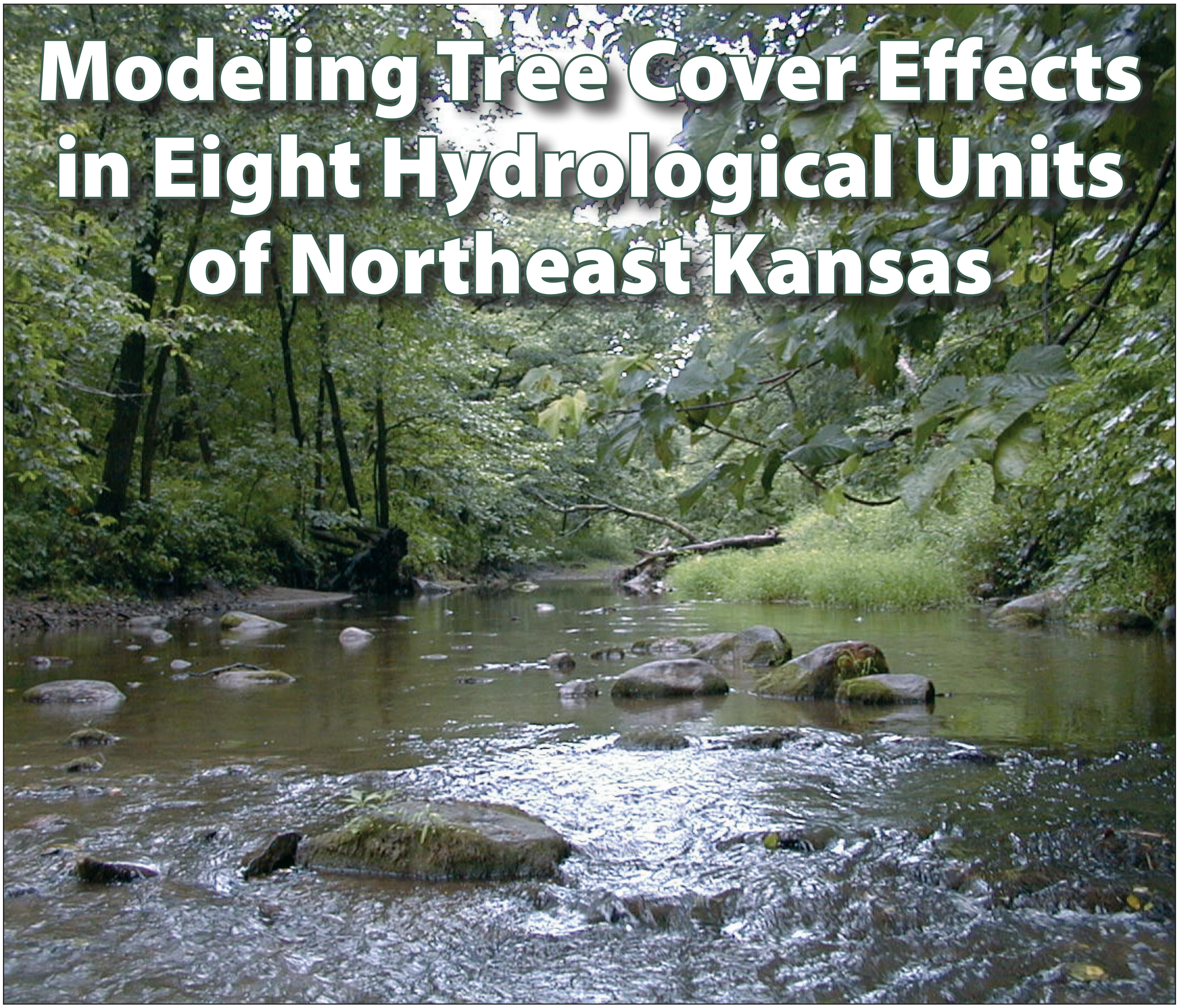
Modeling Tree Cover Effects in Eight Hydrological Units of Northeast Kansas



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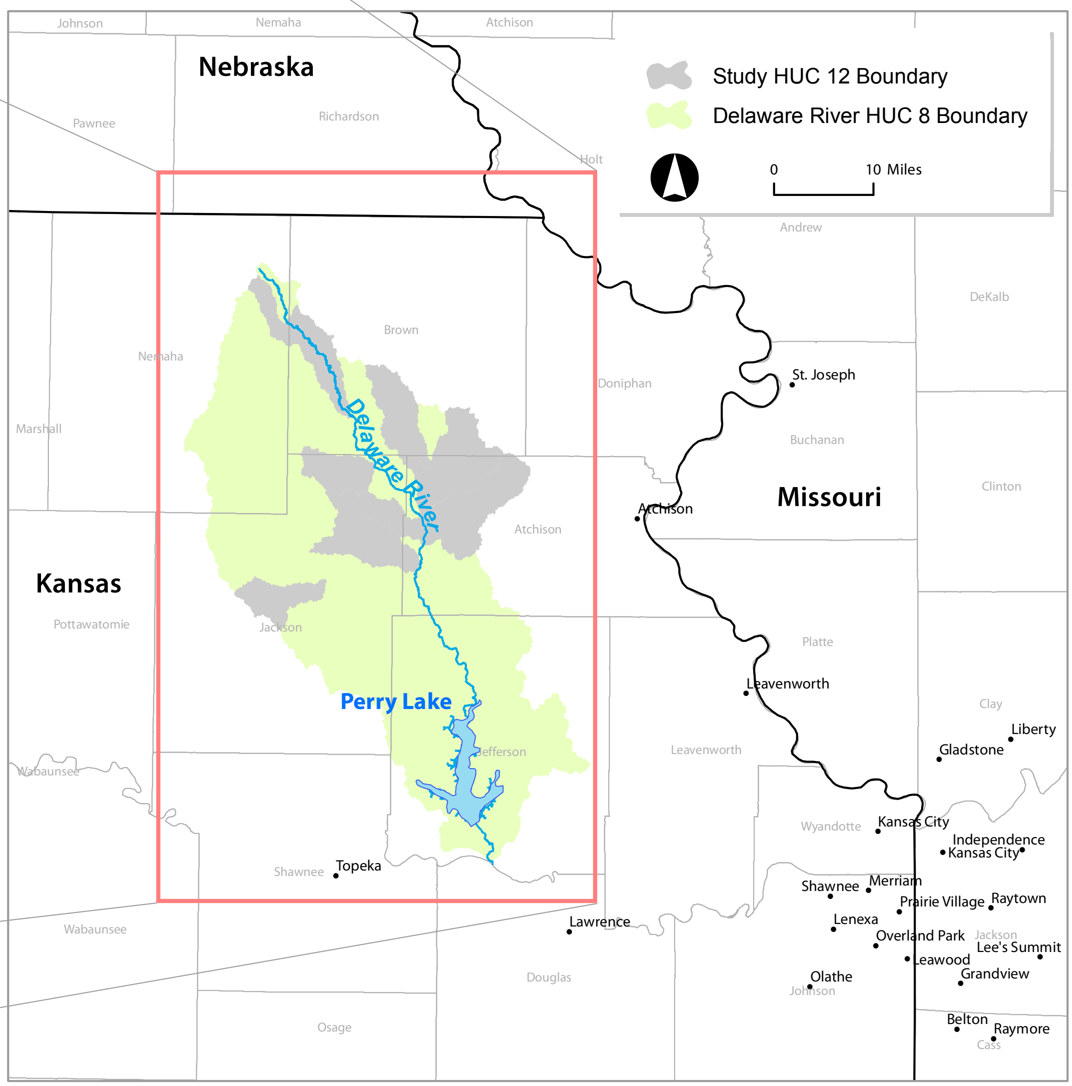
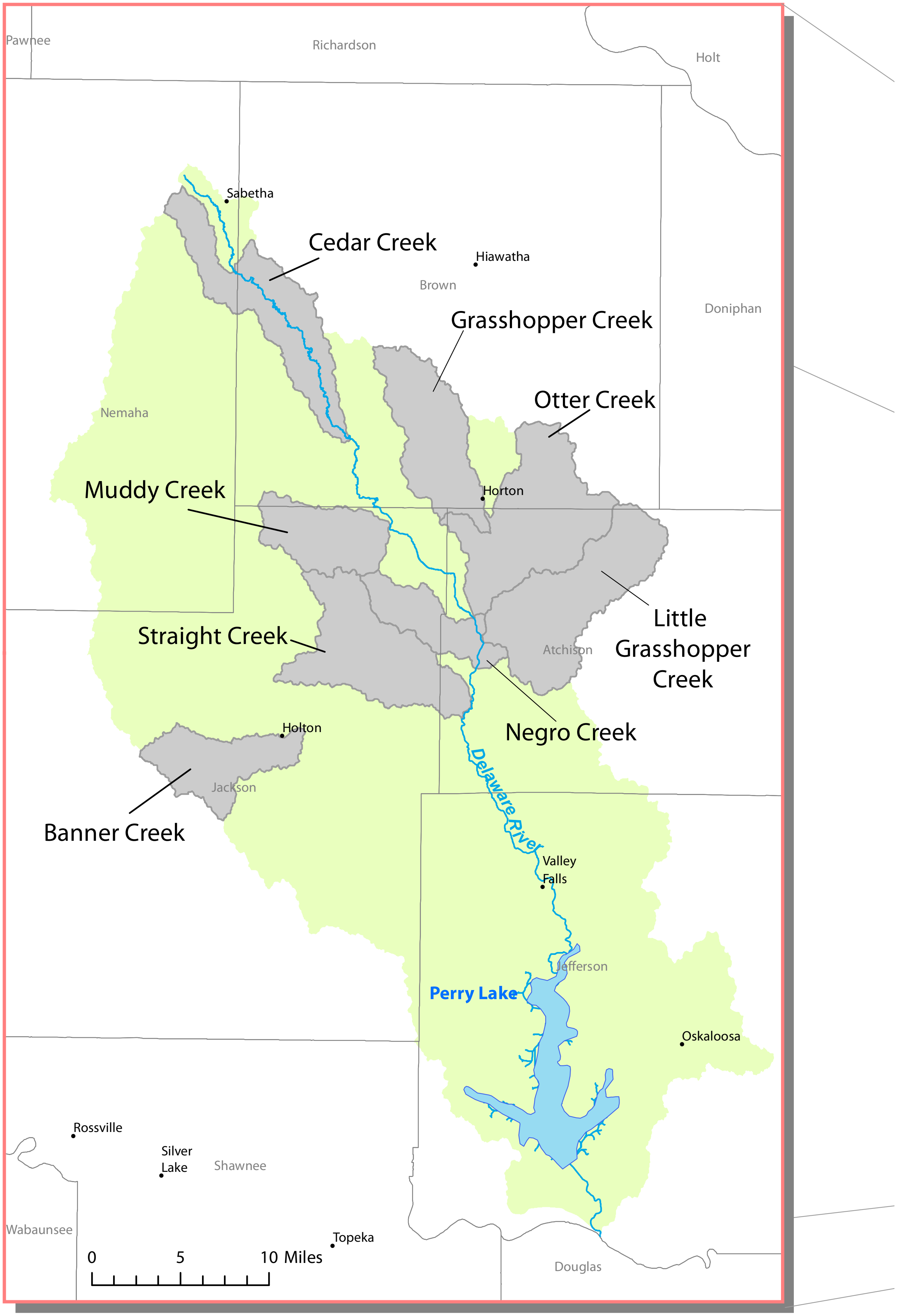
Delaware River Watershed Study Area

Sources:
USGS National Hydrography Dataset
U.S. Census Bureau



HUC 12 Watersheds Study Area



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Figures and Tables

Introduction

This report details two studies focused on eight watersheds (Hydrological Unit (HU)-12s) in northeast Kansas. Hydrological Units are a national standard classification system developed by the United States Geological Survey (USGS) to facilitate water resource management in the United States (USGS, 2017). The watersheds analyzed in this report are given in Figure 1 and Table 1, along with their associated Hydrological Unit Codes (HUCs). The first study, referred to as the Land Cover Scaling Analysis, simulated changes in stream flow due to the effects of tree and impervious cover changes in the eight watersheds using the i-Tree Hydro model (Wang et al., 2008). This study also analyzed a proximate reference watershed that streamflow records are available for, which allowed for calibration of hydrological parameters for the main eight watersheds. The second study, referred to as the Analysis of Riparian Tree Effects on Streambank Erosion, investigates the role of trees in streambank erosion in general, and specifically streambank erosion effects on the watersheds.

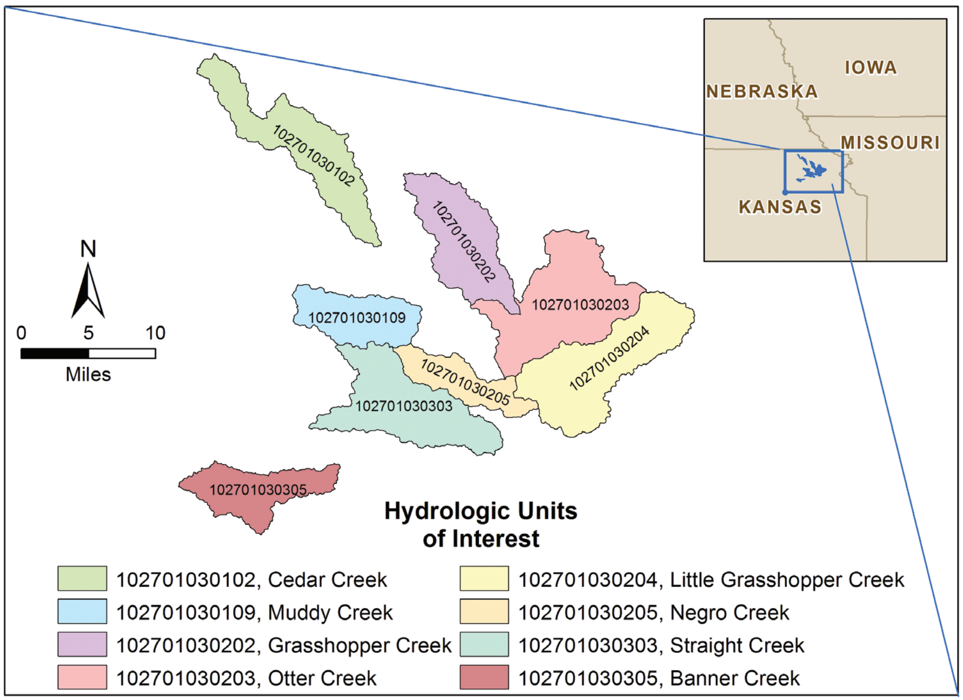

Figure 1. *Map of watersheds (HUC-12s) in northeast Kansas.*

Table 1. *Study area Hydrologic Unit Code (HUC) or USGS Gage ID, name, and size.*

Study area IDs	Watershed names	Size (acres)
HUC 102701030102	Cedar Creek-Delaware River	25,311
HUC 102701030109	Outlet Muddy Creek	15,235
HUC 102701030202	Headwaters Grasshopper Creek	22,038
HUC 102701030203	Outlet Grasshopper Creek (a.k.a. Otter Creek)	32,475
HUC 102701030204	Little Grasshopper Creek	30,749
HUC 102701030205	Negro Creek-Delaware River	11,839
HUC 102701030303	Outlet Straight Creek	27,287
HUC 102701030305	Banner Creek	15,438
USGS 06890100 (HUC 10270103)	Drainage basin of stream gauge at Delaware River near Muscotah, KS	275,838

Study 1. Land Cover Scaling Analysis

The i-Tree Hydro model is designed to assess changes in streamflow due to changes in tree and other land cover types. Hydrological parameters of the model are calibrated to produce the best fit between predicted and observed streamflow. As none of the eight watersheds of interest had stream gauges that record water flow, model hydrologic parameters were calibrated based on observed flows of a nearby, geomorphologically similar drainage basin (USGS 06890100, "Delaware River near Muscotah, KS" Figure 1.1). Using this reference-calibrated parameter set, land cover scaling simulations were run for each of the watersheds to demonstrate the impacts of land cover changes on stream flow. Water quality impacts were also simulated based on national and localized event mean concentration (EMC) pollutant coefficients.

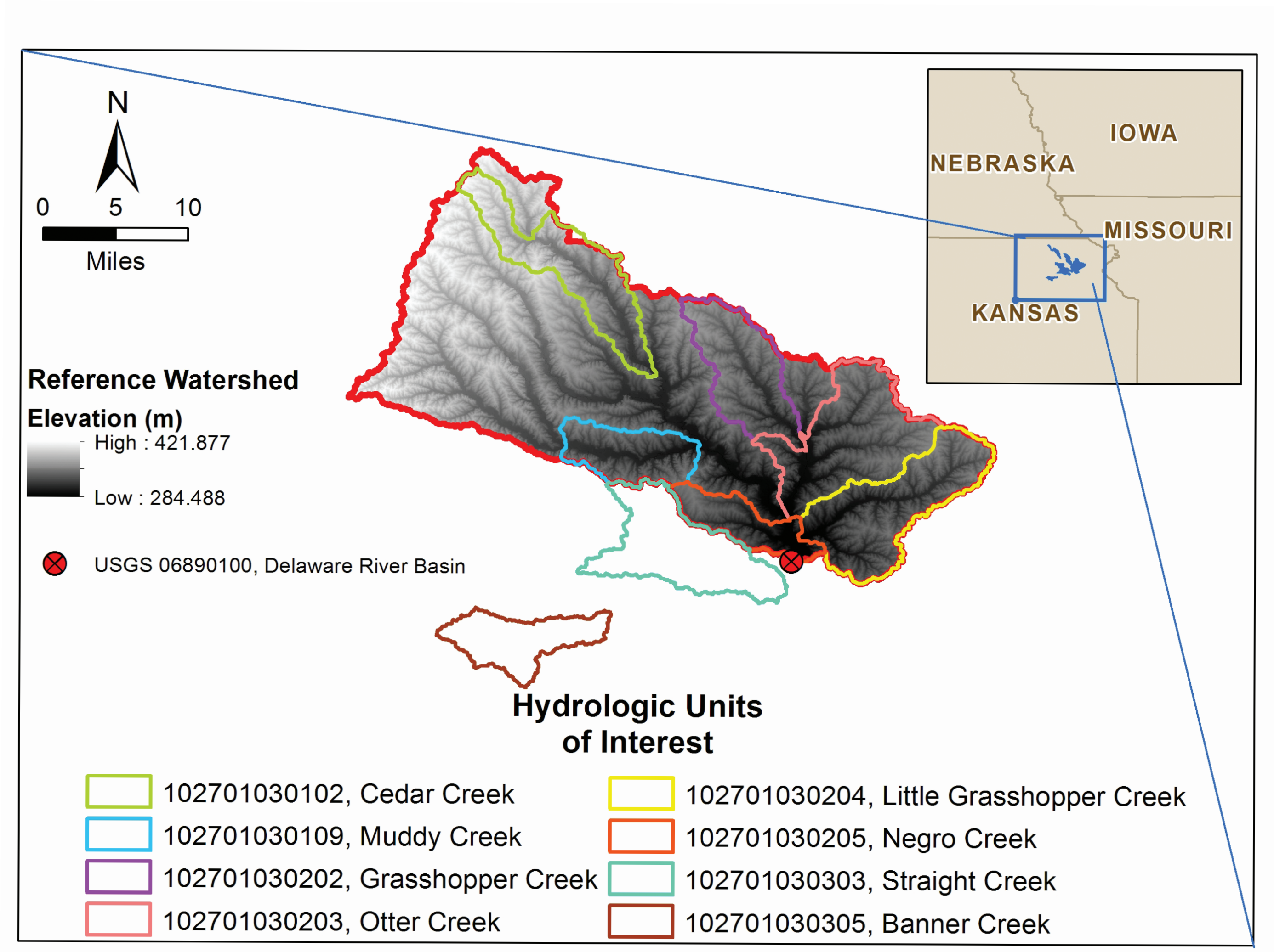

Figure 1.1. *HUC-8 reference watershed used to calibrate hydrological parameters for eight non-gauged HUC-12 watersheds.*

Input Data and Model Calibration

Hourly weather data for all watersheds were derived from the closest weather station with sufficient required weather parameters: the Philip Billard Municipal Airport weather station in Topeka, KS (USAF-WBAN 724560-13996). Land cover percentages were derived for each watershed using photo-interpretation of Google Earth imagery (image date circa 2017) using 200 randomly located points. This analysis produced land cover estimates with standard errors of less than 3% (Table 1.1). The percentage of woody vegetation that is evergreen was estimated as 0.05% using National Land Cover Dataset (NLCD) land cover data (Homer et al., 2015) for the eight watersheds combined.

The model was calibrated using hourly stream flow data collected at the "Delaware River near Muscotah, KS" gauging station (USGS 06890100) from 01/01/2008-12/30/2008. Hydrological parameters from the model were calibrated against measured stream flow to yield the best fit between predicted and observed stream flow results. Calibration coefficients (-1 to +1 with +1.0 = perfect fit) were calculated for peak flow, base flow and balance flow (peak and base) (Table 1.2). A coefficient of +1 indicates a perfect fit, 0 indicates the models predicts the same as using the mean value, and negative values indicate using the mean is a better predictor than the model (Moriasi et al., 2007). Differences between measured and estimated flow can be substantially different due to mismatching of stream flow and weather data, as the weather stations are often outside of the watershed area. For example, it may be raining at the weather station and not in the watershed, or vice versa. In this case the metrics of fit are all positive, indicating that the simulated streamflow fits the observed streamflow better than the overall average observed streamflow, but the metrics of fit are also all far from +1.0, indicating that there are still substantial differences between measured and estimated flow.

The set of hydrological parameters from the calibrated watershed were used as the hydrological parameters for the eight watersheds of interest. The only adjustment made to these hydrological parameters was modifying the soil type based on the dominant soil surface texture of each watershed using data found in the Web Soil Survey (NRCS, 2017).

Tree canopy leaf area index (LAI) was estimated as 5.0 for trees, 2.2 for shrubs, and 1.6 for herbaceous cover. The percent of impervious cover connected to the stream varied with percent impervious cover during land cover scaling simulations, with percent connected increasing as percent of impervious cover increases (Sutherland, 2000). The percentage of directly connected impervious cover represents the portion of impervious cover that drains directly to the modeled stream or any of its tributaries. The phrase "drains directly" describes a situation where precipitation that falls on a portion of the watersheds impervious cover is conveyed, overland or through a storm sewer network, directly into the stream or its tributaries.

Table 1.1. *Land cover percentage estimates for all eight study areas.*

Study area	Impervious surface (under canopy)	Tree/shrub canopy	Grass / herbaceous	Bare soil	Surface water
Cedar Creek	1.0% (0.0%)	10.5%	88.0%	0.5%	0.0%
Muddy Creek	0.0% (0.0%)	13.0%	86.0%	0.5%	0.5%
Grasshopper Creek	4.5% (0.5%)	9.5%	85.0%	1.0%	0.5%
Otter Creek	1.0% (1.0%)	13.5%	86.0%	0.5%	0.0%
Little Grasshopper Creek	1.0% (0.0%)	9.5%	88.0%	0.5%	1.0%
Negro Creek	1.5% (0.5%)	8.0%	89.5%	1.0%	0.5%
Straight Creek	0.8% (0.4%)	11.6%	87.6%	0.0%	0.4%
Banner Creek	3.0% (1.5%)	14.5%	80.5%	2.5%	1.0%
Delaware River Basin	0.5% (0.0%)	12.5%	85.5%	1.0%	0.5%

Table 1.2. *Calibration coefficients for model estimates and gauging station data.*

Watershed	Calibration coefficients		
	Peak flow	Base flow	Balanced flow
Delaware River (USGS 06890100)	0.187	0.013	0.041

Model calibration procedures adjust several model parameters (mostly related to soils) to find the best fit between the observed flow and the model flow on a weekly basis. However, there can be mismatches between the precipitation data, which is often collected outside of the watershed, and the actual precipitation that occurs in the watershed. Even if the precipitation measurements are within the watershed, local variations in precipitation intensity can lead to differing amounts of precipitation than observed at the measurement station. These differences in precipitation can lead to poorer fits between the observed and predicted estimates of stream flow, as precipitation is a main driver of the stream flow. As can be seen in Figure 1.2, the observed and simulated results diverge, which is likely an artifact of the disparate precipitation data. For example, observed flow will rise sharply but predicted flow does not, which is an indication of rain in the watershed but not at the precipitation measurement station. Conversely, the simulated flow may rise while observed flow does not, which is an indication of rain at the weather station but not in the watershed.

Since the model simulations are comparisons between the base simulation flow and another simulated flow where surface cover is changed (e.g., increase or decrease in tree cover), both model runs are using the same simulation parameters. This means that the effects of changes in cover types are comparable, but may not exactly match the flow of the stream. Stated in another way, the estimates of the changes in flow are reasonable (e.g., the relative amount of increase or decrease in flow is sound as both are using the same model parameters and precipitation data), but the absolute estimate of flow may be incorrect. Thus the model results can be used to assess the relative differences in flow due to changes in cover parameters, but should not be used to predict the actual effects on stream flow due to precipitation and calibration imperfections. The model can be used to compare the changes in flow (e.g., increased tree cover leads to an X% change in stream flow), but will likely not exactly match the flow observed in the stream. The model is more diagnostic of cover change effects than predictive of actual stream flow due to imperfections of models and data used in the model.

Overall, the calibration used tends to underestimate observed peak flows (Figure 1.3). The large distances between predicted and observed flow are attributed to difficulties in matching the model drivers (specifically precipitation data and a single set of soil parameters to describe a large area) with actual conditions (reflected in observed streamflow at the gaging station).

