscape. For example, much of the area in the red circles have an ESV value of $100 per acre per year or less (CONNECT 7). Adjacent areas to the red circles depict what these low value areas could achieve in terms of ecosystem services value. Resource investment in the low value areas could increase those areas tenfold.



CONNECT 4



CONNECT 5



CONNECT 6

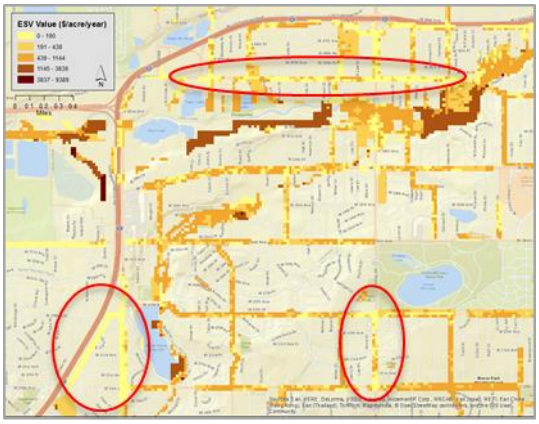
For example, just south of the long narrow circle in the top of the map CONNECT 7 shows the ecosystem services values that could be achieved with some resource investment. These high Natural Asset Rank areas achieve

a value of over $3,000 per acre per year. That area is a riparian zone which includes many Natural Assets of Importance and thus has high value. Even just adding more trees along streets could increase the ecosystem services value to over $1,000 per acre per year. In short, small investments in natural capital in urban areas can pay huge dividends to the locale communities.

Below is a list of potential projects that could improve the functioning of the natural systems within the Denver Metro Area.

Potential Projects:

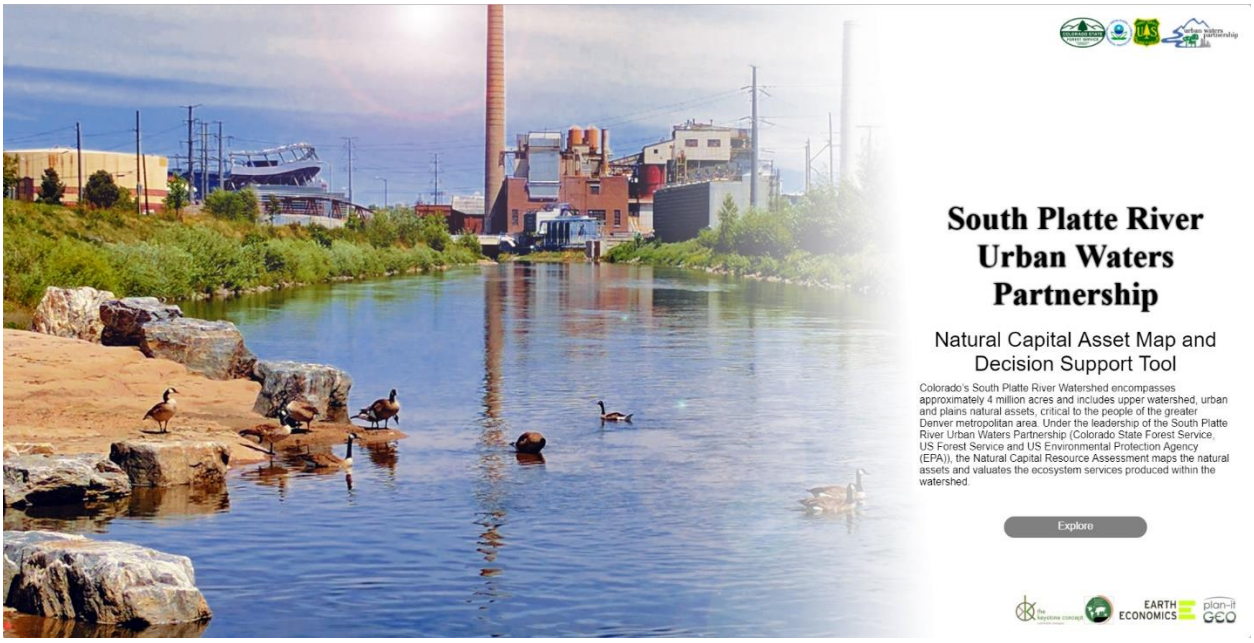
1. Tree Plantings
2. Increase pervious areas (add parks or greenspace)
3. Vegetative strips along roads
4. Traffic calming installations
5. Bike lanes
6. Buffer strip to separate commuters from cars.



CONNECT 7

User Guide

Natural Capital Asset Map and Decision Support Tool
https://pg-cloud.com/NaturalCapital/



Welcome to the User Guide of the South Platte River Urban Waters Partnership's Natural Capital Asset Map and Decision Support Tool. Colorado's South Platte River Watershed encompasses 3.8 million acres and includes upper watershed, urban and plains natural assets, critical to the environment and people of the watershed. Under the leadership of the South Platte River Urban Waters Partnership (Colorado State Forest Service, US Forest Service and US Environmental Protection Agency (EPA)), the Natural Capital Resource Assessment maps the natural assets and valuates the ecosystem services produced within the watershed.

This guide will help orient you to all of the features and functionalities of the tool.

There are five main sections of the tool that this user guide will detail:

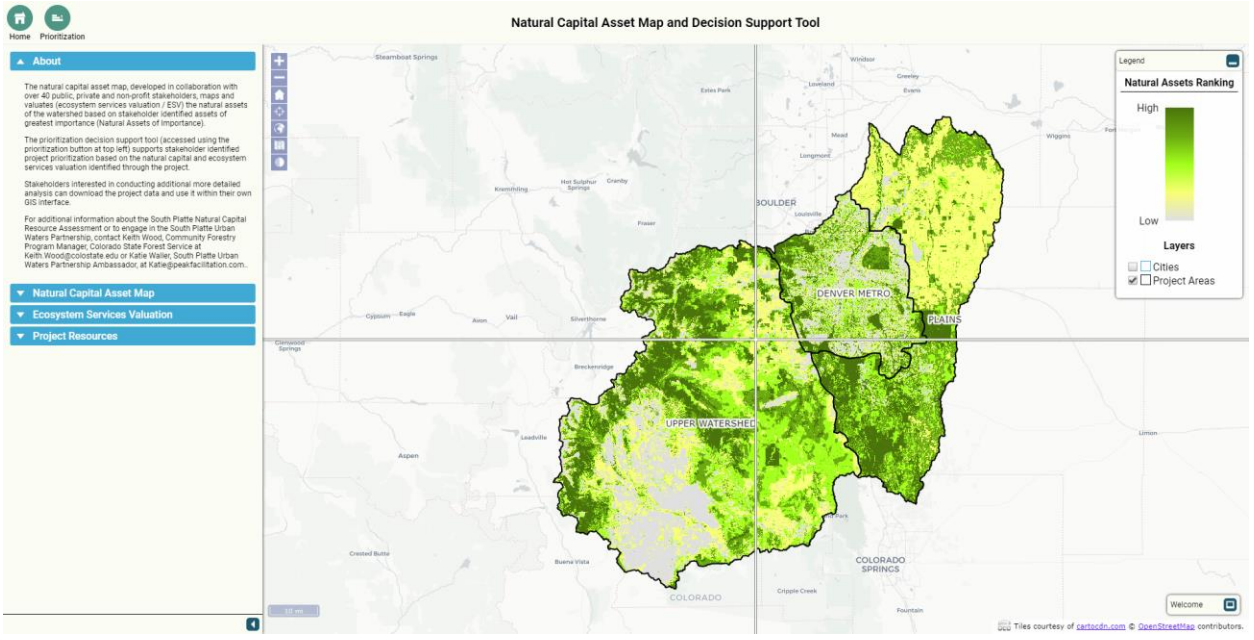
1. About panel
2. Natural Capital Asset Map
3. Ecosystem Services Valuation
4. Download Data panel
5. Prioritization Decision Support Tool

Let's get started by clicking on the Explore button found in the lower-right corner of the welcome screen of the tool (UG Figure 1).

