TECHNICAL MEMORANDUM

To: High Line Canal STEP Team
From: Claudia Browne, Biohabitats
Date: January 14, 2021, Revisions May 13 and December 3, 2021
Re: High Line Canal Benefit Cost Analysis Summary

This memorandum summarizes the benefit cost analysis for the High Line Canal (Canal) Stormwater Transformation and Enhancement Program (STEP) including project background, methods, results and recommended approaches for advancing stormwater projects in the Canal.

PROJECT BACKGROUND

The High Line Canal Conservancy (HLCC) and its partners, including Denver Water, Mile High Flood District (MHFD) and the 11 adjacent jurisdictions, are creating a 71-mile linear park-like feature in the Denver metropolitan area with a primary focus on transforming the former irrigation canal into a regional stormwater management structure and enhanced public green space. In 2018, these partners established STEP with the overarching goal to:

> *Continue to plan for and implement a transformation of the Canal into an inspiring model utilizing smart water planning that demonstrates the benefits of integrated stormwater and urban watershed management for the ecological, physical and social health of our community while protecting precious freshwater resources for our rivers and streams.*

Program objectives include working on a range of green stormwater infrastructure issues such as finance models, maintenance plans, and education and leadership development along with an objective to specifically support *"the identification, advancement, and enlargement of a pipeline of stormwater projects that will demonstrate the benefits of smart water approaches for managing stormwater in the HLC."*

Funding support for STEP has been provided in part by grants from the Pisces Foundation, which seeks ways to accelerate a world where people and nature thrive together. The project has also been generously supported by The JPB Foundation through The Funders Network, an administrative partner in issuing and managing this grant. This funding allowed the HLCC to demonstrate benefits of the Canal for green stormwater infrastructure projects and to help increase project implementation across multiple jurisdictions. HLCC contracted with Biohabitats to conduct the following Pisces grant tasks as described in more detail in Methods:

- selecting key benefits and evaluation method,
- establishing an assessment framework,
- conducting preliminary data analysis, and
- testing and refining evaluation scenarios.

METHODS

STEP is being undertaken as part of a collaborative effort between HLCC, Denver Water, MHFD, Southeast Metro Stormwater Authority (SEMSWA), local jurisdictions along the Canal, RESPEC Engineering and non-governmental organizations such as The Greenway Foundation and The Nature

Conservancy. Since 2018, these stakeholders have been meeting regularly as part of a Technical Leadership Team (Team) to provide input on Canal stormwater project needs. Many of the Team members had been active in previous phases of Canal planning including the High Line Canal Stormwater Feasibility Study (Feasibility Study) (RESPEC, 2014) and the Stormwater and Operations Master Plan (Master Plan) (RESPEC, 2018). Over the past two years, the Team has been involved throughout the benefit cost analysis to review and comment on methods.

Task 1. Selecting Key Benefits & Evaluation Method

During the past decade, sustainable water infrastructure has become a topic of increasing interest nationally, and as a result, there are a variety of existing approaches that describe the multiple benefits of green infrastructure. Therefore, the first step of this analysis was to meet with the Team to review precedent quantitative and qualitative approaches and an initial, broad list of possible environmental and social benefits based on ecosystem services[1] (see diagram).

Example Types of Ecosystems Services (US EPA)

From that review process, the Team chose a quantitative framework for the analysis and narrowed the list of benefits to those that were most relevant to the Canal and those with available data sets. The selected key benefits include *stormwater quality management, habitat enhancement, and community amenities*, which generally aligned with the objectives of the recently completed *The Plan for the High Line Canal* (*The Plan*) to improve stormwater quality, landscape and natural environment, resiliency, and community health and livability (Appendix A). *The Plan* represents the vision of all the jurisdictions adjacent to the Canal, along with Denver Water and the Conservancy, to reclaim the Canal for the region by recommending a series of recreational, ecological and stormwater enhancements that will give new life to this legacy greenway[2].

HLCC and the Team also developed a list of eight co-benefit opportunities related to stormwater projects (which were initially written as goal statements) as shown in Table 1.

---

[1] https://www.epa.gov/enviroatlas/ecosystem-services-enviroatlas-0

[2] https://documentcloud.adobe.com/link/track?uri=urn%3Aaaid%3Ascds%3AUS%3Aff5e2713-e880-4e92-b941-6d0cd960d053#pageNum=1

Table 1. STEP Co-Benefit Opportunities

• **Increase stormwater quality treatment** in the Canal • **Reduce risk** of uncontrolled Canal overflows by providing constructed overflows or raising embankments in reaches with little to no freeboard • **Provide additional capacity for managing stormwater runoff** by directing flows to reaches with moderate to high available freeboard • **Protect** high quality riparian areas by providing stormwater support • **Improve** poor quality riparian areas by providing stormwater and native/drought tolerant tree plantings • **Maintain** areas of high climate resiliency[3] through stormwater-related projects • **Improve** ecosystem benefits (services) through stormwater projects in areas of vulnerable human populations • **Improve** below-average climate resiliency areas by providing stormwater support for riparian health

The above opportunities are intended to help guide jurisdictions and/or developers who are interested in developing a stormwater project along the Canal to consider additional project goals during their scoping processes and alternatives analyses. Another important resource to note for these audiences is the Pathway Guide, an online guide that facilitates the initiation and development of stormwater projects in the Canal. These opportunities were not prioritized for the overall Canal by HLCC and the Team, because it was agreed that each jurisdiction or project developer will likely have different priorities depending on the project, location, existing conditions, funding availability and organizations involved. Examples of project design elements that relate to the above opportunities include stormwater quality berms in the Canal, spillways for flood water management, habitat restoration/integration and sustainable tree planting.

Task 2. Establishing an Assessment Framework

The assessment framework for this analysis defines the geographic extent, zones and indicators for the Canal-wide and reach-scale evaluations. As the name suggests, the "Canal-wide" assessment included the 62 miles of the corridor's 71 miles that are eligible for stormwater management and covered by 11 governmental jurisdictions from Douglas County to the City of Aurora. For the reach-scale evaluation, these 62 miles of the Canal were further subdivided into 52 design reaches covering both stormwater quality and conveyance capacity as established in the Feasibility Study and Master Plan (RESPEC, 2014 and 2018)[4]. See Task 3 for further information on data inputs related to stormwater management.

The Canal flows across a range of geographic zones, transitioning from foothills to plains ecoregions (Figure 1). Ecoregions are areas where the climate, geology and soils, hydrology, plants and animals are

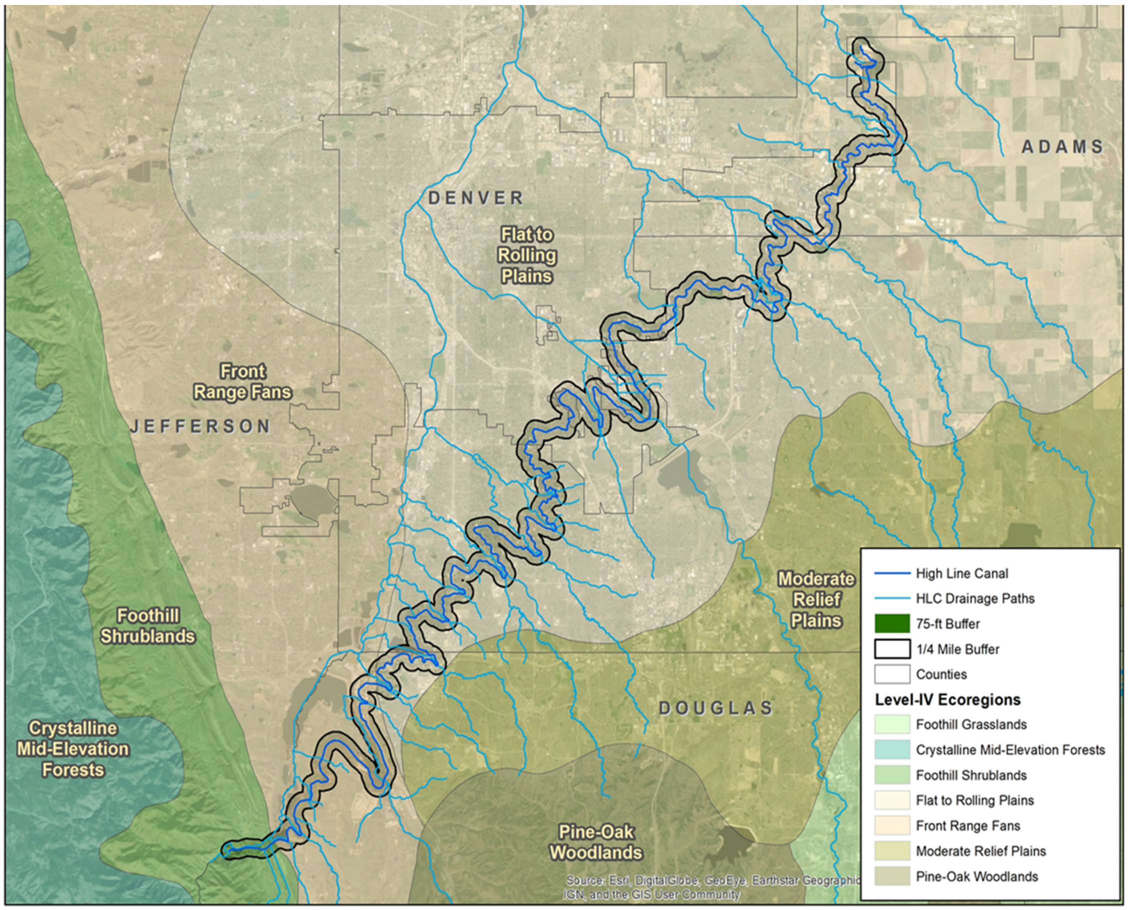
---

[3] Climate "resilience" has been defined by the Intergovernmental Panel on Climate Change *as "capacity of social, economic, and environmental systems to cope with a hazardous event or trend or disturbance, responding or reorganizing in ways that maintain their essential function, identity and structure, while also maintaining the capacity for adaptation, learning and transformation"* [IPCC Fifth Assessment Report: Climate Change 2014 (AR5)]. In the context of the High Line Canal, resiliency relates to ability to maintain and improve the corridor to reduce impacts from negative disturbances such as floods, droughts, heat island effects.

[4] Note that these segments do not include piped or closed portions of the Canal, so BCA reach lengths vary from other HLC reaches (i.e., associated with the trail segments).

similar and make up an interconnected system[5]. Opportunities for native plant cover (and wildlife) vary by ecoregions, making it sometimes difficult or inappropriate to compare plant communities across boundaries. Therefore, another aspect of the assessment framework considered how different evaluation criteria apply to different ecoregions. For example, fewer trees are expected in the plains zone and is not necessarily an indication of poor condition. The three ecoregions which the Canal traverses are shown in Figure 1 (based on U.S. Environmental Protection Agency, Level IV ecoregional mapping) and described briefly below.

Figure 1 Ecoregions along the High Line Canal, US EPA Level IV Ecoregions



- Foothill Shrublands—The most upstream portion of the Canal (0.75 miles of Reach 1) originates in Waterton Canyon, which is in the Foothill Shrublands ecosystem. This zone is unique to the Southern Rockies, and only occurs in Colorado, Wyoming and New Mexico. Mountain mahogany, antelope bitterbrush, skunkbush sumac, and currant are dominant shrubs, which are associated with dry, outcrop areas. In the absence of a normal fire regime, trees can encroach into the shrublands. Rufous-sided and green-tailed towhees, MacGillvray's warbler, and broad-tailed hummingbird are noted bird species, along with small mammals including rock squirrel, deer mouse, northern rock mouse, Mexican woodrat, and gray fox (Colorado Natural Heritage

[5] https://www.epa.gov/eco-research/ecoregions

Program, CNHP 2010). Human disturbances in the foothill shrublands are associated with increased invasive species, erosion and water quality impacts.

- Front Range Fans—Approximately 10 miles of the upstream portion of the Canal (Reaches 2-10) traverse the Front Range Fans ecoregion. Only 520,000 acres of this ecoregion type exist in the United States (and world), all of which are located in northern Colorado. This is a transition zone between the Southern Rockies and High Plains, and typically these types of interface zones are associated with higher biodiversity than nearby, similar zones. Foothill grassland species are dominant on the Fans and include "Shortgrass and mixedgrass prairie: blue grama, needle-and-thread, western wheatgrass, buffalograss, Junegrass, and little bluestem" (Chapman et al., 2006). Portions of the Canal in this zone are within the South Platte River Valley Potential Conservation Area by the CNHP which has high biodiversity value, especially in close proximity to Cheesman Reservoir. Rapid growth of urban development in this region is continuing to cause habitat fragmentation, loss and degradation.
- Flat to Rolling Plains—The vast majority of the Canal is located in the Flat to Rolling Plains ecoregion, which is characterized by grassland habitat with narrow riparian corridors along waterways. Reptiles and amphibians are more abundant in the plains than any other region in Colorado (Rondeau et al. 2010) as well as grassland nesting bird species. However, development and land use changes in grasslands have severely degraded the habitat in Colorado and across the country, with more than 50% of the grassland bird species having been lost nationally since 1970 (Science, 2019). Along the Front Range, remaining patches tend to be "highly fragmented and invaded by cheatgrass (Bromus tectorum), leafy spurge (Euphorbia esula), Dalmatian toadflax (Linaria dalmatica), Canada thistle (Cirsium arvense), and other exotic species" (Colorado Parks and Wildlife (CPW), 2015).