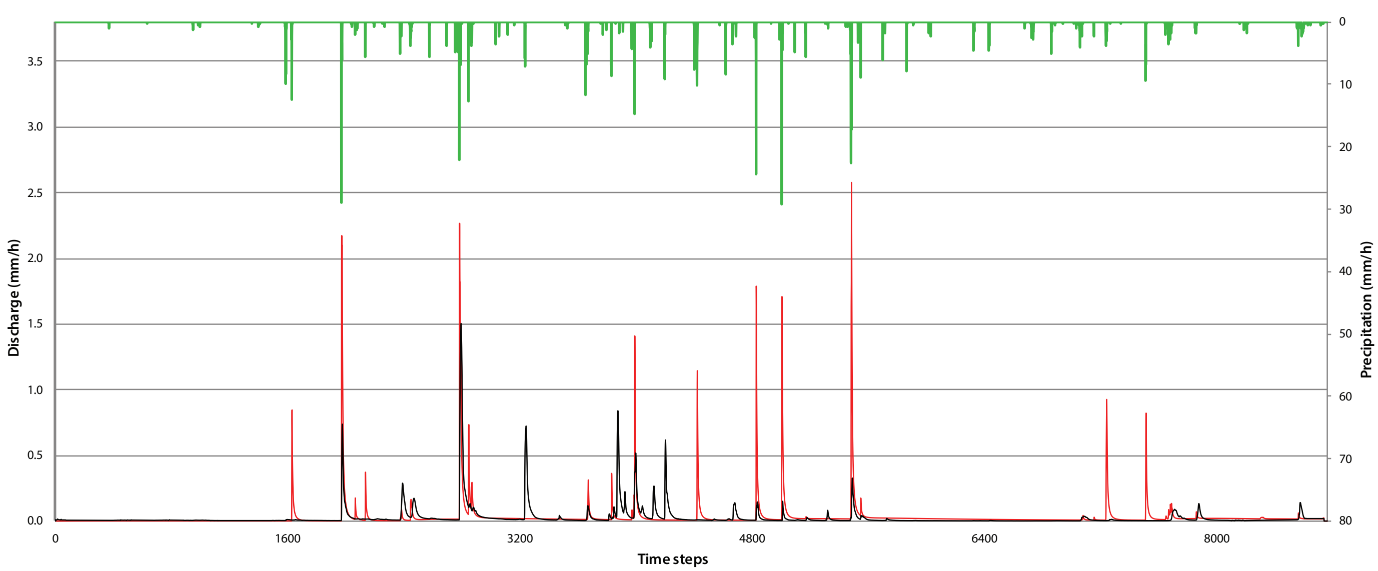

Figure 1.2. *Comparison of simulated flow vs. observed weekly flow in the Delaware River watershed (USGS 06890100) when simulated with the calibrated hydrological parameters. Red line = simulated results; black line = actual flow; and green line = precipitation.*

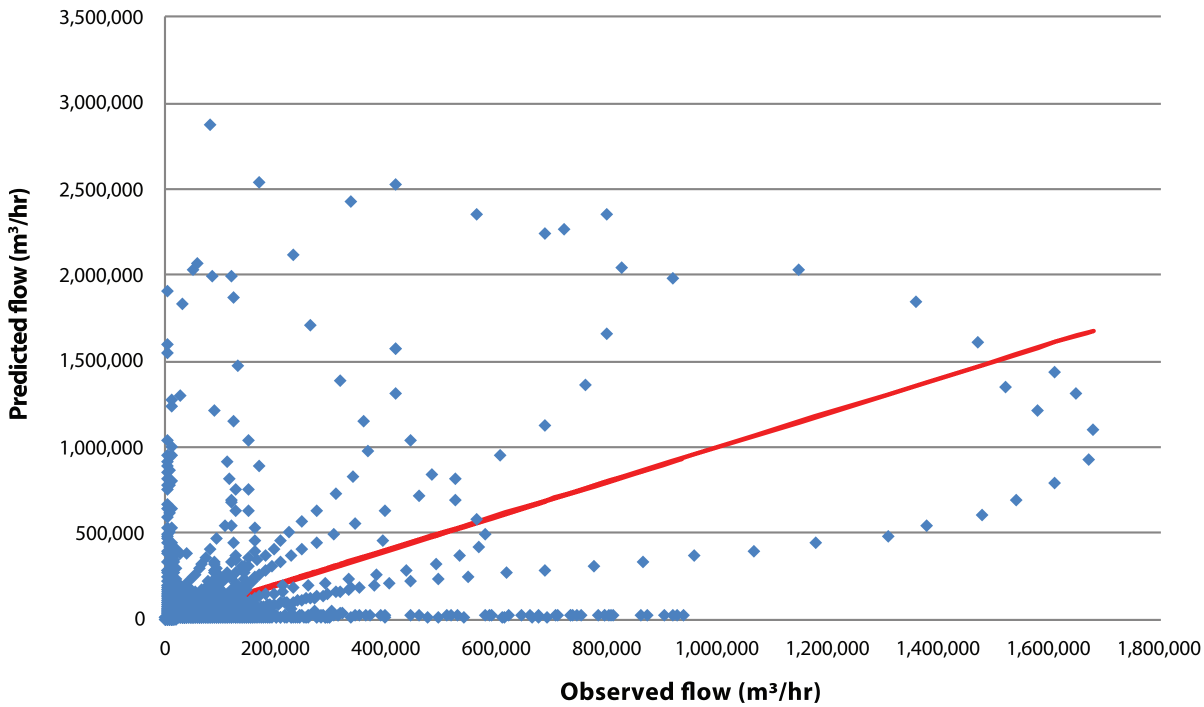

Figure 1.3. *Comparison of observed vs. simulated flow in the Delaware River watershed (USGS 06890100) when simulated with the calibrated hydrological parameters.*

Model Scenarios

After calibration based on the reference watershed, the model was run under various conditions to determine the stream flow response given varying tree and impervious cover values for each of the eight watersheds. For tree cover simulations, impervious cover was held constant at the original value with tree cover varying between 0 and 100%. Increasing tree cover was assumed to fill grass and herbaceous covered areas first, followed by bare soil spaces next and finally impervious land cover. At 100% tree cover, all impervious land is covered by trees. This assumption is unreasonable as all buildings, roads, and parking lots would be covered by trees, but the results illustrate the potential impact. Tree cover reductions assumed that trees were replaced with grass and herbaceous cover.

For impervious cover simulations, tree cover was held constant with impervious cover varying between 0 and 100%. Increasing impervious cover was assumed to fill grass and herbaceous covered areas first, followed by bare soil spaces next and then under tree canopies. The assumption of 100% impervious cover is unreasonable, but the results illustrate the potential impact. In addition, as impervious increased from the current conditions, so did the percent of the impervious cover directly connected to the stream, following equations by Sutherland (2000), such that at 100% impervious cover, all impervious cover (100%) is connected to the stream. Reductions in impervious cover were assumed to be filled with grass and herbaceous cover.

The model was run 121 times varying tree and impervious cover from 0 to 100% within 10% increments to illustrate how varying the amounts of tree and impervious cover affect stream flow. That is, the model was at 0% tree and 0% impervious cover, then 0% tree and 10% impervious cover, 0% tree and 20% impervious cover, etc., until all possible combinations were run up to 100% tree and 100% impervious cover. This results in 11 sets of 11 runs, giving a total of 121 model scenarios.

Water Quality Effects – Event Mean Concentration to Calculate Pollution Load

Event mean concentration (EMC) data are used for estimating pollutant loading into watersheds. The EMC is a statistical parameter representing the flow-proportional average concentration of a given parameter during a storm event and is defined as the total constituent mass divided by the total runoff volume. Estimates of EMC are usually obtained from a flow-weighted composite of concentration samples taken during a storm. Mathematically (Sansalone and Buchberger, 1997; Charbeneau and Barretti, 1998):

$$EMC = \overline{C} = \frac{M}{V} = \frac{\int C(t)\,Q(t)dt}{\int Q(t)dt} \approx \frac{\sum C(t)\,Q(t)\Delta t}{\sum Q(t)\Delta t}$$

Equation 1.1

where $C(t)$ and $Q(t)$ are the time-variable concentration and flow measured during the runoff event, and M and V are pollutant mass and runoff volume as defined in Equation 1.1. Results of EMC are from a flow-weighted average, not simply a time average of the concentration. Data from EMCs are used for estimating pollutant loading into watersheds. The EMCs are reported as a mass of pollutant per unit volume of water (usually mg/L).

The pollution Load (L) calculation from the EMC method is

$$L = EMC \times Q = EMC \times d_r \times A$$

Equation 1.2

Where is event mean concentration (mg/l, mg/m^3, …), Q is runoff of a time period associated with EMC (l/h, m^3/day…), d_r is runoff depth of unit area (mm/h, m/h, m/day…), A is the land area (m^2, …) which is catchment area in i-Tree Hydro.

When the EMC is multiplied by the runoff volume, an estimate of the pollution loading to the receiving water is provided. The instantaneous concentration during a storm can be higher or lower than the EMC, but the use of the EMC as an event characterization replaces the actual time variation of C versus t in a storm with a pulse of constant concentration having equal mass and duration as the actual event. This process ensures that mass loadings from storms will be correctly represented. The EMCs represent the concentration of a specific pollutant contained in stormwater runoff coming from a particular land use type or from the whole watershed. Under most circumstances, the EMC provides the most useful means for quantifying the level of pollution resulting from a runoff event (USEPA, 2002).

Since collecting the data necessary for calculating site-specific EMCs can be cost-prohibitive, researchers or regulators will often use values that are already available in literature. If site-specific numbers are not available, regional or national averages can be used, although the accuracy of using these numbers is questionable. Due to the specific climatological and physiographic characteristics of individual watersheds, agricultural and urban land uses can exhibit a wide range of variability in nutrient export (Beaulac and Reckhow, 1982).

To understand and control urban runoff pollution, The U.S. Congress included the establishment of the Nationwide Urban Runoff Program (NURP) in the 1977 Amendments of the Clean Water Act (PL 95-217). The U.S. Environmental Protection Agency developed the NURP to expand the state knowledge of urban runoff pollution by applying research projects and instituting data collection in selected urban areas throughout the country.

In 1983, the U.S. Environmental Protection Agency (U.S. EPA, 1983) published the results of the NURP, which nationally characterizes urban runoff for 10 standard water quality pollutants, based on data from 2,300 station-storms at 81 urban sites in 28 metropolitan areas.

Subsequently, the USGS created another urban stormwater runoff base (Driver et al. 1985), based on data measured through mid-1980s for more than 1,100 stations at 97 urban sites located in 21 metropolitan areas. Additionally, many major cities in the United States collected urban runoff quality data as part of the application requirements for stormwater discharge permits under the National Pollutant Discharge Elimination System (NPDES). The NPDES data are from over 30 cities and more than 800 station-storms for more than 150 parameters (Smullen et al, 1999).

The data from the three sources (NURP, USGS and NPDES) were used to compute new estimates of EMC population means and medians for the 10 pollutants with many more degrees of freedom than were available to the NURP investigators (Smullen et al, 1999). A "pooled" mean was calculated representing the mean of the total population of sample data. The NURP and pooled mean EMCs for the 10 constitutes are listed in Table 1.3 (Smullen et al, 1999). The NURP or pooled mean EMCs were selected because they are based on field data collected from thousands of storm events. These estimates are based on nationwide data; they do not account for regional variation in soil types, climate and other factors.

A novel approach used in this study is the localization of pollutant coefficient data for three pollutants that were otherwise covered in Table 1.3. The HUC-8 and National Land Cover Database (NLCD) specific data from White et al. (2015) and work conducted by Stephen et al. (2017) were used to compute improved estimates of pollutant coefficient means and medians for 3 pollutants that are particularly relevant in agricultural areas: sediment (equivalent to Tss and replacing Tss from Table 1.3); nitrogen (equivalent to TKN and replacing TKN, NO2 and NO3 from Table 1.3); and phosphorus (equivalent to TP and replacing TP and Soluble P from Table 1.3). White et al. (2015) used sophisticated modeling techniques to estimate water quality data at the HUC-8 scale nationwide based on 45 million stochastic Soil and Water Assessment Tool (SWAT) simulations. Those simulations varied climate, topography, soils, weather, land use, management, and conservation implementation conditions to estimate export coefficient values, and the simulations were successfully validated with edge-of-field monitoring data. Stephan et al. (2017) derived mean and median pollutant coefficients for each HUC-8 based on NLCD data and the surface runoff water quality data from the White et al. (2015) simulations. Table 1.4 contains the localized pollutant coefficients for the HUC-8 that encompassed all eight watersheds in this report.

These localized pollutant coefficients were used to more accurately estimate pollution loads from runoff, though it is not known how well either the national or localized pollutant coefficients represent actual local conditions. Also, due to the nature of the White et al. (2015) study, these pollutant coefficients would be considered maximum amounts potentially passing through a watershed stream gauge. For example, with sediment, once sediment is moved by runoff toward the area's outlet, processes occur that may reduce the amount of suspended sediment that ultimately reaches the area's outlet. The actual versus potential amount of sediment delivery is referred to as the Sediment Delivery Ratio (SDR). Our modeling approach is designed for comparative analyses that examine how land cover affects sediment load, and to simplify the approach we do not account for SDR and thus present results as maximum potential values for each statistic.

Table 1.3. *National pooled EMCs and NURP EMCs.*

		EMCs (mg/L)		
Constitute	**Data source**	**Mean**	**Median**	**No. of events**
Total suspended solids: Tss	Pooled	78.4	54.5	3047
	NURP	17.4	113	2000
Biochemical oxygen demand: BOD_5	Pooled	14.1	11.5	1035
	NURP	10.4	8.39	474
Chemical oxygen demand: COD	Pooled	52.8	44.7	2639
	NURP	66.1	55	1538
Total phosphorus: TP	Pooled	0.315	0.259	3094
	NURP	0.337	0.266	1902
Soluble phosphorus: Soluble P	Pooled	0.129	0.103	1091
	NURP	0.1	0.078	767
Total Kjeldhal nitrogen: TKN	Pooled	1.73	1.47	2693
	NURP	1.67	1.41	1601
Nitrite and nitrate: NO_2 and NO_3	Pooled	0.658	0.533	2016
	NURP	0.837	0.666	1234
Copper: Cu	Pooled	0.0135	0.0111	1657
	NURP	0.0666	0.0548	849
Lead: Pb	Pooled	0.0675	0.0507	2713
	NURP	0.175	0.131	1579
Zinc: Zn	Pooled	0.162	0.129	2234
	NURP	0.176	0.140	1281

Note:

Pooled data sources include: NURP, USGS, NPDES.

No BOD5 data available in the USGS dataset - pooled includes NURP+NPDES.

NO TSP data available in NPDES dataset - pooled includes NURP+USGS.

Table 1.4. *Localized pollutant coefficients based on White et al. (2015) and Stephan et al. (2017).*

	EMCs (mg/L)						
Constitute	Median	Mean	5th Percentile	25th Percentile	50th Percentile	75th Percentile	95th Percentile
Sediment	392.2	432.2	94.8	279.3	392.2	541.2	910.6
Nitrogen	3.846	4.365	1.771	2.946	3.846	5.219	8.772
Phosphorus	0.4623	0.4867	0.2174	0.3605	0.4623	0.5678	0.8730

Estimates of absolute reduction in pollutant loads for each study area are included in Appendices 1-8.

The pooled median and mean EMC value for each pollutant (Table 1.3), with sediment, nitrogen, and phosphorus coefficients updated to the median and mean pollutant coefficients from Table 1.4, were applied to the runoff regenerated from pervious and impervious surface flow, not the base flow values, to estimate effects on pollutant load across the entire modeling time frame. All rain events are treated equally using the EMC value, which mean some events may be over-estimated and others underestimated. In addition, local management actions (e.g., street sweeping) can affect these values. However, across the entire season, if the pollutant coefficient value is representative of the watershed, the estimate of cumulative effects on water quality should be relatively accurate. Accuracy of pollution estimates is generally increased by using locally derived coefficients. It is not known how well the national or localized pollutant coefficient values used in this study represent local conditions.

Results

Model results include estimates for four interrelated components: tree cover effects; impervious cover effects; land cover scaling trends; and water quality benefits from trees. In this section, those components are explained overall, and results about each of those components are summarized for all eight watersheds in Table 1.5. More detailed results specific to each watershed are available in Appendices 1 - 8.

Valuation of tree benefits is based on the Midwest edition of the Community Tree Guide series. Community Tree Guides are published by the U.S. Department of Agriculture Forest Service to help quantify the long-term benefits and costs of tree planting projects in climate regions around the United States, and these guides estimate valuation of avoided runoff based on the municipal stormwater treatment costs and/or stormwater service fees associated with each ecoregion's reference city. In the Midwest Community Tree Guide, stormwater runoff reduction is valued at $0.0046 per gallon based on single-family residential sewer service fees in the reference city Minneapolis, MN. This value is considered a conservative proxy for the actual cost of stormwater runoff, and "is below the average price of stormwater-runoff reduction ($0.089/gallon) assessed in similar studies (McPherson and Xiao, 2004)" (McPherson et al., 2005).

Tree Cover Effects

As tree cover increases, total streamflow and total overland runoff decreased in all modeled study areas. Trees can be effective components of a runoff control system as they attenuate flows through interception, leaf storage, and throughfall. Attenuation of stormwater runoff has many potential benefits including increased infiltration, reduced water quality impacts, and in cities, attenuation can result in a greater capacity for infrastructure to handle stormwater volumes. Another benefit trees provide is increased evapotranspiration through the uptake and transpiration of water from root zone storage, as well as through the evaporation of intercepted water from leaf storage. Underground, there are potential tree benefits that are still being assessed and are not yet included in this model: tree roots increase of macropore space that can lead to increased infiltration, and tree roots hosting microbiota that can improve water quality. Estimates from this model can be considered conservative, with predicted effects likely being lesser in magnitude than actual effects.

Impervious Cover Effects

Impervious cover increases reduce infiltration and significantly increase overland runoff. As impervious cover increases, its connectivity to streams increases as well, and this connection results in less opportunities for stormwater to be slowed, filtered, or infiltrated through pervious surfaces. The lack of porosity and the smoothness of impervious surfaces cause detrimental effects, including fast rainfall-runoff responses, fast overland runoff and a lack of infiltration or filtration and uptake by soils and plants.

Land Cover Scaling Trends

Increasing tree cover will reduce stream flow, but the dominant cover type influencing stream flow is impervious surfaces. As impervious cover is increased, its connectivity is also increased, and total streamflow and the overland impervious runoff increases exponentially. Trees help buffer this negative impact of impervious cover while providing ancillary environmental benefits.

Water Quality Benefits from Trees

Water quality benefits are provided by reducing total overland runoff. Additional water quality benefits come from other tree processes that are still being studied and are not included in this report, including nutrient uptake by trees and biochemical transformations of pollutants by microbiota that are hosted by tree roots and associated soil conditions.

Table 1.5. *Summary of results for land cover scaling analysis (see Tables 0.1 and 1.1 for input data).*

Study area (creeks)	Tree cover effect (%)[1]	Impervious cover effect (%)[2]	Non-runoff precipitation (%)[3]	Avoided runoff[4]	Value[5]
Cedar	- 0.18	+ 1.25	72.7	3.43% (191 Mgal)	$878,000
Muddy	- 0.18	+ 1.22	72.2	1.5% (54.6 Mgal)	$251,000
Grasshopper	- 0.19	+ 1.25	71.2	1.8% (92.8 Mgal)	$427,000
Otter	- 0.18	+ 1.25	72.6	3.4% (241 Mgal)	$1,110,000
Little Grasshopper	- 0.18	+ 1.21	71.8	1.0% (75.5 Mgal)	$347,000
Negro	- 0.19	+ 1.24	72.4	2.3% (61.2 Mgal)	$282,000
Straight	- 0.18	+1.22	72.0	1.6% (102 Mgal)	$470,000
Banner	- 0.18	+ 1.22	67.2	4.1% (172 Mgal)	$791,000
Average	- 0.18	+ 1.23	71.5	2.4% (123 Mgal)	$570,000

[1]Average change in total flow due to 1% change in tree cover (%).

[2]Average change in total flow due to 1% change in impervious cover effect (%).

[3]Estimated precipitation returned to atmosphere or infiltrated into ground water (i.e., the percent of precipitation that was evaporated from surfaces, evapotranspired from root zone (shallow subsurface) storage, or infiltrated into deep subsurface flow (baseflow)).

[4]Avoided runoff and associated pollutant load reduction from trees. Avoided runoff from trees is estimated by subtracting predicted surface runoff with current tree cover from predicted surface runoff with no tree cover. Pollutant loads are estimated based on surface runoff, thus % reduction in surface runoff = % reduction in pollutant loads. Estimates of absolute reduction in pollutant loads for each study area are included in Appendices 1-8.

[5]Value of Avoided Runoff is based on $0.0046/gal (McPherson et al., 2005).

Study 2. Analysis of Riparian Tree Effects on Streambank Erosion

Streambank erosion is a complex process that occurs at the channel-scale and contributes significantly to water quality degradation through increases in sediment and other indirect impacts (Ghosh et al., 2016). Riparian forests are known to have water quality benefits, including reducing streambank erosion (Sass and Keane, 2012). It is difficult to model streambank erosion due to the complexity of factors that influence erosion and the high variability of those factors (Sass, 2011).

In this study to explore the effects of riparian trees on streambank erosion, a modified version of the Rosgen's Bank Erosion Hazard Index (BEHI) model was used that accounts for woody riparian vegetation. The BEHI model scores various qualities of a point along a stream channel to estimate the erosion risk rating for that channel point, with higher BEHI scores corresponding with more severe erosion risk ratings. The woody vegetation modification to the BEHI model emerged due to the important influence that woody riparian vegetation has on erosion in northeast Kansas, as recognized in Sass and Keane (2012). This study applied Rosgen's BEHI-Near Bank Stress (NBS) model to predict streambank erosion in northeast Kansas and noted that "vegetation seems to play a vital role in maintaining bank stability in this region of northeast Kansas" (Sass and Keane, 2012). It is important to note that our method described below, which applies the work of Sass and Keane (2012), is a simplified approach to explore a highly complex and locally-dependent phenomenon. Thus, there is a high degree of uncertainty of the results.

Using the vegetation modifications to BEHI conducted by Sass and Keane, 2012, many necessary model parameters were not directly available due to the remote nature of this study. The vegetation modified BEHI model required scoring of the following channel qualities: study bank height ratio (SBH:BkfH); bank angle (BA); surface protection (SP); bank material adjustment (BMA); stratification adjustment (SA); and woody vegetation presence (WV). Scores for each of these parameters is added to assign a qualitative Bank Erosion Hazard Index rating. All of these parameters, except for WV, require ground-based observations of channel geomorphological properties. Because our study is being conducted remotely, we used field measurements taken by Sass and Keane (2012) in their development and testing of the vegetation modified BEHI model in a proximate watershed (Table 2.1). Sass and Keane (2012) field measurements include 18 channel sample points within HUC 10270205, Lower Big Blue Basin – a proximate watershed that begins within 10 miles west of this study's areas of interest in HUC 10270103, Delaware River Basin.

Table 2.1. *Select field data from Sass and Keane, (2012, Table 8) along with average, minimum, and maximum score-sets for each BEHI parameter.*

Location	SBH:BkfH	BA	SP	BMA	SA
MS 1p	8.5	3	2	0	0
MS 1s	8.5	4	6.5	0	0
MS 2p	8	2.5	10	0	0
MS 2s	8	3	10	0	5
MS 3p	10	3	5	0	5
MS 3s	10	3	5	0	5
NF 1p	10	3	10	0	0
NF 1s	8.5	4	10	0	0
NF 2p	9	4	10	0	0
NF 2s	8.5	3.5	10	0	0
NF 3p	8.5	3.5	10	0	0
NF 3s	8	3.5	10	0	0
IC 1p	10	3.5	10	0	5
IC 1s	10	1	1	0	0
IC 2p	10	2.5	2	0	0
IC 2s	10	4.5	10	0	0
IC 3p	10	3.5	10	0	0
IC 3s	9	3.5	10	0	0
Average	9.14	3.25	7.86	0	1.11
Minimum	8	1	1	0	0
Maximum	10	4.5	10	0	5

Notes: MS, Black Vermillion Main Stem; NF, North Fork; IC, Irish Creek; corresponding number indicates reach location, 3 is the lowest reach and 1 is the most upstream reach; "p" indicates pool study bank; "s" indicates study bank. All sample locations are within HUC 10270205, Lower Big Blue Basin – a proximate watershed for the eight study areas within the nearby HUC 10270103, Delaware River Basin.

SBH:BkfH - study bank height ratio.

BA - bank angle.

SP - surface protection.

BMA - bank material adjustment.

SA - stratification adjustment.

To calculate the vegetation-modified BEHI scores for our eight study areas, all average, minimum, and maximum parameter values were added up respectively to derive the potential average, minimum, and maximum score. This summation was based on the field observations from Sass and Keane (2012) shown in Table 2.1, along with either a minimum woody riparian vegetation rating of 0, an average of 2.5 or a maximum of 8.5, depending on the extent of each WV classification (Table 2.2) in each study area. Those potential woody riparian vegetation scores are derived from Sass and Keane (2012). Lesser extents of woody riparian vegetation correspond with higher WV scores because higher BEHI scores correspond with more severe risk ratings.

To localize vegetation modified BEHI results, i-Tree Canopy was used to estimate WV scores for each of the eight study areas. National Hydrography Dataset (NHD) Flowlines (NRCS et al., 2017) were clipped to the extent of each study area and then an approximately 1 meter buffer was applied to each area's flowline to produce a suitable area for photo-interpreting the presence of woody riparian vegetation. Google Earth imagery, viewed through i-Tree Canopy, enabled scoring of WV at 100 random points within 1 meter of the riparian buffer of each study area (e.g. Figure 2.1). If the assessment polygon did not cover the stream, the assessment of WV was conducted from the stream center point perpendicular to the polygon and random point.

The i-Tree Canopy point classification was based on the criteria put forth by Sass and Keane (2012): "No [Trees] included those banks influenced by tillage agriculture, brome pasture, and shallow-rooted herbaceous plants only. [Some trees] included some woody vegetation, corridor widths usually less than two rows of trees [on both sides of the stream] with little age or species diversity. Willow thicket influence was also included in this category. [Many trees] included those areas with strong influences from surrounding large riparian vegetation. This grouping exceeded two rows of woody vegetation [on both sides of the stream] and included diverse age and species composition in the riparian corridor." In photo-interpretation, species and age diversity was indeterminable. Each random i-Tree Canopy point was given the highest score possible depending on whether there were: no rows of woody vegetation on either side of the stream (no trees, Figure 2.2); ≥1 rows of woody vegetation on either side of the stream (some trees, Figures 2.3 and 2.4); or ≥2 rows of woody vegetation on both sides of the stream (many trees, Figure 2.5). The scoring system is depicted in Table 2.2, and results for each study area are shown in Table 2.3 and Figure 2.6.

Table 2.2. *WV classification system for associating i-Tree Canopy photo-interpretation points with modified BEHI model WV scores.*

Tree cover extent (# of rows)		WV classification	WV score
Left bank	Right bank		
0	0	No trees	8.5
0	1	Some trees	2.5
1	1	Some trees	2.5
0	2+	Some trees	2.5
1	2+	Some trees	2.5
2+	2+	Many trees	0.0

Lesser extents of woody riparian vegetation correspond with higher WV scores because higher BEHI scores correspond with more severe streambank erosion risk ratings.