UG Figure 1. Splash page and getting started

About Panel

After clicking on the Explore button, the tool opens to the About panel (UG Figure 2). This panel provides a brief overview of the main sections of the tool. More detailed information can be found within each section.

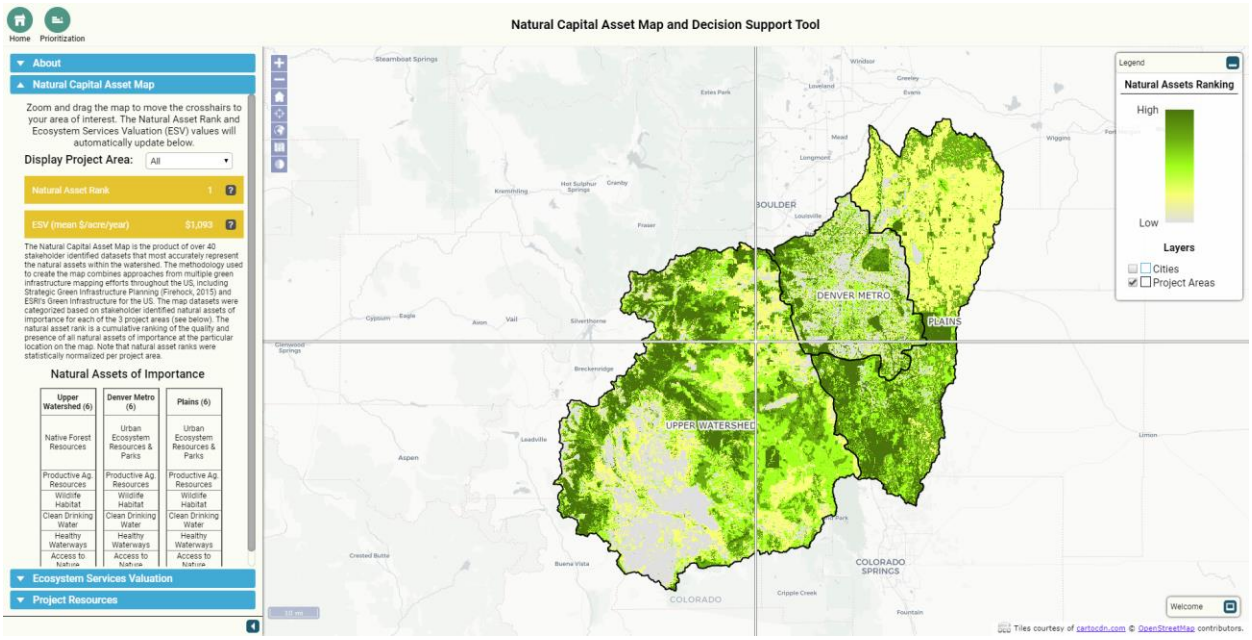


UG Figure 2. About Panel

Natural Capital Asset Map

Click on the blue Natural Capital Asset Map button on the left side of your screen to access it (UG Figure 3). The Natural Capital Asset Map is the product of over 40 stakeholder identified datasets that most accurately represent the natural assets within the watershed. The map on the right side of your window is interactive. You can zoom in and out using the zoom buttons in the blue toolbar or your mouse scroll wheel. You can also pan the map from side to side by clicking and dragging the map.

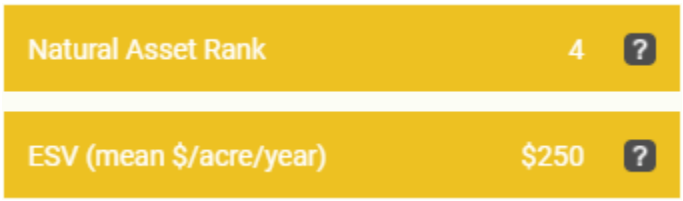
The Natural Capital Asset Map displays natural asset ranking from green to yellow to gray representing a high (4) to low (0) ranking, respectively. The natural asset rank is a cumulative ranking of the quality and presence of all natural assets of importance at the particular location on the map. Notice that there is a crosshair that connects in the center of the map (UG Figure 4).



UG Figure 3. Natural Capital Asset Map

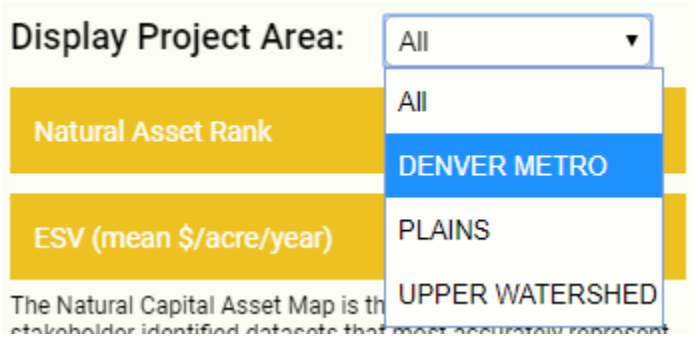
UG Figure 4. Assessment tool crosshairs

This crosshair is used to determine the natural asset rank. After moving the map to your area of interest, look at the yellow boxes in the panel on the left (UG Figure 5). The top yellow box displays the natural asset rank at that location, and the bottom yellow box displays the ecosystem services valuation (ESV - further discussion on this is found in the following section). These values are dynamically displayed as you move the map.



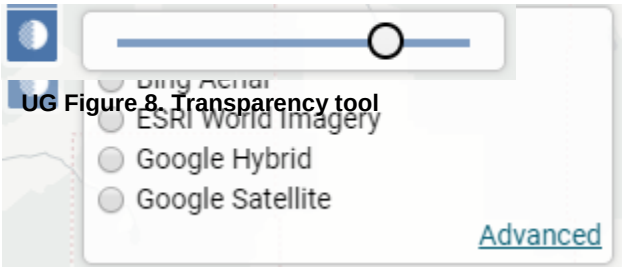
UG Figure 5. Pixel Natural Capital Asset Rank and ESV Value

If you are interested in viewing a specific project area, you can use the Display Project Area dropdown list (UG Figure 6). When you select a project area, the map will zoom and pan to that area and also only display data for that area.



UG Figure 6. Display Project Area drop-down

As you zoom in closer on the map, the basemap will automatically change from a light gray reference map to a high resolution aerial imagery basemap. If you would like to change the basemap to a specific one of your preference, click on the Base Map button found in the blue map toolbar and then select the basemap of your choice (UG Figure 7). The basemap will not automatically change once it is manually set.



