EARTH ECONOMICS

BENEFIT-COST ANALYSIS OF BEST MANAGEMENT PRACTICES IN THE BLUE RIVER WATERSHED OF OKLAHOMA

PHASE II OF EARTH ECONOMICS' ECOSYSTEM SERVICES IN THE BLUE RIVER WATERSHED REPORT

Benefit-Cost Analysis of Best Management Practices in the Blue River Watershed of Oklahoma

Phase II of Earth Economics' *Ecosystem Services in the Blue River Watershed* Report

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Earth Economics acknowledges that the Blue River Watershed lies within the Chickasaw Nation and Choctaw Nation. These two Nations were forcibly relocated to this territory by the Indian Intercourse Act of 1834.

Earth Economics acknowledges that we operate on the lands of the Coast Salish peoples, specifically the ancestral homelands of the Puyallup Tribe of Indians, and the 1854 Medicine Creek Treaty.

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Executive Summary

This report is an extension of an earlier analysis conducted by Earth Economics (*Ecosystem Services in the Blue River Watershed*), which estimated the total value of nonmarket ecosystem services provided within the basin ranged from $927 million to $1.7 billion per year. This report builds upon that effort by including Benefit-Cost Analyses of five Best Management Practices (BMPs) that would improve ecosystem services provisioning: cover cropping, conservation tilling, grazing management, riparian buffers, and removal of the invasive Eastern Red Cedar.

We conducted an extensive review of peer-reviewed articles and federal reports (prioritizing research conducted near the study area) and applied Benefit Transfer Methods to estimate the total benefits and costs of BMP implementation. Benefits included increased ecosystem services provisioning (e.g., improvements to soil, water, and air quality) and savings associated with switching practices (e.g., reduced fuel consumption, increased forage, grazing fee income). Costs extend to labor and materials for implementation, operations, maintenance. After standardizing benefits and costs (e.g., per acre, per year), we scaled relevant benefits and costs by the landcover types associated with each BMP within the watershed.

We developed three scenarios in which BMPs are implemented on 1-percent, 5-percent, and 25-percent of each landcover type, each discounted at multiple rates over a 50-year project period to report a range of net present benefits and benefit-cost ratios. Across these scenarios, we found that implementing BMPs would provide net present benefits between $19.3 million and $2.8 billion, with benefit-cost ratios ranging from 1.46 to 6.72. Next steps for this project would include selecting implementation sites and surveying current and planned practices.

Introduction

The lands and waters of the Blue River watershed support Oklahoma residents with clean air, clean water, and outdoor recreational opportunities. A source of water for thousands within the watershed and the larger Arbuckle Simpson Aquifer, the river is also economically critical to those who work the basin's farms, pastures, and rangelands. From the river's role as a unique habitat and its impact on property values, Earth Economics' 2020 report *Ecosystem Services in the Blue River Watershed* found that the natural assets of the watershed contribute $1–$1.85 billion in ecosystem services benefits each year (updated to 2021 dollars).

By contrast, Aqua Strategies' 2022 *Economic Valuation Study of the Blue River* applied a total (market) economic value approach for the mainstem of the Blue River. Looking at the contribution of the river to water supplies in Bryan County, the study found that the Blue River adds $1.5 billion per year to the county's GDP. The Aqua Strategies report also studies non-use values, such as recreation and tourism, as well as effects of the river's aesthetic beauty on real estate near the mainstem. The river provides at least $26 million in non-use values every year, particularly in terms of fish and wildlife habitat, and in support of Oklahoman heritage and identity. Due to data and analytical limitations, both reports necessarily underestimate the full value produced by the Blue River and the lands within the basin each year.

Ultimately, these benefits are affected by the quality and quantity of flows in the mainstem and tributaries. Maintaining the health of the river supports working lands, communities, and public health throughout the region. As demands for resources within the basin rise (e.g., sand mining), some benefits may decline, leaving residents to bear additional costs of flood damage, water shortages, or compliance with the Clean Water Act.[1] Replacing or supplementing ecosystem services with built solutions is often costlier and less-resilient, increasing burdens on ratepayers and taxpayers. As the Aqua Strategies 2022 report emphasizes, changes to the river and surrounding watershed also threaten the cultural significance of the river, particularly for the Chickasaw and Choctaw Nations.[2] Efforts to protect, conserve, and restore the Blue River watershed can improve and increase the value of the services provided by the river and its surrounding lands.