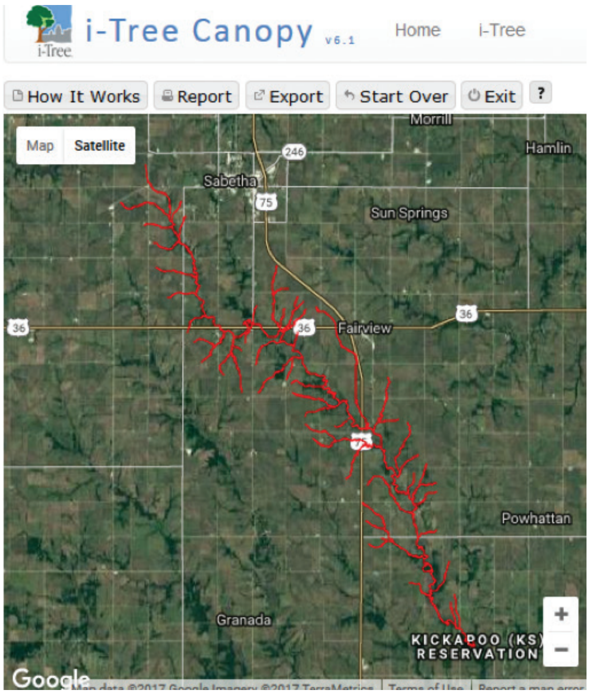

Figure 2.1. *Screen capture of i-Tree Canopy assessment, highlighting flowline buffer area used in photo-interpretation of WV scores in one study area (HUC 102701030102, Cedar Creek).*

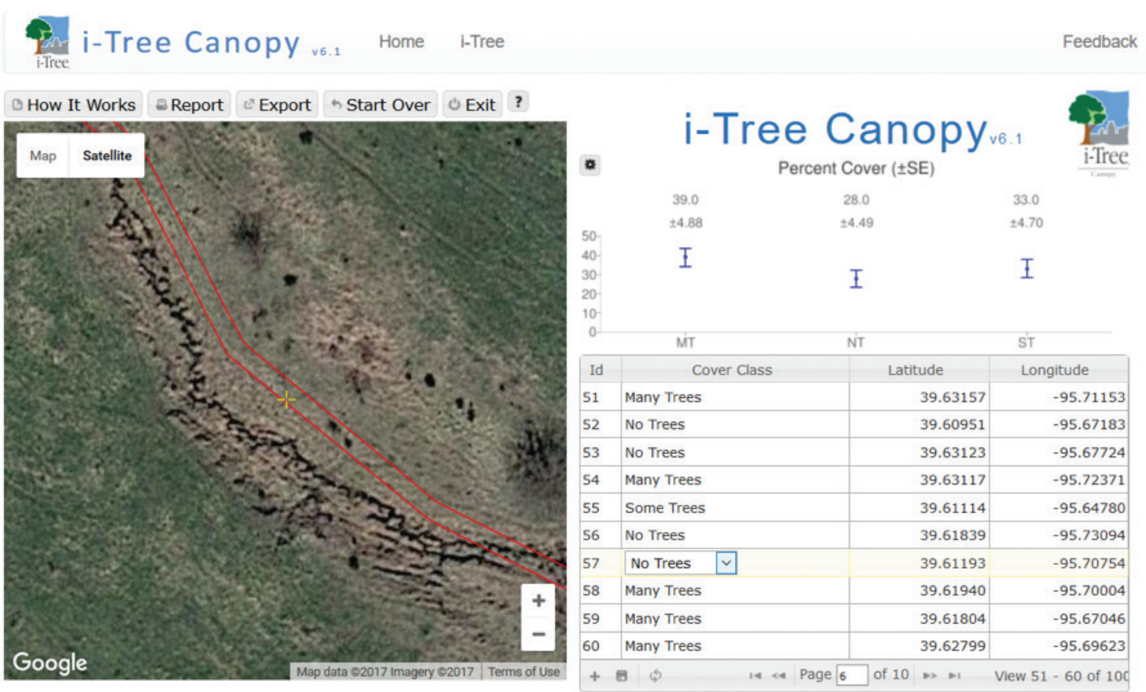

Figure 2.2. *Screen capture of i-Tree Canopy assessment, highlighting a point classified as 'No trees' due to no rows of woody vegetation on either side of that stream point in photo-interpretation of WV scores in one study area (HUC 102701030109, Muddy Creek).*

Figure 2.3. *Screen capture of i-Tree Canopy assessment, highlighting a point classified as 'Some trees' with 1-2 rows of woody vegetation on either side of that stream point in photo-interpretation of WV scores in one study area (HUC 102701030109, Muddy Creek).*

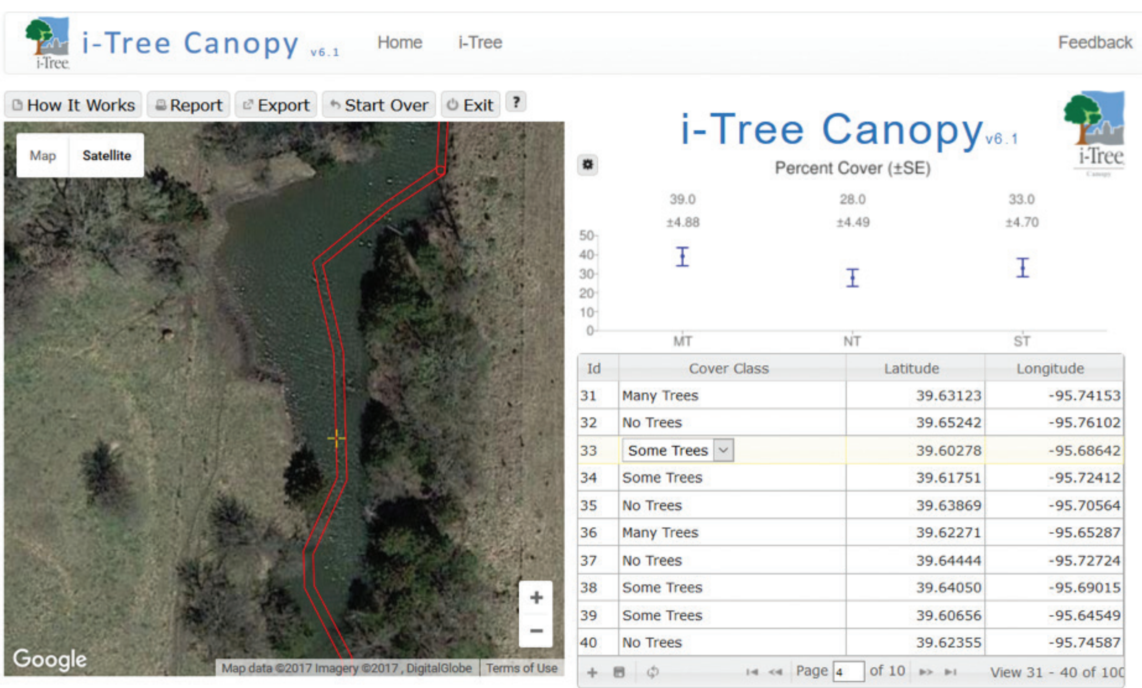

Figure 2.4. *Screen capture of i-Tree Canopy assessment, highlighting a point classified as 'Some trees' with ≥1 rows of woody vegetation on one but not both sides of that stream point in photo-interpretation of WV scores in one study area (HUC 102701030109, Muddy Creek).*

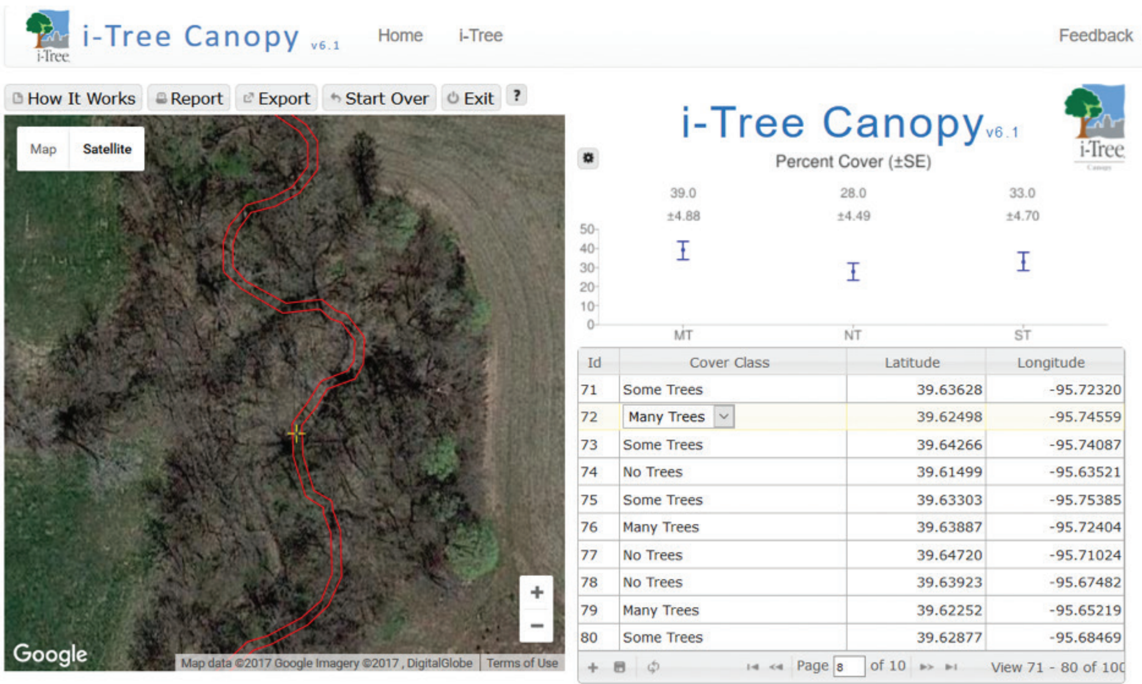

Figure 2.5. *Screen capture of i-Tree Canopy assessment, highlighting a point classified as 'Many trees' with ≥2 rows of woody vegetation on both sides of that stream point in photo-interpretation of WV scores in one study area (HUC 102701030109, Muddy Creek).*

Table 2.3. *WV scores in each study area based on 100-point i-Tree Canopy assessment.*

Study Area	No trees (NT)	Some trees (ST)	Many trees (MT)
Cedar Creek	36%	41%	23%
Muddy Creek	28%	33%	39%
Grasshopper Creek	43%	18%	39%
Otter Creek	29%	22%	49%
Little Grasshopper Creek	30%	32%	38%
Negro Creek	18%	34%	48%
Straight Creek	34%	35%	31%
Banner Creek	26%	43%	31%

Notes: Classification of NT, ST, and MT are based on February 2017 i-Tree Canopy assessments using methods described above and in Table 2.2 and Figures 2.1-2.5.

The distribution of WV scores in each study area was mapped out to visualize where i-Tree Canopy points were found to have no trees, some trees, or many trees (Figures 2.7-2.15).

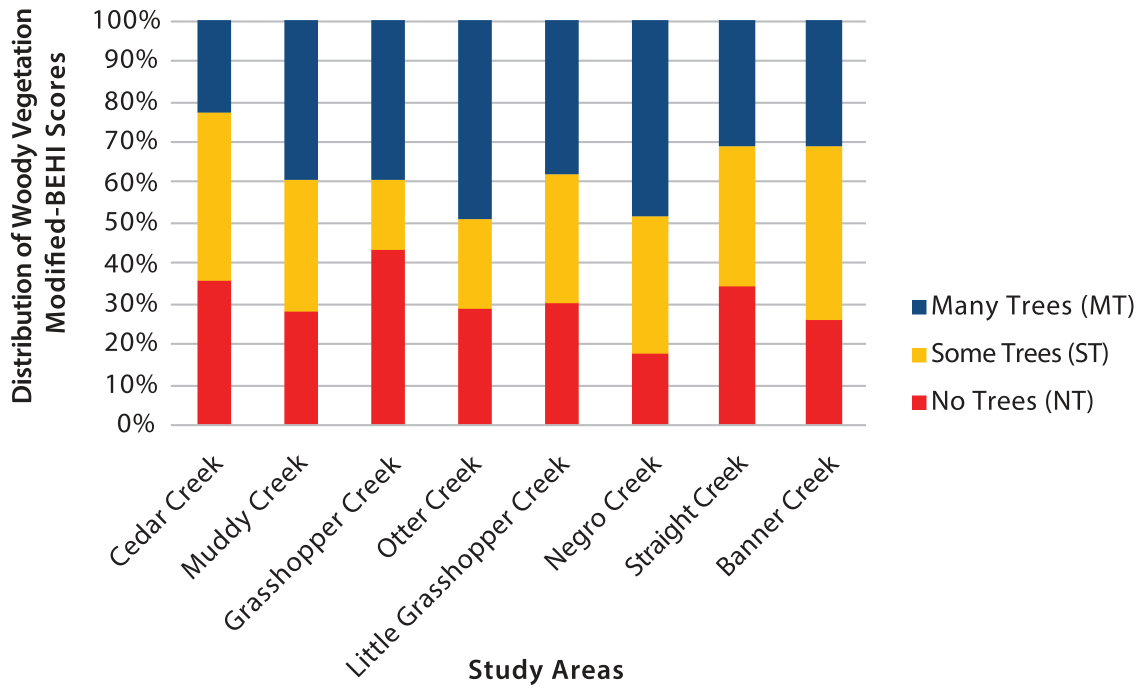

Figure 2.6. *Distribution of WV scores as percentages in each study area.*

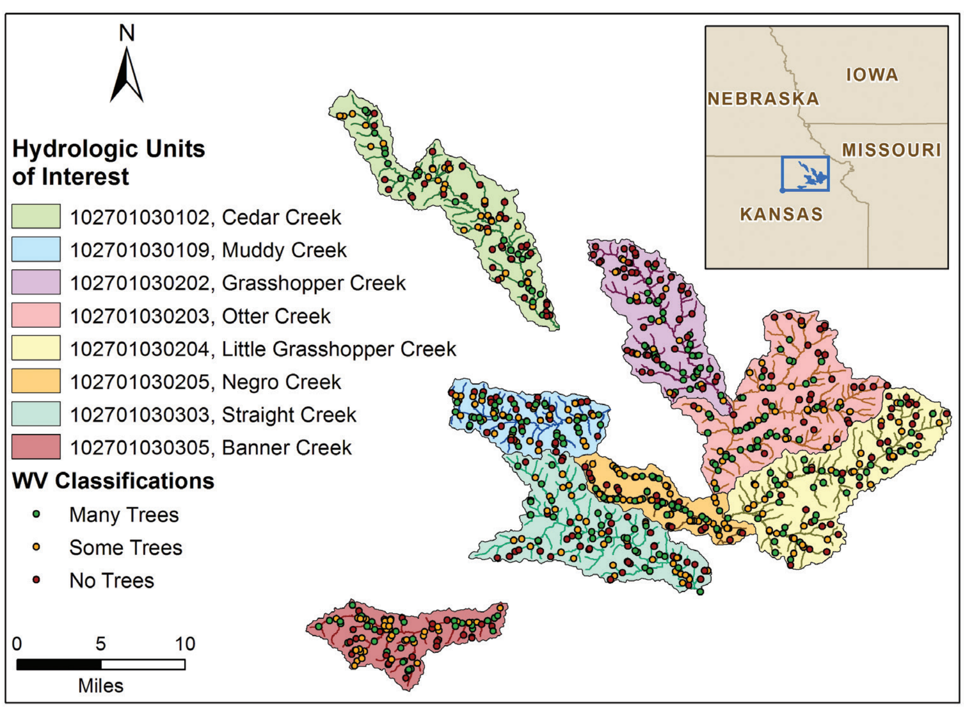

Figure 2.7. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of all study areas.*

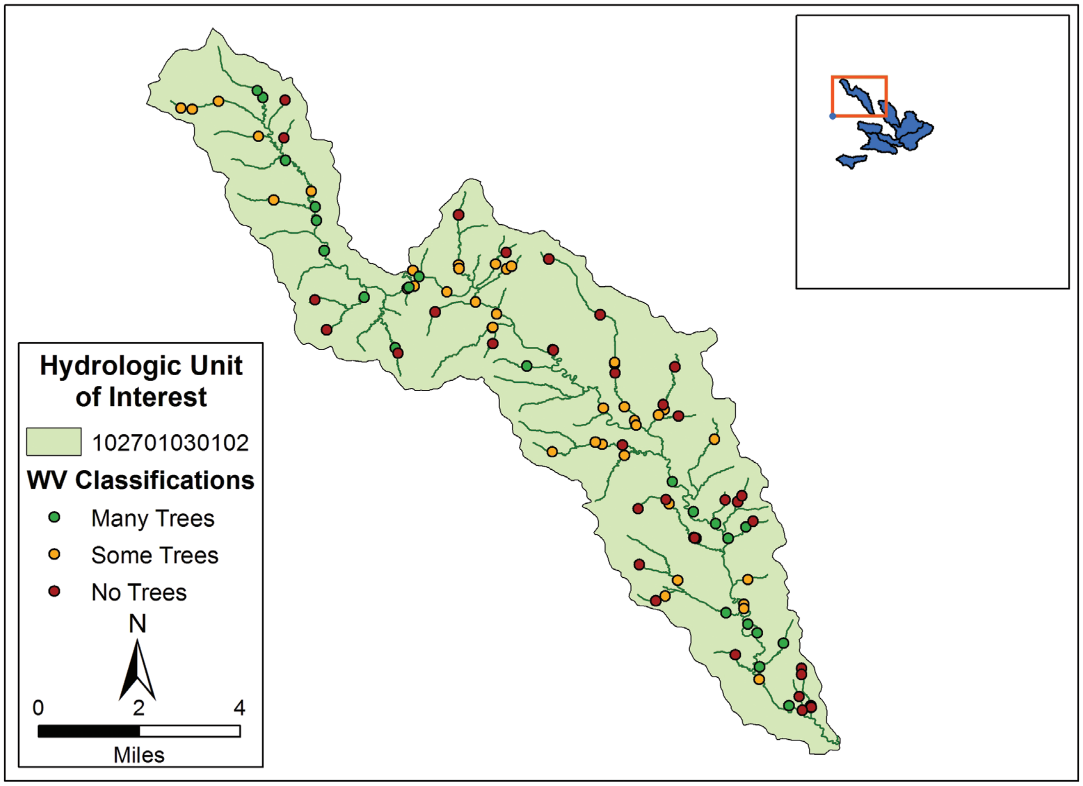

Figure 2.8. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of Cedar Creek.*

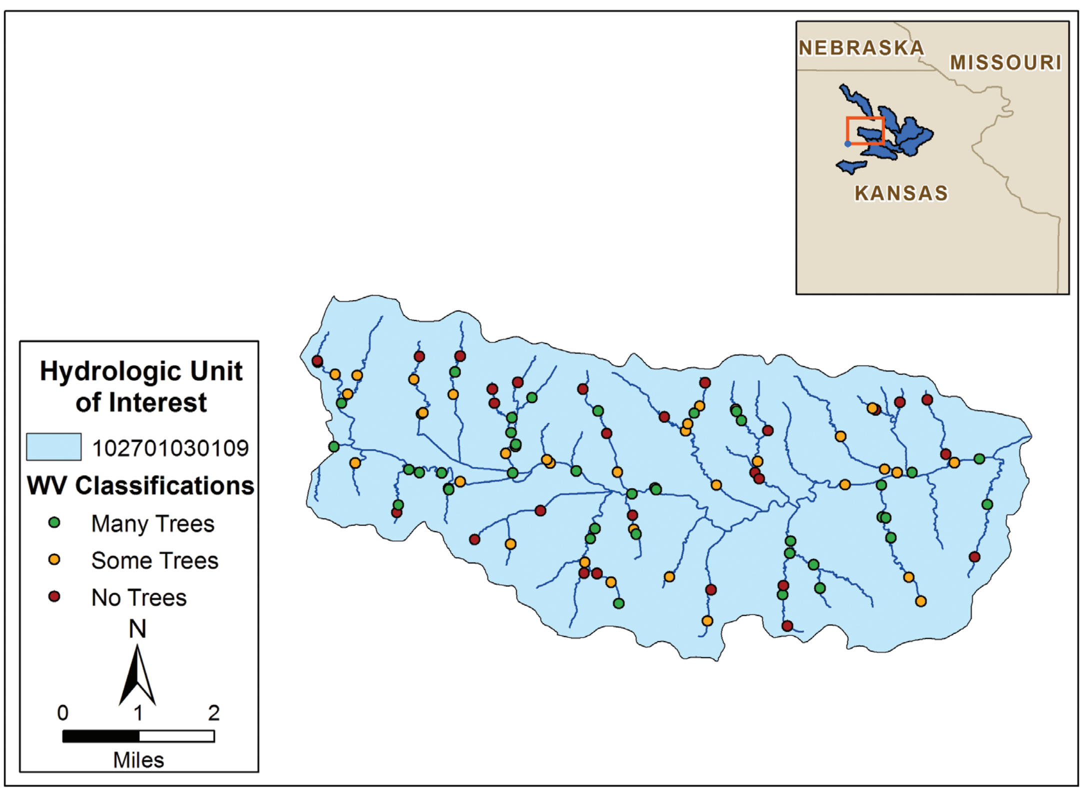

Figure 2.9. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of Muddy Creek.*

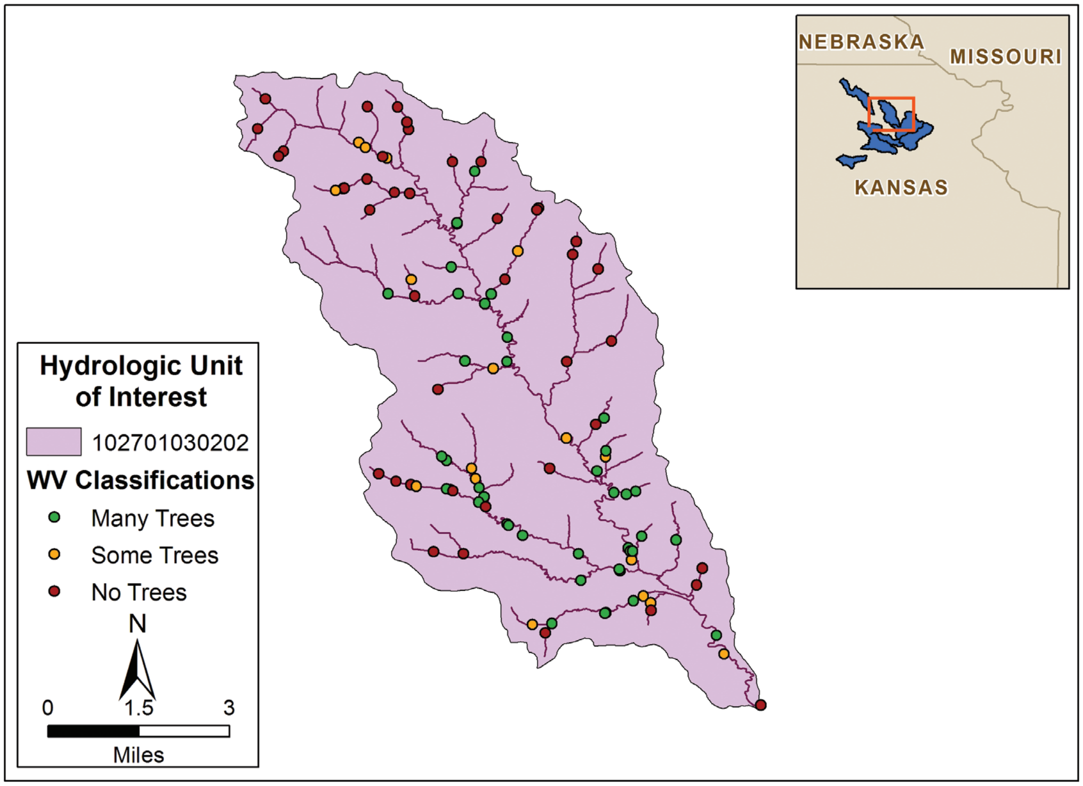

Figure 2.10. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of Grasshopper Creek.*

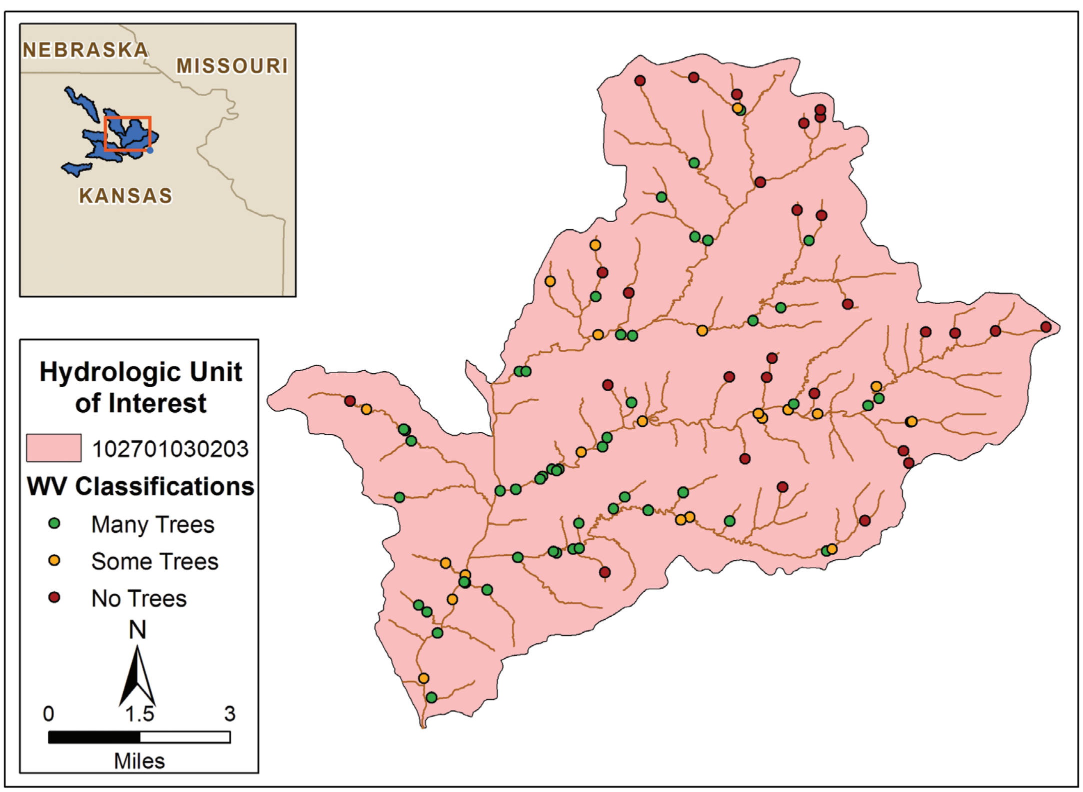

Figure 2.11. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of Otter Creek.*

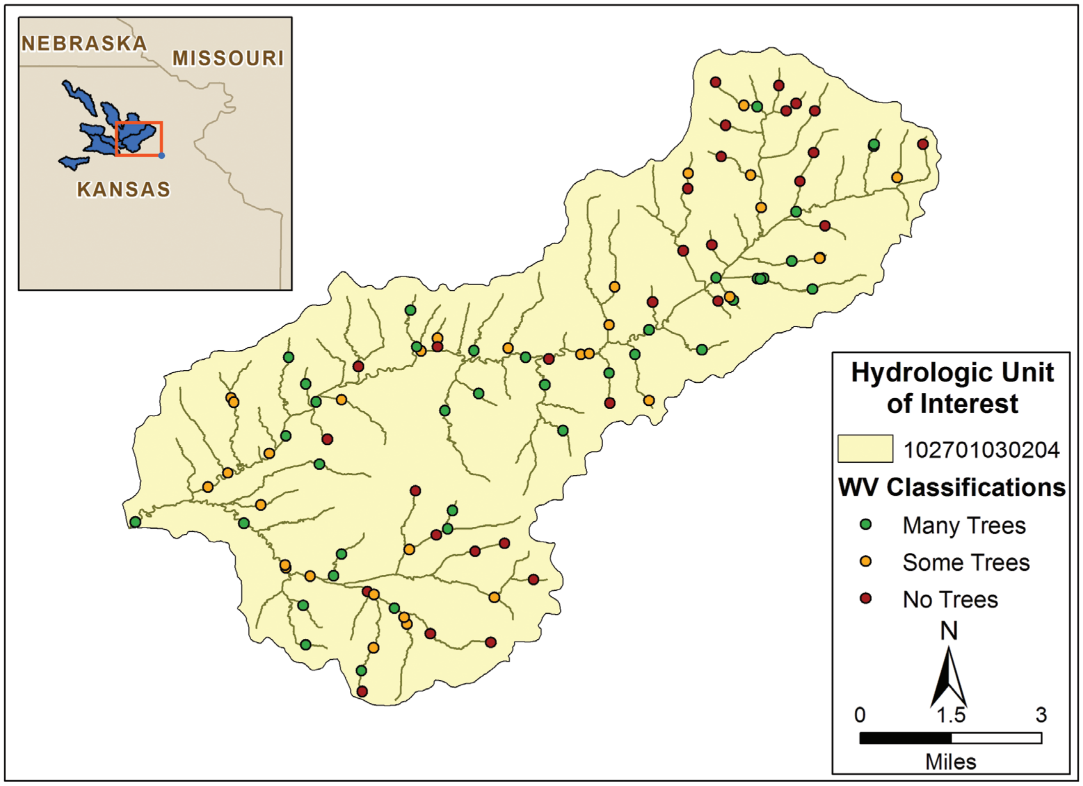

Figure 2.12. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of Little Grasshopper Creek.*