Canal assessment indicators were developed specifically for the current analysis. Typically, stormwater infrastructure assessments evaluate performance and maintenance needs, which is a much different purpose than the current analysis. For an assessment of the Canal's benefits, it was necessary to use a more ecologically based framework, which first recognized that the Canal's green infrastructure system is a novel (i.e., man-made) ecosystem, and therefore, indicators were selected from an applicable *reference* natural ecosystem type.

For this analysis, the Canal corridor is considered most similar to a natural *riparian ecosystem*, which refers to the transitional area between land and water where physical characteristics (like riverbanks), vegetation and wildlife are influenced by the nearby surface water and groundwater patterns. Riparian and wetland areas are also particularly critical for wildlife and vegetation in Colorado. In semi-arid environments, 80% of the wildlife, including songbirds and pollinators, rely on riparian and wetland habitat to survive because of the vegetation, diversity of food supply, and proximity to water. Generally, riparian health indicators may include overall size or extent; native plant cover, diversity, structure (herbaceous, shrub, sub canopy, trees) and extent of non-native species. Therefore, riparian ecological assessment indicators were incorporated into the Canal-wide assessment.

Two buffers were established to assist with the riparian evaluation in Geographic Information System (GIS): 1) adjacent areas 75 feet on either side of the Canal (centerline) to analyze riparian health of the corridor, and 2) a wider buffer at 1/4-mile distance on either side of the Canal for the analysis of floodplain and landscape connectivity.

Task 3. Conducting Preliminary Data Analysis

The benefit cost analysis was conducted at a Canal-wide scale and at the reach-specific scale for three pilot reaches (described more in Task 4). Available data for possible indicators were reviewed to evaluate the potential for multiple benefit cost opportunities along the Canal. Over 60 data sets were collected and reviewed from HLCC, RESPEC and available public sources to assess potential relevance to the study (Attachment A). In some cases, tabular data needed to be converted to a geospatial database to spatially relate them to the pre-established reaches and allow data extraction. Primary themes explored were Stormwater Management, Riparian Habitat, Community Health and Unit Costs. Key indicators, data sources, and evaluation criteria are described below.

Stormwater Management: Stormwater quality and conveyance capacity

- *Stormwater quality*: The Feasibility Study (RESPEC 2014, Table 6-1) provided information on existing inflow volumes by reach and available capacity for additional inflow or treatment, also referred to as 'treatable inflow under current (existing) conditions. For purposes of this memo, this volume will be referenced as "existing inflow." This baseline information was used to evaluate potential opportunities and costs for additional treatment along the Canal and to establish ranking criteria (Table 2). High-ranked opportunity reaches are those with the most potential to treat new inflows through the introduction of stormwater into the Canal and the addition of water quality berms to slow and treat the flow.

Table 2. Opportunity for Additional Stormwater Quality Treatment

Canal capacity for future inflows (ac ft)	Opportunity Ranking (4 = greatest opportunity)
>5 ac ft	4
>1 – 5 ac ft	3
None, but maintain existing inflow >1 ac ft	2
<1 ac ft existing inflow (with excess capacity unused)	1
No potential future inflows and no improvements for existing	0

- *Reducing the Risk of Uncontrolled Canal Overtoppings*: The Master Plan (RESPEC, 2018) provided information on the amount of freeboard (e.g., available capacity) in each reach in a 100-year storm event and identified reaches where the Canal is at risk of overtopping during these major storms based on the existing inflow. Reaches with a known spill location modeled to overtop in a 100-year storm have a high need for improvements that will reduce the risk of uncontrolled spills from the Canal. The Master Plan proposes infrastructure to reduce the risk of uncontrolled Canal overtoppings, including 13 constructed overflows where overflow water is redirected to a nearby drainage and eight spillways that would carry water safely to a drainage in a major storm event. This information was also used to establish ranking criteria (Table 3), prioritizing reaches with known spill locations as having the greatest need for and would benefit from infrastructure improvements as they are most likely to overtop during a 100-year storm event. Reaches with zero to low freeboard, e.g., less than 0.5 feet, will also have risk of uncontrolled Canal overtoppings during a 100-year event, and have the next greatest need for and would benefit most from a stormwater improvement project in the Canal.

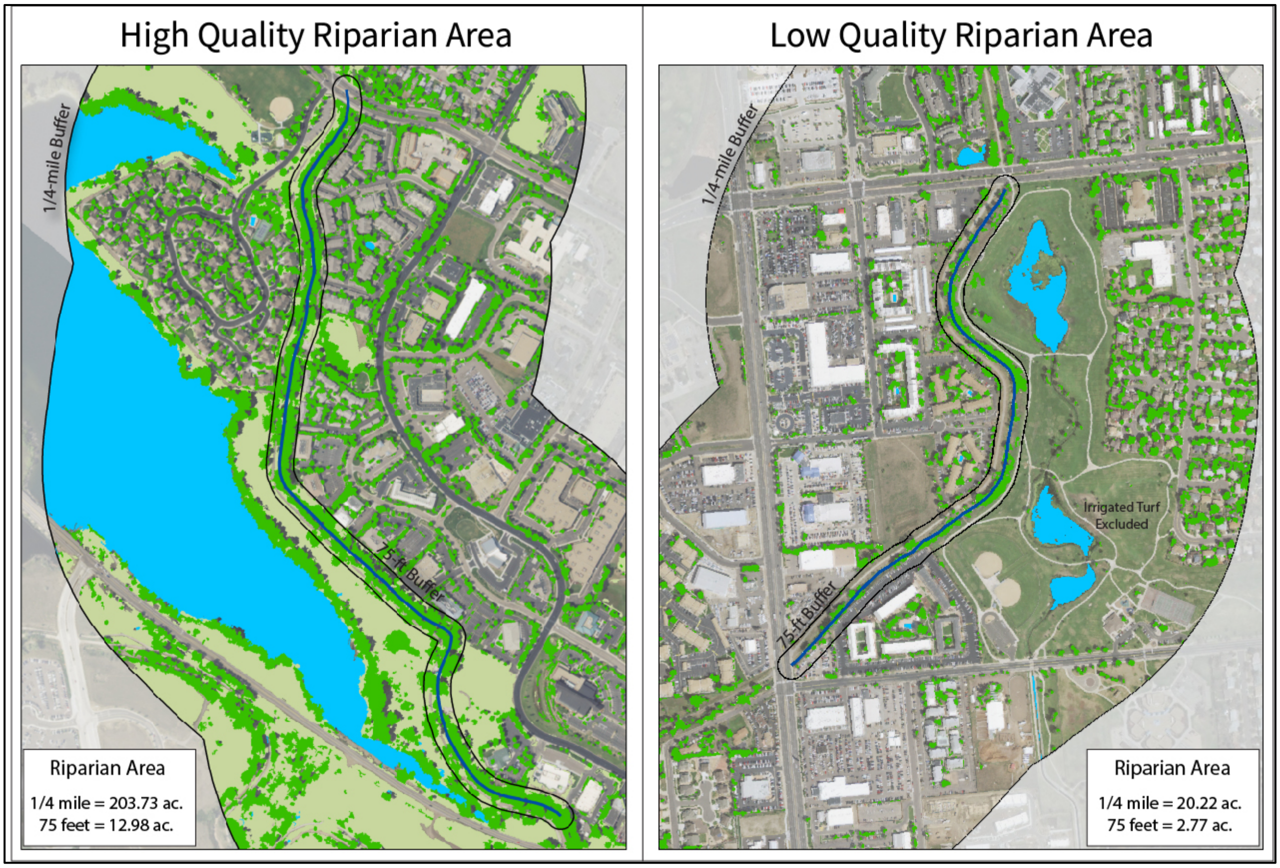
Table 3. Existing 100-year Freeboard Criteria and Risk Ranking

Existing 100-Year Freeboard	Ranking the Risk of 100-year Overtopping (3 = greatest risk)
<0 ft	3
0-0.5 ft	2
0.5-1 ft	1
>1 ft	0

<u>Riparian Habitat</u>: Four data sets were used to evaluate the riparian health or habitat quality -- tree data, land cover within the 75-ft buffer, land cover within the ¼-mile buffer and species of concern (indicators address riparian protection and improvement parameters in Table 1) as described below.

- *Tree data.* HLCC provided 2016 tree inventory data of the entire corridor which included information on the number of existing species greater than six inches in diameter within a 75-ft buffer of the Canal. The data set also contained information on tree size and health. Standing dead trees – although valuable for some ecosystem benefits – could not be evaluated and were removed from the inventory.
- *Land cover.* Denver Regional Council of Government's (DRCOG's) 1-meter regional land cover data was used to evaluate habitat quality and connectivity. The southern-most extent of the study was not covered by DRCOG's land cover data and was classified by Biohabitats using ArcGIS Pro Image Classification. Riparian vegetation was defined as the aggregate of multiple cover classes from the land cover data set (Tree Canopy, Prairie, Grassland, Natural Cover, Water). Vegetation land cover data was quantified by reach to determine the total acreage of each vegetation type and the overall extent of riparian area as a percentage of the reach area. The analysis results provided valuable information for comparing riparian quantity and quality along the Canal and for identifying areas where ecological values could be improved or protected. Figure 2 shows a comparison of two reaches, Littleton on the left and Aurora on the right, and their relative rankings based on land cover.
- *Species of concern*. Preble's Meadow Jumping Mouse, a federally listed endangered species, has been mapped along the corridor by CPW. Reaches where occupied range has been mapped received a "bonus" point for the opportunities' analysis (absence of range received a zero score).

Figure 2 Comparison of Riparian Vegetation along 2 High Line Canal Segments (DRCOG 2019 data)



Each of the inputs described above were assigned points as shown in Table 4. The points were summed to rank overall riparian condition, with total scores ranging from 0.75 in one reach to 3.5 in three reaches. These total scores were then converted to descriptive categories of "poor to high quality" (Table 5) and mapped (in Figure 7).

Table 4. Riparian Criteria

Points applied to each category	**Native tree density** (# native trees/ acre)	**Percent riparian vegetation within 75 ft buffer**[a] (# of reaches)	**Percent riparian vegetation within ¼-mi buffer**[a]	**Preble's Meadow Jumping Mouse occupied range**
1	8-11	74-82% (15)	$\geq$52%	Yes
0.75	6-7	64-72% (18)	31-49%	
0.5	3-5	46-61% (13)	17-27%	
0.25	1-2	23-42 % (6)	5-14%	

[a] Riparian vegetation was defined as the aggregate of multiple cover classes including Tree Canopy, Prairie, Grassland, Natural Cover, Water. Percent ranges per category based on natural breaks.

Table 5. Riparian Rankings

Total scores (based on sum of inputs in Table 4)[a]	**Riparian condition of reach**
3.5-3.25	High quality
3-2.5	Moderate quality
2.25-1.75	Fair quality
0.75-1.25	Poor quality

[a] Note in Aurora's Prairie Retreat zone, 1.75 is Moderate quality and 1.25 is Fair quality, to adjust for expected low tree density in the plains.

Community Health

According to the Centers for Disease Control (CDC), only half of adults get the physical activity they need to help reduce and prevent chronic diseases[6]. Regular physical activity lowers the risk of high blood pressure and stroke, improves aerobic fitness and mental health and prevents weight gain. Based on the CDC's health cost of inactivity, access to open space improves one's health benefits which can be translated into a savings of **$355 per person per year** in avoided medical costs. Through access to the Canal, residents across the region can get regular physical activity and enjoy the physical and mental health benefits public green space provides. To understand the community health benefit of the Canal, this analysis considers the number of residents within the ¼-mile buffer of the Canal who stand to benefit from access to open space.

To estimate the number of people within the ¼-mile Canal buffer, population data from the U.S. Census American Community Survey (ACS), 2012-2016 (5-year) were used to calculate the percentage of a census *area* that falls within the ¼-mile Canal buffer and then apply that percentage to the total tract population. For example, if 30% of a tract area fell within the ¼-mile buffer, then the population was estimated to be 30% of the total population from that census tract. To make the analysis more reliable, all non-private lands were removed from analysis to exclude parcels that would not have resident populations. This also reduced the total amount of area from census tracts and slightly reduced population totals where applicable. (See inset box.)