To date, The Nature Conservancy in Oklahoma (TNC OK) has spent $3 million to restore 28 acres along the Blue River. These projects aim to restore degraded areas or conserve those still in good health. A recent study finds that 71 percent of the basin requires restoration or improvement, particularly areas near urban boundaries and pastures (Rosado, 2020). Threats to the river and its water quality include agricultural production in addition to gravel mining, sediment from county roads, agricultural runoff, over-grazing, cattle instream, feral hogs, windmill development, monocultures of bermudagrass, commercial poultry farms, riparian degradation, urban development and construction, and encroachment of Eastern Red Cedar (ibid.). Assessments of river and watershed planning reports have recommended establishing *buffer zones* around the river, *prescribed grazing*, *secondary water sources* for cattle, protection of *grasslands and shrubland*, and *soil armoring* to support the health of the river and surrounding lands.

Building on Earth Economics' 2020 *Blue River Watershed Ecosystem Services Valuation* study, this report presents benefit-cost analyses of select best management practices (BMPs) to protect or enhance the services provided by nature throughout the Blue River Watershed.

[1] See Aqua Strategies' 2022 *Economic Valuation Study of the Blue River* for more information

[2] For example, The United Nations World Water Development Report. 2021. Valuing Water. UNESCO, Paris. Pg 97

Specifically, we evaluated the following BMPs:

1. Cover cropping
2. Reduced tillage
3. Grazing management
4. Riparian buffer zones
5. Invasive species management

These practices were selected based on a review of Blue River Watershed planning reports (Rosado, 2020; Shideler, Toole and Pope, 2009; The Blue River Foundation of Oklahoma, 2019; Moody, 2019; Oklahoma Water Resources Board, 2012) and recommendations from TNC OK and Aqua Strategies, in consultation with representatives of the Chickasaw Nation and Choctaw Nation.

This report summarizes Earth Economics' valuation methodologies, benefit-cost analysis findings, a discussion of beneficiaries, and conclusions based on these analyses, with detailed results available in the appendices. For further detail on nonmarket ecosystem services produced within the Blue River Watershed, please refer to Earth Economics' 2020 *Blue River Watershed Ecosystem Services Valuation.* For more information on the market economic value of the Blue River, please refer to the 2022 *Economic Valuation Study of the Blue River.*

Valuation Approach

Earth Economics' ecosystem service framework is adapted from the MEA (The Millennium Ecosystem Assessment) and TEEB (The Economics of Ecosystems and Biodiversity) frameworks.[1] The adapted framework clearly articulates and values the vast array of critical benefits provided by natural capital (see the Phase I report for more details).

This section describes the steps taken in the natural capital valuation and benefit-cost analysis. The primary tools and methods for this analysis are Geographic Information System (GIS) software, benefit transfer methods (primarily point transfer), Earth Economics' Ecosystem Valuation Toolkit (EVT), and benefit-cost analysis. The methodologies we used to value the basin's natural capital and compare BMP benefits and costs to improve its natural resources are detailed below. Additional background on ecosystem services valuation (including discount rates) are available in the Phase I Earth Economics report.

Benefit-Cost Analysis

Benefit-cost analysis (BCA) is a systematic decision-making process used to estimate expected return-on-investment. It is typically used to strategically compare lifetime benefits and costs of alternative investment opportunities or implementation strategies. Here, we have compared various levels of implementation of five BMPs throughout the Blue River basin: cover cropping; reduced tilling; prescribed grazing; riparian buffer zones; and local extirpation of the invasive Eastern Red Cedar. We have used the national Consumer Price Index (as reported by the US Bureau of Labor and Statistics) to convert all prior benefits or costs to 2021 values. We have discounted future benefits and costs to account for factors such as opportunity costs (i.e., the expected returns of alternative investments), or expectations about scarcity or risk. However, because opinions about the magnitude and significance of discounting factors vary, we have modeled each scenario using multiple discount rates.