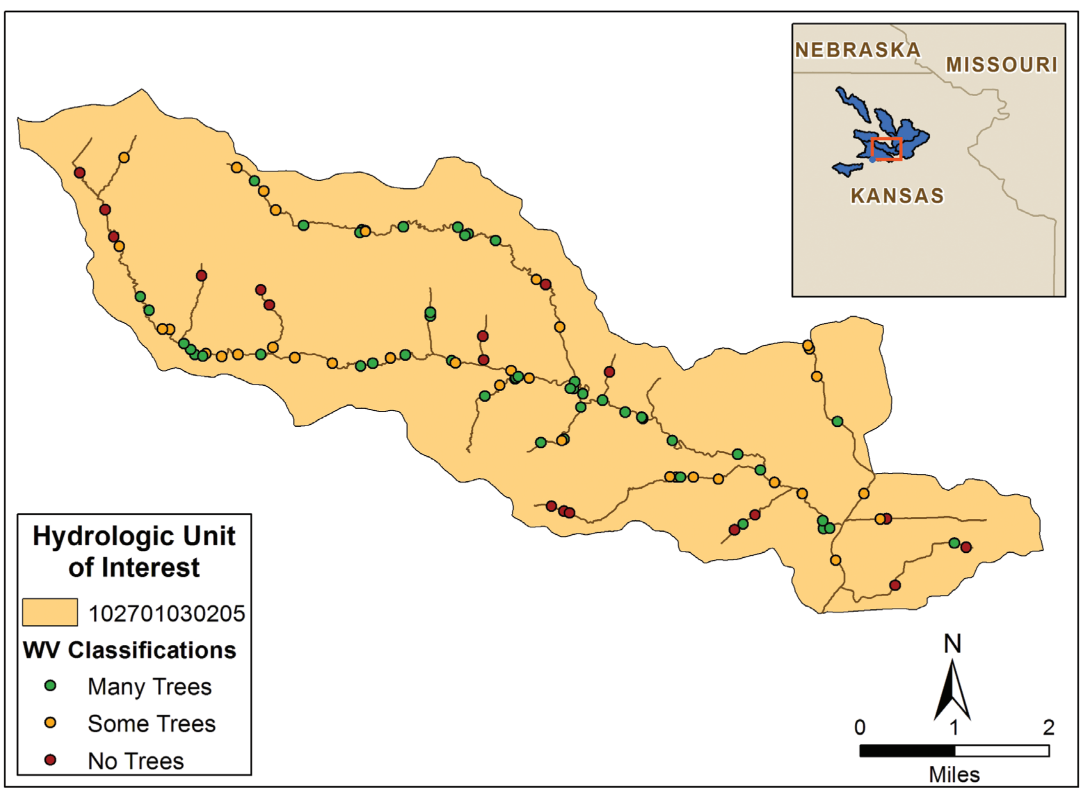

Figure 2.13. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of Negro Creek.*

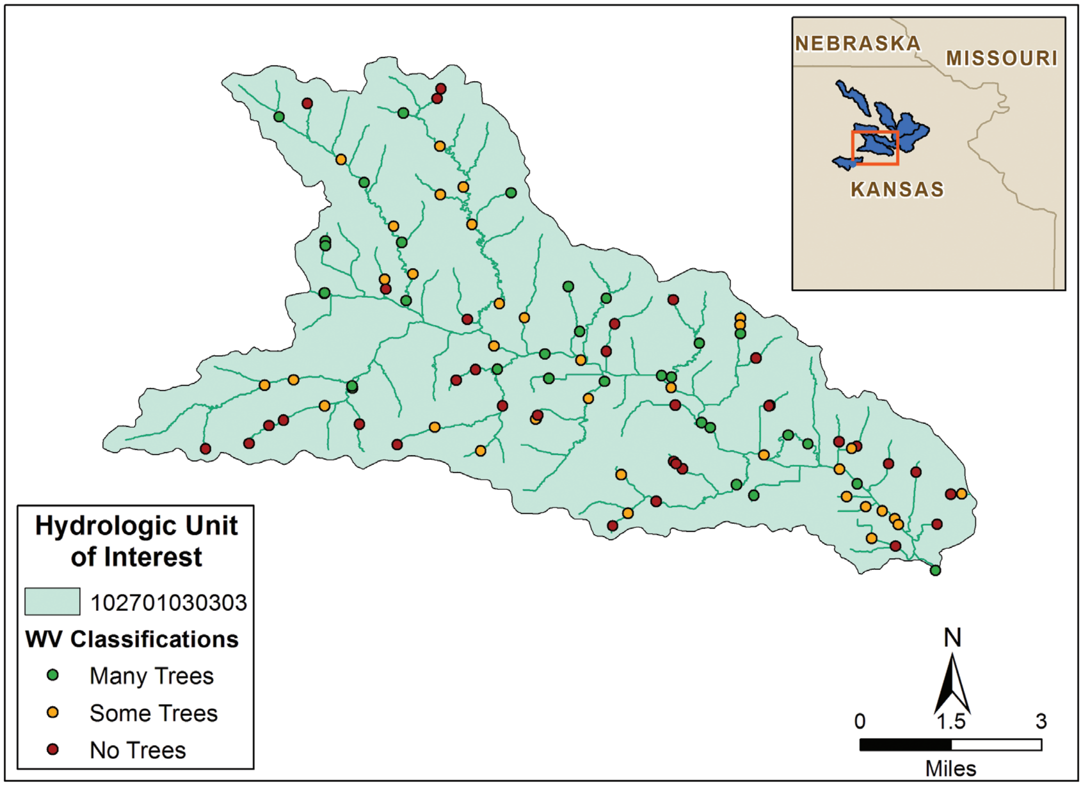

Figure 2.14. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of Straight Creek.*

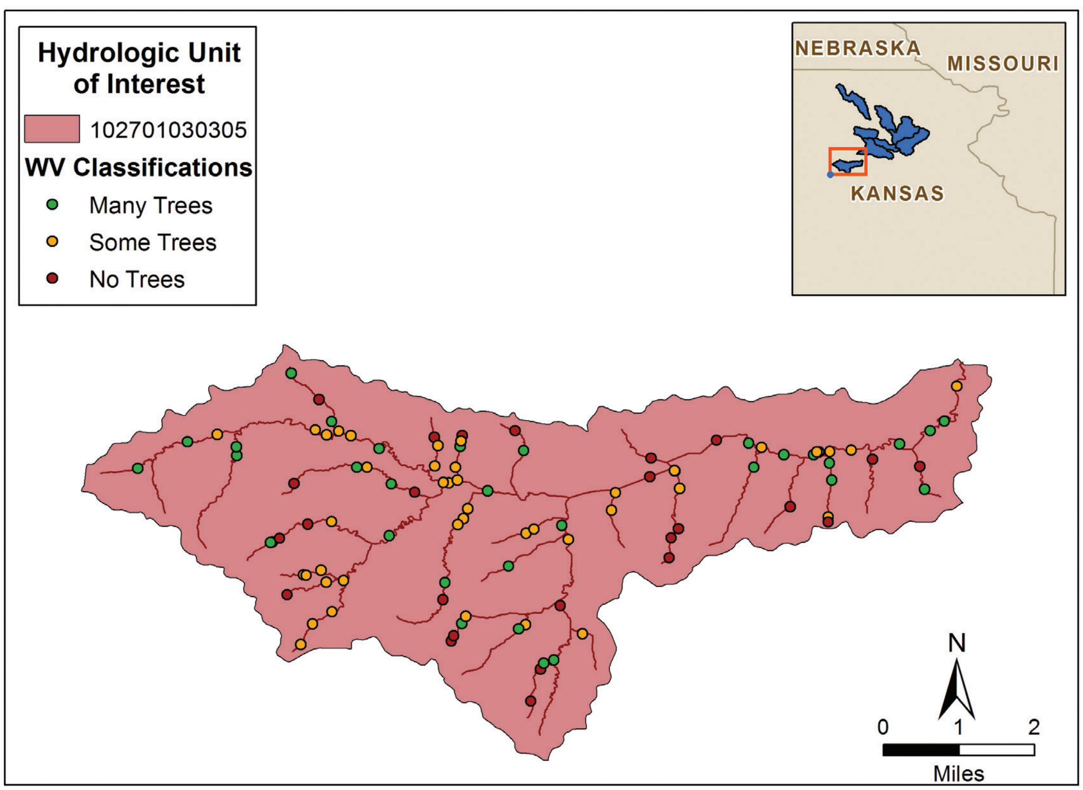

Figure 2.15. *Distribution of WV classifications from i-Tree Canopy photo-interpretation points, plotted on a map of Banner Creek.*

The potential average, minimum, and maximum BEHI score-sets – derived from the proximate watershed studied by Sass and Keane (2012) (Table 2.1) – were combined with each potential WV score (0 for many trees, 2.5 for some trees, 8.5 for no trees; Table 2.2) weighted by the percent distribution of each WV score in each watershed (Table 2.3). That process results in an overall average, minimum, and maximum vegetation modified BEHI score for each study area (Table 2.4). Results indicate some variability among the eight study areas, but all watersheds have similar risk ratings (Figure 2.16). A '100% No Tree' area is included to illustrate results if a study area had absolutely no riparian tree cover. This no tree analysis was done to help indicate the relative impact a riparian forest has on reducing the risk of streambank erosion.

The study area with the overall lowest risk of bank erosion is Negro Creek. The areas with the highest risks are Cedar Creek and Grasshopper Creek. As Table 2.3 and Figure 2.6 depict, that lowest risk area has the

Table 2.4. *Overall average, minimum, and maximum vegetation modified BEHI score for each study area, including associated qualitative BEHI risk ratings as defined in Sass and Keane, 2012. A '100% No Tree' area is included for comparison to highlight how trees reduce bank erosion risk.*

	BEHI* score (risk rating)		
Study Area	**Minimum**	**Average**	**Maximum**
Cedar Creek	14.1 – Low risk	25.4 – Moderate risk	33.6 – High risk
Muddy Creek	13.2 – Low risk	24.6 – Moderate risk	32.7 – High risk
Grasshopper Creek	14.1 – Low risk	25.5 – Moderate risk	33.6 – High risk
Otter Creek	13.0 – Low risk	24.4 – Moderate risk	32.5 – High risk
Little Grasshopper Creek	13.4 – Low risk	24.7 – Moderate risk	32.9 – High risk
Negro Creek	12.4 – Low risk	23.7 – Moderate risk	31.9 – High risk
Straight Creek	13.8 – Low risk	25.1 – Moderate risk	33.3 – High risk
Banner Creek	13.3 – Low risk	24.6 – Moderate risk	32.8 – High risk
'100% No Tree' area	18.5 – Low risk	29.9 – High risk	38.0 – Very high risk

* BEHI with Vegetation Modifications based on Sass and Keane (2012). Results for each area were determined based on the minimum, mean and maximum BEHI values from 18 study points in a nearby, proximate watershed (Table 8 in Sass and Keane, 2012) combined with woody vegetation scores for each area based on i-Tree Canopy photo-interpretation.

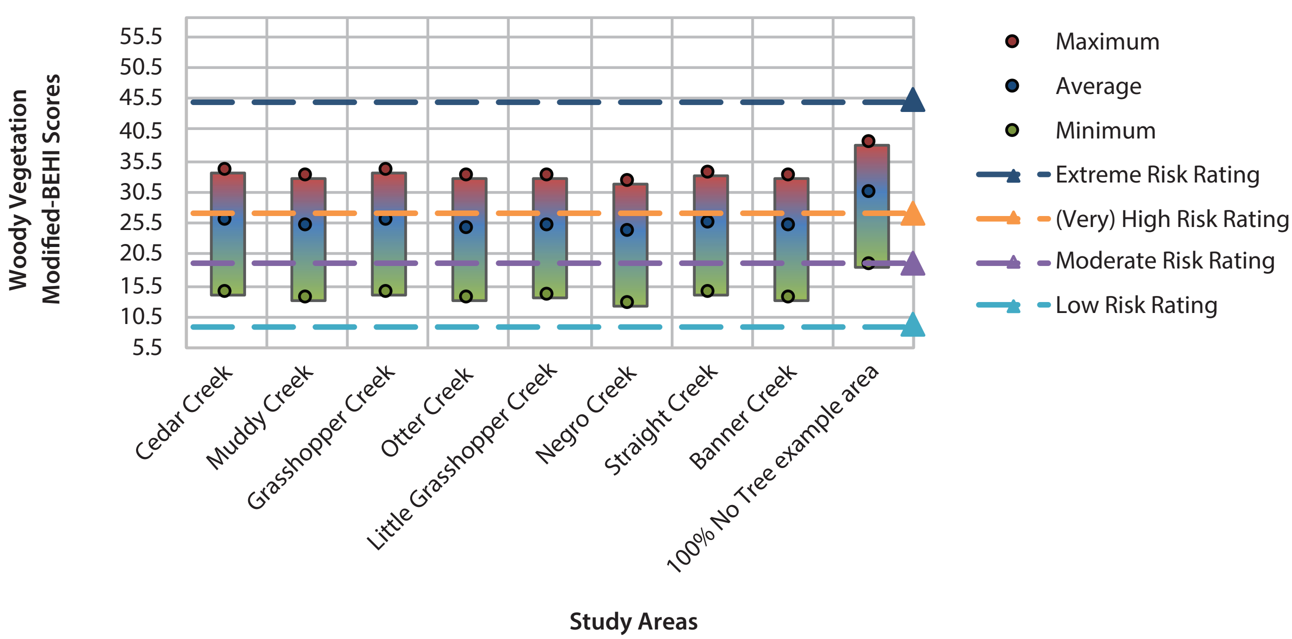

Figure 2.16. *Overall mean, minimum, and maximum vegetation modified BEHI scores for each study area, including tiers of qualitative BEHI risk ratings as defined in Sass and Keane, 2012.*

second greatest portion of its riparian area classified as having many trees (48%) and it has the least portion of its riparian area classified as having no trees (18%). One of the highest risk areas, Cedar Creek, has the least portion of its riparian area classified as having many trees (23%). The other highest risk area, Grasshopper Creek, has the greatest portion of its riparian area classified as having no trees (43%). In other words, the least at-risk area has the second most forested riparian area and the least completely-deforested riparian area, while the two most at-risk areas have the least forested riparian area and the greatest completely-deforested riparian area, respectively.

It is important to reiterate that this erosion risk analysis is a simple and lumped approach that examines the effects of riparian trees on the highly complex and locally-dependent process of streambank erosion in eight study areas. Thus, these estimates of erosion are highly uncertain due to these complexities. The risk results among these watersheds are also similar to each other in terms of overall risk classes (i.e., all streams are estimated as moderate risk on average).

This report uses a novel approach to remotely assess woody riparian vegetation and its impacts on streambank erosion, and provides a first-order estimate of streambank erosion risk based on riparian vegetation. The results enable managers to highlight areas of concern for further analysis that can guide riparian forest conservation efforts or streambank reforestation and restoration efforts to minimize the risk of streambank erosion.

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Appendix 1. HUC 10270102, Cedar Creek

Tree Cover Effects

Loss of current tree cover in the Cedar Creek watershed (Figure A1.1) increased total overland runoff during the simulation period by an average of 3.4% (722.8 thousand m^3). Increasing canopy cover from 10.5 to 50.0% reduced total overland runoff by 6.2% (1.3 million m^3) during this 12-month period (Figure A1.2).

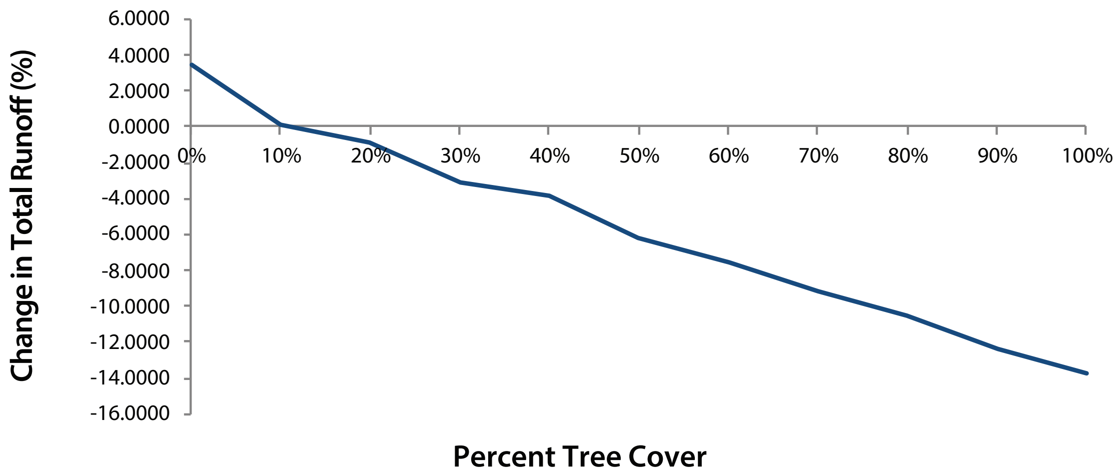

Figure A1.1. *Percent change in total overland runoff with changes in percent tree cover in Cedar Creek.*

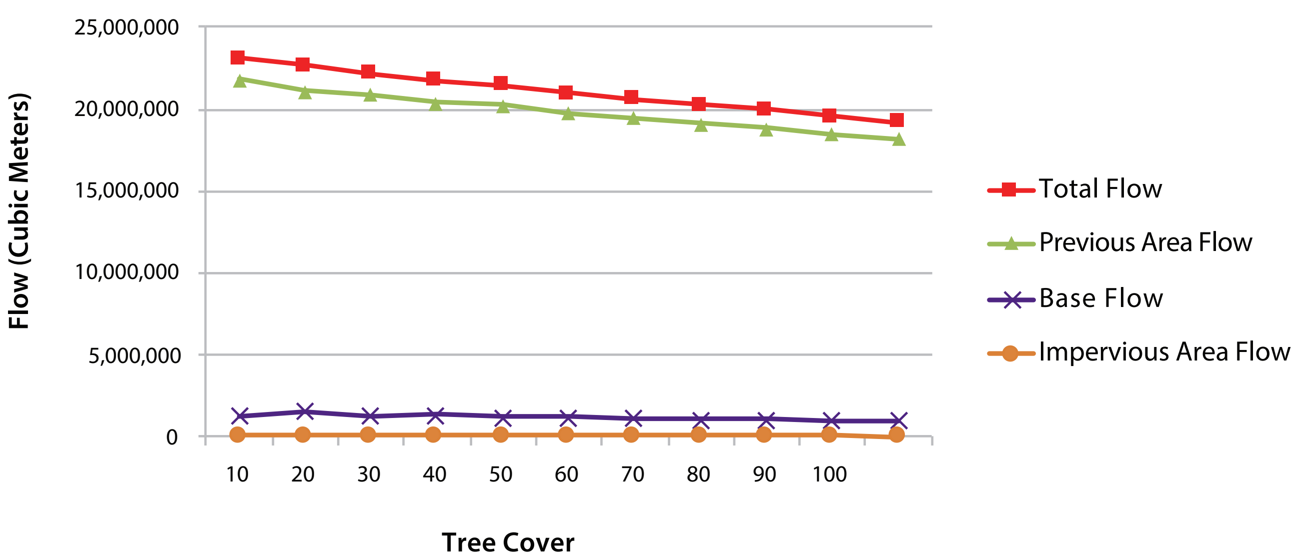

Figure A1.2. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent tree cover in Cedar Creek.*

Impervious Cover Effects

Removal of current impervious cover (Figure A1.3) reduced total overland runoff during the simulation period by an average of 1.5% (316.0 thousand m^3). Increasing impervious cover from 1.0 to 20% of the watershed increased total overland runoff 26.4% (5.6 million m^3) during this 12-month period (Figure A1.4).

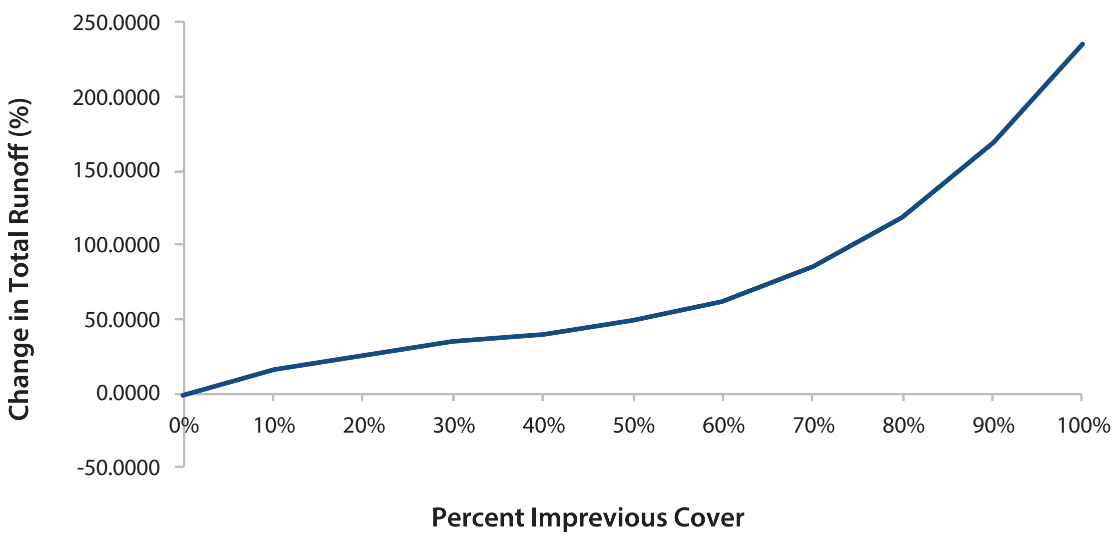

Figure A1.3. *Percent change in total overland runoff with changes in percent impervious cover in Cedar Creek.*

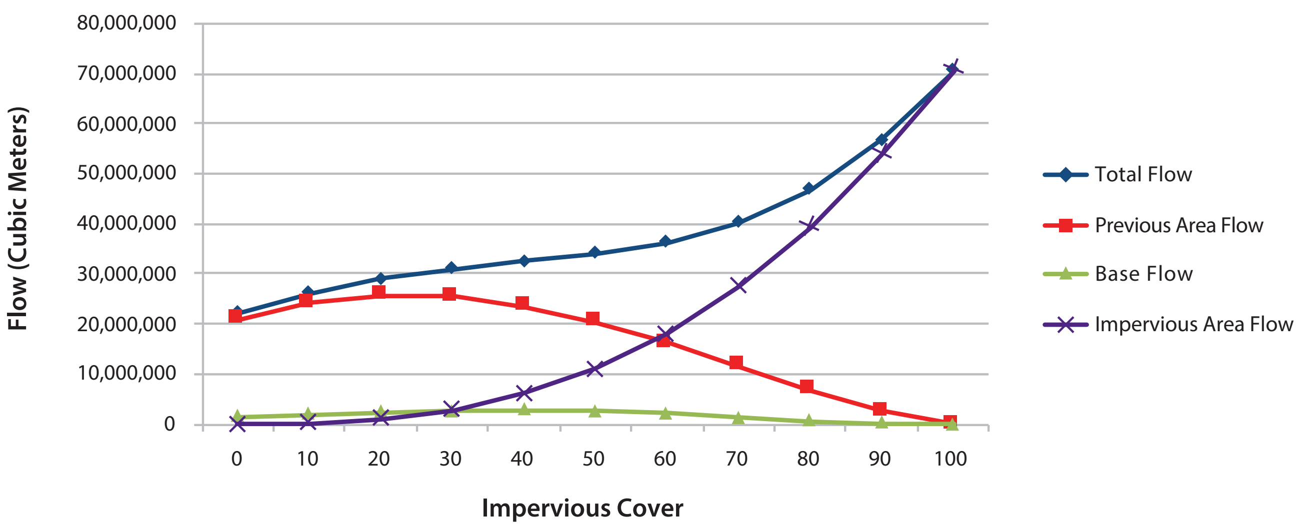

Figure A1.4. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in Cedar Creek.*

Land Cover Scaling Trends

Under current cover conditions, increasing impervious cover had an approximately 7 times greater impact on flow relative to tree cover. Increasing impervious cover by 1% averaged a 1.25% increase in total flow, while increasing tree cover by 1% averaged only a 0.18% decrease in total flow. The interactions between changing both tree and impervious cover are illustrated for total flow during the simulation period (Figure A1.5) and for percent changes in flow (Figure A1.6).

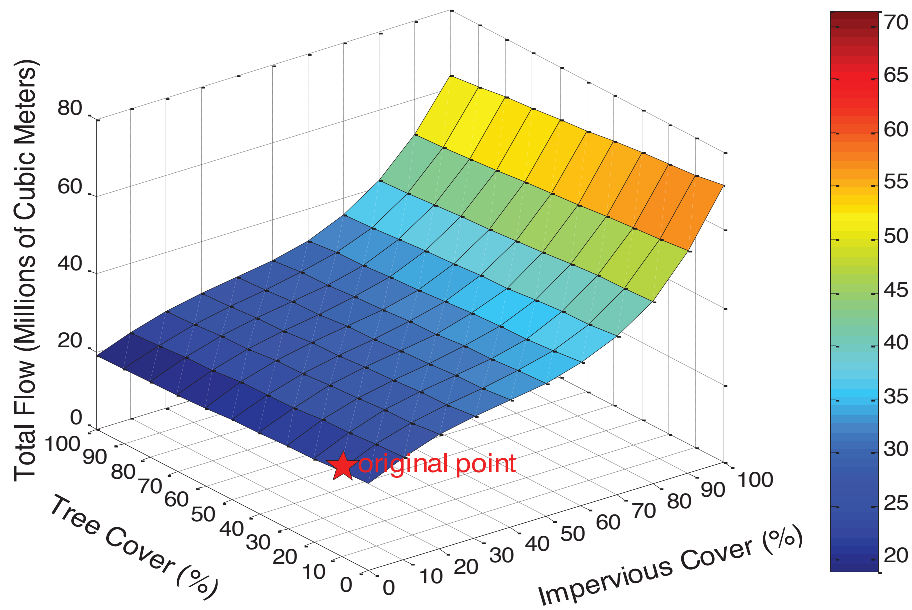

Figure A1.5. *Changes in total flow during simulation period based on changes in percent impervious and percent tree cover in Cedar Creek. Red star indicates current conditions.*

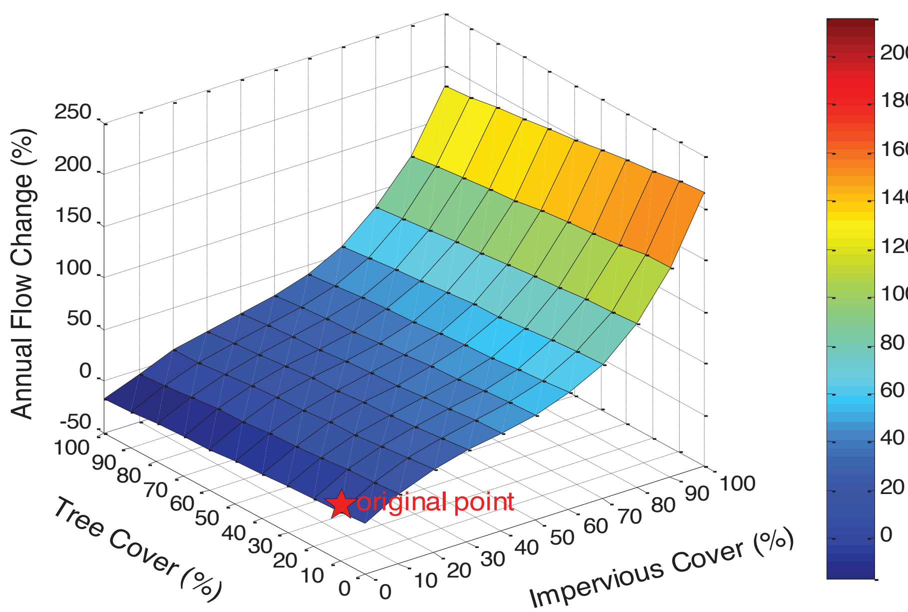

Figure A1.6. *Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover in Cedar Creek. Red star indicates current conditions.*

During the simulation period the total rainfall recorded was 967.49 millimeters. Since that amount is assumed to have fallen over the entire 102 square kilometer watershed, a total of 99.1 million cubic meters of rain fell on the watershed during the simulation time. The total modeled flow in the Cedar Creek watershed throughout the simulation time for the base case scenario (no landscape change) was 22.6 million cubic meters. The total flow is made up of surface runoff (from pervious and impervious areas) and baseflow (water that travels underground to the stream). Runoff from pervious areas and baseflow are the biggest contributors to this watershed's stream flow with 93.2 and 6.8% of total flow generated from pervious runoff and baseflow, respectively. Runoff from impervious areas was estimated to generate <0.05% of total flow. Areas of tree canopies intercepted about 11.8% of the total rainfall, but as only 10.5% of this watershed is under tree cover, interception of total precipitation in the watershed by trees was only 1.2% (1.2 million cubic meters). Areas of grass/herbaceous cover intercepted about 3.6% of the total rainfall, but as only 88.0% of this watershed is under grass/herbaceous cover, interception of total precipitation in the watershed by grass/herbaceous cover was only 3.2% (3.2 million cubic meters). About 72.7% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration (including evaporation from interception) or go to ground water recharge.