Buffer Population Calculation for Example Census Tract

This example demonstrates how the benefitting population was estimated based on proportion of area in a hypothetical reach.

- **Total census tract area:** 11,000 acres
- **Total census tract area after non-private land removed** (i.e., to exclude areas where no one lives)**:** 10,000 acres
- **Census tract area within ¼-mile buffer with non-private land removed:** 3,000 acres (30% of total non-private land area in the tract)
- **Census tract estimated total population:** 8,621
- **Calculation:** 8,621 * 0.3 (30% of total non-private land area in the tract is in the ¼-mile buffer) = 2,586
- **Resulting 10% of proportional population with expected health benefits:** 2,586 * 0.1 = 258

For the purposes of this analysis, it was then assumed that a baseline of 2.5% of the existing population in the ¼-mile buffer would receive a regular health benefit.[7] This results in 2,643 people estimated to be receiving *regular*, existing health benefits annually

[6] https://www.cdc.gov/physicalactivity/about-physical-activity/why-it-matters.html

[7] Because data does not exist to estimate Canal use by residents within each census tract, 2.5% was selected with HLCC staff input to represent a reasonable proportion of the total ¼-mile population that may receive health benefit.

within ¼-mile buffer Canal wide as shown in Table 6.[8] (For the reach scale analysis, 2.5% of the buffer populations in pilot reaches ranged from 26 to 174 people expected to receive regular benefits per reach.) The actual number of benefitting users is expected to be much higher; however, to attribute reduced medical expenses to Canal use alone, a smaller (more conservative) number was used. This estimated number of users receiving regular, quantifiable health benefits could be further studied by analyzing Canal user data and its change over time.

Table 6. Estimated population within ¼-mile buffer of Canal

Area	Population	2.5% of buffer population, estimated to be receiving regular health benefit
Canal Wide, ¼-mile buffer	105,709	2,643
Pilot Reaches		
Design Reach 21, ¼-mile buffer	1,025	26
Design Reach 30, ¼-mile buffer	2,595	65
Design Reach 34, ¼-mile buffer	6,962	174

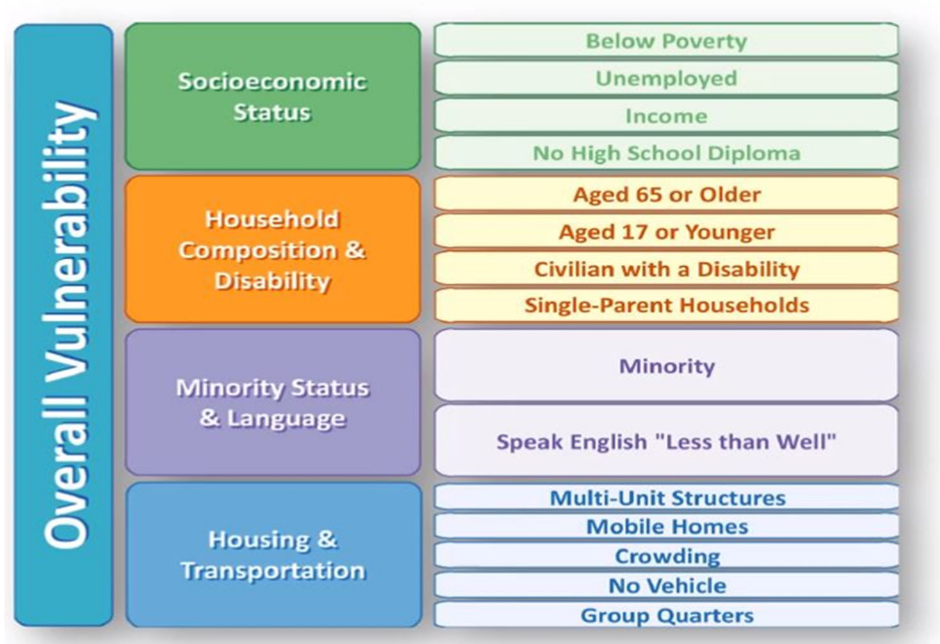
The community health evaluation also looked at the relationship of vulnerable communities to the Canal, as those groups might receive the greatest benefit from access to open space. This process began with the Team and other representatives from their jurisdictions vetting available social data sets, including the CDC's Social Vulnerability Index (SVI[9]). While some county representatives noted they may have more detailed data, e.g., health metrics, the Team agreed that SVI would be most useful as it is readily available, well-documented, covers multiple metrics and is easy to use for high-level analysis.

According to the CDC, "*Social vulnerability refers to the resilience of communities when confronted by external stresses on human health, stresses such as natural or human-caused disasters, or disease outbreaks. …CDC's Social Vulnerability Index uses 15 U.S. census tract-level variables to help local officials identify communities that may need support in preparing for hazards; or recovering from disaster*." Specifically, CDC uses percentile comparisons of census tracts within the state (e.g., so users can avoid having to figure out what is a "high" unemployment rate, what is a "high" minority rate, etc.). See Figure 3 for list of inputs included in the index.

[8] Note that TPL and other NGOs often use the 10-minute walk within ½-mile of a park as an indicator of accessibility. Using the HLCC ¼-mile buffer, as opposed to the ½ mile distance further improves the certainty of the population in the buffer having access to receive health benefits from recreational activities.
[9] https://svi.cdc.gov/

To quantify the vulnerable populations along the Canal, population data for census tracts with overall rankings of highly vulnerable (80th to 100th percentile) and vulnerable (60th to 79th percentile) were tallied. This approach found approximately 50% of the total ¼-mile buffer population resides in a socially vulnerable census tract (Table 7). However, vulnerable populations vary significantly by reach, with the highest numbers concentrated in Denver, Aurora and unincorporated Arapahoe County (see Figure 4). It is possible that in some reaches, the vulnerable population may make up the majority of the baseline 2.5% of residents estimated to be benefitting from the Canal. For example, in one pilot reach that had highly vulnerable tracts in the ¼-mile buffer (Reach 34 in unincorporated Arapahoe County), the highly vulnerable population was estimated to be 416 residents or roughly 6% of the buffer population (out of 6,962 as shown in Table 6).

Figure 3 Social Vulnerability Index



https://svi.cdc.gov/

Table 7. Estimated Vulnerable Population in ¼ mile Canal Buffer

Overall Vulnerability Population	Population	% of total Canal Wide population in ¼-mile buffer
Canal Wide, ¼-mile buffer	105,709	
Canal Wide, ¼-mile buffer, SVI Most Vulnerable (80th to 100th Percentile)	39,093	37%
Canal Wide, ¼-mile buffer, SVI Vulnerable (60th to 79th Percentile)	13,313	13%
Canal Wide, ¼-mile buffer, SVI Most Vulnerable AND Vulnerable together (60th to 100th Percentile)	**52,406**	**50%**
Notes: 1. Design Reaches 21 and 30, ¼-mile buffer do not have census tracts categorized as Most Vulnerable (80th to 100th percentile) or Vulnerable (60th-70th percentile). 2. In Design Reach 34 ¼-mile buffer, census tracts indicated the population in the Most Vulnerable (80th to 100th percentile) category was 416, and no census tracts had Vulnerable (60th to 70th percentile) populations.		

Unit Cost Data

Unit cost information for project components was obtained primarily from HLCC, existing engineering reports, national precedent analyses and stakeholders. The GIS data was used to quantify resources along the Canal and in three stormwater pilot reaches (Cities of Greenwood Village and Littleton and City and County of Denver). Based on the quantities and costs, individual values were summarized by category. Descriptions of the unit costs are below, and summaries are discussed in more detail in the Results subsection.

- **Land.** For land values, assessor records were reviewed for parcels adjacent to the Canal in the locations of the three stormwater pilot projects. These values varied from $18,000 per acre (Eisenhower reach, Wellshire Golf Course parcel) to $200,000 per acre (near deKoevend Park). An average of **$34,000 per acre** was used for this analysis. While this value may seem low for metropolitan Denver, it is reasonable to assume that existing public lands (which are often slated for green infrastructure) would tend to be lower than commercial property values.[10]
- **Trees.** Tree values were obtained from the Metro Denver Urban Forest Assessment (Macpherson et al. 2013) which estimated the annual ecosystem benefit of trees as **$52 per year.** This is the combined value of carbon dioxide reduction, energy and air quality regulation, rainfall interception, and property value enhancement. Another consideration is the cost of tree replacement ($250 each) and tree removal expenses ($500), which are also incorporated into the benefit cost analysis.
- **Community health.** Access to open space improves one's health benefits which can be translated into a savings of **$355 per person per year** (based on the health cost of inactivity per CDC). The cost of inactivity was used for this analysis, estimating the savings realized as residents near the Canal utilize the corridor for physical activity.
- **Construction and maintenance.** Construction costs for berms and conveyance improvements as well as off-site alternative operation and maintenance (O&M) costs were obtained from the Feasibility Study (2014). O&M costs for the Canal including the greenway were based on The Plan (2019).

Task 4. Testing and refining evaluation scenarios

As noted previously, the geospatial and benefit cost information were evaluated at two scales -- Canal-wide and reach scale. The results of the Canal-wide evaluation were 1) a summary of stacked benefits and costs, and 2) identification of priority reaches where stacked benefits could be realized by converting the Canal to green stormwater infrastructure. In three pilot project reaches, the analysis established three "generic" scenarios for types of projects and compared net benefit-costs of each scenario. Note that both the Canal-wide and the reach-scale analyses focused on water quality costs described in the Feasibility Study, and therefore do not include the costs or benefits of reducing the risk of uncontrolled Canal overtoppings or any potential localized flood moderation at this time.

Canal-wide analysis

Cost-benefit. The geospatial analysis was used to estimate the value of select Canal-wide benefits measured over a 50-year period to account for up-front costs as well as ongoing costs and benefits. The evaluation method varied somewhat depending on the benefit category.

[10] This value also aligns closely to land values in the Feasibility Study which used $35,000 for undeveloped land and park land.

- Stormwater management was based on the volume of existing and future inflows treated in the Canal using a "*green to green*" infrastructure approach. The net benefit-cost was calculated as the difference between the cost of alternative offsite treatment to replace the Canal's capacity minus the cost of construction improvements recommended in the Canal. The stormwater management cost also considered the increased maintenance required to manage stormwater in the Canal compared to maintenance of offsite treatment facilities.
- Riparian habitat value was estimated using the replacement cost for the existing habitat acreage (avoided cost of purchasing new park land) and native tree replacement cost estimate[11].
- Community health value was based on offset medical costs for the portion of the population within ¼-mile of the Canal that was assumed to benefit from physical activity and avoid the higher health costs associated with inactivity. As previously noted, for the purposes of this study, it was assumed that 2.5% of the population would benefit from access to the Canal green space.

Reach prioritization. Overlay mapping was used to review the relationships between different opportunities for green stormwater infrastructure, reduced risks of uncontrolled Canal overtoppings, localized flood moderation, riparian habitat and community health. These overlay maps were used by HLCC to select three pilot projects to test the benefit cost analysis, as described below.

<u>Reach-specific analysis</u>

The reach-specific analysis provides a tool to help developers or project advocates compare the environmental, social and economic benefits under various scenarios. A key step in developing the evaluation method was to identify which scenarios to use. With input from HLCC and the Team, the three selected scenarios included:

Scenario 1: no stormwater project in the reach (i.e., offsite treatment)
Scenario 2: *only* a green stormwater infrastructure project in the reach (no other amenities)
Scenario 3: a green stormwater infrastructure project in the reach plus other social and ecological enhancements.