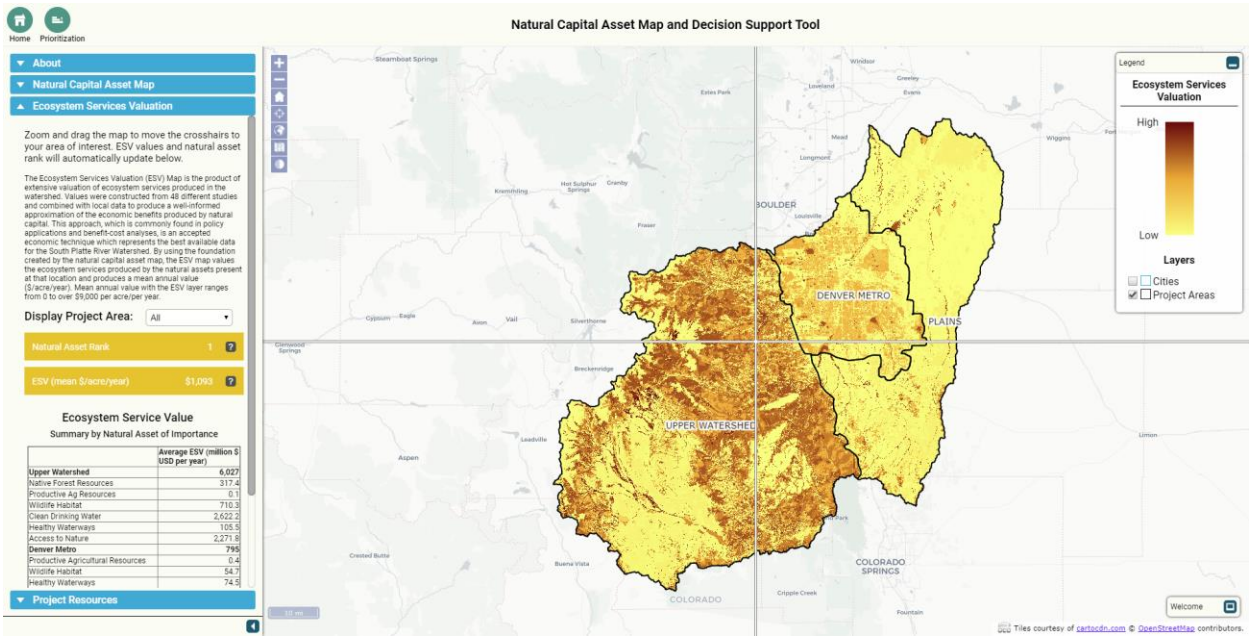
UG Figure 8. Transparency tool

UG Figure 7. Basemap selection

Sometimes it is helpful to see the basemap underneath the natural asset and ESV maps. You can use the Opacity tool in the blue map toolbar to make these map layers transparent. Click on the Opacity tool, then slide the circular button left to make the layers more transparent and right to make them less transparent (UG Figure 8).

Ecosystem Services Valuation

Click on the blue Ecosystem Services Valuation button on the left side of your screen to access the map (UG Figure 9). This map displays the mean annual value ($/acre/year) of ecosystem services that are provided by the natural assets present at the center location of the map. The same basic functions that are available in the Natural Capital Asset Map can also be found in the Ecosystem Services Valuation map. High to low ecosystem services values are displayed from reddish-brown (over $9,000/acre/year) to yellow ($0/acre/year). The yellow boxes in the left-hand panel dynamically display natural asset rank and ecosystem services values as you move the map to your location of interest.



UG Figure 9. Ecosystem Service Valuation (ESV) screen

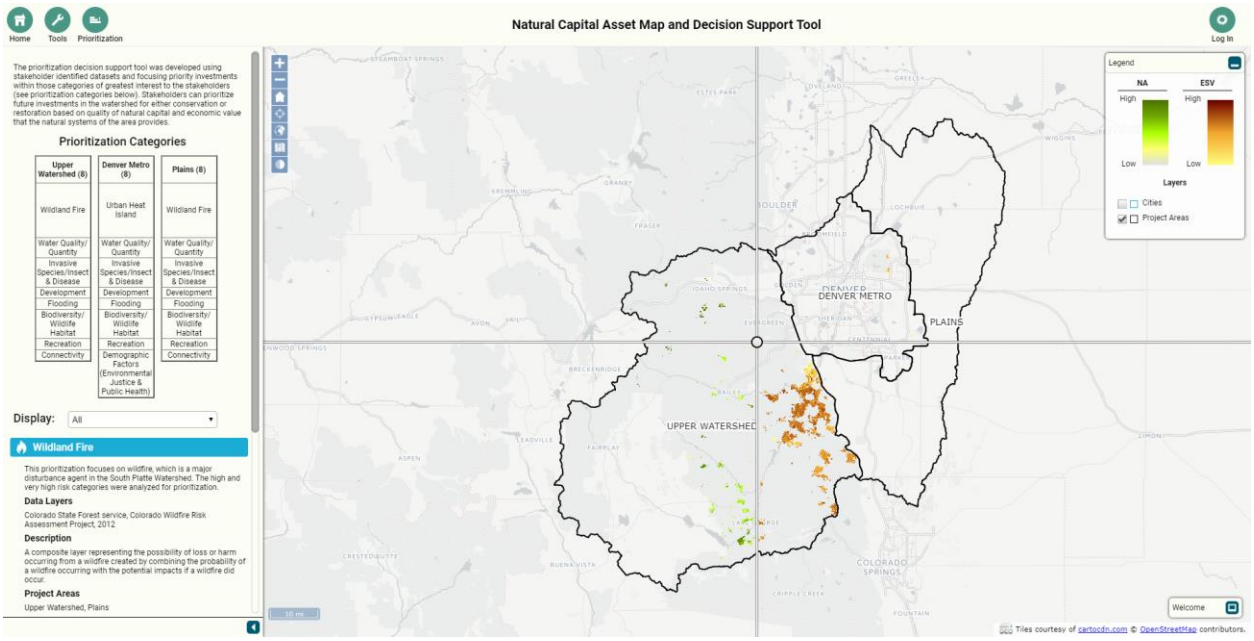
Project Resources

Click on the blue Project Resources button on the left side of your screen to access a download link for the project data as well as a comprehensive report on the Natural Capital Resource Assessment (UG Figure 10). This online tool is meant to provide basic interaction with the data produced by this study for users without GIS software. If you are interested in performing further analysis of the data or using them in your own GIS software, click on the download data link and unzip the contents of the downloaded file. The following datasets are provided: natural capital asset map, ecosystem services valuation map, and all prioritization layers. The comprehensive report provides further detail on the sources and uses of these data layers.

UG Figure 10. Download Project Resources

Prioritization Decision Support Tool

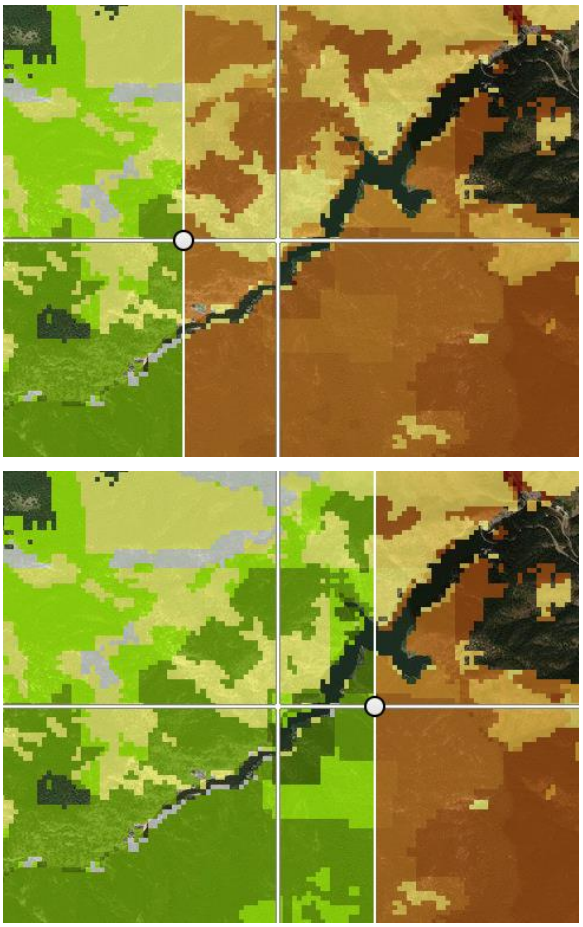
To access the Prioritization Decision Support Tool, click on the blue-green button labeled Prioritization in the top-left corner of your window (UG Figure 11). This tool was developed using stakeholder identified datasets and by focusing priority investments within those categories of greatest interest to the stakeholders. The prioritization categories are shown in a table in the left-hand panel. The data in each category represent a focused subset of the overall project data. For instance, the Water Quality/Quantity category filters the natural asset and ESV data to only show those areas that are within the highest drinking water importance category. To display and interact with the data from each category, scroll down and click the blue button representing your category of interest.