Water Quality Benefits from Trees

Based on the simulated changes in flow rates and the pollutant coefficient values used, the current tree cover is estimated to reduce suspended sediment during the simulation period by about 283.5 tonnes. Other pollutants are also reduced (Table A1.1).

Table A1.1. *Estimated reduction in chemical constituents in Cedar Creek watershed due to existing tree cover during simulation period based on median and mean EMC values (Tables 1.3 and 1.4).*

	Reduction (tonnes)	
Constituent	**Median**	**Mean**
Suspended sediment	283.494	312.407
Biochemical oxygen demand	8.313	10.192
Chemical oxygen demand	32.310	38.165
Total phosphorus	0.334	0.352
Total nitrogen	2.780	3.155
Copper	0.008	0.010
Lead	0.037	0.049
Zinc	0.093	0.117

Appendix 2. HUC 10270109, Muddy Creek

Tree Cover Effects

Loss of current tree cover in the Muddy Creek watershed (Figure A2.1) increased total overland runoff during the simulation period by an average of 1.5% (206.6 thousand m^3). Increasing canopy cover from 13.0 to 50.0% reduced total overland runoff by 7.6% (1.0 million m^3) during this 12-month period (Figure A2.2).

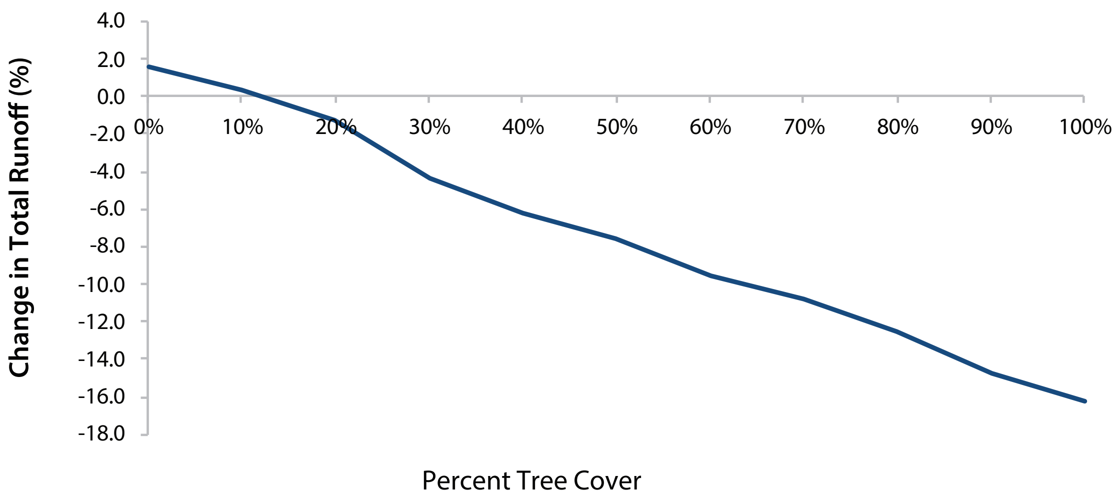

Figure A2.1. *Percent change in total overland runoff with changes in percent tree cover in Muddy Creek.*

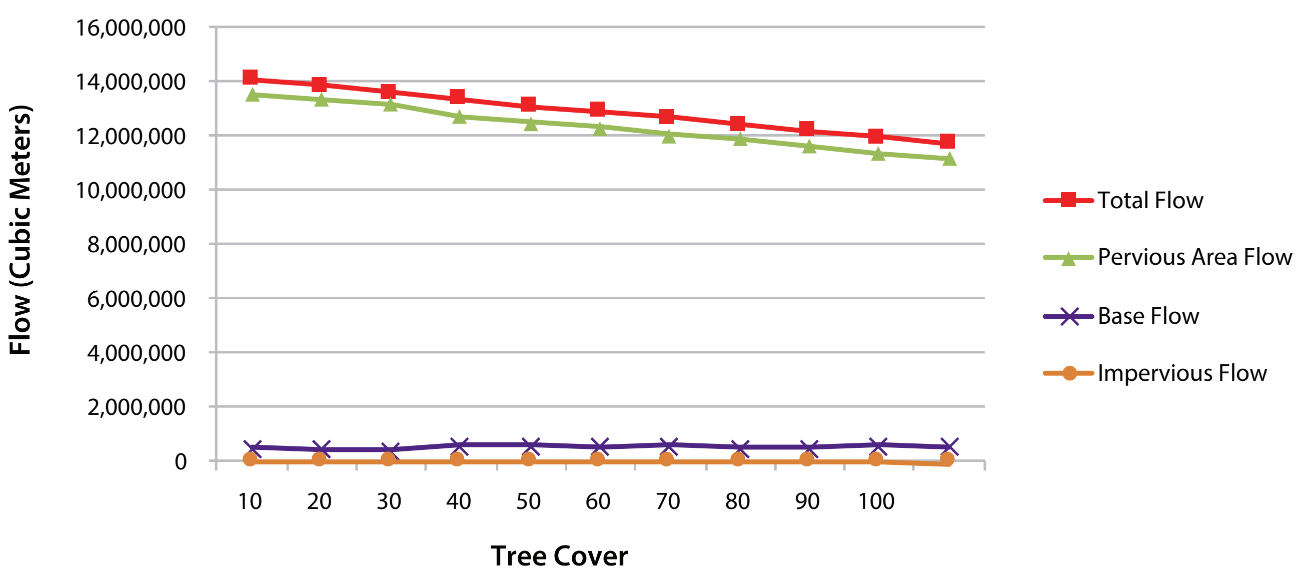

Figure A2.2. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent tree cover in Muddy Creek.*

Impervious Cover Effects

Removal of current impervious cover (Figure A2.3) reduced total overland runoff during the simulation period by an average of 1.2% (164.8 thousand m^3). Increasing impervious cover from 0.5 to 20% of the watershed increased total overland runoff 23.0% (3.1 million m^3) during this 12-month period (Figure A2.4).

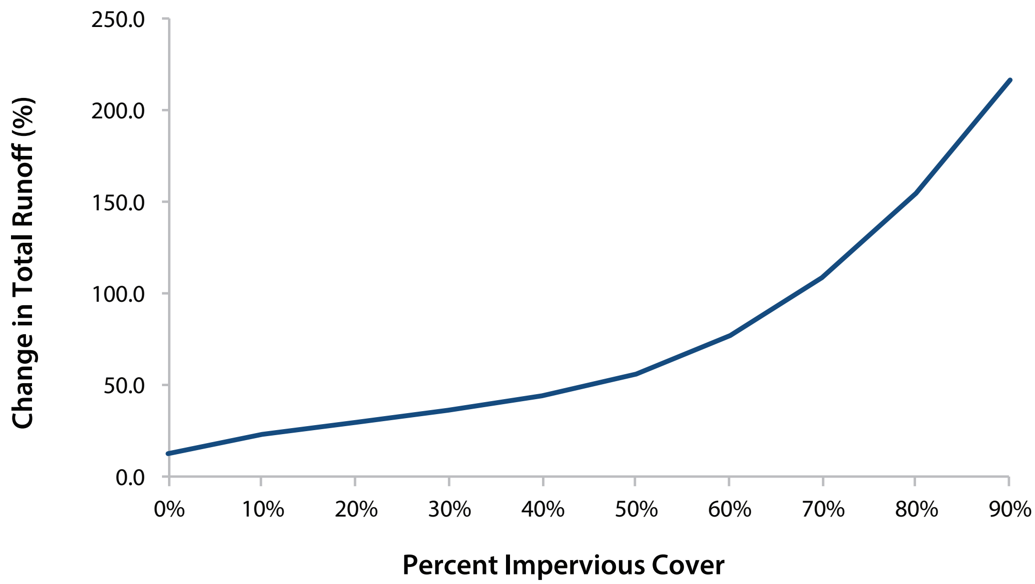

Figure A2.3. *Percent change in total overland runoff with changes in percent impervious cover in Muddy Creek.*

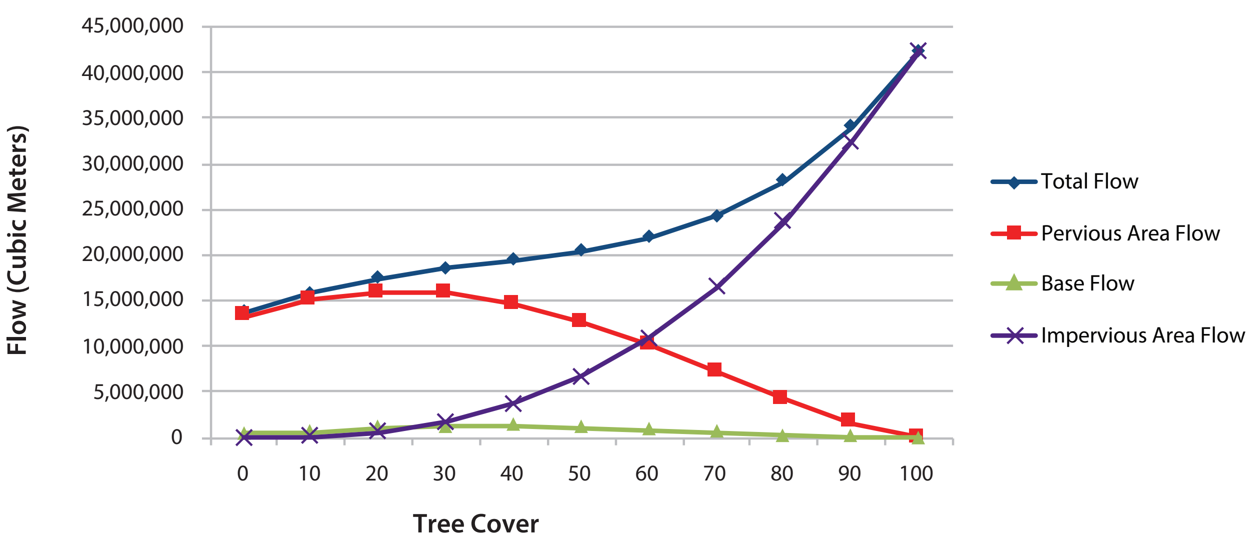

Figure A2.4. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in Muddy Creek.*

Land Cover Scaling Trends

Under current cover conditions, increasing impervious cover had an approximately 7 times greater impact on flow relative to tree cover. Increasing impervious cover by 1% averaged a 1.22% increase in total flow, while increasing tree cover by 1% averaged only a 0.18% decrease in total flow. The interactions between changing both tree and impervious cover are illustrated for total flow during the simulation period (Figure A2.5) and for percent changes in flow (Figure A2.6).

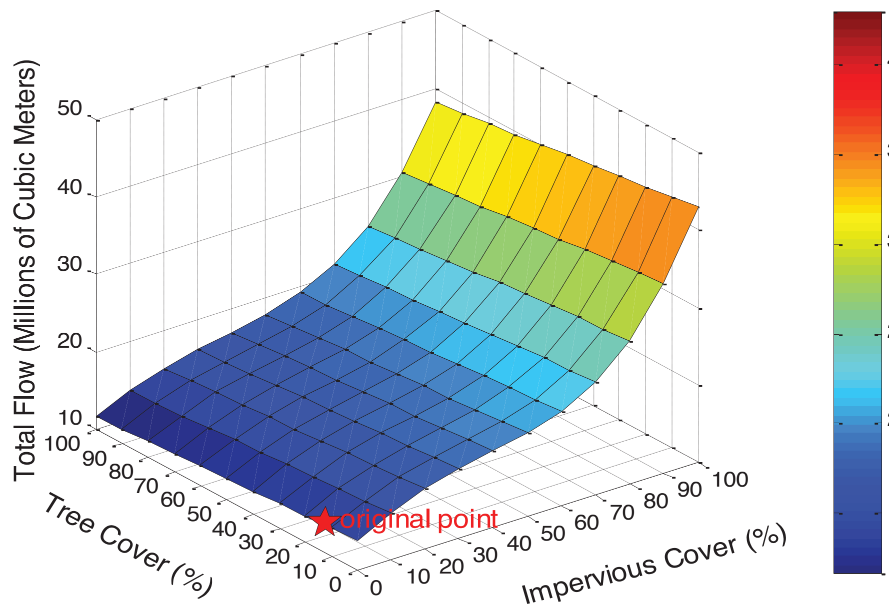

Figure A2.5. *Changes in total flow during simulation period based on changes in percent impervious and percent tree cover in Muddy Creek. Red star indicates current conditions.*

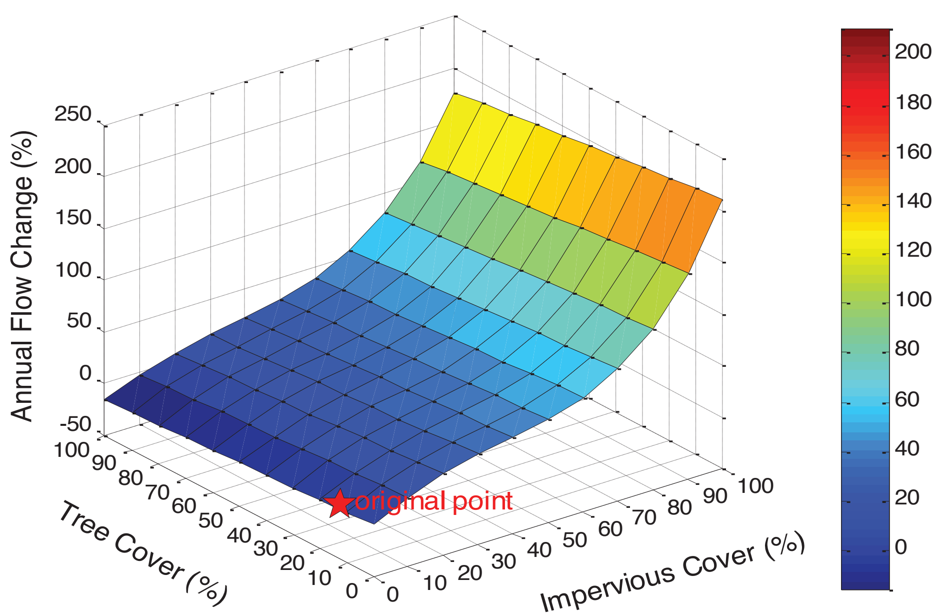

Figure A2.6. *Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover in Muddy Creek. Red star indicates current conditions.*

During the simulation period the total rainfall recorded was 967.49 millimeters. Since that amount is assumed to have fallen over the entire 62 square kilometer watershed, a total of 59.6 million cubic meters of rain fell on the watershed during the simulation time. The total modeled flow in the Muddy Creek watershed throughout the simulation time for the base case scenario (no landscape change) was 13.8 million cubic meters. The total flow is made up of surface runoff (from pervious and impervious areas) and baseflow (water that travels underground to the stream). Runoff from pervious areas and baseflow are the biggest contributors to this watershed's stream flow with 96.6 and 3.4% of total flow generated from pervious runoff and baseflow, respectively. It was estimated that there is no runoff from impervious areas because no impervious areas were identified in the land cover survey of this watershed. Areas of tree canopies intercepted about 11.8% of the total rainfall, but as only 13.0% of this watershed is under tree cover, interception of total precipitation in the watershed by trees was only 1.5% (918.8 thousand cubic meters). Areas of grass/herbaceous cover intercepted about 3.6% of the total rainfall, but as only 86.0% of this watershed is under grass/herbaceous cover, interception of total precipitation in the watershed by grass/herbaceous cover was only 3.1% (1.9 million cubic meters). About 72.2% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration (including evaporation from interception) or go to ground water recharge.

Water Quality Benefits from Trees

Based on the simulated changes in flow rates and the pollutant coefficient values used, the current tree cover is estimated to reduce suspended sediment during the simulation period by about 81.0 tonnes. Other pollutants are also reduced (Table A2.1).

Table A2.1. *Estimated reduction in chemical constituents in Muddy Creek watershed due to existing tree cover during simulation period based on median and mean EMC values (Tables 1.3 and 1.4).*

	Reduction (tonnes)	
Constituent	Median	Mean
Suspended sediment	81.016	89.278
Biochemical oxygen demand	2.376	2.913
Chemical oxygen demand	9.234	10.907
Total phosphorus	0.095	0.101
Total nitrogen	0.794	0.902
Copper	0.002	0.003
Lead	0.010	0.014
Zinc	0.027	0.033

Appendix 3. HUC 10270202, Grasshopper Creek

Tree Cover Effects

Loss of current tree cover in the Grasshopper Creek watershed (Figure A3.1) increased total overland runoff during the simulation period by an average of 1.8% (351.2 thousand m^3). Increasing canopy cover from 9.5 to 50.0% reduced total overland runoff by 7.1% (1.4 million m^3) during this 12-month period (Figure A3.2).

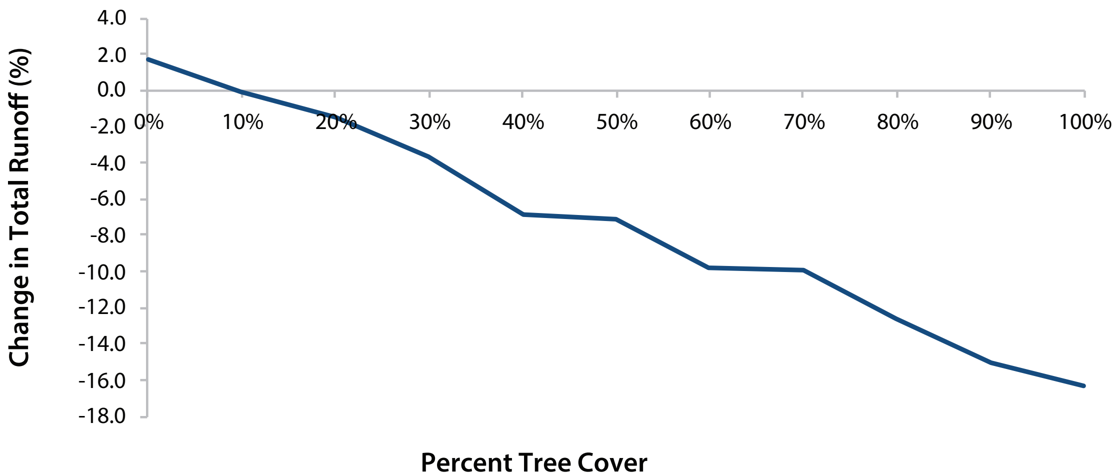

Figure A3.1. *Percent change in total overland runoff with changes in percent tree cover in Grasshopper Creek.*

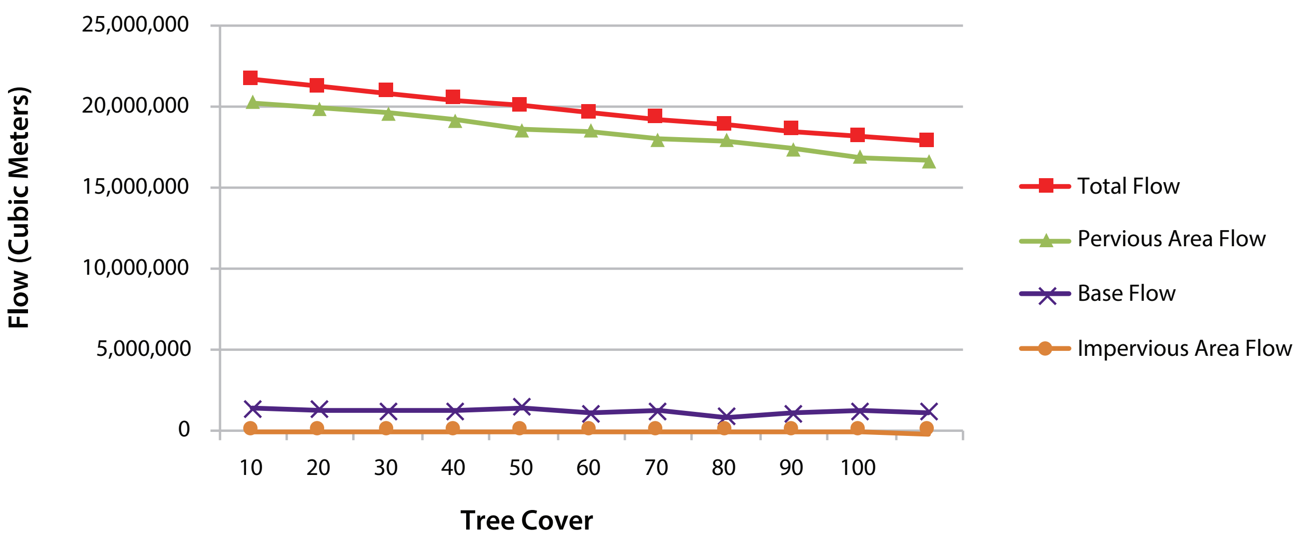

Figure A3.2. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent tree cover in Grasshopper Creek.*

Impervious Cover Effects

Removal of current impervious cover (Figure A3.3) reduced total overland runoff during the simulation period by an average of 9.0% (1.8 million m^3). Increasing impervious cover from 5.0 to 20% of the watershed increased total overland runoff 16.7% (3.3 million m^3) during this 12-month period (Figure A3.4).

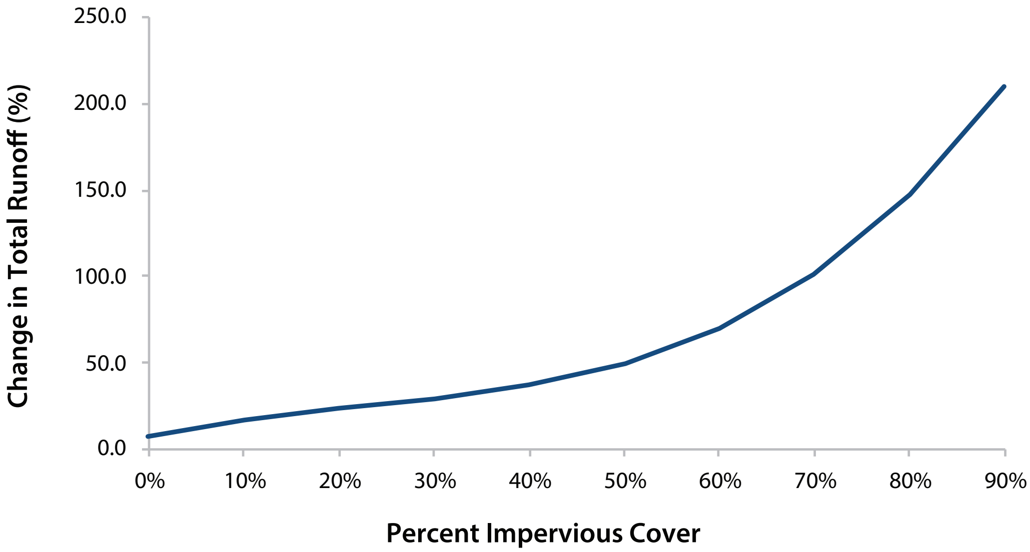

Figure A3.3. *Percent change in total overland runoff with changes in percent impervious cover in Grasshopper Creek.*

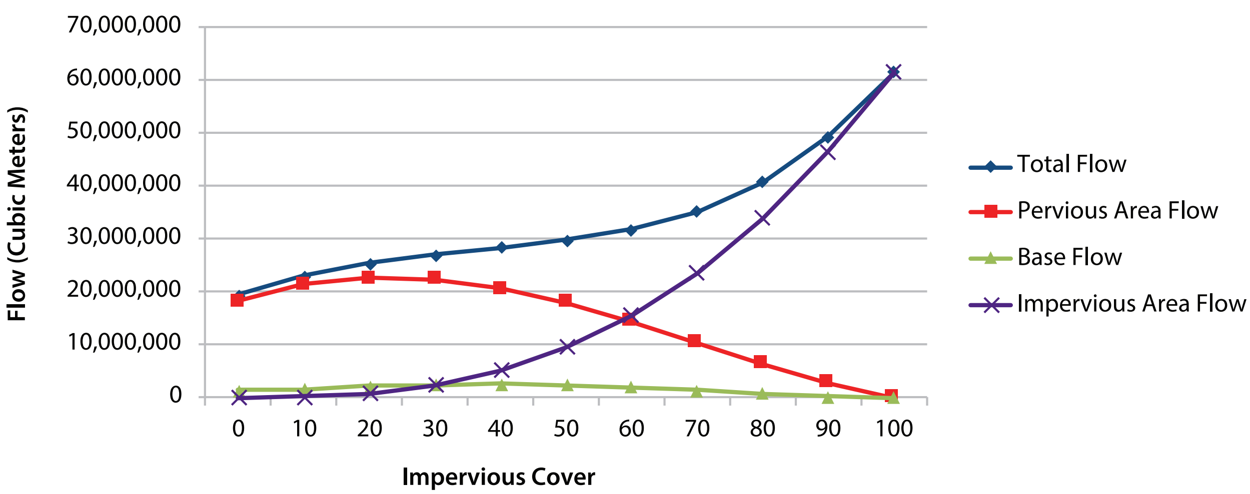

Figure A3.4. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in Grasshopper Creek.*

Land Cover Scaling Trends

Under current cover conditions, increasing impervious cover had an approximately 6 times greater impact on flow relative to tree cover. Increasing impervious cover by 1% averaged a 1.25% increase in total flow, while increasing tree cover by 1% averaged only a 0.19% decrease in total flow. The interactions between changing both tree and impervious cover are illustrated for total flow during the simulation period (Figure A3.5) and for percent changes in flow (Figure A3.6).