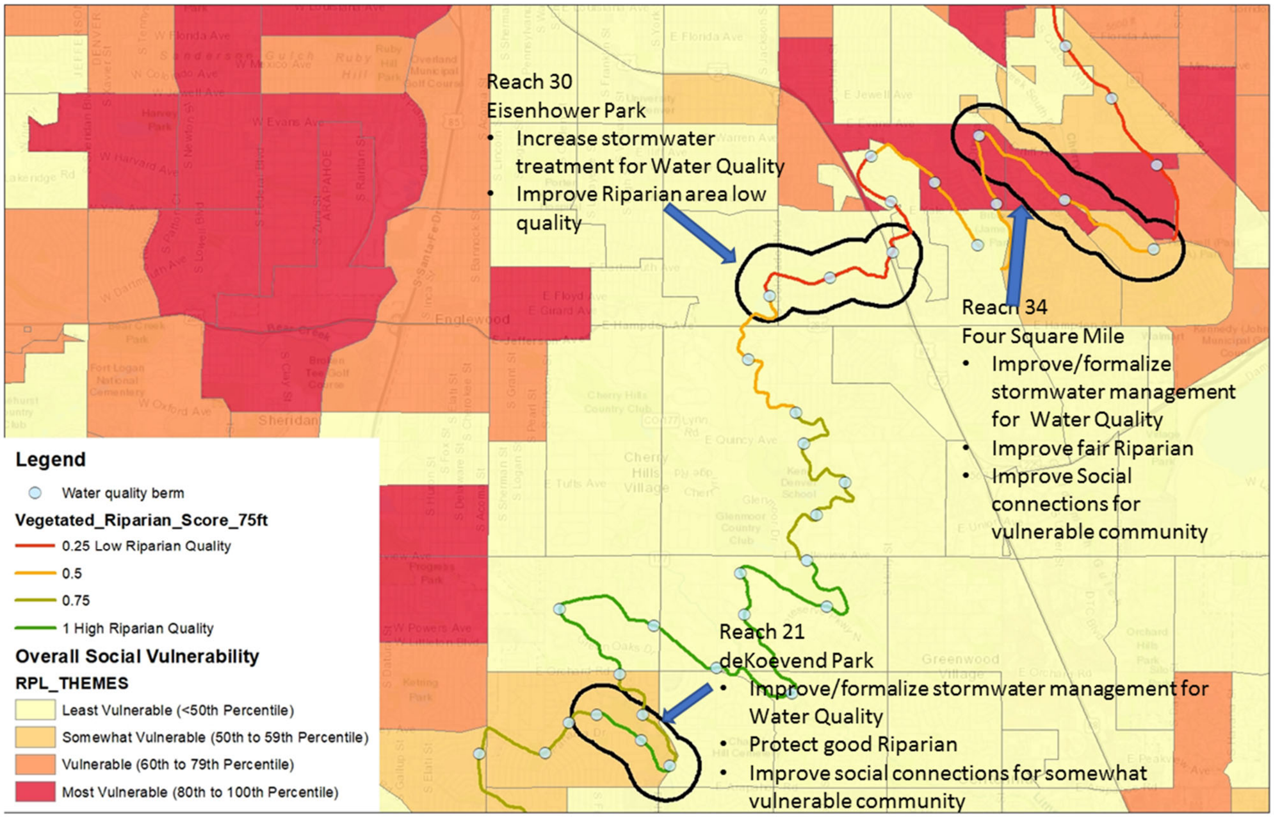
For Scenario 2 with stormwater improvements only, the analysis estimated increased health benefit using the same assumption as the Canal-wide analysis (based on 2.5% of buffer population). For Scenario 3 with additional social and ecological enhancements, the analysis assumed an additional 2.5% (total 5%) would benefit from increased use of the corridor due to enhanced access, signage, amenities and outreach.

The pilot reaches are intended to demonstrate the evaluation and potential for the analysis to be applied to specific reaches as stakeholders consider stormwater projects. The three pilot locations and the rationale for their selection are shown in Figure 4 and summarized in Table 7. While Reaches 21 and 30 have active stormwater projects underway, the analysis for Reach 34 is purely conceptual.

---

[11] Note that the Canal-wide analysis did not include costs of other riparian or community enhancements as those are not yet developed and will be reach-specific as described in the next subsection.

Figure 4 Pilot locations for reach-specific analysis



Site visits were conducted in each reach to ground-truth GIS data and better understand existing conditions, surrounding area context, opportunities, and limitations. Field data collection included an online tool template (in ArcCollector) to identify opportunities and constraints. Preliminary concepts were then developed in GIS to allow quantification of improvements. For Reach 21, concept sketches were prepared to present integrated strategies/conceptual designs (see Figures 7 and 8). For Reach 30, a stakeholder meeting with the City and County of Denver was held to review and refine assumptions.

Table 7. Selected Pilot Reaches

Reach ID	Selection Rationale	Opportunities
21	Good quality riparian habitat Existing stormwater treatment with excess capacity Somewhat vulnerable population	**Protect** high quality riparian areas by providing stormwater support **Improve** ecosystem benefits (services) through stormwater projects in areas of vulnerable human populations
30	Low quality riparian habitat Potential for stormwater treatment	**Improve** poor quality riparian areas by providing stormwater and plantings
34	Fair riparian habitat No existing stormwater with good future inflow potential Most socially vulnerable	**Increase stormwater quality treatment** in the Canal and **improve** ecosystem benefits (services) through stormwater projects in areas of vulnerable human populations

CANAL-WIDE RESULTS

Canal-wide mapping was used to measure and calculate select benefits of transitioning all 62 eligible miles of the Canal to green stormwater infrastructure.

Stormwater Management

One of the project goals was to evaluate existing and future benefits of the Canal to "*increase stormwater quality treatment in the Canal*," which was done by determining the cost of alternative treatment off-site (avoided costs) compared to using the Canal. Additionally, estimated construction costs for water quality treatment berms along the whole Canal, as well as additional conveyance for existing inflows, were used to estimate improvement costs[12]. The net benefit is the difference between the value of the avoided costs less the construction costs. To determine costs over a 50-year life cycle, the increased costs to maintain the Canal as green stormwater infrastructure were then compared to the costs of maintaining off-site treatment facilities.

Note: The requirement to treat stormwater varies within jurisdictions and in reaches. Regardless of the need for treatment, jurisdictions need to manage all stormwater. Therefore, the concept for valuing the cost for alternative treatment described above also applies to valuing the costs of alternative conveyance and detention benefits in those reaches which may not require treatment but for which the Canal provides conveyance and detention benefits. Future iterations and applications of the benefit cost analysis can distinguish between the Canal-wide and reach-specific benefit (for treatment and/or conveyance and detention) to further refine the analysis and make it more reflective of existing and future conditions.

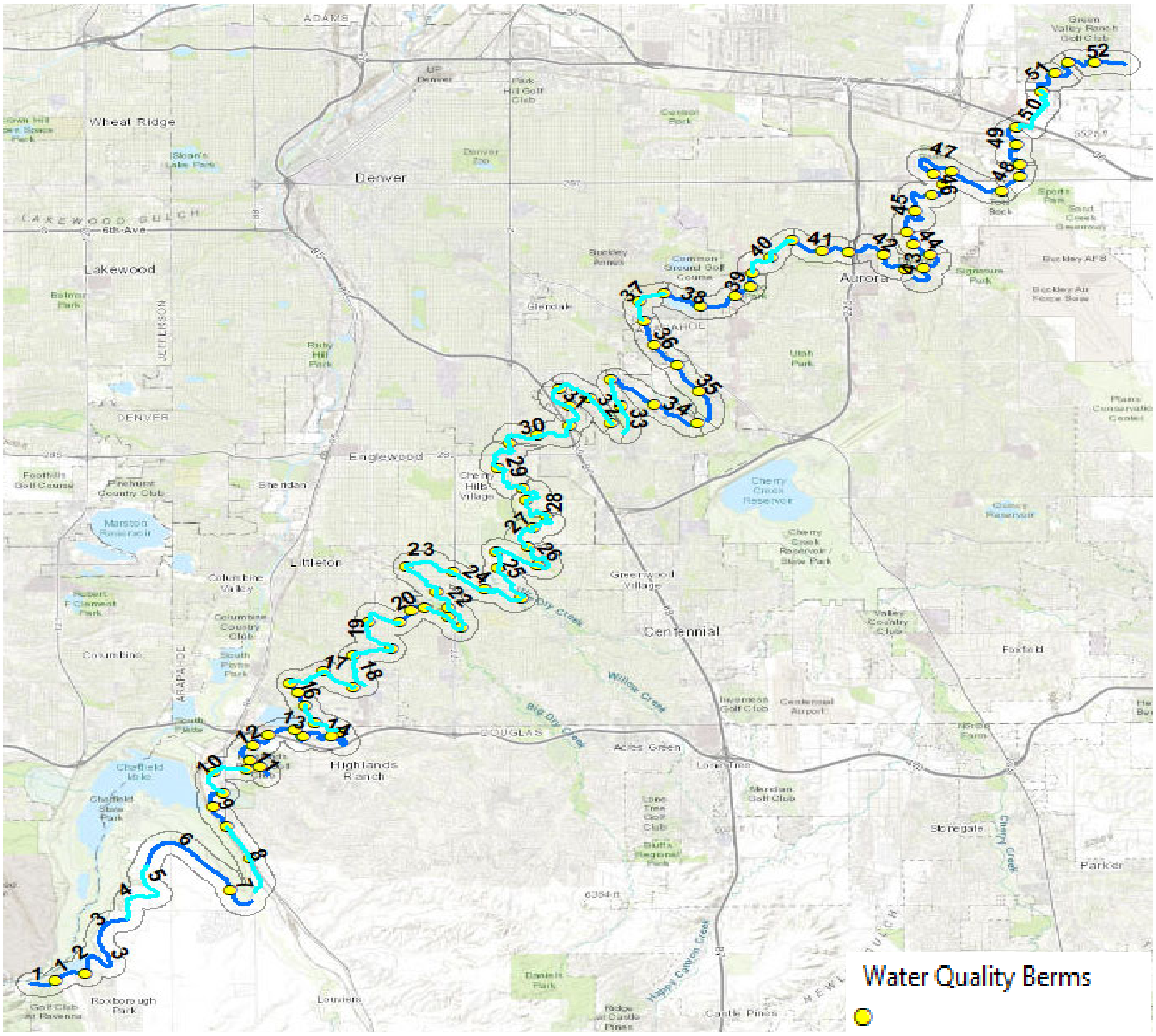
Existing Water Quality Treatment Benefits

A total of 24 of the 52 reaches along the Canal currently receive existing inflow (Figure 5) and are assumed to provide some stormwater quality benefits by filtering and absorbing pollutants for 73.2 ac-ft of stormwater. To calculate the value of the existing stormwater quality benefit provided by the Canal, the estimated "Cost for Alternative Water Quality Treatment" from the Feasibility Study was used. The Feasibility Study estimate for an alternative treatment for existing and future flows to the Canal was based on:

> "*UDFCD's BMPREALCOST spreadsheet program, assuming the installation of extended detention basins as a comparable method of treatment…The alternative cost estimate includes land costs since the construction of new extended detention basins will likely require the acquisition of existing developed property for their installation. The estimated land costs may be low considering very few properties exist that are not already developed. This estimate does not include any storm sewers that may be needed to direct flow to the extended detention basins. The estimated cost of the alternative facilities is $75,452,000. (RESPEC 2014)"*

[12] http://www.highlinecanalcolorado.com/

Figure 5 High Line Canal Reaches Currently Receiving Existing Inflow, highlighted in light blue.



Source: RESPEC 2014, Table 6-1

The ~$75M estimate for the Canal alternative was then divided by total volume to be treated (~201.8 ac-ft[13]), resulting in a unit cost of $373,895/ac-ft. Based on this unit cost for alternative treatment and the existing volume (73.2 ac-ft), the current value of the Canal to manage existing inflow is ~$27.4M (avoided cost to manage offsite).

According to the Feasibility Study, to improve water quality benefits will require construction of berms in reaches with existing treatment. The estimated total cost of berms in the reaches with existing inflow (~100 berms) is ~$4.3M[14]; therefore, the net *benefit-cost* of water quality treatment for existing inflow is ~$23.1M ($27.4M-$4.3M).

[13] Note, this number has since been updated to 203.7 ac ft existing and future flow capacity; however 201.8 was used for consistency with the existing plans. Alan Leak personal communication 2021.

[14] The estimated price of construction for berms and conveyance for the entire canal is $35,733,737, of which $31,485,737 is for future inflows, per Feasibility Study and RESPEC personal communication with Alan Leak, 2021. Note: no conveyance costs are associated with the existing inflows.

Potential Future Water Quality Treatment Benefits

Similar to the existing flow analysis above, the value of the Canal to treat future inflows (128.6 ac-ft) is the avoided costs of offsite treatment $48.1M ($373,895/ac-ft * 128.6 ac-ft) less the construction costs ($31.5M[15]). The resulting net benefit-cost for construction of treatment onsite for future inflows is $16.6M.

Operation and Maintenance

Operation and maintenance (O&M) costs for stormwater management were reviewed for both offsite alternatives and onsite O&M. The 50-year cost for alternative offsite treatment is estimated to be $45M or $4,465/ac-ft annually, or $15,000/mi per year.[16] From The Plan, the estimated 50-year cost for O&M related to stormwater is $46.4M, for an overall increased cost of maintenance for the Canal of $1,445,000 compared to offsite maintenance over 50 years. As maintenance data become available, these estimates can be reviewed and refined in future analyses.