UG Figure 11. Prioritization Support Tool

For each prioritization category, the source data layers, a description, and the project areas that it covers are displayed. This decision support tool provides similar functionality to the natural capital asset map and the ESV map, but, additionally, allows you to view the natural asset rank

and ESV simultaneously (UG Figure 12). The yellow boxes in the left-hand panel dynamically display the natural asset rank and ESV at the location of the crosshairs in the map. You can also slide the vertical crosshair left and right to swipe between the natural asset rank map and the ESV map (see image showing this functionality). This can be particularly useful if you are a project manager looking for potential project locations that may meet certain criteria such as having a low natural asset rank and low ESV. Use the Display dropdown list if you are only interested in a specific project area or city within the study area.

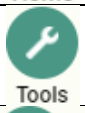
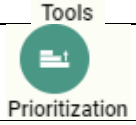
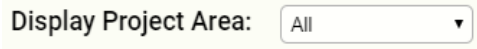
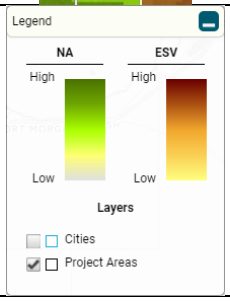


UG Figure 12. Simultaneous view of Natural Capital and ESV

Index of Tool Elements

The table below provides a quick reference to all of the different elements that are found within the Natural Capital Asset Map and Decision Support Tool. Consult with this table if you are uncertain of the functionality of a tool element (UG Table 1).

UG Table 1.South Platte Natural Capital Index of Tools

Element	Description
	Open the Home panel containing the About panel, Natural Capital Asset Map, Ecosystem Services Valuation, and Download Data panel
	Open the Tools panel
	Open the Prioritization Decision Support Tool
	Display the data within a specific project area or city
	Dynamic display of natural asset rank and ecosystem services valuation based on the crosshair location in the center of the map
	Show more information about natural asset rank or ESV
	Zoom in
	Zoom out
	Zoom to project extent
	Zoom to your location. This is useful if you are in the field and on a mobile device that has GPS capability.
	Zoom to a location based on address
	Change basemap (Bing, ESRI, Google, Streets, Aerial Imagery)
	Set the transparency of the natural asset and ESV maps. This is useful to see the underlying basemap.
	Crosshairs used to control dynamic display of natural asset rank and ecosystem services valuation. Move the map until these crosshairs fall on the location of interest.
	In the Prioritization Decision Support Tool, slide the vertical bar using circular button in the middle of the map to swipe between the natural asset map and the ESV map.
	Legend showing the symbology for low (0) to high (4) natural asset rank and low ($0/acre/year) to high (over $9,000/acre/year) ecosystem services valuation. Use the Cities checkbox to display city boundaries of the cities within the project area. Use the Project Areas checkbox to display the three project areas (Upper Watershed, Denver Metro, Plains).

Appendix A: Glossary of Terms

The South Platte River Watershed Natural Capital Project provides a complex analysis of the Natural Capital Assets within this 4-million-acre watershed. By building upon local and national resources and expertise in the arena of green infrastructure and ecosystem services, the project team (consultant team, project directors and stakeholder team), through a highly collaborative approach, produced a resource that will inform future strategic investments in the watershed. Defined below are a number of terms, developed throughout the course of this project, with foundations in the body of green infrastructure work.

Natural Capital – The interconnected network of natural resources (also called green infrastructure) throughout the South Platte Watershed that produce a variety of natural capital assets. These natural capital assets provide the people of the South Platte Watershed with a wide range of ecosystem services, which contribute to the local economy, society and the environmental health.

Natural Capital Asset Map – Produced by the consultant team in collaboration with the project directors and stakeholder team, the Natural Capital Asset Map, displays the distribution of natural capital assets throughout the watershed. This map incorporates over forty sources of data provided by the stakeholder team to represent the natural assets that are of greatest importance to the people and environment of the watershed. The Natural Capital Asset Map is a raster dataset ranging in value from 0 to 4. A pixel with a zero value indicates that that pixel contains limited to no Natural Capital Assets. Conversely, a pixel value of 4 indicates that that pixel supports a wealth of Natural Capital Assets.

Natural Assets of Importance (NAI) – The stakeholder team identified seven natural assets that are of greatest importance to the people of the watershed. These Natural Assets of Importance produce essential ecosystem services that influence the local economy and quality of life in the South Platte Watershed. The seven NAI's identified by the stakeholder team include:

Native Forest Resources – Native Forest Resources include trees and associated native vegetation in the mountainous area of the South Platte Watershed. These resources are a critical component to a healthy environment for the citizens of the upper watershed.

Productive Agricultural Resources – Productive Agricultural Resources include cultivated crops and rangeland within the watershed. These resources produce food and sustain a local agricultural economy, critical to the health and sustainability of the environment and people of the watershed.

Wildlife Habitat – Wildlife habitat includes high quality native vegetation and water resources that provide food and shelter for local wildlife throughout the watershed. This habitat is critical for a thriving environment and also provides habitat for game species that support a local hunting and recreation opportunities.

Clean Drinking Water – Clean drinking water is produced by high elevation snowpack and retention in the Upper Watershed and retained by reservoirs throughout the South Platte Watershed. This drinking water is critical to the health and sustainability of local municipalities and citizens within the watershed.

Healthy Waterways – Healthy waterways are high quality waterways that originate in the upper watershed and weave throughout the entire watershed. These waterways are critical to sustain healthy wildlife and human populations and support local recreational opportunities.

Access to Nature – Access to Nature includes trails, parks and open space that provide access to outdoor recreational opportunities that are important to the people who live and recreate within the watershed.

Urban Ecosystem Resources and Parks – Urban Ecosystem Resources and Parks include: urban trees and vegetation; green stormwater infrastructure (vegetation and pervious surfaces, both naturally occurring and human constructed that helps absorb and clean stormwater); and parks and greenspace throughout the urban area. These urban ecosystem resources are critical to sustaining a thriving living environment for the citizens of the Denver Metro Urban Area.

Prioritization Categories – During the initial meetings for the Natural Capital Project the stakeholder team and project directors informed the consultant team that an outcome of this project is a means to prioritize key areas for conservation and restoration based on the economic value of the natural systems that the area provides. This prioritization would guide future investments into the watershed's three project areas (Upper Watershed, Metro, and Plains). Based on these meetings and further direction from the stakeholders and project directors, a list of ten prioritization categories, described below, were developed. Many groups within the South Platte Watershed (e.g. Metro Denver Nature Alliance (MDNA), CUSP, USPP etc.) have performed their own prioritization and this project does not intend to replace these efforts. Rather, prioritization within the Natural Capital project aims to aid in the decision process of where to invest resources through additional data, namely the Natural Capital mapping and ESV.

The wealth of data that the stakeholders and project directors provided to the consultant team through the meta-analysis process made it apparent that an inclusive approach to prioritization was warranted. The volume of data coupled with categorization facilitates prioritization for multiple purposes. This allows a diverse group of stakeholders to employ the Natural Capital data (Mapping and ESV) as a decision support tool to help guide future investment and further each organization's goals.

Below is a description of each prioritization category and the layer's that assisted in the initial project prioritization for the Upper South Platte Watershed Natural Capital Project.