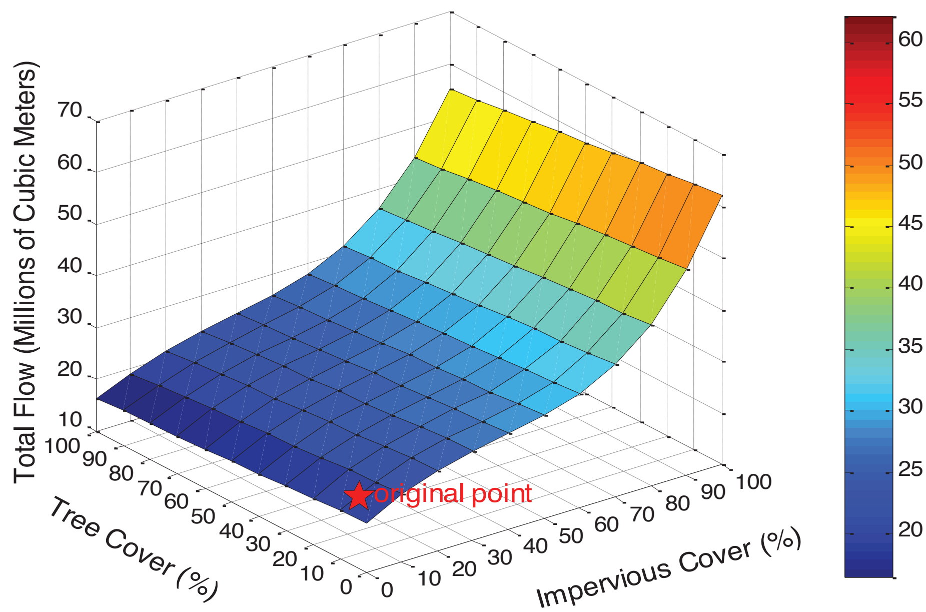

Figure A3.5. *Changes in total flow during simulation period based on changes in percent impervious and percent tree cover in Grasshopper Creek. Red star indicates current conditions.*

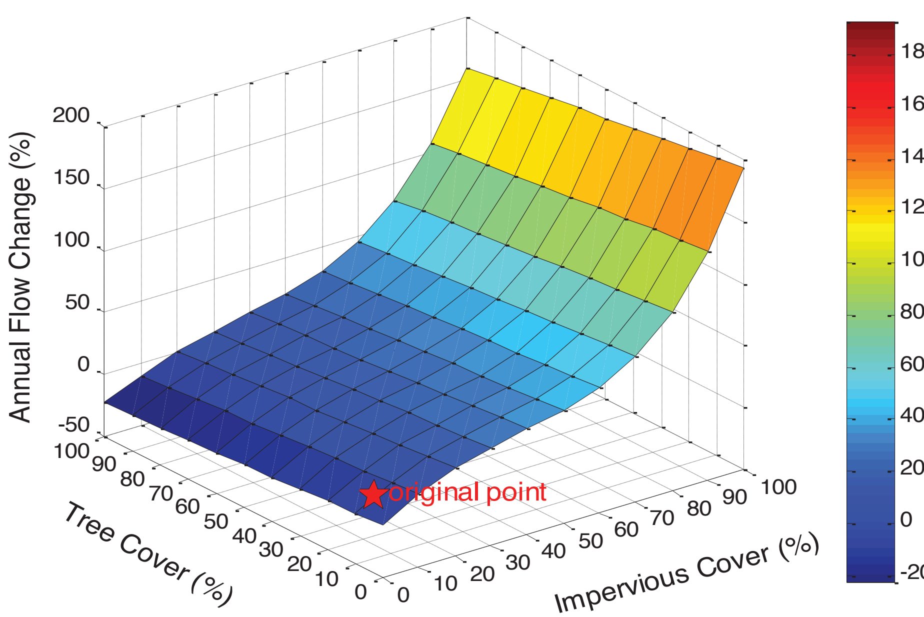

Figure A3.6. *Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover in Grasshopper Creek. Red star indicates current conditions.*

During the simulation period the total rainfall recorded was 967.49 millimeters. Since that amount is assumed to have fallen over the entire 89 square kilometer watershed, a total of 86.3 million cubic meters of rain fell on the watershed during the simulation time. The total modeled flow in the Grasshopper Creek watershed throughout the simulation time for the base case scenario (no landscape change) was 21.2 million cubic meters. The total flow is made up of surface runoff (from pervious and impervious areas) and baseflow (water that travels underground to the stream). Runoff from pervious areas and baseflow are the biggest contributors to this watershed's stream flow with 93.7 and 6.3% of total flow generated from pervious runoff and baseflow, respectively. Runoff from impervious areas was estimated to generate <0.1% of total flow. Areas of tree canopies intercepted about 11.8% of the total rainfall, but as only 9.5% of this watershed is under tree cover, interception of total precipitation in the watershed by trees was only 1.1% (971.3 thousand cubic meters). Areas of grass/herbaceous cover intercepted about 3.6% of the total rainfall, but as only 85.0% of this watershed is under grass/herbaceous cover, interception of total precipitation in the watershed by grass/herbaceous cover was only 3.1% (2.7 million cubic meters). About 71.2% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration (including evaporation from interception) or go to ground water recharge.

Water Quality Benefits from Trees

Based on the simulated changes in flow rates and the pollutant coefficient values used, the current tree cover is estimated to reduce suspended sediment during the simulation period by about 137.8 tonnes. Other pollutants are also reduced (Table A3.1).

Table A3.1. *Estimated reduction in chemical constituents in Grasshopper Creek watershed due to existing tree cover during simulation period based on median and mean EMC values (Tables 1.3 and 1.4).*

Constituent	Reduction (tonnes) Median	Reduction (tonnes) Mean
Suspended sediment	137.757	151.806
Biochemical oxygen demand	4.039	4.952
Chemical oxygen demand	15.700	18.546
Total phosphorus	0.162	0.171
Total nitrogen	1.351	1.533
Copper	0.004	0.005
Lead	0.018	0.024
Zinc	0.045	0.057

Appendix 4. HUC 10270203, Otter Creek

Tree Cover Effects

Loss of current tree cover in the Otter Creek watershed (Figure A4.1) increased total overland runoff during the simulation period by an average of 3.4% (911.2 thousand m^3). Increasing canopy cover from 13.5 to 50.0% reduced total overland runoff by 6.3% (1.7 million m^3) during this 12-month period (Figure A4.2).

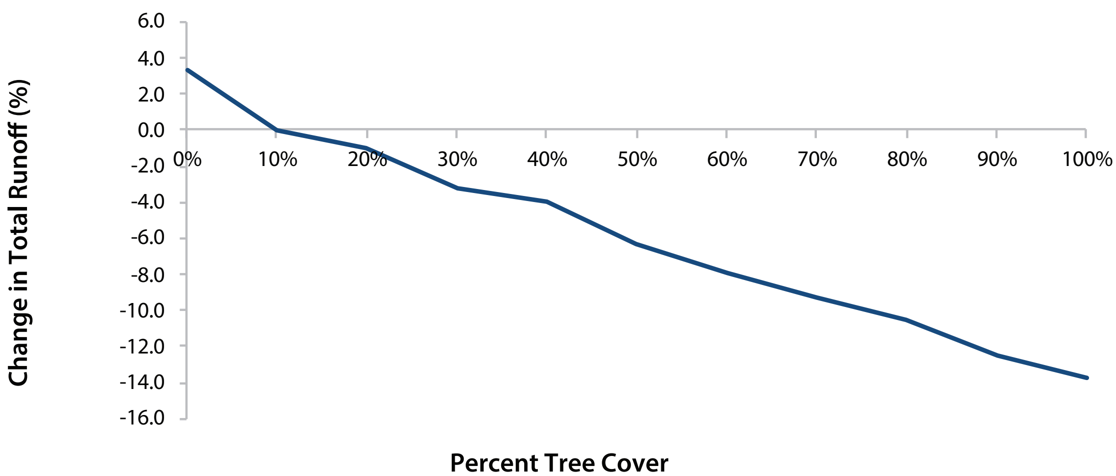

Figure A4.1. *Percent change in total overland runoff with changes in percent tree cover in Otter Creek.*

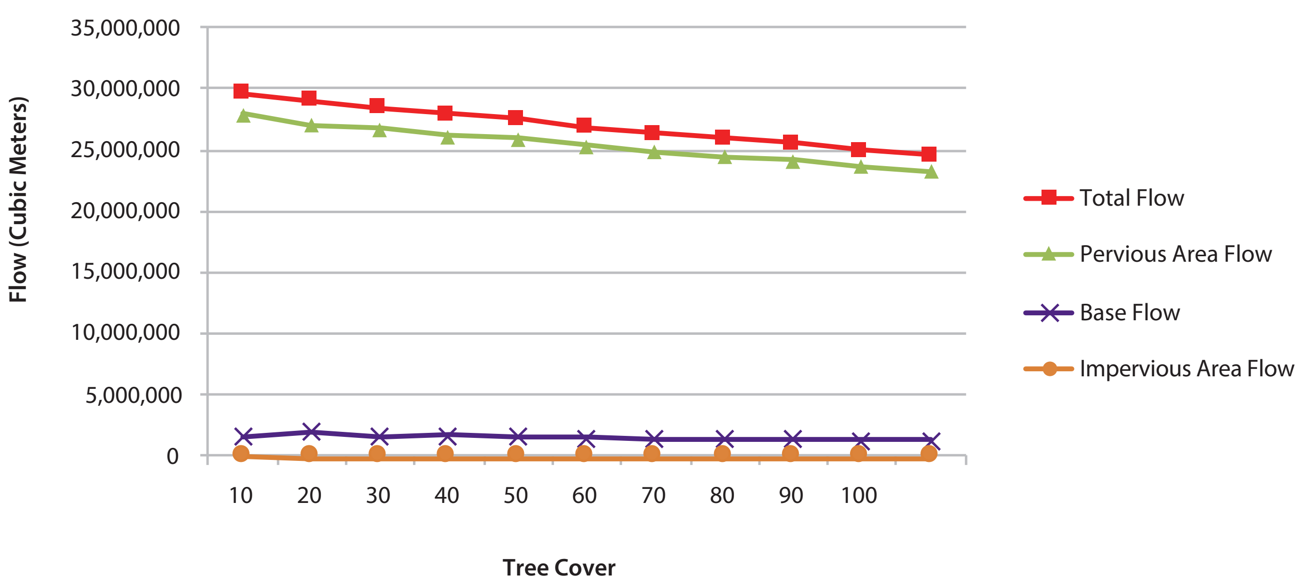

Figure A4.2. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent tree cover in Otter Creek.*

Impervious Cover Effects

Removal of current impervious cover (Figure A4.3) reduced total overland runoff during the simulation period by an average of 1.9% (515.1 thousand m^3). Increasing impervious cover from 1.0 to 20% of the watershed increased total overland runoff 25.7% (7.0 million m^3) during this 12-month period (Figure A4.4).

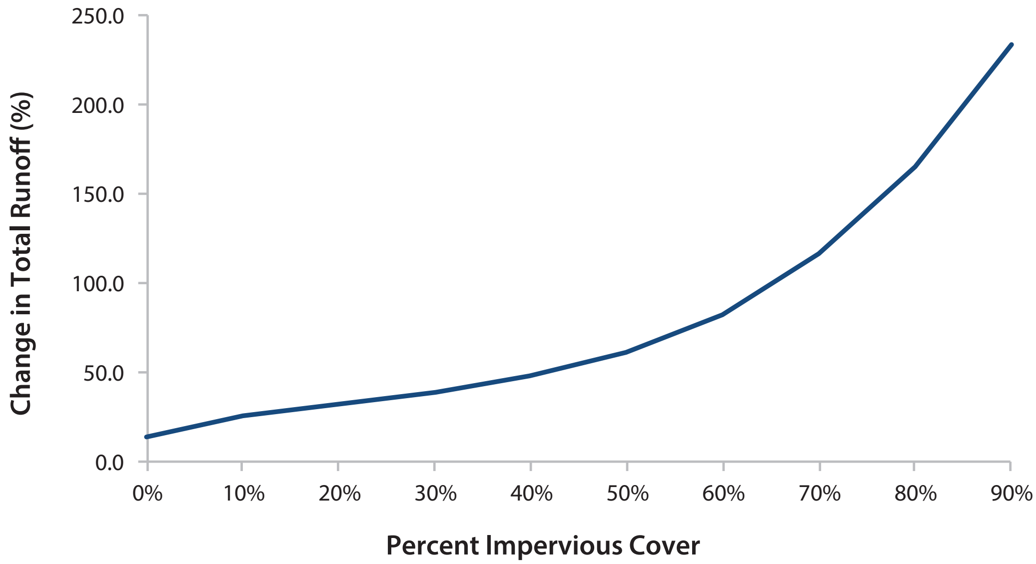

Figure A4.3. *Percent change in total overland runoff with changes in percent impervious cover in Otter Creek.*

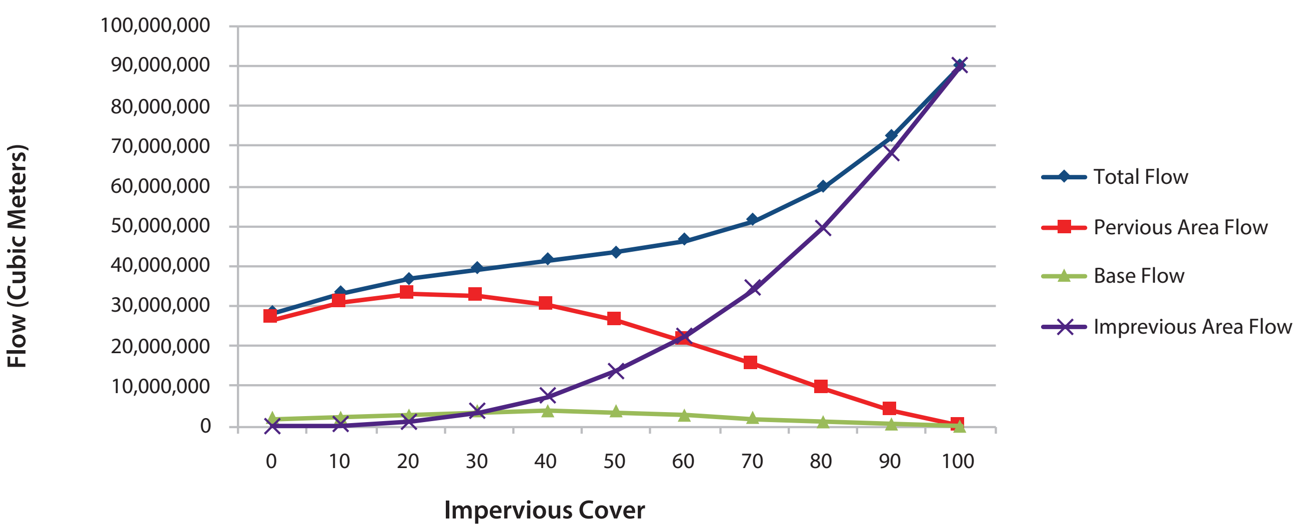

Figure A4.4. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in Otter Creek.*

Land Cover Scaling Trends

Under current cover conditions, increasing impervious cover had an approximately 7 times greater impact on flow relative to tree cover. Increasing impervious cover by 1% averaged a 1.25% increase in total flow, while increasing tree cover by 1% averaged only a 0.18% decrease in total flow. The interactions between changing both tree and impervious cover are illustrated for total flow during the simulation period (Figure A4.5) and for percent changes in flow (Figure A4.6).

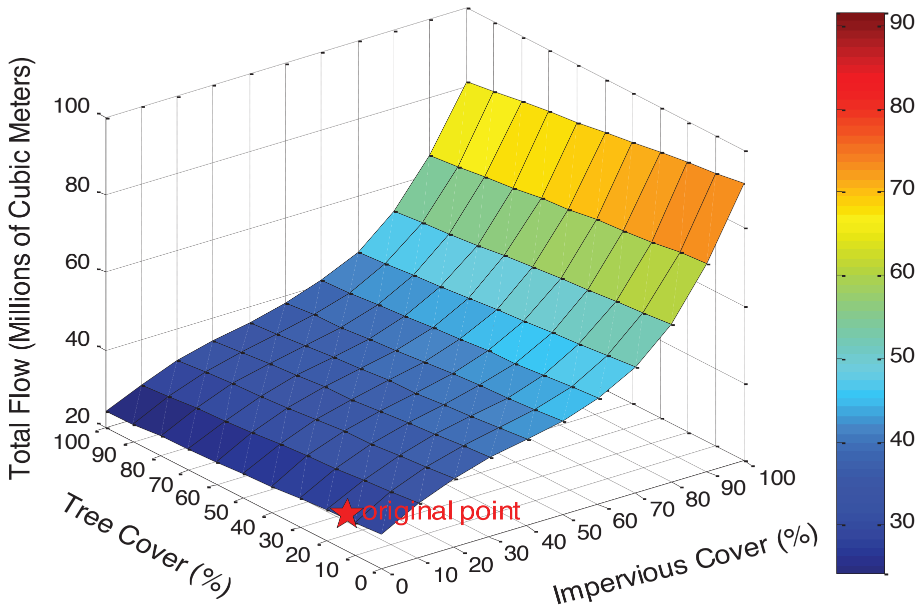

Figure A4.5. *Changes in total flow during simulation period based on changes in percent impervious and percent tree cover in Otter Creek. Red star indicates current conditions.*

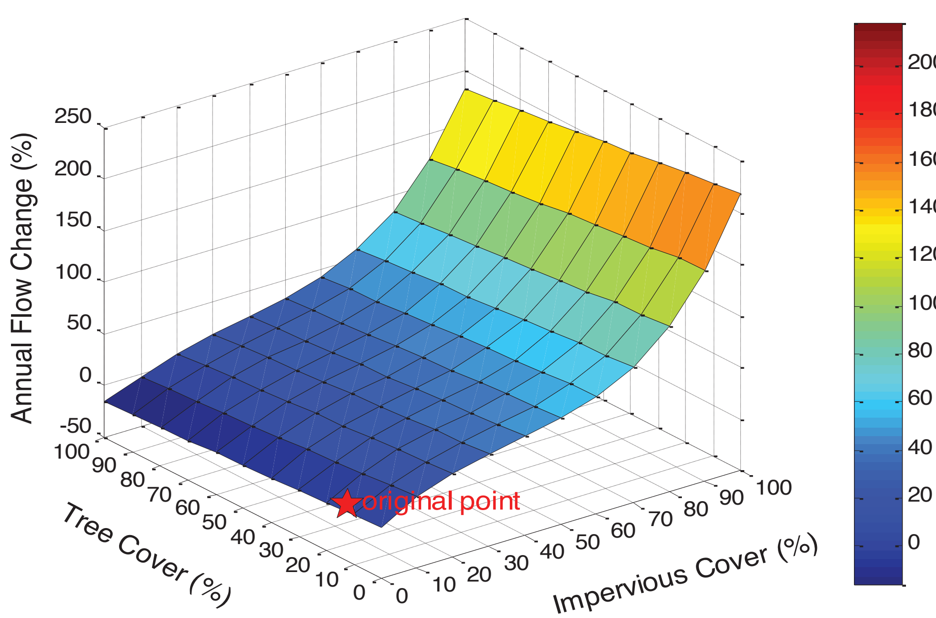

Figure A4.6. *Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover in Otter Creek. Red star indicates current conditions.*

During the simulation period the total rainfall recorded was 967.49 millimeters. Since that amount is assumed to have fallen over the entire 131 square kilometer watershed, a total of 127.2 million cubic meters of rain fell on the watershed during the simulation time. The total modeled flow in the Otter Creek watershed throughout the simulation time for the base case scenario (no landscape change) was 28.8 million cubic meters. The total flow is made up of surface runoff (from pervious and impervious areas) and baseflow (water that travels underground to the stream). Runoff from pervious areas and baseflow are the biggest contributors to this watershed's stream flow with 93.9 and 6.1% of total flow generated from pervious runoff and baseflow, respectively. Runoff from impervious areas was estimated to generate <0.05% of total flow. Areas of tree canopies intercepted about 11.8% of the total rainfall, but as only 13.5% of this watershed is under tree cover, interception of total precipitation in the watershed by trees was only 1.6% (2.0 million cubic meters). Areas of grass/herbaceous cover intercepted about 3.6% of the total rainfall, but as only 85.0% of this watershed is under grass/herbaceous cover, interception of total precipitation in the watershed by grass/herbaceous cover was only 3.1% (4.0 million cubic meters). About 72.6% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration (including evaporation from interception) or go to ground water recharge.

Water Quality Benefits from Trees

Based on the simulated changes in flow rates and the pollutant coefficient values used, the current tree cover is estimated to reduce suspended sediment during the simulation period by about 357.4 tonnes. Other pollutants are also reduced (Table A4.1).

Table A4.1. *Estimated reduction in chemical constituents in Otter Creek watershed due to existing tree cover during simulation period based on median and mean EMC values (Tables 1.3 and 1.4).*

	Reduction (tonnes)	
Constituent	Median	Mean
Suspended sediment	357.390	393.840
Biochemical oxygen demand	10.479	12.849
Chemical oxygen demand	40.733	48.114
Total phosphorus	0.421	0.444
Total nitrogen	3.505	3.978
Copper	0.010	0.012
Lead	0.046	0.062
Zinc	0.118	0.148

Appendix 5. HUC 102701030204, Little Grasshopper Creek

Tree Cover Effects

Loss of current tree cover in the Little Grasshopper Creek watershed (Figure A5.1) increased total overland runoff during the simulation period by an average of 1.0% (285.9 thousand m^3). Increasing canopy cover from 9.5 to 50.0% reduced total overland runoff by 6.3% (1.7 million m^3) during this 12-month period (Figure A5.2).

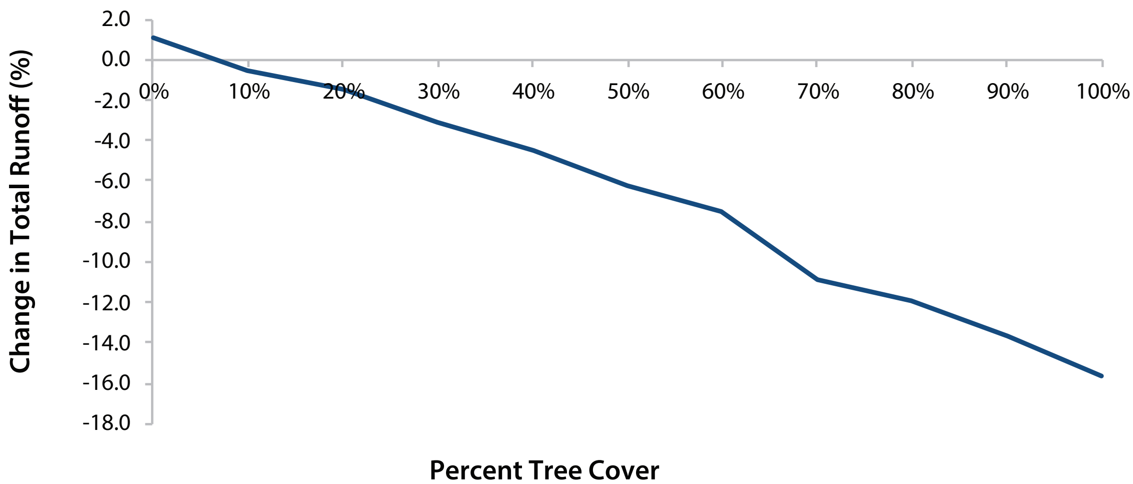

Figure A5.1. *Percent change in total overland runoff with changes in percent tree cover in Little Grasshopper Creek.*

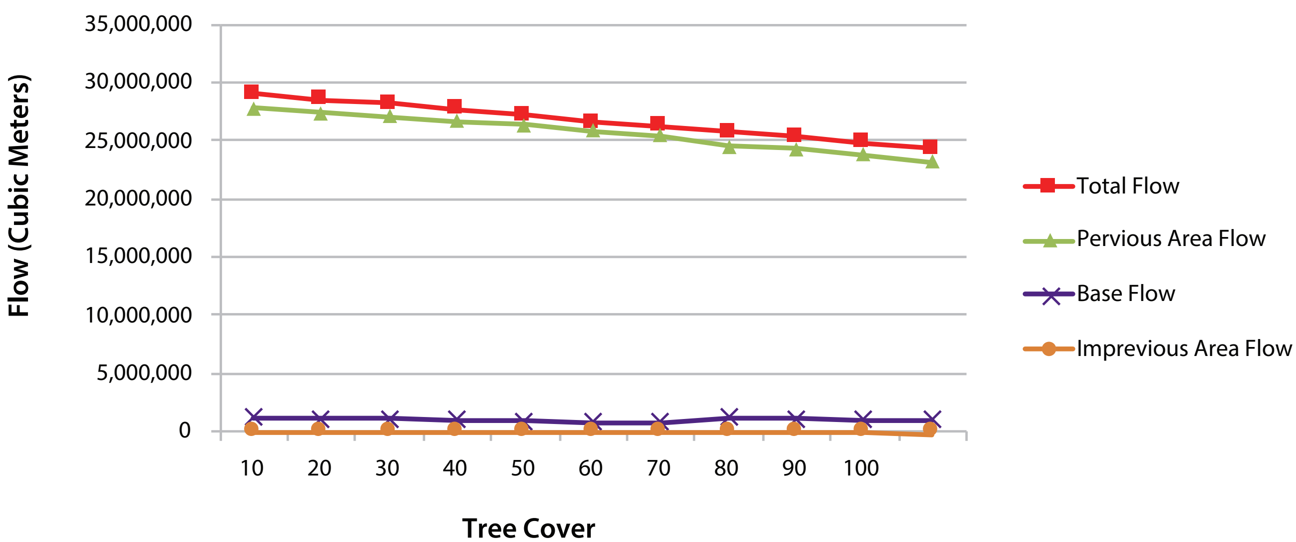

Figure A5.2. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent tree cover in Little Grasshopper Creek.*

Impervious Cover Effects

Removal of current impervious cover (Figure A5.3) reduced total overland runoff during the simulation period by an average of 3.0% (818.1 thousand m^3). Increasing impervious cover from 2.0 to 20% of the watershed increased total overland runoff 21.3% (5.9 million m^3) during this 12-month period (Figure A5.4).