Reducing the Risk of Uncontrolled Canal Overtoppings

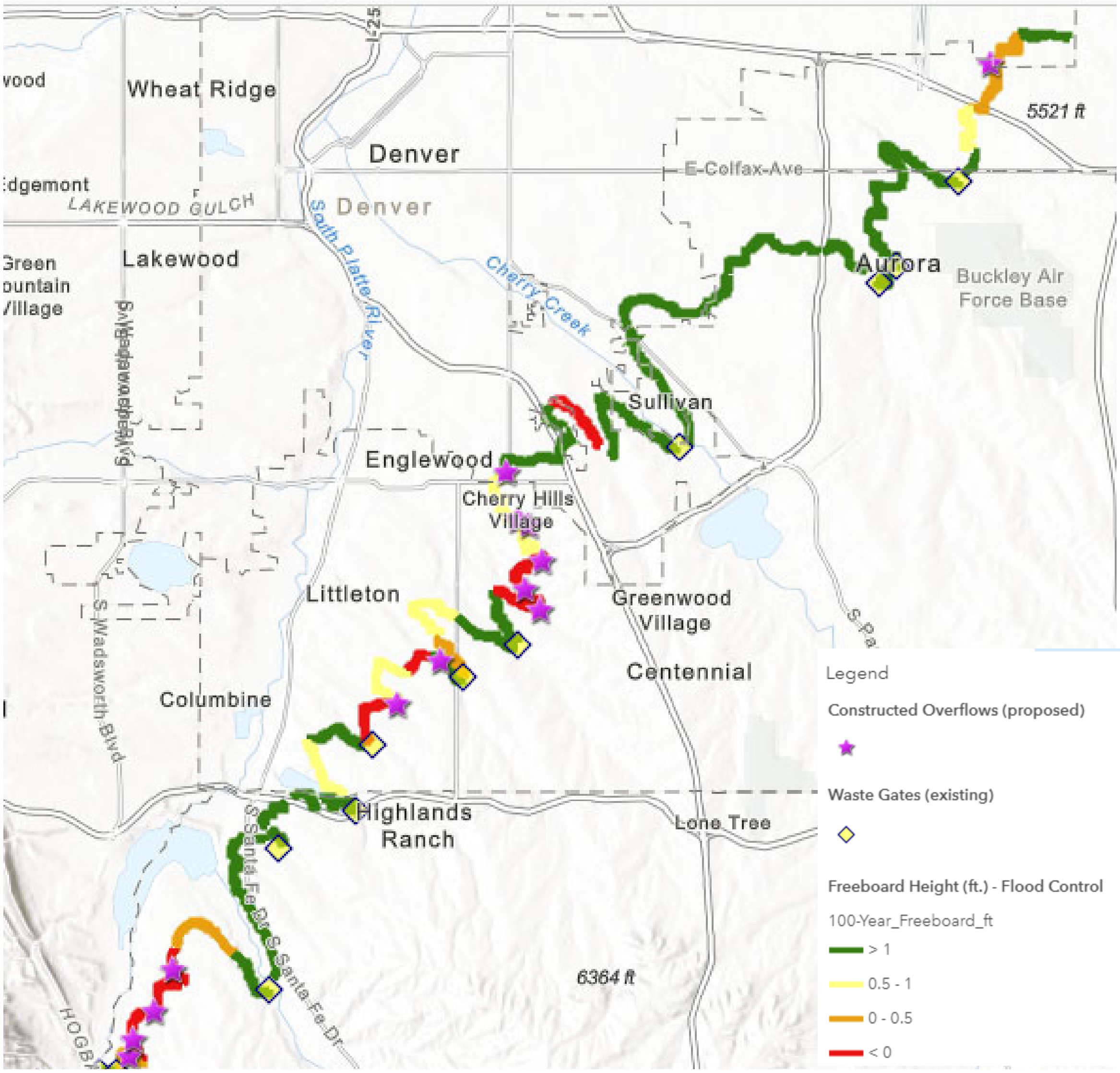
The geospatial analysis provided qualitative information about potential locations for future project prioritization. As described in the Methods section, reaches that lack capacity during a 100-year storm event (i.e., negative freeboard) have a higher risk of overtopping and are ranked as having higher need for improvement. Figure 6 shows priority reaches with the greatest risks of uncontrolled spills from the Canal (red and orange) that could be improved with constructed overflows and spillways to natural water courses.[17] Reaches shown in green and yellow are not as high of priorities as they have enough capacity (and existing overflow controls such as "waste gates" as shown) that flooding in 100-year storm events would not be expected to occur. The capital costs required to mitigate uncontrolled spills from the Canal through the installation of constructed overflows and spillways are detailed in the Master Plan.

[15] The $31.5M cost is based on total Canal-wide improvement cost $35,733,737 minus the portion for berms in reaches with existing inflow $4,248,000, per RESPEC's Alan Leak personal communication, 2021.

[16] Breakout detail from HLC Feasibility Study provided by Alan Leak and based on Alternative Off-site Facility Equivalent Costs from MHFD BMP-REALCOST spreadsheet V1.21.

[17] As noted, valuation of existing and proposed benefits for local flood reduction were not included in the current study. If this valuation is desired in the future, one approach would be to estimate the volume of water to be released from the Canal to nearby drainages, which could otherwise flood adjacent properties. Then, either estimate the cost of a detention basin to handle the water or the cost of improvements to safely convey the un-detained runoff to a natural drainageway with capacity for the un-detained flow.

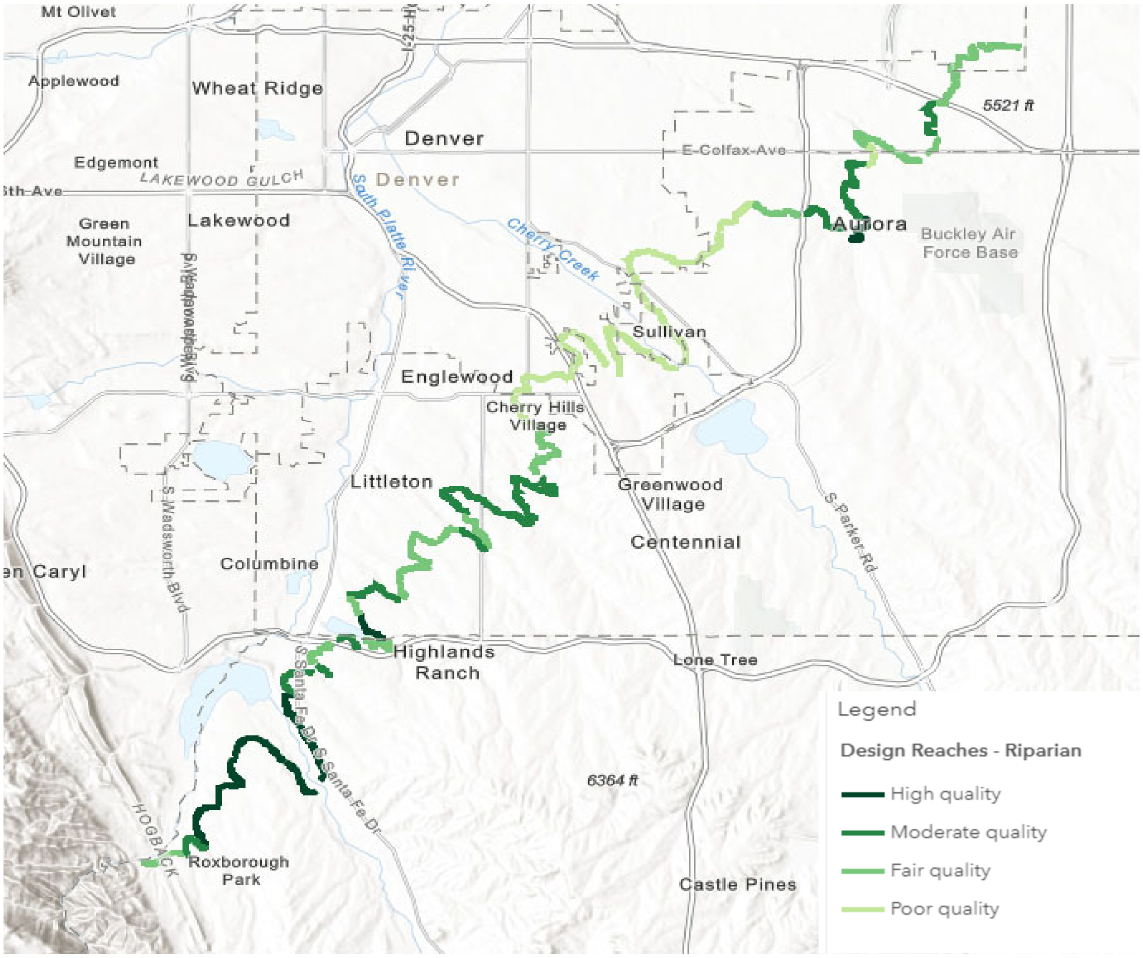
Figure 6 High Line Canal Local Flood Control Opportunities



Riparian Habitat

As described in Methods, prioritization of riparian habitat along the Canal was based on the combined inputs of percent vegetated land cover (in 75-ft and ¼- mile buffers), structure (using tree canopy), and known habitat for the endangered Preble's Meadow Jumping Mouse. High-value areas in Figure 7 represent priority locations for protection and lower-quality areas represent opportunities for improvement.

Figure 7 Riparian Conditions Along the High Line Canal



<u>Existing Riparian Benefits</u>

Land values were used to estimate the benefit of the existing riparian area. The total area within the 75-ft buffer on either side of the Canal is 1,152 acres, of which 737 (64%) are vegetated riparian habitat. At the average public land value of $34,000 per acre[18], the value of the existing riparian area in the 75-ft canal buffer is estimated to be $25M.

<u>Trees</u>

The Canal-wide habitat evaluation includes estimating the value of the trees that are greater than 6" in diameter, based on the inventoried total of 19,055 live trees. Using the Denver urban forest value of $52/tree/year, the total value of the existing trees is $990,860 per year, or a 50-year value of $49.5M.

Of the existing trees, 53% are native species which are considered to have more important ecological value. The study assumed that the jurisdictions would want to replace native trees in the future to maintain their tree canopy (i.e., if the native trees were lost because the Canal was not used for stormwater). At an average price of $250/tree, the cost to replace native trees would be approximately

[18] Note, the land value used in the Feasibility Study and the current analysis were not compared, and this may be an item to resolve in future refinements of the method.

$2.7M. In addition, if the native trees were lost, the maintenance cost to remove the dead tree is estimated to be $500/tree for a total deferred maintenance expense of $5.4M.

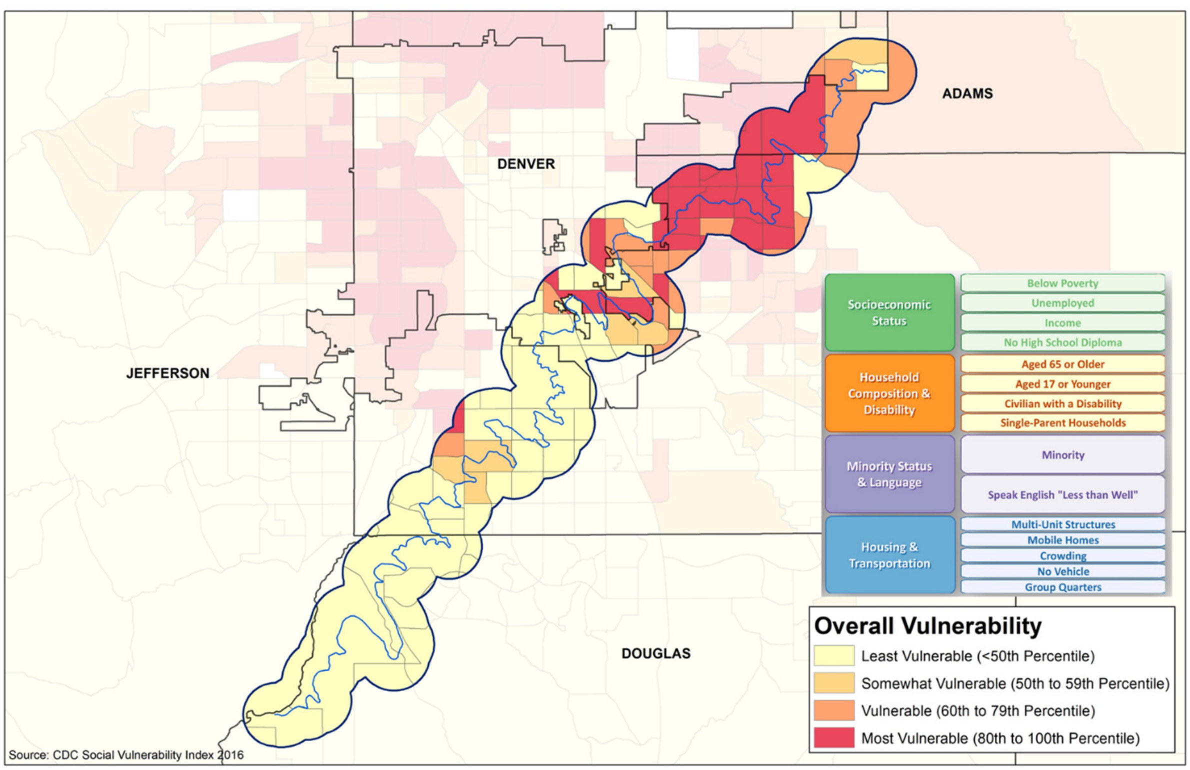
Community Health

Of the total population within the ¼-mile buffer, it was assumed that 2.5% of the residents (2,643) will receive health benefits from regular use of the Canal green space. Based on the CDC's health costs of inactivity, the avoided medical costs for those residents would be $355/year for an estimated total of $938,167 benefit annually or $46.9M over 50 years for the Canal-wide analysis.