Wildland Fire – Wildland fire is a major concern in Colorado and especially within the Upper South Platte Watershed, which is home to the largest wildfire in Colorado history; 2002's Hayman Fire. The example Wildland Fire prioritization is informed by the CSFS wildfire risk layer and can be further summarized and evaluated using several layers identified in the meta-analysis (e.g. CUSP and USPP priorities watersheds) (Figure 10).

Water Quality / Quantity – Water quality and quantity are essential to human health. The Upper South Platte Watershed is the water source for the Denver Metropolitan Area and its residents. Therefore, clean and abundant water is not only a priority, it is an essential service that the Upper South Platte provides to the populous of all project areas. An example Water Quality/Quantity prioritization would be informed by Denver Water's Priority Source Water Areas. There are many other layers and information that can assist in further prioritization and project identification for Water Quantity and Quality (Figure 10). In fact, the stakeholder team identified several datasets that provide very site-specific water quality information for fine -scale project identification (e.g. Barr Lake Milton Watershed Association (BMW) – water quality data, Colorado Data Sharing Network (CDSN) water quality data, EPA – water quality assessment) (Figure 10).

Invasive Species / Insect & Disease – Invasive species and insect and disease are problematic within the Upper South Platte Watershed. Invasive species negatively affect natural systems by outcompeting native vegetation and altering fire regimes (e.g. cheatgrass). Insect and disease is a major concern in the Upper Watershed project area, particularly in the forested areas. The data provided by the Stakeholders and Project Directors offers several layers and ways to prioritize areas for interventions related to Invasive Species and Insect and Disease. CSFS Threats layers (from COWRAP) is a perfect example of an existing prioritization data layer that can be supported by the Natural Asset and ESV layers created through this project. Additionally, highways are often vectors for invasive species and therefore another potential prioritization would employ the CDOT's highway network to identify places potential project areas for interventions. CDOT also provided a layer consisting of point locations of noxious weeds along highways (Figure 10). This data assists in further project site location refinement for combating Invasive Species and Insect and Disease issues within the South Platte Watershed.

Development – The Upper South Platte Watershed will continue to develop and change as Colorado's population grows. Development offers benefits to the populous of the region through increased economic activity, but can have a negative impact on natural resources if planning is not sound. For prioritizing projects for Development, the CSFS Human modification layer was used. Several other datasets are available to employ for more specific Development related projects (Figure 10).

Flooding – Flooding is a major concern in the Upper South Platte Watershed, as evidenced by the 2013 events. There are several datasets available to groups looking to prioritize projects to address flooding. For this project's prioritization, FEMA's flood hazard layer could be employed to identify high value landscapes within flood prone areas. Public and private entities have also examined prioritizing watersheds within the project area for flooding potential (e.g. USPP and Denver Water) (Figure 10). The data created through this project can assist further project refinement for these groups to combat the negative effects of flooding or restore watershed processes that can ameliorate the effects of flood events.

Biodiversity / Wildlife – Biodiversity and wildlife are vital to Colorado, as this prioritization category provides essential ecosystem services (e.g. recreation and aesthetic) value to the project areas populous. For the Natural Capital Project's prioritization, the CSFS imperiled species of economic concern layer was used as an example. There are many other layers that

can assist groups interested in employing the data created in this project to refine existing prioritizations or create new prioritizations (Figure 10).

Recreation – Recreation is very important to populous of the Upper South Platte River Watershed. Each project area offers different recreation opportunities, such as urban trails in the Metro Area, ORV use in the Upper Watershed, or fishing in many of the lakes found in the Plains area. An example prioritization for the Natural Capital Project's recreation priorities could center on the densest recreational use areas in the Upper South Platte Watershed. The CSFS recreation density layer identifies priority recreation areas for Coloradans. The ESV and natural Capital mapping data created for this project can assist in determining where to invest resources. Other data that can assist in recreation prioritization can be found in the meta-analysis section (Figure 10).

Connectivity – The consultant team created a composite GIS layer to examine connectivity within the project area. The composite layer consists of the intersection of three individual layers; Greenprint Trails, CoMAP's Parks and Open Space and River Preservation Areas from MetroVision 2035. The composite layer merges several layers to examine how people move through developed areas using non-motorized transportation.

Urban Heat Island – Urban heat island effects the health and livability of urban communities throughout the United States. The Denver metro area experiences warm sun soaked summers leading to higher temperature in urban areas that lack tree cover and are dominated by impervious surfaces. The City of Denver created an urban heat island map through their Urban Tree Canopy Assessment. The Urban Heat Island layer was employed to prioritize areas for investment in resources to combat the deleterious effects of increased temperatures based on Urban Heat island effect.

Demographic Factors (Environmental Justice & Public Health) – Environmental Justice (EJ) seeks to ensure that low income and minority dominated communities are offered the same environmental protection and quality of life as all other communities. Several groups have performed EJ analyses in the Upper South Platte Watershed (e.g. EPA, MDNA, etc.). These efforts will be analyzed to determine the most applicable EJ data to employ for prioritization within the Denver Metro region.

Ecosystem Services Valuation (ESV) – Ecosystem service valuation: Ecosystem service valuation is the quantification of the benefits that people derive from ecosystems, generally expressed as non-market values or market value equivalents.

Ecosystem Service Value - Measure of the benefit provided by an ecosystem using market proxies to infer a dollar value equivalent.

Benefit Transfer Methodology (BTM) – BTM is an ecosystem service valuation method that uses values derived from published studies for application in similar ecosystems. It resembles a house or business appraisal that is based on comparable characteristics of similar houses or businesses.

Economic Benefit – Value expressed in monetary terms that represents the well-being that a consumer derives from consumption of a specific good or service (usually obtained from ecosystems). All monetary values are in 2015 dollars.

Ecosystem Valuation Toolkit (EVT) – The EVT is a computational engine and database developed and maintained by Earth Economics for the application of "benefit transfer methodology" in "ecosystem service valuation". It houses the world's largest library of ecosystem goods and services valuation studies.

Appendix B. Ecosystem Valuation Methodology

The benefit transfer method (BTM) is used to derive values for ecosystem services. BTM, broadly defined as "…the use of existing data or information in settings other than for what it was originally collected," is frequently used to indirectly estimate the value of ecological goods or services (Rosenberger and Loomis 2003).

Primary studies are selected from Earth Economics' Ecosystem Service Toolkit (EVT). The EVT is one of the largest repositories of published, peer-reviewed primary valuation studies, reports, and gray literature on the value of ecosystem services. Before a value is added to a report, we examined the degree of correspondence, or the similarity of location and socioeconomic indicators from the primary data and the applied study region. Conducting a defensible benefit transfer requires careful thought, research, and choices, particularly in regards to the transferability between the study site (the site of the original published literature) and the transfer site (the site to be valued through benefit transfer). The following criteria were used to assess the transferability of literature values from the EVT to the South Platte River Watershed:

1. Similarity of ecosystem goods and services: At the most basic level, the commodity being valued in the literature and that being valued in our study site should be the same. For example, a value for protection from a natural disaster such as a hurricane should not be used in the South Platte, but a value for protection from a flood disaster should.
2. Similarity of land cover types: Like criteria 1, the similarity between land covers in the South Platte and those valued in the literature is important. Errors associated with benefit transfers are lessened as this similarity increases. Therefore, we did not use land cover types which did not appear in the South Platte.
3. Studies use sound methodologies: we ensured that the dataset for this project only included credible sources with well-vetted methodologies. Additionally, studies using primary valuation methods were prioritized over those using secondary methodologies. Where a gap in primary valuations existed, a secondary valuation study was used.
4. Studies were conducted in the United States: because of issues with demographics, cultural attitudes, and general transferability of ecosystem services, we only chose studies conducted in the United States. This helps maintain similarity in important socioeconomic characteristics in the valuation studies chosen. Where possible, studies from Colorado and the southwest were prioritized.