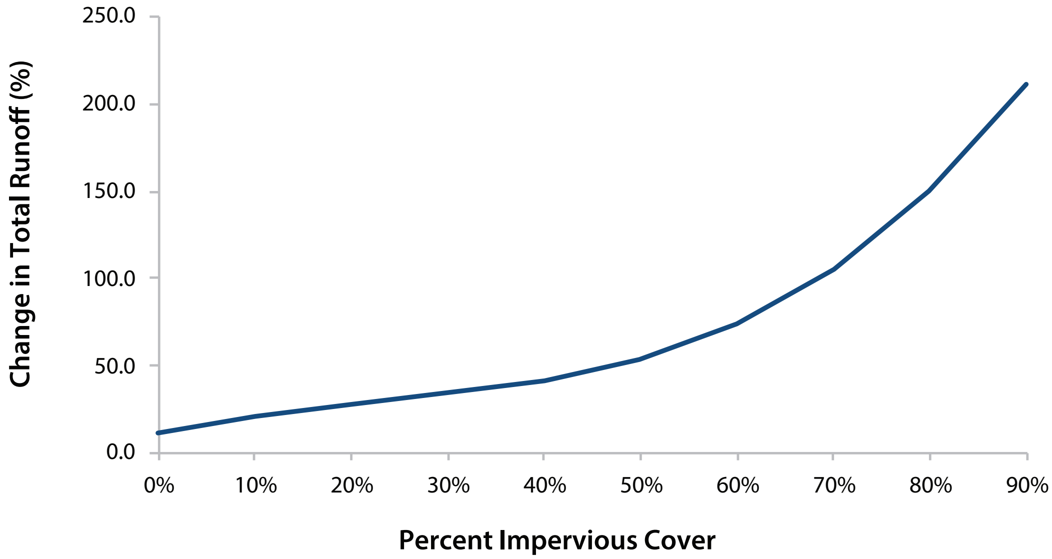

Figure A5.3. *Percent change in total overland runoff with changes in percent impervious cover in Little Grasshopper Creek.*

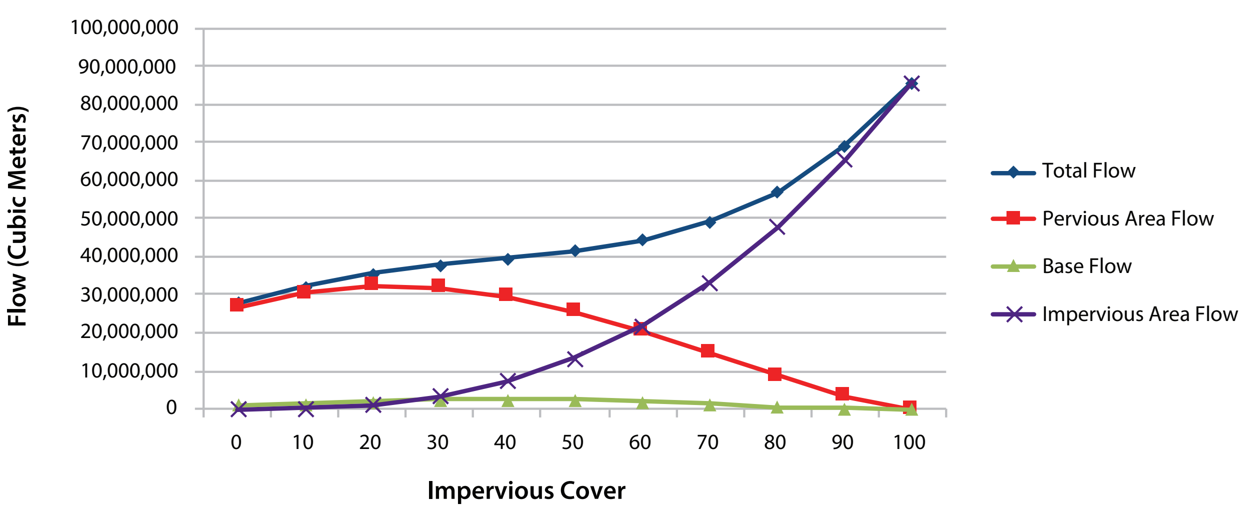

Figure A5.4. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in Little Grasshopper Creek.*

Land Cover Scaling Trends

Under current cover conditions, increasing impervious cover had an approximately 7 times greater impact on flow relative to tree cover. Increasing impervious cover by 1% averaged a 1.21% increase in total flow, while increasing tree cover by 1% averaged only a 0.18% decrease in total flow. The interactions between changing both tree and impervious cover are illustrated for total flow during the simulation period (Figure A5.5) and for percent changes in flow (Figure A5.6).

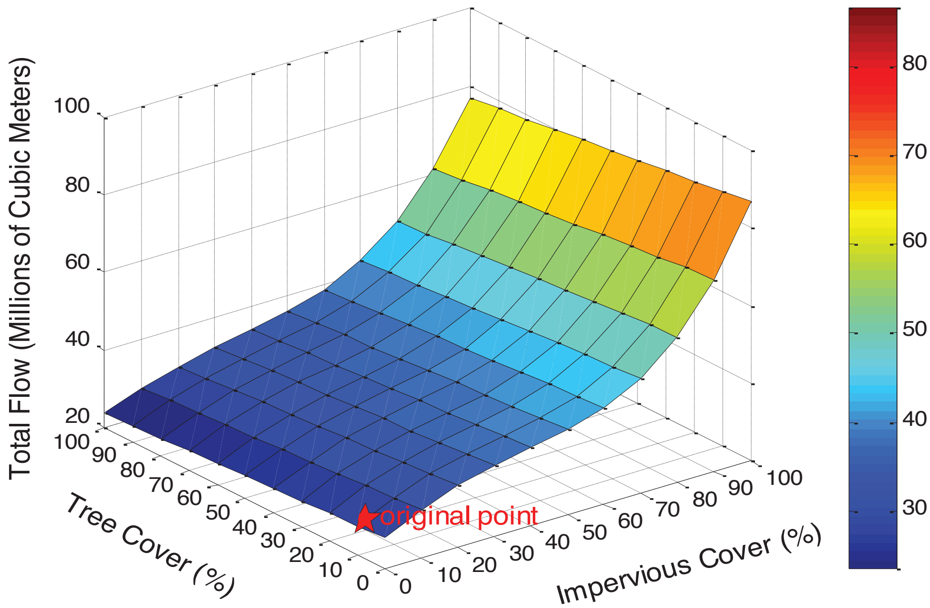

Figure A5.5. *Changes in total flow during simulation period based on changes in percent impervious and percent tree cover in Little Grasshopper Creek. Red star indicates current conditions.*

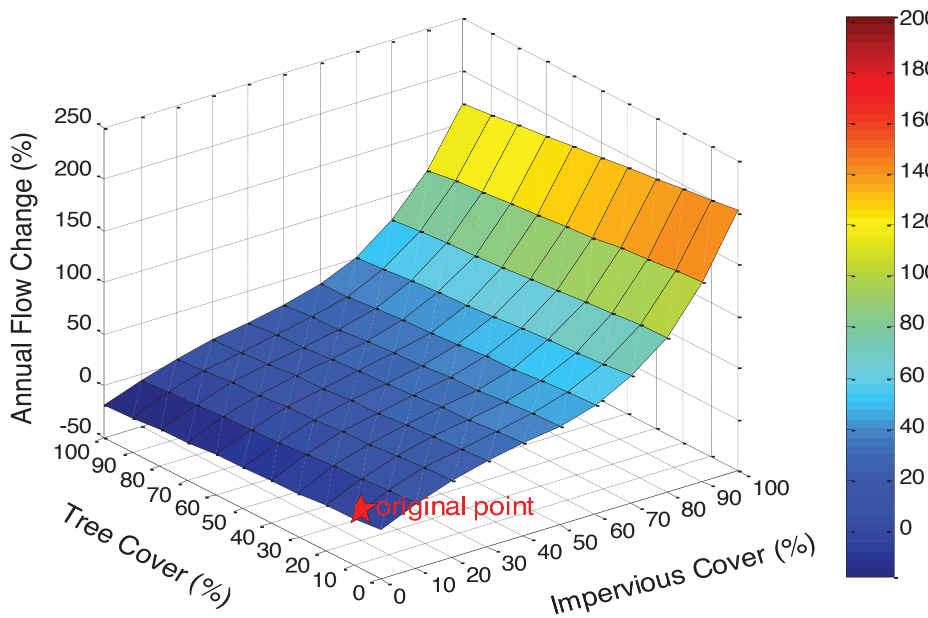

Figure A5.6. *Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover in Little Grasshopper Creek. Red star indicates current conditions.*

During the simulation period the total rainfall recorded was 967.49 millimeters. Since that amount is assumed to have fallen over the entire 124 square kilometer watershed, a total of 120.4 million cubic meters of rain fell on the watershed during the simulation time. The total modeled flow in the Little Grasshopper Creek watershed throughout the simulation time for the base case scenario (no landscape change) was 28.7 million cubic meters. The total flow is made up of surface runoff (from pervious and impervious areas) and baseflow (water that travels underground to the stream). Runoff from pervious areas and baseflow are the biggest contributors to this watershed's stream flow with 96.0 and 4.0% of total flow generated from pervious runoff and baseflow, respectively. Runoff from impervious areas was estimated to generate <0.05% of total flow. Areas of tree canopies intercepted about 11.8% of the total rainfall, but as only 9.5% of this watershed is under tree cover, interception of total precipitation in the watershed by trees was only 1.1% (1.4 million cubic meters). Areas of grass/herbaceous cover intercepted about 3.6% of the total rainfall, but as only 88.0% of this watershed is under grass/herbaceous cover, interception of total precipitation in the watershed by grass/herbaceous cover was only 3.2% (3.8 million cubic meters). About 71.8% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration (including evaporation from interception) or go to ground water recharge.

Water Quality Benefits from Trees

Based on the simulated changes in flow rates and the pollutant coefficient values used, the current tree cover is estimated to reduce suspended sediment during the simulation period by about 112.1 tonnes. Other pollutants are also reduced (Table A5.1).

Table A5.1. *Estimated reduction in chemical constituents in Little Grasshopper Creek watershed due to existing tree cover during simulation period based on median and mean EMC values (Tables 1.3 and 1.4).*

Constituent	Reduction (tonnes) Median	Reduction (tonnes) Mean
Suspended sediment	112.115	123.549
Biochemical oxygen demand	3.287	4.031
Chemical oxygen demand	12.778	15.093
Total phosphorus	0.132	0.139
Total nitrogen	1.099	1.248
Copper	0.003	0.004
Lead	0.014	0.019
Zinc	0.037	0.046

Appendix 6. HUC 102701030205, Negro Creek

Tree Cover Effects

Loss of current tree cover in the Negro Creek watershed (Figure A6.1) increased total overland runoff during the simulation period by an average of 2.3% (231.8 thousand m³). Increasing canopy cover from 8.0 to 50.0% reduced total overland runoff by 6.7% (678.5 thousand m³) during this 12-month period (Figure A6.2).

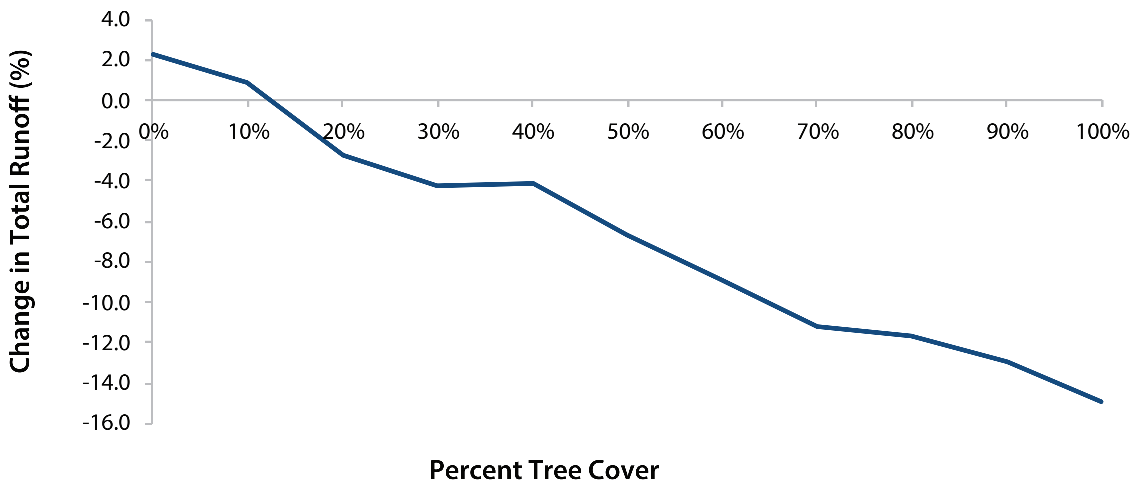

Figure A6.1. *Percent change in total overland runoff with changes in percent tree cover in Negro Creek.*

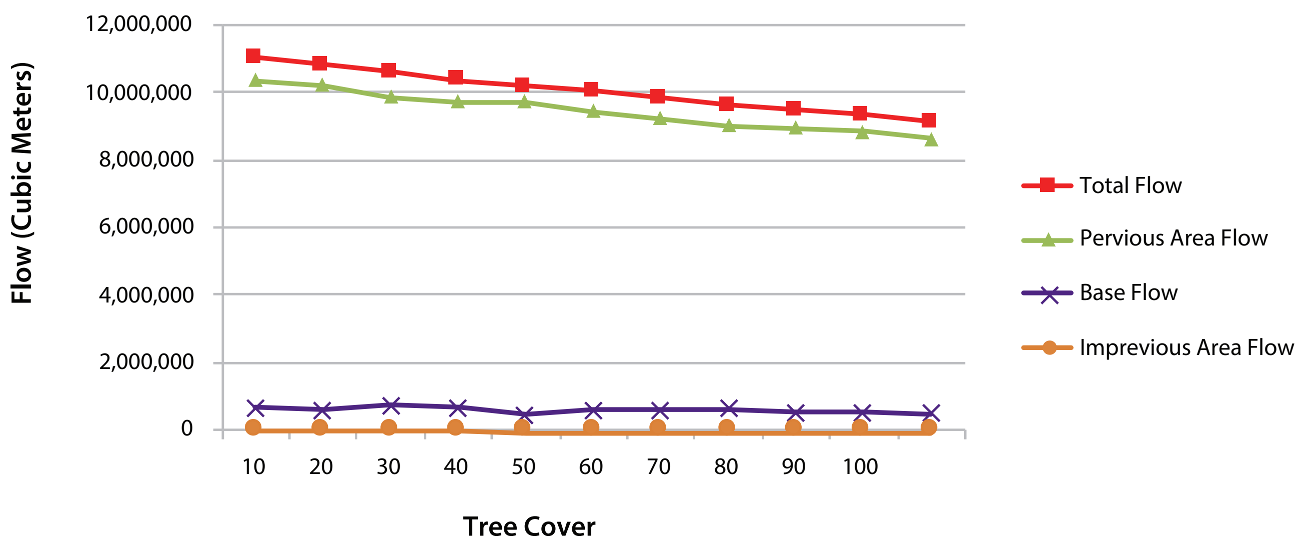

Figure A6.2. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent tree cover in Negro Creek.*

Impervious Cover Effects

Removal of current impervious cover (Figure A6.3) reduced total overland runoff during the simulation period by an average of 2.9% (296.3 thousand m^3). Increasing impervious cover from 2.0 to 20% of the watershed increased total overland runoff 23.3% (2.4 million m^3) during this 12-month period (Figure A6.4).

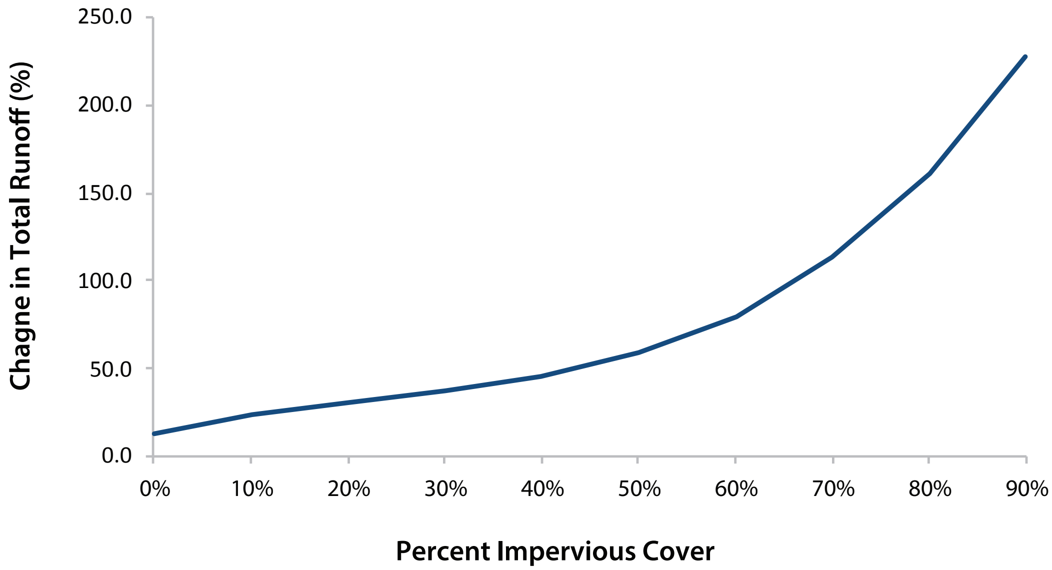

Figure A6.3. *Percent change in total overland runoff with changes in percent impervious cover in Negro Creek.*

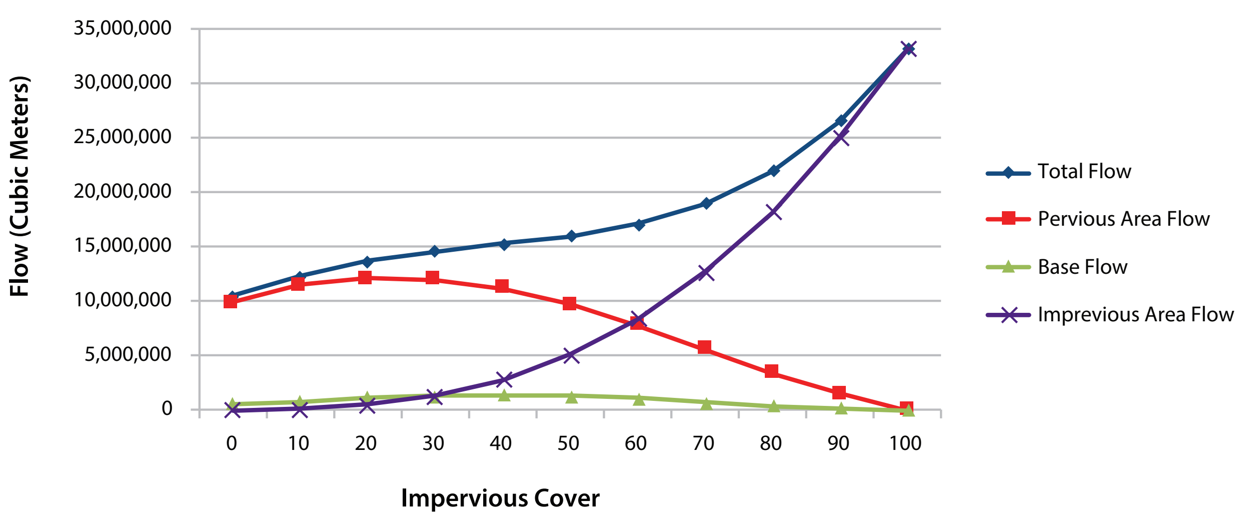

Figure A6.4. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in Negro Creek.*

Land Cover Scaling Trends

Under current cover conditions, increasing impervious cover had an approximately 6.5 times greater impact on flow relative to tree cover. Increasing impervious cover by 1% averaged a 1.24% increase in total flow, while increasing tree cover by 1% averaged only a 0.19% decrease in total flow. The interactions between changing both tree and impervious cover are illustrated for total flow during the simulation period (Figure A6.5) and for percent changes in flow (Figure A6.6).

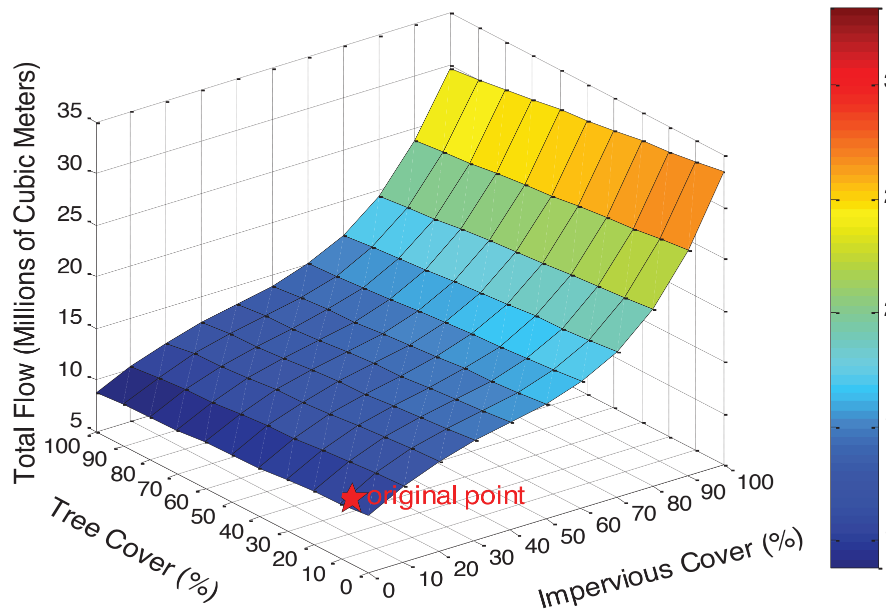

Figure A6.5. *Changes in total flow during simulation period based on changes in percent impervious and percent tree cover in Negro Creek. Red star indicates current conditions.*

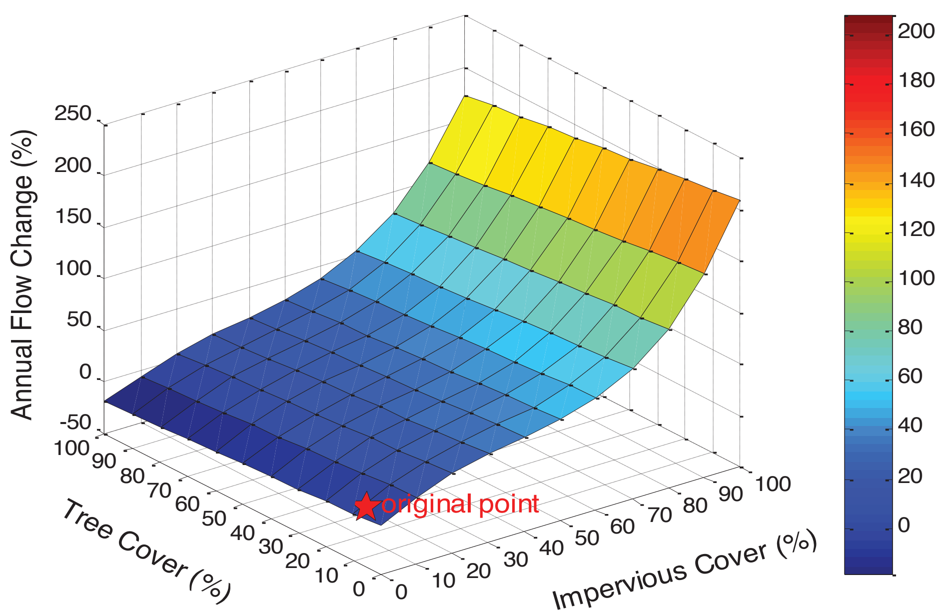

Figure A6.6. *Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover in Negro Creek. Red star indicates current conditions.*

During the simulation period the total rainfall recorded was 967.49 millimeters. Since that amount is assumed to have fallen over the entire 48 square kilometer watershed, a total of 46.4 million cubic meters of rain fell on the watershed during the simulation time. The total modeled flow in the Negro Creek watershed throughout the simulation time for the base case scenario (no landscape change) was 10.8 million cubic meters. The total flow is made up of surface runoff (from pervious and impervious areas) and baseflow (water that travels underground to the stream). Runoff from pervious areas and baseflow are the biggest contributors to this watershed's stream flow with 93.4 and 6.6% of total flow generated from pervious runoff and baseflow, respectively. Runoff from impervious areas was estimated to generate <0.05% of total flow. Areas of tree canopies intercepted about 11.8% of the total rainfall, but as only 8.0% of this watershed is under tree cover, interception of total precipitation in the watershed by trees was only 0.9% (439.4 thousand cubic meters). Areas of grass/herbaceous cover intercepted about 3.6% of the total rainfall, but as only 89.5% of this watershed is under grass/herbaceous cover, interception of total precipitation in the watershed by grass/herbaceous cover was only 3.3% (1.5 million cubic meters). About 72.4% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration (including evaporation from interception) or go to ground water recharge.

Water Quality Benefits from Trees

Based on the simulated changes in flow rates and the pollutant coefficient values used, the current tree cover is estimated to reduce suspended sediment during the simulation period by about 90.9 tonnes. Other pollutants are also reduced (Table A6.1).

Table A6.1. *Estimated reduction in chemical constituents in Negro Creek watershed due to existing tree cover during simulation period based on median and mean EMC values (Tables 1.3 and 1.4).*

	Reduction (tonnes)	
Constituent	Median	Mean
Suspended sediment	90.898	100.169
Biochemical oxygen demand	2.665	3.268
Chemical oxygen demand	10.360	12.237
Total phosphorus	0.107	0.113
Total nitrogen	0.891	1.012
Copper	0.003	0.003
Lead	0.012	0.016
Zinc	0.030	0.038

Appendix 7. HUC 102701030303, Straight Creek

Tree Cover Effects

Loss of current tree cover in the Straight Creek watershed (Figure A7.1) increased total overland runoff during the simulation period by an average of 1.6% (386.9 thousand m^3). Increasing canopy cover from 11.6 to 50.0% reduced total overland runoff by 6.0% (1.5 million m^3) during this 12-month period (Figure A7.2).

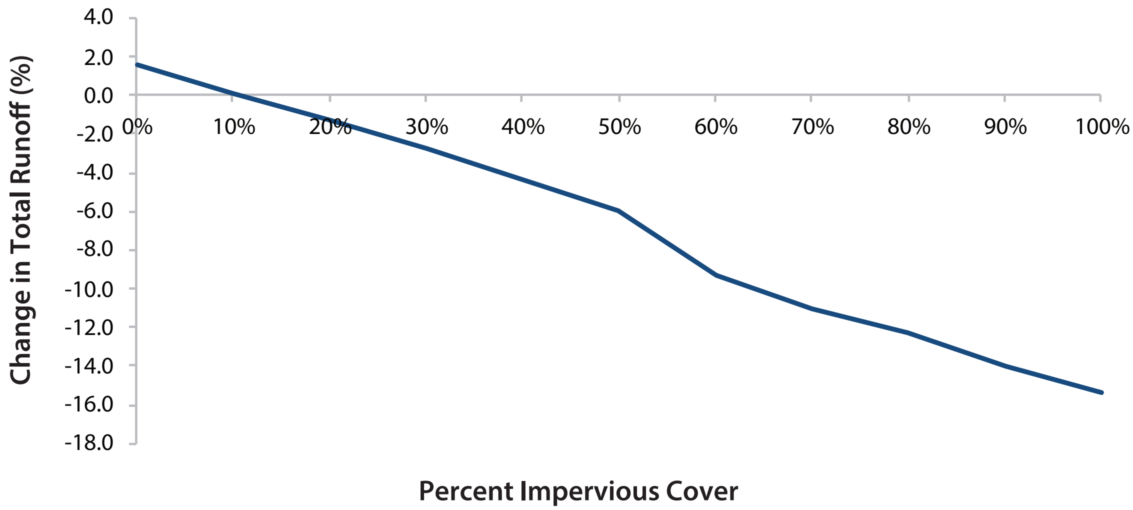

Figure A7.1. *Percent change in total overland runoff with changes in percent tree cover in Straight Creek.*

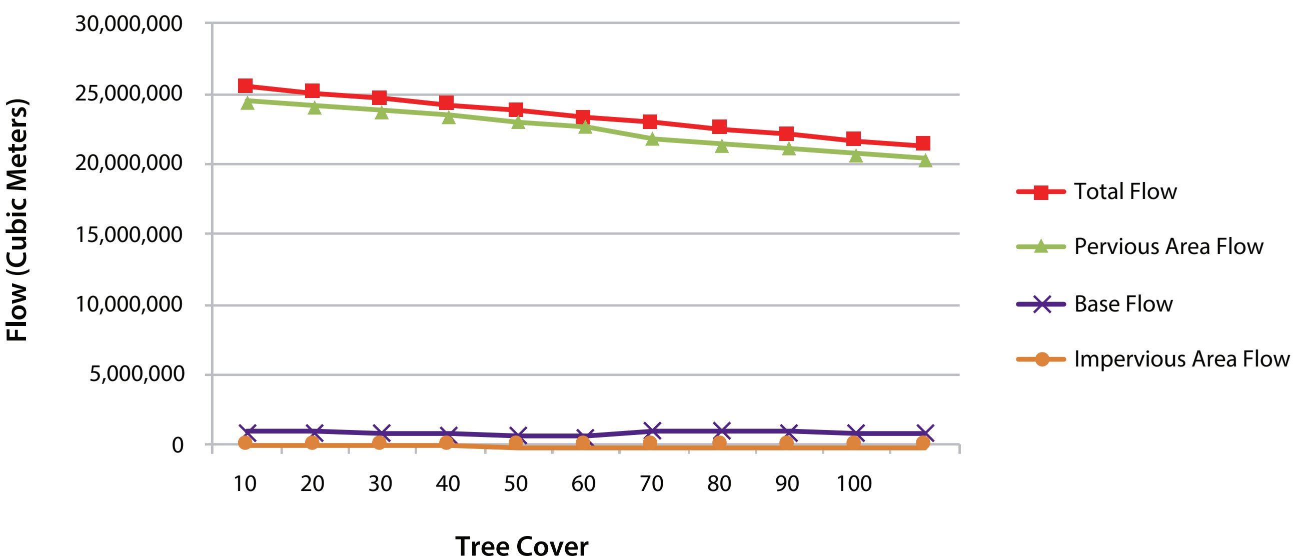

Figure A7.2. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent tree cover in Straight Creek.*

Impervious Cover Effects

Removal of current impervious cover (Figure A7.3) reduced total overland runoff during the simulation period by an average of 1.9% (452.3 thousand m^3). Increasing impervious cover from 1.2 to 20% of the watershed increased total overland runoff 21.8% (5.3 million m^3) during this 12-month period (Figure A7.4).