While this benefit was distributed evenly across the Canal, future reach-level analyses could take into acount the vulnerability of the population at a more local level. A key strategy for STEP is to prioritize reaches where stormwater quality projects will provide opportunity to enhance areas with vulnerable human populations and social vulnerability can be used as an overlay when jurisdictions begin to analyze benefits at the reach level.

Social vulnerability mapping illustrates where the Canal intersects areas where populations may be underserved or otherwise in need. Figure 8 depicts the overall social vulnerability along the Canal for the four combined categories of economic status, household composition/disabilities, minority and language status, and housing and transportation (refer to Figure 3). (Note: separate maps for each variable may be more appropriate for inputs to specific project development.) Reaches of the Canal that traverse the vulnerable (orange areas) and most vulnerable (red areas) are priority locations for projects to improve social and ecological benefits in communities with the greatest need.

Figure 8 Overall Social Vulnerability along the High Line Canal



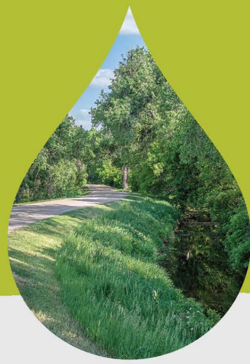
Summary of Canal-wide Costs-Benefits

Table 8 and the following infographic summarize the Canal-wide benefits and associated costs. As shown, the total value over 50 years is estimated at $168M (in present day dollars), or roughly $2.7M per mile of stormwater reaches (62 total miles). This estimate does not include the benefits and costs of local flood moderation, which can be added in future iterations or reach-specific analyses.

Table 8. Summary of Canal-wide Benefits

Benefits	Quantity	Unit $	Value (or Cost) $ present day	Basis
Water Quality Existing Inflow	73.2 ac-ft	$373,895/ac-ft	$27.4M	Avoided cost of alternative treatment offsite
	24 reaches with existing inflows	1 (lump sum for all reaches)	($4.25M)	Berms construction
Water Quality Future Inflow*	128.6 ac-ft	$373,895/ac-ft	$48.1M	Avoided costs to treat future inflow offsite
	28 reaches with future inflows	1 (lump sum for all reaches)	($31.5M)	Berms and conveyance construction
Water Quality O&M	62 miles	$23,311/mi	($1.45M)	Increased Canal O&M for in-Canal treatment compared to off-site alternative
Habitat	737 acres forest/natural riparian habitat in 75 ft buffer	$34,000/acre	$25M	Avoided costs to purchase land with riparian habitat
	19,055 trees along Canal	$52/tree/yr	$49.5M	Value of existing trees (50-yr projection)
	10,787 high value native trees along Canal	$500/tree $250/tree	$5.4M $2.7M	O&M costs deferred by using stormwater to prevent tree loss Native tree replacement
Community Health	2,643 residents benefitting within ¼-mile of Canal	$355/person/yr	$46.9M	Potential avoided medical costs from health benefits (50-yr projection)
Total			**$168 M**	**~$2.7M/mile**

*These values assume jurisdictions fully utilize the Canal for both existing and future inflows. However, because management of future inflows is not required in all locations, site-specific evaluations would be needed to confirm.



STORMWATER

It can make the world green.
That's the power of STEP.

OVER 50 YEARS, THE HIGH LINE CANAL (CANAL) WOULD PROVIDE $168M IN BENEFITS OR $2.7M PER MILE AS GREEN STORMWATER INFRASTRUCTURE

Evaluating the Multiple Benefits of the Canal's Transition to Green Stormwater Infrastructure.

The Stormwater Transformation and Enhancement Program (STEP) seeks to advance stormwater projects that will realize the social, economic and environmental benefits of managing stormwater in the Canal.

$38 MILLION

Water Management Benefits = $38M

Value of Treating Stormwater $39M
Jurisdictions can save $39M over 50 years by managing stormwater in the Canal as opposed to the cost of managing it off site

Increased Cost of Maintenance (–$1M)
Increased cost of maintenance for the Canal compared to offsite maintenance

$83 MILLION

Environmental Benefits = $83M

Tree Value & Preservation $58M
Value of the Canal's 19,055 healthy, mature trees + avoided costs to replace over 10,000 trees

Wildlife Habitat Value $25M
Avoided cost to replace the Canal's wildlife habitat

$47 MILLION

Community Health Benefits = $47M

Medical Cost Savings $47M
Avoided medical costs for 2,643 residents living within ¼ mile of the Canal through regular use of the Canal trail

Supporting Vulnerable Populations 50%
Over half of the residents that live along the Canal are considered socially vulnerable as defined by the Centers for Disease Control

All values represent a 50-year life cycle and assume that the 62 miles of the 71-mile Canal that are eligible for stormwater management are transformed.

DENVER WATER | MHFD MILE HIGH FLOOD DISTRICT | Pisces Foundation | HIGH LINE CANAL CONSERVANCY

ONE CANAL. ONE COMMUNITY. ONE WATER.

REACH-SPECIFIC PROJECT CONCEPTS

After completing the Canal-wide analysis, three reaches were used as pilots to apply the analysis at a finer scale. These pilot reaches demonstrate the potential for the analysis to be applied to help evaluate potential stormwater projects, while detailing project concepts that would allow the Canal to maximize benefits to the surrounding communities. Based on a field assessment and GIS mapping, a list of possible project elements and concepts were developed for the pilot reaches. Project elements related to landscape enhancement and recreational improvements are recommended in *The Plan* and will be implemented along the Canal over time. Riparian habitat improvements that were considered include invasive species management, cottonwood tree care and enhancement, increasing plant biodiversity, improving habitat connectivity and planting trees. Recreational and social enhancements could include providing features to benefit mental or physical health such as community access points, gathering spaces, educational signage, exercise stations, nature play areas, wayfinding signage and trail connections.

Figure 9 Example of Concept Development for deKoevend Park (Reach 21)

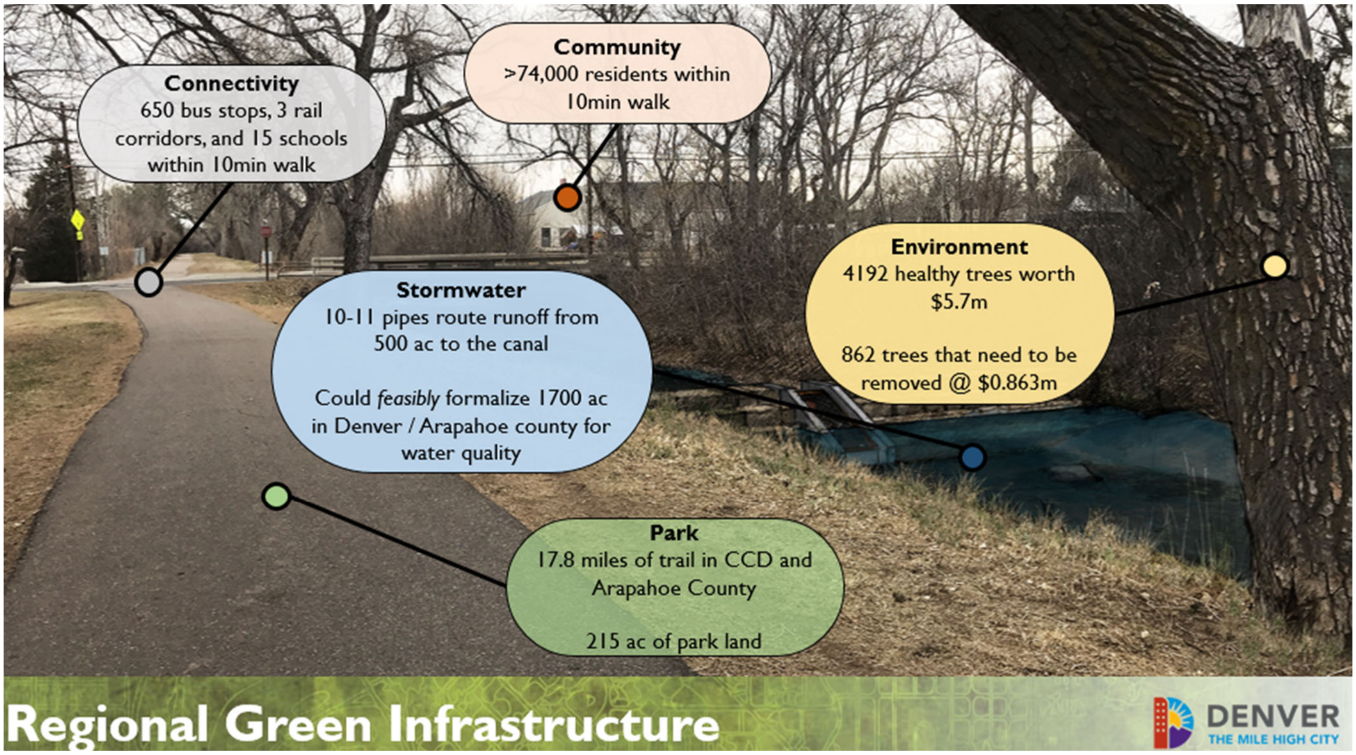
Figure 10 Example of Conceptual Improvement Opportunities for deKoevend Park Reach

Using the proposed concepts for improvements as indicated in Figure 10, water quality improvements, trees, etc. were estimated, and the relative benefits and costs were calculated. As shown in Table 9, the analysis showed that at all three locations, Scenario 3 produced the highest net benefit for projects with stormwater and ecological and/or social benefits. Additionally, as would be expected, the benefits of using the Canal are greater (in Reaches 30 and 34), where the volume of water that needs to be managed by an alternative offsite treatment is greater (compared to Reach 21).

Table 9. Summary of Reach-Specific Benefit-Cost Analysis, 50-year values (based on net difference between benefits minus costs). Refer also to Appendix C.

	Scenario 1	**Scenario 2**	**Scenario 3**
	No stormwater project in Canal	**Stormwater project only in Canal**	**Stormwater project + social and ecological benefits**
deKoevend Park (Reach 21) --2 ac-ft existing inflow treated, no new inflows			
50-yr costs	($1,930,928)	$56,331	$516,919
Annual Costs	($38,619)	$1,127	$10,338
Expected annual benefit, as savings compared to Scenario 1		$39,745	$48,957
50-year expected benefit		*$1,987,259*	*$2,447,847*
Eisenhower Park (Reach 30) --7.5 ac-ft existing inflow, no new inflows			
50-yr costs	($5,141,978)	$961,926	$2,134,349
Annual Costs	($102,840)	$19,239	$42,687
Expected annual benefit, as savings compared to Scenario 1		$122,078	$145,527
50-year expected benefit		*$6,103,903*	*$7,276,327*
Four Square Mile (Reach 34) --no existing inflow, 7.4 ac-ft new inflows proposed			
50-yr costs	($5,732,991)	$2,014,606	$4,973,933
Annual Costs	($114,660)	$40,292	$99,479
Expected annual benefit, as savings compared to Scenario 1		$154,952	$214,138
50-year expected benefit		*$7,747,596*	*$10,706,924*

An example of how reach information was applied at a jurisdiction scale is shown in the infographic prepared by the City and County of Denver as shown below.



Example Infographic for City and County of Denver Jurisdiction Benefits

RECOMMENDATIONS FOR ADVANCING STORMWATER PROJECTS

The study clearly demonstrates that preserving the value of the corridor depends on enhancing its use for stormwater projects and offsetting roughly $75M which would need to be spent on alternative infrastructure in the jurisdictions if the Canal were not used. Integrating environmental and social project elements can leverage the value of the stormwater projects to increase the total value of benefits received, e.g., by approximately $2M to $11M in the pilot reaches (over a 50-year period) as shown in Table 9.

Based on experience with other green infrastructure programs across the country, there are several catalysts to help advance projects, including *developing a compelling story of why it is the right thing to do, identifying* a *local champion(s) or sponsor(s), supporting policies that incentivize or help drive green infrastructure, using innovative funding mechanisms, and facilitating collaboration of governmental and non-governmental partners*. Currently, the HLCC is working on all of these elements through STEP and should continue to be built upon for the foreseeable future. Recommendations for increasing momentum and implementing strategic approaches to increase the pipeline of stormwater projects are suggested below for each of the catalysts.