Benefits

The first step to identifying potential benefits is a review of the scientific literature comparing biophysical impacts of conventional management practices to those of the selected BMPs. The goal is to identify unit-level impacts (per acre, per year) for each benefit provided by each practice. For example, cover cropping is known to decrease erosion rates, increase nitrogen retention, reduce fertilizer and pesticide use, and increase carbon sequestration relative to conventional practices, and cover cropped lands may also be leased for grazing purposes outside of harvest seasons (Clark, 2015; Clark et al., 2012). See Table 1 for the full list, descriptions, and sources for the benefits and biophysical impacts per BMP.

Table 1: Best Management Practices Benefits and Descriptions

BMP	Benefits	Description	Source
Cover Crops	Reduced Erosion	Limit soil loss via wind and water transport	Clark, 2015
	Nitrogen Savings	Increases nitrogen retention in soil reducing fertilizer inputs	Clark et al., 2012
	Reduced Herbicides	Outcompete weeds and promote soil health reducing disease	
	Grazing Fee Income	Farmer may lease land for livestock grazing	
	Carbon Sequestration	Crops sequester carbon then are tilled into and stored in soil to be used by other crops	Clark, 2015
Conservation Tilling	Reduced Erosion	Limit soil loss via wind and water transport	Hansen and Ribaedo, 2008
	Reduced Fuel Consumption	Reduced machinery and fuel use	USDA, 2016
	Reduced CO_2 Emissions	Reduced fuel consumption limits CO_2 emissions	EIA, 2021
Grazing Management	Reduced Erosion	Limit soil loss via wind and water transport	USDA, 2010
	Increased Forage Harvest	Limiting overgrazing promotes total forage recovery	
	Increased Water Infiltration	Reducing bare soil limits runoff	
	Carbon Sequestration	Increased herbaceous cover sequesters more carbon	
	Recreation	Healthy rangelands promote biodiversity and increase recreation opportunities	
Riparian Buffers	Nitrogen Removal	Vegetation buffer filters water runoff promoting stream health	EPA, 2002; Esralew and Tortorelli, 2010
	Phosphorus Removal	Vegetation buffer filters water runoff promoting stream health	Esralew and Tortorelli, 2010
	Reduced Erosion	Vegetation stabilizes stream banks and limits soil loss	Rempel and Buckley, 2018
	Carbon Sequestration	Increased vegetation sequesters more carbon	
	Air Quality	Increased vegetation promotes cleaner air	
Eastern Red Cedar Removal	Aggregated Annual Benefit	Reduced wildfires, water consumption, increased forage availability, habitat, and recreation	USDA, 2021

To account for uncertainties and variations in the literature, we report both lower and upper impact estimates, as available. Table 2 shows the ranges of annual biophysical impacts per benefit per BMP and the source for each estimate.

Table 2: Biophysical Impacts of Best Management Practices

BMP	Benefits	Low	High	Unit	Source
Cover Crops	Reduced erosion	14.3	19.6	tons/acre/year	Clark,2015
	Nitrogen savings	25	50	lbs/acre/year	Clark et al., 2012
	Reduced herbicides	NA	NA	$/acre	
	Grazing fee income	NA	NA	$/acre	
	Carbon sequestration		0.82	tons/acre/year	Clark, 2015
Conservation Tilling	Reduced erosion	8.2	36.3	tons/acre/year	Hansen and Ribaedo, 2008
	Reduced fuel consumption	2.5	4.2	gallons/acre/year	USDA, 2016
	Reduced co_2 emissions	55.9	93.4	lbs/acre/year	EIA, 2021
Grazing Management	Reduced erosion		0.69	tons/acre/year	USDA, 2010
	Increased forage harvest	NA	NA	$/acre	
	Increased water infiltration		2.58	acre-inches/acre/year	USDA, 2010
	Carbon sequestration		0.03	tons/acre/year	USDA, 2010
	Recreation	NA	NA	$/acre	
Riparian Buffers	Nitrogen removal	1.37	11.35	lbs/acre/year	EPA, 2002; Esralew and Tortorelli, 2010
	Phosphorus removal	0.17	0.39	lbs/acre/year	Esralew and Tortorelli, 2010
	Reduced erosion	0.1	0.5	tons/acre/year	Rempel and Buckley, 2018
	Carbon sequestration	10	18	tons/acre/year	Rempel and Buckley, 2018
	Air quality	NA	NA	$/acre	
Eastern Red Cedar Removal	Aggregated annual benefit	NA	NA	$/acre	

Once biophysical effects were established for each BMP, we reviewed the economics literature to associate monetary values with each BMP, again with ranges reported as available (see Table 3). Where multiple values were reported in the literature, we also calculated the average value of such estimates. The following subsections detail how the value of each benefit was estimated, and our assumptions.