All ecosystem service values were standardized to account for differences in units and for inflation. The unit of measure for this analysis is dollars per acre per year, adjusted to 2014 United States dollars using World Bank GDP deflator factors.

The ecosystem service valuation results show the range in selected ecosystem service values for each land cover and ecosystem service combination as well as the mean. Values for ecosystem services can vary due to factors such as scarcity, income effects, and uniqueness of habitat, among others. The values provided include an array of marginal and average values and valuation methods for ecosystem services that incorporate different potential demand scenarios and states of the environment. By extracting values from a large pool of studies and contexts, we

illustrate a well-informed value approximation. The mean values represent the central tendency in the data, while the range shows the variability and uncertainty in the data.

A combination not included in the analysis does not necessarily mean that the ecosystem does not produce that service or that the service is not valuable, but rather shows a lack of primary, peer-reviewed data for that service. For example, shrubland provides highly valuable services such as recreation, habitat, and carbon sequestration, yet there are few valuation studies of this land cover type. Caution should be exercised when comparing total ecosystem services values across land covers, as the difference in values could stem from an information gap rather than true differences in ecosystem service value.

Using the previously outlined criteria, total per-acre-per-year values for each land cover, ecosystem service, and spatial attribute combination were selected from the literature. These values are combined with the acres of each corresponding land cover type, and a set of ecosystem health modifiers.

Carbon Biomass Transfer

The same transfer method is employed to determine carbon sequestration values. We transfer biophysical amounts of carbon sequestration derived from EVT studies. These values are in metric tons of carbon per acre per year. We then use the social cost of carbon to place a dollar value on these amounts (Interagency Working Group on Social Cost of Greenhouse Gases 2016).

Land Cover

The acreage was calculated for every land cover category in the NLCD data and summarized among the three project areas: Upper Watershed, Denver Metro, and Plains.

The GIS data was modified in several ways to enable a more detailed description of the natural capital of the study area. “Spatial attributes” were constructed to describe unique locations of ecosystems within the landscape. In this analysis, we considered three spatial attributes that affect ecosystem service values: proximity to agricultural areas, riparian buffers, or urban areas. Identifying the spatial attributes of land cover data allows the application of more granular study values and increases accuracy as each attribute provides information that narrows the scope of values and mitigates uncertainty. Valuations tend to be more accurate when the spatial distribution of values is taken into account (Rosenberger and Johnston 2013).

Spatial Attributes

The GIS data was modified in several ways to enable a more detailed description of the natural capital of the study area. “Spatial attributes” were constructed to describe unique locations of ecosystems within the landscape. In this analysis, we considered four spatial attributes that affect ecosystem service values: proximity to agricultural areas, and the location of land covers within coastal, riparian, or urban zones. Identifying the spatial attributes of land cover data allows the application of more granular study values and increases accuracy as each attribute provides information that narrows the scope of values and mitigates uncertainty. Valuations tend to be

more accurate when the spatial distribution of values is taken into account (Rosenberger and Johnston 2013). In the following paragraphs, we provide examples of how these spatial attributes affect ecosystem service values.

Riparian Zones

Riparian borders are a vegetative buffer that surrounds a body of water. Land covers that reside within these borders often have a large positive effect on nearby waters and are more ecologically productive (Hawes and Smith 2005). Therefore, it is common that ecosystem service provisioning is increased in these areas. For example, the vegetation along a body of water helps reduce nitrogen and phosphorus levels, sedimentation, maintain base flow, and increase erosion control.

Urban Areas

Ecosystem service values vary significantly along the urban-rural gradient (Radford and James 2013). Areas of higher urbanization tend to have degraded ecosystems, but urban parks and open space are also tremendously valuable as they provide services in an urban landscape. It is important to identify which services are provided in land covers that are within and near urban areas to control for the variation in values.

Proximity to Agriculture

Agriculture is a unique land cover because it provides ecosystem goods and services directly to consumers, and it relies on a range of ecosystem services to support production. Non-point sources of pollution related to agriculture risk damage to ecosystems, but management regimes can promote agricultural practices that improve the ecological function of farmland (Belcher, Edwards, and Gray 2001). Pollinating services, weed and pest control, and water purification aid in the production process while minimizing costs.

Ecosystem Health

Current conditions and ecological health was assessed by determining an overall rank of ecosystem health indicators (Phillips and McGee 2014; Aplet, Thomson, and Wilbert 2000). An ecological health metric was constructed using indices of seven different indicators. These were determined on a pixel-by-pixel basis within the study area. Ecosystem service values will be adjusted based on a baseline health metric and a health adjustment for future scenarios.

$$ESV = \sum_{i,j,k} Acres_{j,k} * Baseline\ Health_k * \$/acre/year_{i,k}$$

Where:

- $\mathbf{Acres_{j,k}}$ - the number of acres in land cover j in pixel k
- $\mathbf{Baseline\ Health_k}$ - the initial health index for pixel k
- $\mathbf{\$/acre/year_{i,j}}$ - the average of the dollar value of each ecosystem service i provided from each land use j each year.

Baseline Health was used to adjust the ecosystem services in the South Platte River watershed depending on the priorities in each project area. The following sections describes each health modifier.

Human Modification

The Human Modification dataset, produced for the Colorado State Forest Action Plan (Colorado State Forest Service 2010), shows a spatial impact of development on ecosystems. This dataset incorporates the impacts of road infrastructure and residential development as well as proximity effects of byproducts of human activities such as lights, noise, pets, etc. Effects of human modification decline with distance from these modification sources, up to 100 meters. The human modification scores range from 0 (not human modified/natural) to 1,000 (completely modified/urban).

We categorize these results into an index ranging from 1 (most impacted) to 5 (least impacted) as follows, based on percentiles:

- 1 = 800 - 1000
- 2 = 600 - 799
- 3 = 400 - 599
- 4 = 200 - 399
- 5 = 0 - 199

Contiguous Acreage

Ecological processes in larger, well-connected patches can be assumed to be under less human control than in smaller, disconnected patches (Aplet, Thomson, and Wilbert 2000). Contiguous land cover patches will be analyzed in GIS. Each cell within a continuous land cover patch will be given an index based on the size of the contiguous land cover patch it resides in. The index will be constructed with the following categories:

- 1 = < 5 contiguous acres
- 2 = between 5 and 10 contiguous acres
- 3 = between 10 and 50 contiguous acres
- 4 = between 50 and 100 contiguous acres
- 5 = more than 100 contiguous acres

Historic Wildfire

<u>Aesthetic Value</u>

Studies investigating wildfire effects on housing prices find it takes a considerable time for these prices to recover. Findings show that housing prices can be reduced by 8 percent to 16 percent when adjacent to wildfires (Stetler, Venn, and Calkin 2010). However, a common finding in hedonic studies is that the effect of natural disasters on housing prices diminishes over time (Donovan, Champ, and Butry 2007).

If a fire has occurred less than 15 years ago, rank of 4. If not, rank of 5. This represents about a 20% decrease in value when ecosystems have been burned by wildfire.

- 4 = Pixel is within a fire zone
- 5 = Pixel is not within a fire zone

Recreation

A study on forest-fires and recreation shows that, for hiking, consumer surplus values are higher immediately after a fire, and for biking, consumer surplus values are higher for no-fire zones (Loomis, Gonzalez-Caban, and Englin 2001). On average, the consumer surplus is almost 10% higher than consumer surplus for a no-fire area.

We will assign scores for recreation based on these percent changes. Areas with recent fires (less than 5 years) will be assigned a score of 5, and areas where high-intensity fires have not occurred for at least 5 years will be assigned a score of 4.