Build compelling community stories.

- Social equity and community health are front-page stories today. High Line Canal outreach and projects should **focus on priority locations** to make improvements in vulnerable areas by identifying one or more priority project sites in each jurisdiction using the canal-wide mapping of stormwater, riparian habitat and social vulnerability.
- One of the key treasures of the Canal is the tree canopy enjoyed by many trail users. With nearly 24,000 mature trees, priority is focused on **maintaining a vibrant and healthy tree canopy** continues for future generations. Consideration should be given to ensure specific tree planting plans take into consideration the hydrology of a particular site, as well as slope, soils, riparian habitat, jurisdictional conditions and needs to ensure successful tree growth.
- Highlight the **costs** of NOT using the Canal, e.g., due to increased maintenance, offsite alternative treatment and land costs and increased health expenses as shown herein. **Emphasize the benefits** of the Canal's ecosystem services as well as added capacity HLCC provides through stewardship groups that assist with volunteer implementation of projects such as canal cleanups and brush removals in targeted stormwater sections and xeric and riparian tree plantings. Partners can also highlight current pilot projects as a tool to educate stakeholders, decision makers and the general public about the Canal's transformation.
- **Message stories of hope and improvements** with input from children and citizen science participants by observing wildlife and habitat through Bioblitzes, particularly in priority reaches as well as opportunities to monitor water levels and quality. With the recent news of habitat loss, such as the disappearance of 3 billion birds in North America since 1970 (Science, 2019), the need to protect riparian areas -- even in modified landscapes such as the Canal – is becoming more critical.

Identify a local champion(s) or sponsor(s).

- The COVID pandemic has heightened awareness of the importance of neighborhood-scale resources and community building. To build these types of efforts in priority reaches, **identify local liaisons to help facilitate neighborhood dialogues** and gather input about related needs and opportunities that can be integrated into project designs. This approach will help document future opportunities and improvements while also building "local ownership" and ensuring Canal communication authentically "speaks" to the local neighborhood.
- In addition to neighborhood liaisons, each Team member could serve as a **champion advocate to advance at least one project** in their respective jurisdiction in partnership with the HLCC, Denver Water and MHFD. (This could overlap with the focal priority locations for the compelling story development.) In lieu of their direct participation, the Team member could identify a designee for the champion role.

Establish policies & administrative processes to integrate green infrastructure projects

- **Participate in jurisdictional planning processes.** Provide *multiple* departments in each jurisdiction with prioritization mapping tools and increase HLCC's role as a referral organization when projects are occurring in the vicinity of the Canal.
- Propose **project targets for each jurisdiction** and get commitment for Canal STEP projects to be incorporated into their upcoming Capital Improvement Programs.

Facilitate collaboration of governmental and non-governmental partners

- **Help to break down silos** by facilitating **cross-departmental and cross-organizational dialogues** and reducing barriers to stacked benefit projects.

- Use “lunch and learns” or other outreach to potential partners to **ensure groups are aware of shared resources** and streamlining tools they can leverage such as maintenance agreements and permitting support, as well as the Pathway Guide to help communicate and facilitate necessary implementation steps.

Develop concepts for additional projects that may use innovative funding and partners

- **Expand the current analysis** to include a project area that requires reducing the risk of uncontrolled Canal overtoppings or has the potential to address localized flood moderation by directing new inflows of stormwater to the Canal, perhaps in partnership with MHFD
- **Continue to build the standardized online tool template for social and environmental enhancement** to identify opportunities and constraints (as started in ArcCollector for this project), so partners can see connections between types of opportunities in a reach.
- **Generate interest from non-traditional funders,** such as health organizations or outdoor recreation companies, for new demonstration projects to help illustrate stacked benefits of Canal projects and to refine the analysis and mapping. Conduct before and after assessments of the site-specific environmental and social measures to create additional documentation of improvements (particularly for community health).
- **Establish added capacity and new funding mechanisms for local stewardship.** Consider reach sponsors (e.g., Friends of a Reach). Research green steward program alternatives which could provide economic opportunities/scholarships to underserved residents.

Near-Term Next Steps

Key next steps to begin to implement the above recommendations in the near term include:

- Updating RESPEC’s online map tool to incorporate BCA mapping.
- Creating supporting communication pieces, e.g., Executive Summary and link to Pathway guide.
- Updating the method to test and incorporate flood control benefits and costs.
- Identifying priority SVI and stacked benefit reaches and developing accompanying jurisdiction-specific materials to support meetings about project opportunities.
- Researching potential funds and partners for demonstration project to illustrate stacked benefits and refine analysis.
- Incorporating BCA metrics into EPA’s sustainable infrastructure planning process as well as future HLCC presentations, e.g., for local “lunch & learn” to mixed audiences/partners.

Conclusion

The High Line Canal Benefit Cost Analysis demonstrates a way forward for building stories of transformation and inspiring funding that not only will improve water quality and address local flooding concerns, but also support habitat and neighborhoods in need. As the Canal is being repurposed from its original use as irrigation delivery, innovative solutions are needed to maintain the Canal’s ecological and recreational functions. As the metro area continues to grow, the need for outdoor recreation opportunities that are accessible to a wide range of residents is more essential than ever. This convergence of issues -- water management, habitat, and social equity – is of growing interest to land and water managers, planning and stormwater officials, elected leaders, vested stakeholders and communities abutting the Canal.

BIBLIOGRAPHY

Autocase, 2018. Triple Bottom Line Cost Benefit Analysis of Green Infrastructure/Low Impact Development (GI/LID) in Phoenix, AZ Results Report. Prepared by Autocase (with Stantec and Watershed Management Group) for the City of Phoenix, June 20th, 2018.

Center for Disease Control, 2016. Social Vulnerability Index (SVI), Created by ATSDR's Geospatial Research, Analysis & Services Program (GRASP).

Center for Neighborhood Technology, 2010. The Value of Green Infrastructure A Guide to Recognizing Its Economic, Environmental and Social Benefits.

Chapman, S.S., Griffith, G.E., Omernik, J.M., Price, A.B., Freeouf, J., and Schrupp, D.L., 2006, Ecoregions of Colorado (color poster with map, descriptive text, summary tables, and photographs): Reston, Virginia, U.S. Geological Survey (map scale 1:1,200,000).

City and County of Denver Public Works (CCDPW). 2018. Green Infrastructure Implementation Strategy. https://www.denvergov.org/content/denvergov/en/wastewater-management/stormwater-quality/green-infrastructure/implementation.html.

Clary, J. and H. Piza, Eds. 2017. Cost of Maintaining Green Infrastructure. American Society of Civil Engineers. Reston, VA.

Colorado Natural Heritage Program (CNHP), 2010. Foothills Shrubland Ecosystem blog, https://cnhp.colostate.edu/cnhpblog/2010/12/28/ecological-systems-foothills-shrubland/.

Colorado Parks and Wildlife, 2015. Colorado's State Wildlife Action Plan.

Denver Botanic Gardens, 2018. High Line Canal 2018 Botanical Survey, Prepared For The High Line Canal Conservancy.

Denver Regional Council of Governments, 2019. DRCOG High Resolution Land Use/Land Cover Pilot Project.

Economic & Planning Systems, Inc., 2017. Quantifying our Quality of Life, An Economic Analysis of the East Bay's Unique Environment . Prepared for East Bay Regional Park District.

Environmental Protection Agency. 2017. National Stormwater Calculator V. 1.2.0.3. https://www.epa.gov/water-research/national-stormwater-calculator.

High Line Canal Conservancy, 2019. The Plan for the High Line Canal.

Intergovernmental Panel on Climate Change (IPCC), 2014. IPCC Fifth Assessment Report: Climate Change 2014 (AR5).

McPherson, G., Q. Xiao, C. Wu, J. Bartens, and J. Simpson, 2013. Metro Denver Urban Forest Assessment, support from Parks and Recreation Department, City and County of Denver, CO.

Natureserve, 2020. https://explorer.natureserve.org/Taxon/ELEMENT_GLOBAL.2.722851/Rocky_Mountain_Lower_Montane-Foothill_Shrubland

National Cooperative Highway Research Program. 2014. Long-Term Performance and Life-Cycle Costs of Stormwater BMPs. Report 792. Transportation Research Board.

RESPEC, 2018. High Line Canal Stormwater And Operations Master Plan – Draft Report, August 2018.

RESPEC, 2014. High Line Canal Feasibility Study For Stormwater Runoff Reduction &Treatment August 2014, Prepared For: Urban Drainage & Flood Control District.

Rondeau, R., K. Decker, J. Handwerk, J. Siemers, L. Grunau, and C. Pague. 2011. The state of Colorado's biodiversity. Prepared for The Nature Conservancy by the Colorado Natural Heritage Program, Colorado State University.

Science, 2019. https://www.sciencemag.org/news/2019/09/three-billion-north-american-birds-have-vanished-1970-surveys-show

University, Fort Collins, Colorado. Talberth, J., E. Gray, L. Yonavjak, and T. Gartner. 2013a. Green vs. gray: Nature's solutions to infrastructure demands. Solutions 4(1):40-7. https://www.thesolutionsjournal.com/article/green-versus-gray-natures-solutions-to-infrastructure-demands/ .

Talberth, J., J. Mulligan, B. Bird, and T. Gartner. 2013b. A preliminary green-gray analysis for the Cache la Poudre and Big Thompson watersheds of Colorado's Front Range. https://peakstopeople.org /wp-content/uploads/2017/05/cse-wrifrontrangeggafinalreport.pdf.

The Nature Conservancy, 2013. The Case for Green Infrastructure, Joint-Industry White Paper.

Trust for Public Lands, 2010. The Economic Benefits of Denver's Park and Recreation System.

World Resource Institute, 2019. Green-Gray Assessment: How to Assess the Costs And Benefits Of Green Infrastructure For Water Supply Systems. Working Paper.

ATTACHMENT A
EXAMPLES OF POSSIBLE BENEFITS AND INDICATORS

Types of Environmental and Social Benefits		Possible Indicators	Ecosystem Service (ES) Values $	Recommended analysis: Primary/Secondary/ Delete
Water	Water Quality	impervious surface treated, water quality parameters (pollutants, temperature, etc)	$/ traditional infrastructure savings	Primary
	Flood moderation	change in peak flow discharge, storage capacity (temporary)	volume stored conveyed/$ land acreage cost, Infrastructure replacement cost?	Primary
	Water supply (eg irrigation)	Volume of treated (potable) water conserved	potable water cost	Primary or secondary
	Water cycle support	Groundwater recharge (presence/absence, est. volume)		Secondary
Landscape: Natural Environment	Riparian habitat maintenance & improvement	Size, connectivity, & condition (diversity of community types; native plant richness; structure, etc)	Riparian buffer ES $/acre	Primary
	Wildlife diversity and abundance	Species abundance and trends, species richness, presence of species of priority conservation need		Primary
	Soil formation/protection	Acres impermeable surface; soil fertility		Primary or secondary
	Plant productivity, Pollinator habitat, & seed dispersal	Acres; lbs/ac, floristic diversity; diversity and abundance of pollinator plants	TBD	Primary
Resiliency	Heat island reduction	Temperature decrease by cover, leaf area index	$ Tree installation and maintenance	Primary
	Climate regulation (see below/combine?)	Stored carbon		Secondary
Energy/Carbon	Carbon capture & storage	See above		Secondary or delete/combine with resiliency
	Energy production	?		Delete
Community Health & Livability	Recreation and learning	Open space acres/person, # of people within ¼ mi	Cost of purchasing similar acreage; cost to build/enhance trail?	Primary
	Public use	#s of public users?	Increase in users?	Secondary
	Air quality	Removal of pollutants by vegetation		Secondary
	Physical activity, health & safety	Health impacts such as reduced % Obesity, doctor visits?, police incidents?		Secondary
	Quality of life/Equity/Visual amenity/	Economic (Greenway case studies re housing prices and commercial income within adjacent communities?) Note: sometimes associated with gentrification	Job creation, property value, community amenities within x distance of trail	Primary
	Noise reduction	Distance from roads, DB/a, leaf area		Secondary or delete