Table 3: Economic Value of the Benefits of Best Management Practices (2021$)

BMP	Benefits	Low	High	Unit	Source
Cover Crops	Reduced erosion		$20.75	$/ton	Pimentel et al., 1995
	Nitrogen savings		$0.71	$/lbs	Good, 2022
	Reduced herbicides		$26.83	$/acre/yr	Clark et al., 2012
	Grazing fee income		$52.83	$/acre/yr	SARE, 2019
	Carbon sequestration		$119.65	$/ton	Wang et al., 2019
Conservation Tilling	Reduced erosion		$20.75	$/ton	Pimentel et al., 1995
	Reduced fuel consumption		$4.91	$/gal	EIA, 2022
	Reduced CO_2 emissions		$0.02	$/gal	Wang et al., 2019
Grazing Management	Reduced erosion		$20.75	$/ton	Pimentel et al., 1995
	Increased forage harvest		$22.76	$/acre	USDA, 2010
	Increased water infiltration		$193.79	$/acre-inch	EPA, 2016
	Carbon sequestration		$119.65	$/ton	Wang et al., 2019
	Recreation		$14.05	$/acre	USDA, 2010
Riparian Buffers	Nitrogen removal	$4.48	$64.96	$/lbs	Rempel and Buckley, 2018
	Phosphorus removal	$26.88	$446.88	$/lbs	Rempel and Buckley, 2018
	Reduced erosion		$20.75	$/ton	Pimentel et al., 1995
	Carbon sequestration		$119.65	$/ton	Wang et al., 2019
	Air quality	$3.36	$7.84	$/acre	Rempel and Buckley, 2018
Red Cedar Removal	Aggregated annual benefit		$35.48	$/acre	USDA, 2021

Cover Crops

To estimate the economic value of the benefits provided by planting cover crops, we valued the potential for reduced erosion, lower fertilizer and herbicide inputs, potential grazing fees, and soil carbon. Pimentel et al. (1995) examined the costs of soil erosion related to agricultural productivity, comparing water runoff rates for conservation and agricultural uses, noting that soil erosion reduces soil fertility and crop productivity. Using a replacement cost approach, the study concludes that we can expect 17 tons of soil per hectare per year to be lost, valued at $352.73 , or $20.75 per ton, per year.[3] Using the reduced erosion estimates from Clark (2015) and the revealed cost per ton of erosion from Pimentel et al. (1995) we find that cover crops can provide $296 to $407 in value per acre per year.