- 5 = 0 to 15 years since a high intensity fire in a pixel
- 4 = 6 to 20 years since a high intensity fire in a pixel, or no historical fire data exists for a pixel

Carbon Sequestration

The benefits produced by carbon sequestration are adjusted by age since the last high intensity fire. We assumed an ecosystem's "age" to be the years since the last high intensity fire. This age data was used to derive carbon sequestration values from different forest production functions.

Thinning Activities

For the purposes of this report, "thinning" refers to "understory thinning," "thinning from below" or "low thinning" to describe the cutting and removal of small trees that may be necessary to meet objectives for restoration of habitat and fire regimes.

Habitat

Although wildlife impacts of fuel treatments are less known than those of wildfire, research suggests that thinning and prescribed burning pose relatively modest risks if key habitat structures and conditions can be maintained. Long-term fire suppression, however, has notably altered species composition negatively. With increased fuel loads, wildfires are unlikely to result in pre-settlement vegetation and habitat characteristics without some type of prior fuel treatment to lessen wildfire severity. This has a harmful effect on habitat for some bird species, which are dependent on periodic burning to provide food supply and shelter (Stoddard 1963). Reducing large wildfires by using fuel treatments can be beneficial, particularly to isolated, small, or otherwise vulnerable aquatic populations that face possible extinction from severe fire.

Loomis and Gonzales-Caban 1998 conduct a survey asking US residents about their willingness to pay for a fire protection program which would protect spotted owl old growth habitat. The program removes brush and deadwood on forest floor, prescribed fires once a decade, and implemented other practices that resulted in a quicker and larger fire control response. Based on the data from this study, we set the index score for habitat values as:

- 5 = pixel was treated with thinning activities
- 2 = pixel was not treated with thinning activities

Important Wildlife Habitat
This map, developed in the Colorado Forest Action Plan, identifies habitats important for endangered and threatened species in Colorado. Pixels will be ranked based on the score they were given in this dataset:

- 1 = No Target Species
- 2 = Low
- 3 = Moderate
- 4 = Very High
- 5 = High

Recreation Density
For the recreation analysis, we used a recreation density map provided by the Colorado State Forest Service. The recreation density map overlays publicly accessible lands, access over state lands to hunting units, campgrounds, hiking trails, national and state parks, ski areas, and fishing, rafting and boating opportunities on rivers and accessible water bodies (Colorado State Forest Service 2010). The recreation density map represents opportunities for use and does not incorporate actual use. Sites with high use and amenities were given a score of 5, while study sites with low use and limited access were given a score of 1.

Canopy Cover
This modifier replaced the NLCD land cover for forests within the Denver Metro project area where data was available. Instead of Forest acreage derived from NLCD, acreage of each category of percent canopy coverage was used to calculate ecosystem service values within the Denver Metro project area.

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Limitations of the Benefit Transfer Method

Valuation exercises have limitations that must be noted, although these limitations should not detract from the core finding that ecosystems produce a significant economic value to society. A benefit transfer analysis estimates the economic value of a given ecosystem (e.g., wetlands) from prior studies of that ecosystem type. Like any economic analysis, this methodology has strengths and weaknesses. Some arguments against benefit transfer include:

1. Every ecosystem is unique; per-acre values derived from another location may be irrelevant to the ecosystems being studied.
2. Even within a single ecosystem, the value per acre depends on the size of the ecosystem; in most cases, as the size decreases, the per-acre value is expected to increase and vice versa. (In technical terms, the marginal cost per acre is generally expected to increase as the quantity supplied decreases; a single average value is not the same as a range of marginal values).
3. To value all, or a large proportion, of the ecosystems in a large geographic area is questionable in terms of the standard definition of exchange value. We cannot conceive of a transaction in which all or most of a large area's ecosystems would be bought and sold. This emphasizes the point that the value estimates for large areas (as opposed to the unit values per acre) are more comparable to national income account aggregates and not exchange values (Howarth and Farber 2002). These aggregates (i.e. GDP) routinely impute values to public goods for which no conceivable market transaction is possible. The value of ecosystem services of large geographic areas is comparable to these kinds of aggregates (see below).

Proponents of the above arguments recommend an alternative valuation methodology that amounts to limiting valuation to a single ecosystem in a single location. This method only uses data developed expressly for the unique ecosystem being studied, with no attempt to extrapolate from other ecosystems in other locations. The size and landscape complexity of most ecosystems makes this approach to valuation extremely difficult and costly. Responses to the above critiques can be summarized as follows (Costanza et al. 1997; Howarth and Farber 2002):

1. While every wetland, forest or other ecosystem is unique in some way, ecosystems of a given type, by their definition, have many things in common. The use of average values in ecosystem valuation is no more or less justified than their use in other macroeconomic contexts; for instance, the development of economic statistics such as Gross Domestic or Gross State Product.
2. As employed here, the prior studies upon which we based our calculations encompass a wide variety of time periods, geographic areas, investigators and analytic methods. Many of them provide a range of estimated values rather than single-point estimates. The present study preserves this variance; no studies were removed from the database because their estimated values were deemed to be "too high" or "too low." Also, only limited sensitivity analyses were performed. This approach is similar to determining an asking price for a piece of land based on the prices of comparable parcels ("comps"): Even

though the property being sold is unique, realtors and lenders feel justified in following this procedure to the extent of publicizing a single asking price rather than a price range.

3. The objection to the absence of even an imaginary exchange transaction was made in response to the study by Costanza et al. (1997) of the value of all of the world's ecosystems. Leaving that debate aside, one can conceive of an exchange transaction in which, for example, all of, or a large portion of a watershed was sold for development, so that the basic technical requirement of an economic value reflecting the exchange value could be satisfied. Even this is not necessary if one recognizes the different purpose of valuation at this scale, a purpose that is more analogous to national income accounting than to estimating exchange values.

We have displayed our study results in a way that allows one to appreciate the range of values and their distribution. It is clear from inspection of the tables that the final estimates are not precise. However, they are much better estimates than the alternative of assuming that ecosystem services have zero value, or, alternatively, of assuming they have infinite value. Pragmatically, in estimating the value of ecosystem services, it seems better to be approximately right than precisely wrong.

General Limitations

- **Static Analysis.** This analysis is a static, partial equilibrium framework that ignores interdependencies and dynamics, though new dynamic models are being developed. The effect of this omission on valuations is difficult to assess.
- **Increases in Scarcity.** The valuations probably underestimate shifts in the relevant demand curves as the sources of ecosystem services become more limited. The values of many ecological services rapidly increase as they become increasingly scarce (Boumans et al. 2002). If ecosystem services are scarcer than assumed, their value has been underestimated in this study. Such reductions in supply appear likely as land conversion and development proceed. Climate change may also adversely affect the ecosystems, although the precise impacts are difficult to predict.

Benefit Transfer/Database Limitations

- **Incomplete coverage.** That not all ecosystems have been valued or studied well is perhaps the most serious issue, because it results in a significant underestimate of the value of ecosystem services. More complete coverage would almost certainly increase the values shown in this report, since no known valuation studies have reported estimated values of zero or less for an ecosystem service.
- **Selection Bias.** Bias can be introduced in choosing the valuation studies, as in any appraisal methodology. The use of ranges partially mitigates this problem.

Primary Study Limitations

- **Price Distortions.** Distortions in the current prices used to estimate ecosystem service values are carried through the analysis. These prices do not reflect environmental externalities and are therefore again likely to be underestimates of true values.