ATTACHMENT B

Table B1 Data Inventory

Category	Name	Source	Biohabitats notes/Year
GENERAL	High Line Canal	NHD	
	Reach ID	RESPEC	Used Design Reaches from RESPEC
	Creeks	RESPEC	
	Level IV Ecoregions in the U.S.	EPA	
WATER	Water Quality Berms	RESPEC	
	Waste Gates	RESPEC	
	Freeboard Height (ft.) - Flood Control	RESPEC	
	FEMA Floodplain	FEMA	
	Subcatchments	RESPEC	
	DEN_Park_Landscape_Typologies	Denver Parks and Recreation	2019
	MDNA_HU12_Watersheds	NHD	
	USA National Hydrography Dataset Plus Version 2.1 - Seamless	NHD	
	Watershed Boundary Dataset: HUC 12s	USGS	
	USA Wetlands	USFWS	
	Highline_Stormwater_Pilots	HLCC	
	Highline_Opportunity_Areas	HLCC	
COMMUNITY HEALTH	SVI - Overall Vulnerability	CDC	2017
	SVI - Housing & Transporation	CDC	2017
	SVI - Minority Status & Language	CDC	2017
	SVI - Socio-Economic Status	CDC	2017
	SVI - Household Composition & Disability	CDC	2017
WILDLIFE	Bald Eagle Nest Sites	CPW	2019
	Bald Eagle Roost Sites	CPW	2019
	Bald Eagle Communal Roosts	CPW	2019
	Bald Eagle Winter Concentration	CPW	2019
	Bald Eagle Summer Forage	CPW	2019
	Bald Eagle Winter Forage	CPW	2019
	Bald Eagle Winter Range	CPW	2019
	Preble's Meadow Jumping Mouse Overall Range	CPW	2019

Category	Name	Source	Biohabitats notes/Year
	Prebles Meadow Jumping Mouse Occupied Range	CPW	2019
	Great Blue Heron Foraging Area	CPW	2019
	Black-tailed Prairie Dog Colony Potential Occurrence	CPW	2019
CONSERVATION	Potential Conservation Areas	CNHP	
	Networks of Conservation Areas	CNHP	
	Element Occurrence	CNHP	CONFIDENTIAL DATA!!
	Habitat Connectors	ESRI	
	Habitat Cost Surface	ESRI	
	Habitat Fragments	ESRI	
	Intact Habitat Cores	ESRI	
	Intact Habitat Cores by Connectivity Importance	ESRI	
	TNC Resilience	TNC	
	TB_HabitatFunctions	David M. Theobald	
	CONUS LANDFIRE 2014 (LF 1.4.0.)	USGS LANDFIRE	2014
	USA Wildland Fire Potential	ESRI/USDA Forest Service	
HUMAN IMPACTS	COMaP_20170505	COMaP	2017
	Theobald - Human Modification Index	David M. Theobald	
ANALYSIS OUTPUTS	Design Reaches - Water Combined	Biohabitats	
	Design Reaches - Flood Control	Biohabitats	
	Design Reaches - Riparian	Biohabitats	
	Design Reaches - Water Quality	Biohabitats	
	Design Reaches Quarter Mile Buffer	Biohabitats	
	Design Reaches 75 ft Buffer	Biohabitats	
	Design Reaches - Riparian - (Reach 21, 30, 34)	Biohabitats	
	High Value - DRCOG	Biohabitats	
	Threats/Needs - DRCOG	Biohabitats	
	High Line Canal _ Land Cover Classification	Biohabitats	Derived from NAIP
OTHER DATA	DRCOG 1-meter Landcover Data	DRCOG	2019

ATTACHMENT C

Detailed benefit cost tables

Category	Description	Unit	Existing Qty
Project Description	**Reach ID-21**		
	Project Location-deKoevend Park (Littleton)		
	approx address:6301 S University Blvd, Centennial, CO 80121		
	Character zone-wooded village		
	Goal:Protect and enhance good quality reach		
	SVI indicator: most vulnerable for composition & disability		
Site Parameters	Contributing area	ac	118
	Impervious percent	%	51%
	impervious treatment area	ac	60
	Reach length	mi	0.9
	Reach length	ft	4,604
	reach width	ft	18
	75 ft buffer planning area	sq ft	708,029
	acreage of 75ft planning area	ac	16

COBENEFIT EVALUATION

Category	Description	Unit	Unit value + or (-), negative is cost $	Existing Qty	Proposed Qty	Existing value	Scenarios: 1. No SW project--grey infrastructure retrofit; loss of trees and native veg; park value decline/loss	Scenarios: 2. WQ treatment project only	Scenarios: 3. Proposed Full concept project: WQ + additional trees and native veg plantings; social amenities
Water-- Quality & Flood	Existing channel BMP volume inflow	ac ft		**2.02**					
	Proposed water quality features								
	Capital cost	reach	$ (177,000)			$ (177,000)	na	$ (177,000)	$ (177,000)
	O&M w stormwater (includes greenway)	mi	$ (28,598)			$ (24,936)	na	$ (1,246,818)	$ (1,246,818)
	O&M without stormwater (includes greenway)	mi	$ (13,598)			$ (11,857)	$ (592,840)		
	Off-Site Water Quality Treatment Equivalence	ac ft	$ 373,895	2.02			$ (754,968)		
	O&M for Off-Site Water Quality Treatment	ac ft	$ 4,465	2.02			$ (450,815)		
Landscape Natural Environment	**Existing Trees & Vegetation**								
	Trees asset value - CO2, energy, Air qualty, rainfall interception, prop values	no./tree	$ 52	380		$ 19,760		$ 988,000	$ 988,000
	Low ES quality Prairie/Grassland/Natural Ground Cover @367/ac/yr * 50 yrs	ac	$ 18,350	2		$ 37,305	$ (37,305)	$ 37,305	na
	Increased O&M for tree loss/removal (native only)		*$ (500.00)*		190		$ (95,000)		
	Proposed Trees and Vegetation:								
	Trees (3" B&B) cost	no./tree	$ (250.00)		10				
	Shrubs (#5 container) cost	no./shrub	$ (30.00)		21				$ (630)
	Herbaceous/seeding	ac	*$ (1,250.00)*		1.8				$ (2,225)
	Tree value (present value)	no./tree	$ 52.00		10				$ 520
	Improved ES Prairie/Grassland/Natural Ground Cover @510/ac/yr * 50 yrs	ac	$ 25,500		1.8				$ 45,384
Resilience	Heat island effecty mortality								
	Heat island effecty morbidity								
Community Health	Health value - improved physical condition	reduced m	$ 355		51			$ 454,844	$ 909,688
TOTAL CO-BENEFIT	***50 year period (present day dollars)***						***$ (1,930,928)***	***$ 56,331***	***$ 516,919***
	Annual						***$ (38,619)***	***$ 1,127***	***$ 10,338***

Category	Description	Unit	Existing Qty
Project Description	**Reach ID-30 Eisenhower Park**		
	Project Location-Denver		
	approx address:4300 East Dartmouth Ave, Denver CO 80222		
	HLCC Character zone-Urban Reuge		
	Goal:Improve existing WQ treatment and improve poor quality riparian reach (most of trees are invasives)		
	SVI indicator: Overall= least vulnerable; Minority and Language=somewhat		
Site Parameters	Contributing area	ac	[illegible]
	Impervious percent	%	5[illegible]
	impervious treatment area	ac	[illegible]
	Reach length	mi	[illegible]
	Reach length	ft	3,[illegible]
	reach width	ft	
	75 ft buffer planning area	sq ft	1,163,[illegible]
	acreage of 75ft planning area	ac	27

Category	Description	Unit	Unit value + or (-), negative is cost $	Existing Qty	Proposed Qty	Existing value	Scenarios: 1. No SW project--offsite green infrastructure; loss of trees and native veg; park value decline/loss	Scenarios: 2. WQ treatment project only	Scenarios: 3. Proposed Full concept project: WQ + additional trees and native veg plantings; social amenities
	COBENEFIT EVALUATION								
Water-- Quality & Flood	Existing channel BMP volume inflow	ac ft		**7.5**					
	Proposed water quality features								
	Capital cost	reach	$ (177,000)			$ (177,000)	na	$ (177,000)	$ (177,000)
	O&M w stormwater (includes greenway)	mi	$ (28,598)			$ (20,744)	na	$ (1,037,209)	$ (1,037,209)
	O&M without stormwater (includes greenway)	mi	$ (16,170)			$ (11,729)	$ (586,459)		
	Off-Site Water Quality Treatment Equivalence	ac ft	$ 373,895	7.5			$ (2,789,573)		
	O&M for Off-Site Water Quality Treatment	ac ft	$ 4,465	7.5			$ (1,665,740)		
Landscape Natural Environment	**Existing Trees & Vegetation**								
	Trees asset value - CO2, energy, Air qualty, rainfall interception, prop values	no./tree	**$ 52**	**391**		$ 20,338		$ 1,016,897	$ 1,016,897
	Low ES quality Prairie/Grassland/Natural Ground Cover @367/ac/yr * 50 yrs	ac	$ 18,350	**0.42**		$ 7,706	$ (7,706)	$ 7,706	na
	Increased O&M for tree loss/removal (native only)		*$ (500.00)*		**185**		$ (92,500)		
	Proposed Trees and Vegetation:								
	Trees (3" B&B) cost	no./tree	$ (250.00)		30				$ (7,504)
	Shrubs (#5 container) cost	no./shrub	$ (30.00)						$ -
	Herbaceous/seeding cost	ac	*$ (1,250.00)*		1.4				$ (1,781)
	Tree value (present value)	no./tree	$ 52.00		30				$ 1,560
	Improved ES Prairie/Grassland/Natural Ground Cover @510/ac/yr * 50 yrs	ac	$ 25,500		1.4				$ 36,323
Community Health	Health value - improved physical condition	reduced med$/per	$ 355.00		*130*			$ 1,151,531	$ 2,303,063
TOTAL CO-BENEFIT	***50 year period (present day dollars)***						$ (5,141,978)	$ 961,926	$ 2,134,349
	Annual						$ (102,840)	$ 19,239	$ 42,687

Category	Description	Unit
Project Description	**Reach 34 Four Square Mile** Project Location-Denver & Arapaho County W of South Quebec to W of Hentzell (South of Iliff) HLCC Character zone-Urban Reuge Goal: improve fair quality riparian reach; improve SW magmt; improve social connections SVI indicator: Overall=most vulnerable; Minority and Language=somewhat	
Site Parameters	Contributing area	ac
	Impervious percent	%
	impervious treatment area	ac
	Reach length	mi
	Reach length	ft
	reach width	ft
	75 ft buffer planning area	sq ft
	acreage of 75ft planning area	ac

	COBENEFIT EVALUATION						Scenarios		
Category	**Description**	**Unit**	**Unit value + or (-), negative is cost $**	**Existing Qty**	**Proposed Qty**	**Existing value**	**1. No SW project--offsite green infrastructure; loss of trees and native veg; park value decline/loss**	**2. WQ treatment project only**	**3. Proposed Full concept project: WQ + additional trees and native veg plantings; social amenities**
Water-- Quality & Flood	Existing channel BMP volume inflow	ac ft		**7.4**					
	Proposed water quality features								
	Capital cost	reach	$ (1,124,491)			$ (1,124,491)	na	$ (1,124,491)	$ (1,124,491)
	O&M w stormwater (includes greenway)	mi/yr	$ (28,598)			$ (39,441)	na	$ (1,972,052)	$ (1,972,052)
	O&M without stormwater (includes greenway)	mi/yr	$ (16,170)			$ (22,301)	$ (1,115,037)		
	Off-Site Water Quality Treatment Equivalence	ac ft	$ 373,895	7.4			$ (2,781,609)		
	Off-Site Water Quality Treatment Equivalence	ac ft	$ 4,465	7.4			$ (1,660,984.32)		
Landscape Natural Environment	**Existing Trees & Vegetation**								
	Trees asset value - CO2, energy, Air qualty, rainfall interception, prop values	no./tree	**$ 52**	**739**		$ 38,428		$ 1,921,400	$ 1,921,400
	Low ES quality Prairie/Grassland/Natural Ground Cover @367/ac/yr * 50 yrs	ac	$ 18,350	**5.47**		$ 100,360	$ (100,360)	$ 100,360	na
	Increased O&M for tree loss/removal (native only)		$ *(500.00)*		**150**		$ (75,000)		
	Proposed Trees and Vegetation:								
	Trees (3" B&B) cost	no./tree	$ (250.00)		150				$ (37,500)
	Shrubs (#5 container) cost	no./shrub	$ (30.00)						$ -
	Herbaceous/seeding cost	ac	$ *(1,250.00)*						$ -
	Tree value (present value)	no./tree	$ 52.00		150				$ 7,800
	Improved ES Prairie/Grassland/Natural Ground Cover @510/ac/yr * 50 yrs	ac	$ 25,500						$ -
Community Health	Health value - improved physical condition	reduced med$/per	$ 355.00		*348*			$ 3,089,388	$ 6,178,775
TOTAL CO-BENEFIT	***50 year period (present day dollars)***						***$ (5,732,991)***	***$ 2,014,606***	***$ 4,973,933***
	Annual						***$ (114,660)***	***$ 40,292***	***$ 99,479***