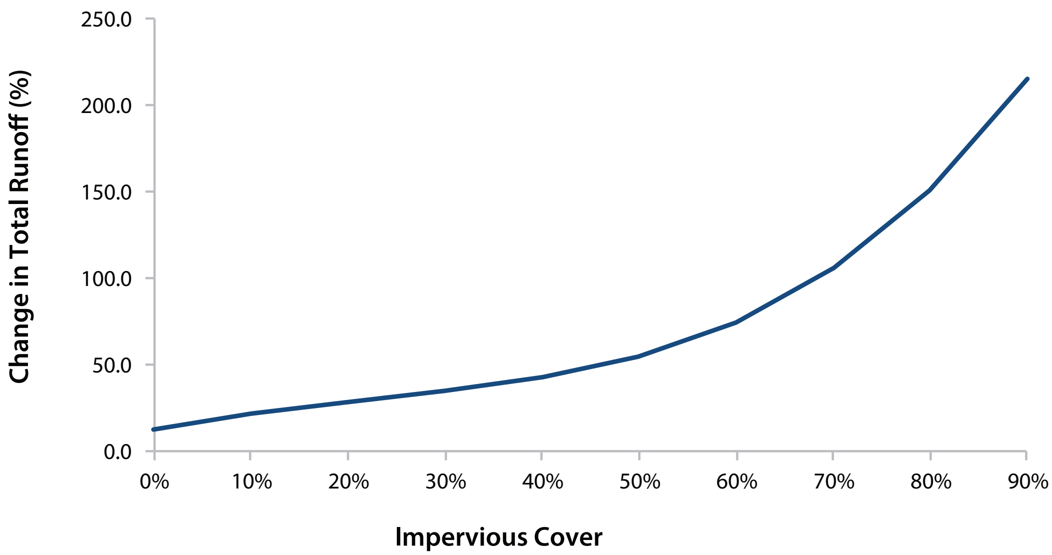

Figure A7.3. *Percent change in total overland runoff with changes in percent impervious cover in Straight Creek.*

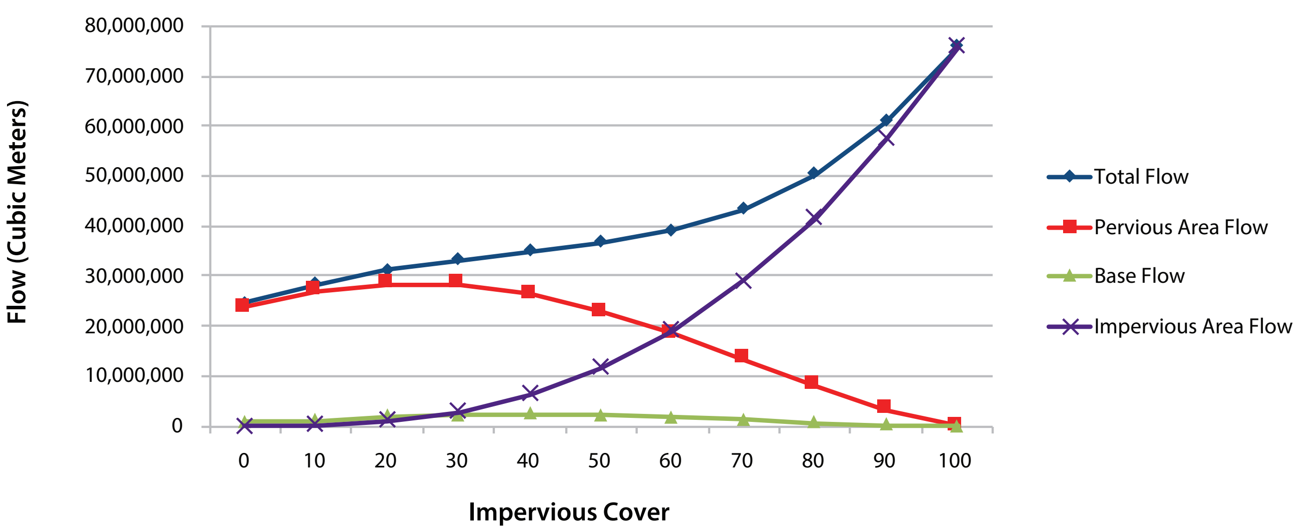

Figure A7.4. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in Straight Creek.*

Land Cover Scaling Trends

Under current cover conditions, increasing impervious cover had an approximately 7 times greater impact on flow relative to tree cover. Increasing impervious cover by 1% averaged a 1.22% increase in total flow, while increasing tree cover by 1% averaged only a 0.18% decrease in total flow. The interactions between changing both tree and impervious cover are illustrated for total flow during the simulation period (Figure A7.5) and for percent changes in flow (Figure A7.6).

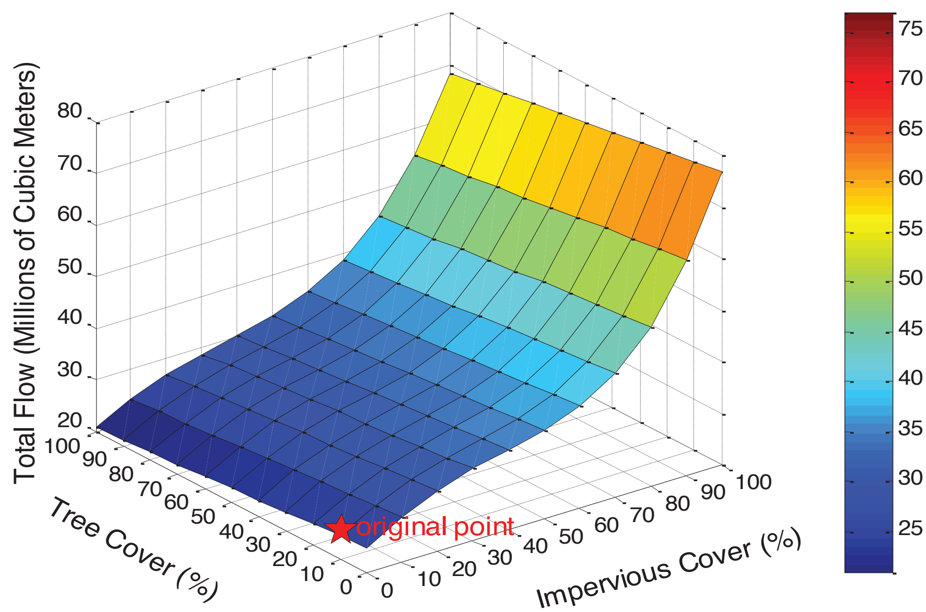

Figure A7.5. *Changes in total flow during simulation period based on changes in percent impervious and percent tree cover in Straight Creek. Red star indicates current conditions.*

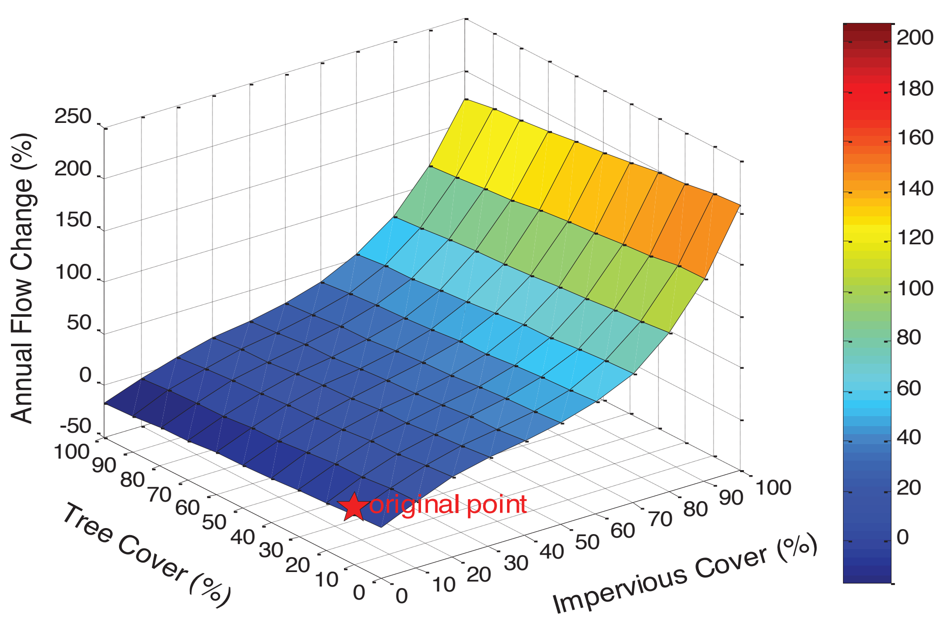

Figure A7.6. *Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover in Straight Creek. Red star indicates current conditions.*

During the simulation period the total rainfall recorded was 967.49 millimeters. Since that amount is assumed to have fallen over the entire 110 square kilometer watershed, a total of 106.8 million cubic meters of rain fell on the watershed during the simulation time. The total modeled flow in the Straight Creek watershed throughout the simulation time for the base case scenario (no landscape change) was 25.0 million cubic meters. The total flow is made up of surface runoff (from pervious and impervious areas) and baseflow (water that travels underground to the stream). Runoff from pervious areas and baseflow are the biggest contributors to this watershed's stream flow with 96.3 and 3.7% of total flow generated from pervious runoff and baseflow, respectively. Runoff from impervious areas was estimated to generate <0.05% of total flow. Areas of tree canopies intercepted about 11.8% of the total rainfall, but as only 11.6% of this watershed is under tree cover, interception of total precipitation in the watershed by trees was only 1.4% (1.5 million cubic meters). Areas of grass/herbaceous cover intercepted about 3.6% of the total rainfall, but as only 87.6% of this watershed is under grass/herbaceous cover, interception of total precipitation in the watershed by grass/herbaceous cover was only 3.2% (3.4 million cubic meters). About 72.0% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration (including evaporation from interception) or go to ground water recharge.

Water Quality Benefits from Trees

Based on the simulated changes in flow rates and the pollutant coefficient values used, the current tree cover is estimated to reduce suspended sediment during the simulation period by about 151.7 tonnes. Other pollutants are also reduced (Table A7. 1).

Table A7.1. *Estimated reduction in chemical constituents in Straight Creek watershed due to existing tree cover during simulation period based on median and mean EMC values (Tables 1.3 and 1.4).*

Constituent	Reduction (tonnes) Median	Mean
Suspended sediment	151.737	167.212
Biochemical oxygen demand	4.449	5.455
Chemical oxygen demand	17.294	20.428
Total phosphorus	0.179	0.188
Total nitrogen	1.488	1.689
Copper	0.004	0.005
Lead	0.020	0.026
Zinc	0.050	0.063

Appendix 8. HUC 102701030305, Banner Creek

Tree Cover Effects

Loss of current tree cover in the Banner Creek watershed (Figure A8.1) increased total overland runoff during the simulation period by an average of 4.1% (651.2 thousand m^3). Increasing canopy cover from 14.5 to 50.0% reduced total overland runoff by 4.0% (632.6 thousand m^3) during this 12-month period (Figure A8.2).

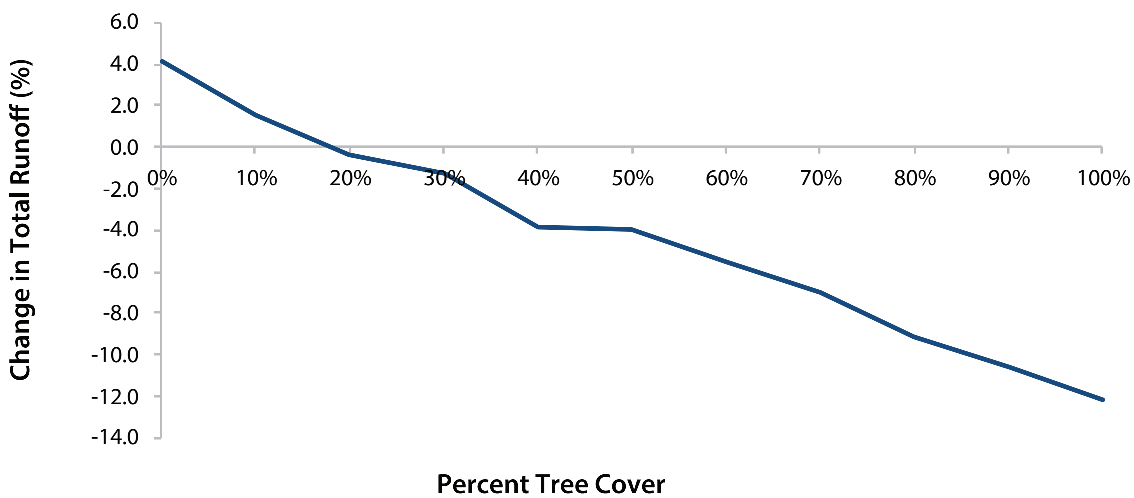

Figure A8.1. *Percent change in total overland runoff with changes in percent tree cover in Banner Creek.*

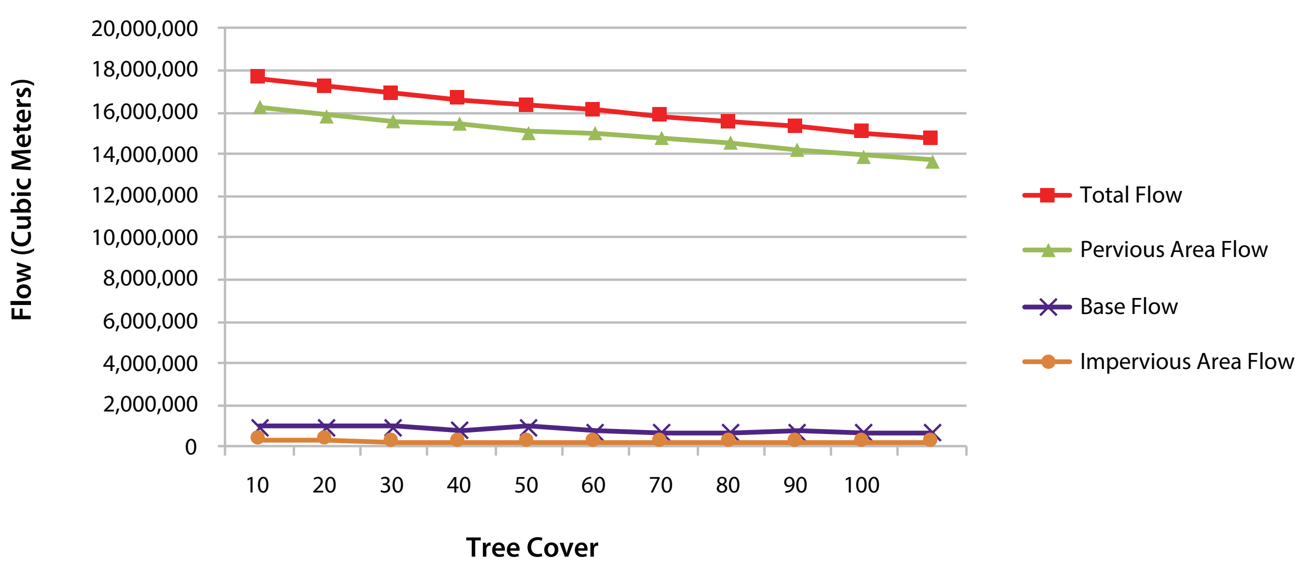

Figure A8.2. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent tree cover in Banner Creek.*

Impervious Cover Effects

Removal of current impervious cover (Figure A8.3) reduced total overland runoff during the simulation period by an average of 16.6% (2.6 million m^3). Increasing impervious cover from 17.0 to 30% of the watershed increased total overland runoff 9.9% (1.6 million m^3) during this 12-month period (Figure A8.4).

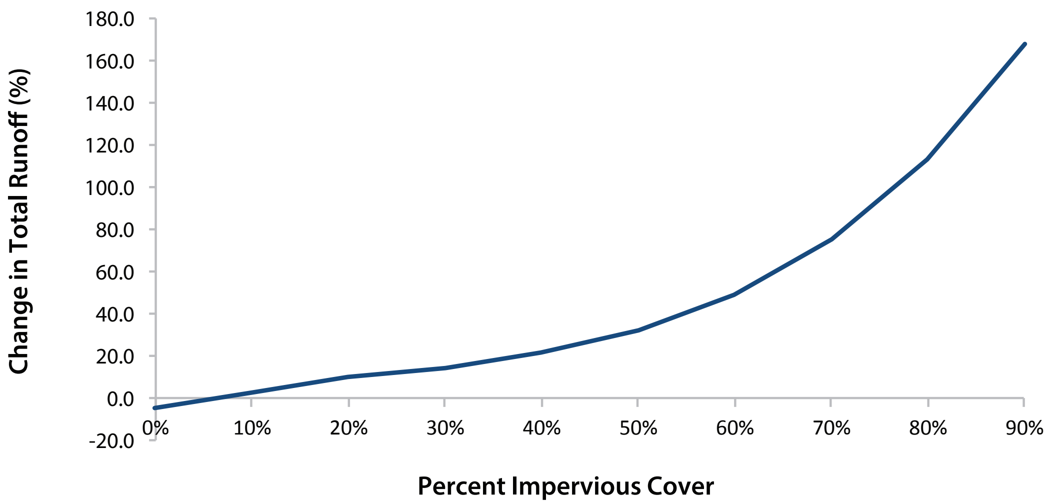

Figure A8.3. *Percent change in total overland runoff with changes in percent impervious cover in Banner Creek.*

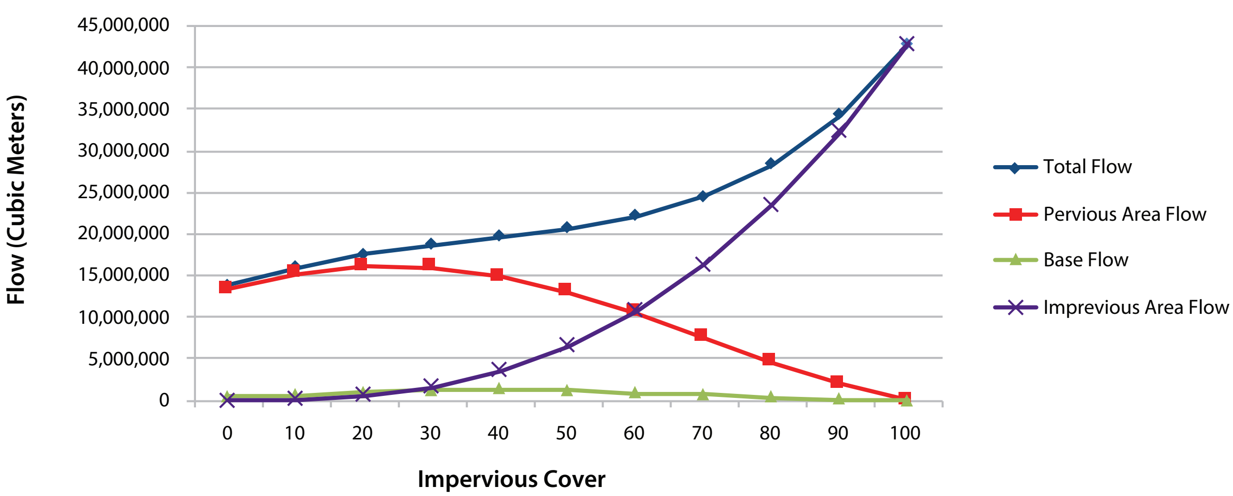

Figure A8.4. *Changes in total flow and components of total flow (pervious area runoff, impervious area runoff and base flow) with changes in percent impervious cover in Banner Creek.*

Land Cover Scaling Trends

Under current cover conditions, increasing impervious cover had an approximately 7 times greater impact on flow relative to tree cover. Increasing impervious cover by 1% averaged a 1.22% increase in total flow, while increasing tree cover by 1% averaged only a 0.18% decrease in total flow. The interactions between changing both tree and impervious cover are illustrated for total flow during the simulation period (Figure A8.5) and for percent changes in flow (Figure A8.6).

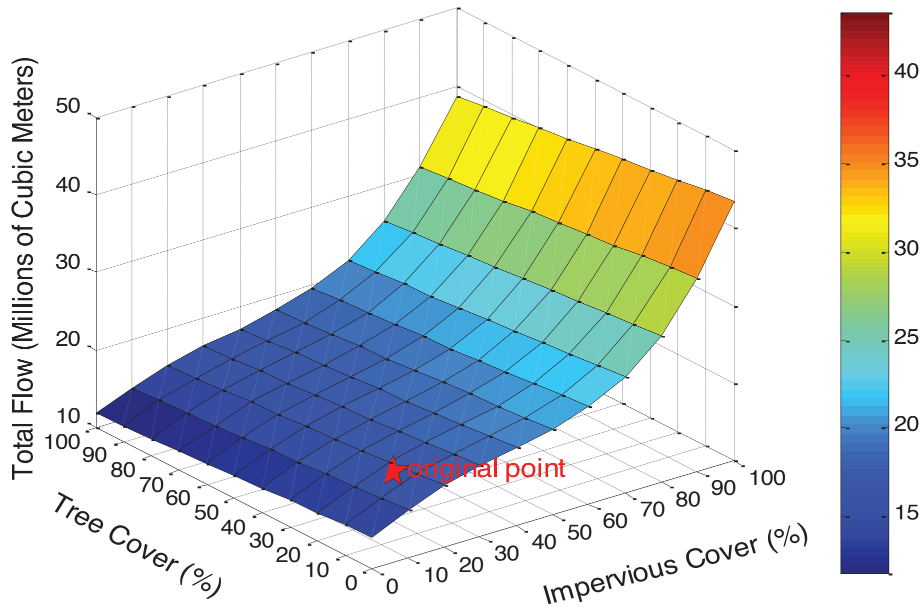

Figure A8.5. *Changes in total flow during simulation period based on changes in percent impervious and percent tree cover in Banner Creek. Red star indicates current conditions.*

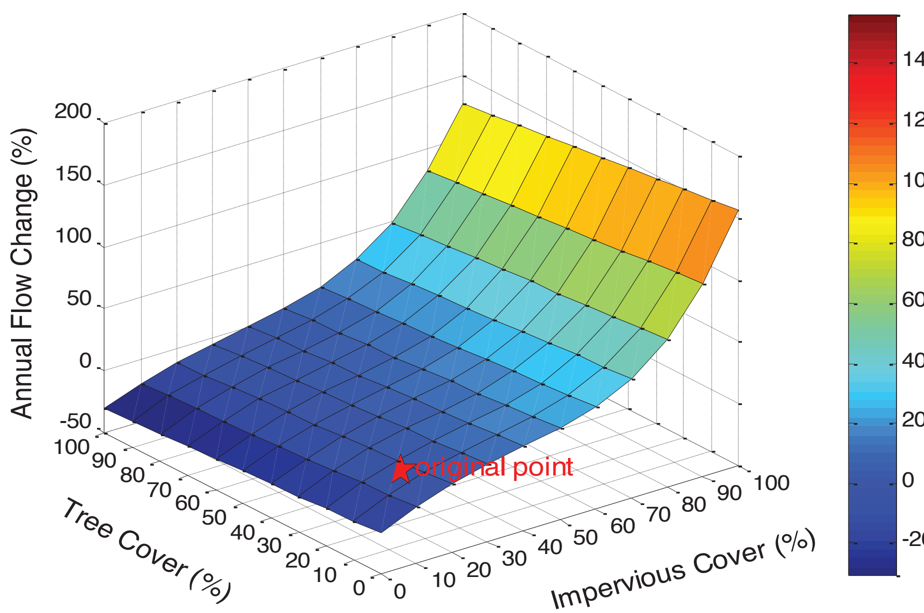

Figure A8.6. *Percent change in total flow during simulation period based on changes in percent impervious and percent tree cover in Banner Creek. Red star indicates current conditions.*

During the simulation period the total rainfall recorded was 967.49 millimeters. Since that amount is assumed to have fallen over the entire 62 square kilometer watershed, a total of 60.4 million cubic meters of rain fell on the watershed during the simulation time. The total modeled flow in the HUC 102701030305, Banner Creek watershed throughout the simulation time for the base case scenario (no landscape change) was 17.0 million cubic meters. The total flow is made up of surface runoff (from pervious and impervious areas) and baseflow (water that travels underground to the stream). Runoff from pervious areas and baseflow are the biggest contributors to this watershed's stream flow with 94.0 and 6.0% of total flow generated from pervious runoff and baseflow, respectively. Runoff from impervious areas was estimated to generate <0.05% of total flow. Areas of tree canopies intercepted about 11.8% of the total rainfall, but as only 14.5% of this watershed is under tree cover, interception of total precipitation in the watershed by trees was only 1.7% (1.0 million cubic meters). Areas of grass/herbaceous cover intercepted about 3.6% of the total rainfall, but as only 80.5% of this watershed is under grass/herbaceous cover, interception of total precipitation in the watershed by grass/herbaceous cover was only 2.9% (1.8 million cubic meters). About 67.2% of total precipitation is estimated to re-enter the atmosphere through evaporation or evapotranspiration (including evaporation from interception) or go to ground water recharge.

Water Quality Benefits from Trees

Based on the simulated changes in flow rates and the pollutant coefficient values used, the current tree cover is estimated to reduce suspended sediment during the simulation period by about 255.4 tonnes. Other pollutants are also reduced (Table A8.1).

Table A8.1. *Estimated reduction in chemical constituents in Banner Creek watershed due to existing tree cover during simulation period based on median and mean EMC values (Tables 1.3 and 1.4).*

	Reduction (tonnes)	
Constituent	**Median**	**Mean**
Suspended sediment	255.406	281.455
Biochemical oxygen demand	7.489	9.182
Chemical oxygen demand	29.109	34.384
Total phosphorus	0.301	0.317
Total nitrogen	2.505	2.843
Copper	0.007	0.009
Lead	0.033	0.044
Zinc	0.084	0.105

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