- **Non-linear/Threshold Effects.** The valuations assume smooth and/or linear responses to changes in ecosystem quantity with no thresholds or discontinuities. Assuming (as seems likely) that such gaps or jumps in the demand curve would move demand to higher levels than a smooth curve, the presence of thresholds or discontinuities would likely produce higher values for affected services (Limburg et al. 2002). Further, if a critical threshold is passed, valuation may leave the normal sphere of marginal change and larger-scale social and ethical considerations dominate, as with an endangered species listing.
- **Sustainable Use Levels.** The value estimates are not necessarily based on sustainable use levels. Limiting use to sustainable levels would imply higher values for ecosystem services as the effective supply of such services is reduced. If the above problems and limitations were addressed, the result would most likely be a narrower range of values and significantly higher values overall. At this point, however, it is impossible to determine more precisely how much the low and high values would change.

GIS Limitations

- **GIS Data.** Since this valuation approach involves using benefit transfer methods to assign values to land cover types based, in some cases, on the context of their surroundings, one of the most important issues with GIS quality assurance is reliability of the land cover maps used in the benefits transfer, both in terms of categorical precision and accuracy.
- **Spatial Effects.** This ecosystem service valuation assumes spatial homogeneity of services within ecosystems, i.e. that every acre of forest produces the same ecosystem services. This is clearly not the case. Whether this would increase or decrease valuations depends on the spatial patterns and services involved. Solving this difficulty requires spatial dynamic analysis. More elaborate system dynamic studies of ecosystem services have shown that including interdependencies and dynamics leads to significantly higher values (Boumans et al. 2002), as changes in ecosystem service levels cascade throughout the economy.

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Appendix D. Stakeholder List

Name	Title	Agency / Organization	Sector
	Project Directors		
Keith Wood	Community Forestry Program Manager (S Platte **Natural Capital Project Director**)	CSFS	State
Dana Coelho	Urban & Community Forestry Program Manager	USFS, Rocky Mountain Region	Federal

Stacey Eriksen	Urban Watershed Revitalization Coordinator (S Platte **Natural Capital project lead for EPA**)	EPA, Region 8	Federal
	Consultant Team		
Lance Davisson	Project Manager	Ecosystem Sciences Foundation (ESF)	
Tim Maguire	Watershed Analysis / Principal Scientist	Ecosystem Sciences Foundation (ESF)	
Zac Christin	Economic Analysis	Earth Economics (EE)	
Angela Fletcher	Economic Analysis	Earth Economics (EE)	
Ian Hanou	GIS & Tool Development	Plan-It Geo (PG)	
Jeremy Cantor	GIS & Tool Development	Plan-It Geo (PG)	
	Stakeholder Team		
Amy Conklin	Coordinator	Barr Lake and Milton Reservoir Watershed Association	Local
Chris Poulet	Environmental Health Scientist, Regional Representative	CDC, ATSDR	Federal
Jon Novick	Environmental Administrator, Water Quality	City and County of Denver, Department of Environmental Health	Local
Sara Davis	Program Manager	City and County of Denver, Office of the City Forester	Local
Sarah Anderson	Water Quality Program Manager	City and County of Denver, Public Works, Policy, Planning & Sustainability	Local
Ashlee Grace	Water Quality Planner **(attended on behalf of Sarah)**	City & County of Denver	Local
Mike McHugh	Ecosystem Services	Aurora Water	Local
Brett Wolk	Assistant Director at CFRI	CO Forest Resoration Institute (CFRI)	Academic
Name	**Title**	**Agency / Organization**	**Sector**
Lexine Long	Wetland Ecologist	Colorado Natural Heritage Program (CNHP)	State
Carol Ekarius	Executive Director	Coalition for the Upper South Platte	NGO
Kristin Maharg	Director of Programs	Colorado Foundation for Water Education	NGO

Chase Moore	Youth Education Coordinator	Colorado Trout Unlimited	NGO
Christina Burri	Watershed Scientist	Denver Water	Private
Billy (William) Bunch	Wetlands & Water Quality	EPA, Region 8	Federal
Rachel Hansgen	Program Manager	Groundwork Denver	NGO
Carol Lyons	Executive Director	Institute for Environmental Solutions	NGO
Joseph Hansen	Conservation Forester	Jefferson Conservation District	Local
Jeff Lakey	Principal & Landscape Architect	LLG International	Private
Barbara Biggs	Chair	Metro Basin Roundtable (Metro BRT)	Local
Hope Dalton	Strategic Partnerships	Littleton / Englewood Wastewater Treatment Plant (LEWWTP)	Local
Alan Ragins	Program Manager	National Parks Service - RTCA Program	Federal
Joe Frank	Chair	South Platte Basin Roundtable (S Platte BRT)	Local
Lauren Berent		The Greenway Foundation	NGO
Paige Lewis	Deputy State Director, Conservation	The Nature Conservancy	NGO
Chris Hawkins	Urban focus	The Nature Conservancy - Colorado	NGO
Kim Yuan-Farrell	Executive Director	The Park People	NGO
Emily Patterson	Director of Park Planning Design and Construction	The Trust for Public Land (TPL), Colorado Program	NGO
Jonas Feinstein	State Conservation Forester	USDA NRCS	Federal
Pam Sponholtz	Project Leader	USFWS, Colorado Fish & Wildlife Conservation Office	Federal
Name	**Title**	**Agency / Organization**	**Sector**
Krystal Phillips	USFWS Biologist **(attended on behalf of Pam)**	USFWS, Colorado Fish & Wildlife Conservation Office	Federal
Bill Battaglin	Research Hydrologist	USGS	Federal
Darius Semmens	Research Physical Scientist	USGS	Federal
Ben Tyler		Leonard Rice Engineers	Private

Karl Hermann	Senior Water Quality Analyst	EPA, Region 8 - Water Quality Unit	Federal
Brian Tavernia	Spatial Analyst	The Nature Conservancy - Colorado	NGO
John Wieber	GIS Coordinator	EPA, Region 8	Federal
Ryan Bahnfleth	Environmental Protection Specialist **(on behalf of John)**	EPA, Region 8	Federal
Pete Barry	GIS Coordinator	Colorado State Forest Service	State
Additional Engaged			
Evan Burks	Partnership Coordinator	USFS - PSICC	Federal
Mikele Painter	Biologist	USFS, PSICC - S. Platte Ranger District	Federal
Kaw Ng	Region Economist	US Forest Service, Rocky Mountain Region	Federal
Claire Harper	Forest Legacy & Watershed Partnerships	US Forest Service, Rocky Mountain Region	Federal
Jeff Shoemaker	Executive Director	The Greenway Foundation	NGO
Karl Brummert		Denver Audubon Society	NGO
Elizabeth Fint		City of Brighton - Stormwater & Environmental Division	Local
Scott Olsen		City of Brighton - Stormwater & Environmental Division	Local
Peter Ismert	Watershed Coordinator	EPA, Region 8	Federal
Interested in or attended final project launch workshop			
Scott Woods	Program Manager	CO State Forest Service	State
Kathy Boyer	Environmental Health Specialist	Tri County Health Department (TCHD)	Local
Ken MacClune	Director	ISET International	Private
Name	**Title**	**Agency / Organization**	**Sector**
Donny Roush	Environmental Ed	Denver Public Works	Local
Mike Smith	Managing Director	Renew West	Private
Rob Pressly	Resilience Program Manager	CO Resilience & Recovery	State
Elaine Hassinger	Water Quality Specialist	Tri County Health Department (TCHD)	Local

Bryan West	NEPA Planner	US Forest Service, Rocky Mountain Region	Federal
Beth Nobles	Executive Director	Sand Creek Greenway	NGO
Ben Wise	Environmental Specialist	Littleton / Englewood Wastewater Treatment Plant (LEWWTP)	Local
Katie Spahr, PhD		Colorado School of Mines	Academic