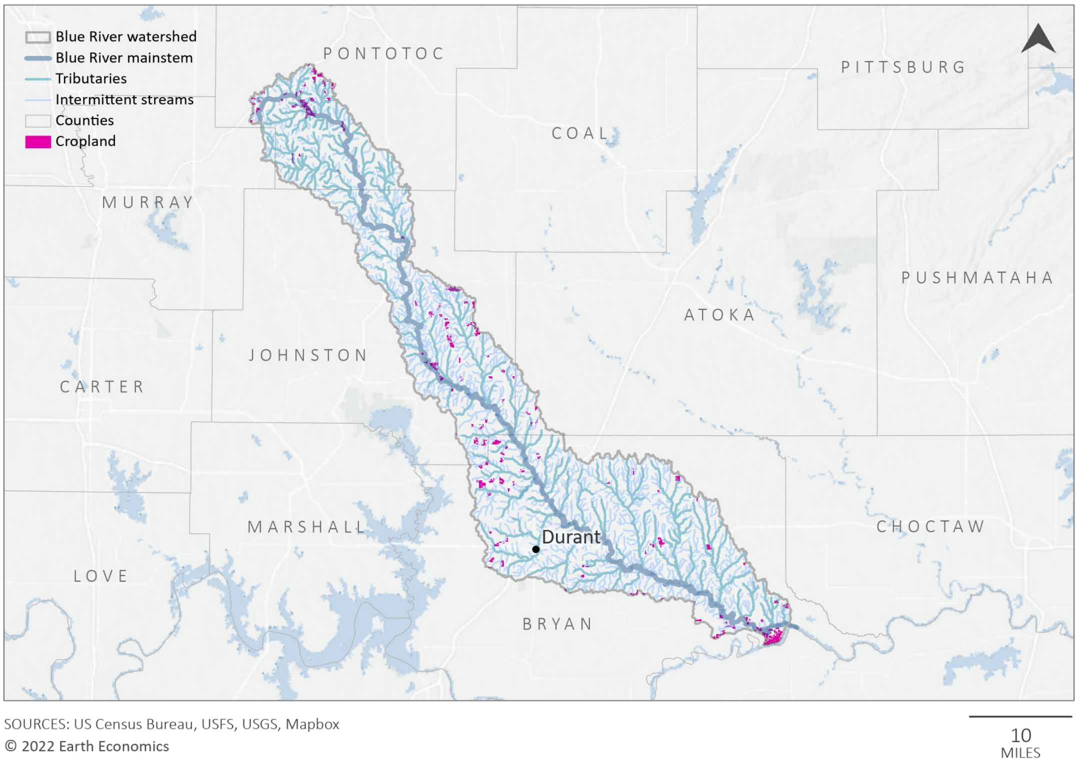
Similarly, in 2019 Sustainable Agriculture Research and Education (SARE) surveyed 500 farmers nationwide about the effects of cover cropping on necessary fertilizer and herbicide inputs, grazing fees, and yields. They found that cover cropping reduced annual herbicide applications by $26.83 per acre, and lowered nitrogen supplements by 25-50 pounds per acre, valued at $0.71 per pound (ibid.). They also estimated the value of using cover crops for forage. They reported that cover crops yield an average of 1,093 pounds of forage per acre per year, and that machinery and labor costs would also decrease by $5.90 per acre, per year. Overall, they found that using cover crops for forage leads to an average annual savings of $52.83 per acre.

Clark (2015a) reviewed the carbon sequestered by cover crops in a meta-analysis of 26 separate laboratory trials in the USDA's SARE program. They found that cover crops can sequester 0.82 tons of carbon per acre, per year within the top two inches of soil. Using a Social Cost of Carbon (SCC) of $119.65 per ton (Wang et al. 2019) we estimate that each year, cover crops can sequester $97.88 of atmospheric carbon per acre. Overall, cover crops are estimated to produce between $492 to $620 in benefits each year.

During the initial years of cover cropping, only a portion of the biophysical benefits are expected to be realized. SARE (2019) estimates that cover crops can be fully productive five years after beginning the practice. Here, we assumed a linear increase in benefits each of the first five years, in which the first year of cover cropping produces one-fifth of the benefits, growing by the same amount each year until the full potential is achieved in year five.

[3] All monetary values in this report have been adjusted to 2021 dollars.

Figure 1: Cropland in the Blue River Basin



Conservation Tilling

There are multiple approaches to conservation tilling, ranging from low-till to no-till. Following discussions with TNC OK, we valued implementation of no-till practices in terms of reductions in erosion, fuel consumption, and carbon emissions. Hansen and Ribaedo (2008) reported that switching from conventional to no-till systems can reduce erosion from 8.2 to 36.3 tons per acre per year. Again, we apply Pimentel et al.'s (1995) erosion cost estimates to find that no-till practices can reduce erosion costs from $170.15 to $753.21 per acre per year.

NRCS (2016) estimated the annual fuel savings for multiple conservation tilling practices, finding that switching to no-till practices can save 2.49 to 4.16 gallons per acre, per year. Based on the Energy Information Administration's (EIA) 2022 average non-road diesel price of $4.91 per gallon, we find that no-till practices could save approximately $12.23-$16.33 per acre per year in fuel.

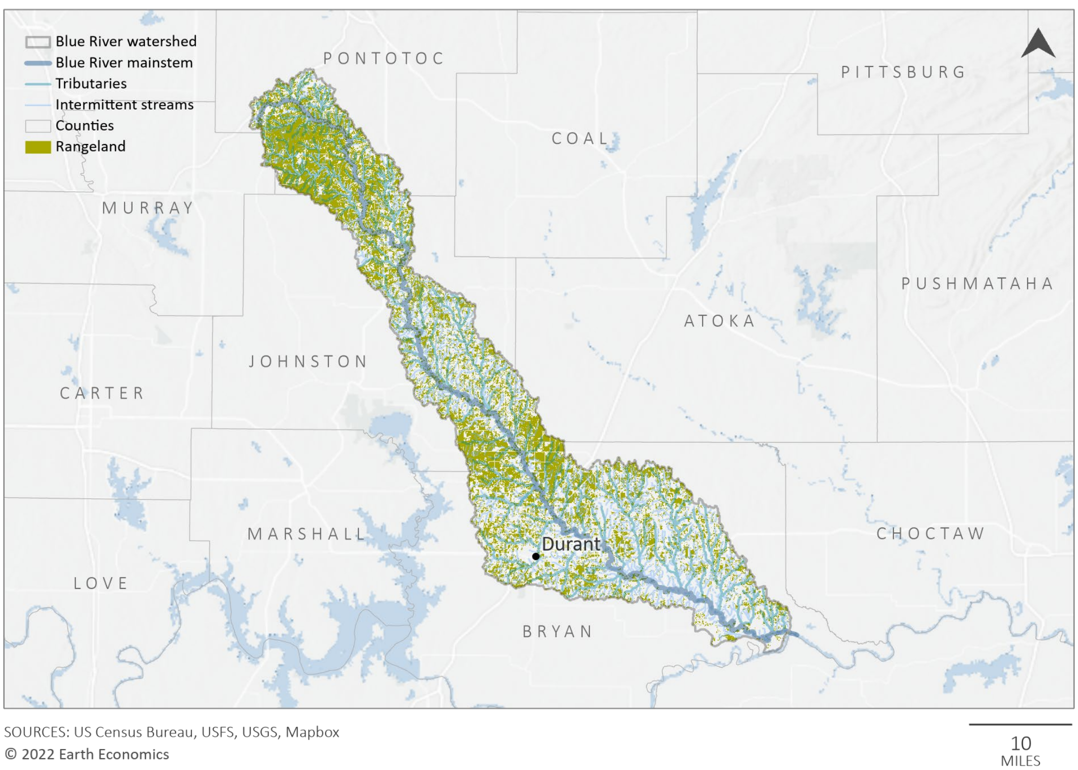
Finally, we valued the emissions avoided by reducing fuel consumption. The EIA reports that 22.46 pounds of carbon dioxide are emitted for every gallon of diesel fuel burned (2021). Multiplying this by the reductions in fuel consumption and applying the SCC, (Wang et al. 2019), we found that switching from conventional tilling to no-till practices can produce $1.37 to $1.83 in avoided climate change costs each year. Overall, each acre where conservation tillage replaces conventional practices generates between $184 and $776 in total benefits each year.

Grazing Management

Grazing management practices can range from reducing stocking rates to shifting grazing intensity. A common grazing management practice is rotational grazing, in which herds are moved between pastures sectioned into multiple paddocks. These practices reduce both soil disturbance and compaction, allow forage to regenerate (increasing total available forage and soil carbon), and improve recreational opportunities by reducing sediment runoff (NRCS, 2010).

In 2010, NRCS analyzed the benefits and costs of the Grassland Reserve Program, a voluntary program focused on a range of conservation practices. They reported that rotational grazing reduced annual erosion by 0.69 tons per acre; applying Pimentel et al.'s (1995) erosion costs, this translates to $14.32 per acre, per year. They also estimated that rotational grazing increases forage by 1,013 pounds per acre, an annual value of $23 per acre. The forage sequesters approximately 0.03 tons of carbon per acre per year; applying the SCC from Wang et al. (2019) translates this to $3.59 per acre per year. The NRCS also reported that rotational grazing increases water infiltration by 2.58 acre-inches per year.[4] To value groundwater recharge, we communicated with a local expert about water rights transfer payments (B. Austin, personal communication, November 11, 2022). We find that, in Oklahoma, it costs approximately $194 to secure the rights to one acre-inch of water in perpetuity. Accordingly, we treat groundwater recharge as a one-time benefit occurring in the first year; this translates to $501 per acre. Finally, the 2010 NRCS report estimated rotational grazing improved downstream recreational opportunities by $14 per acre each year. Overall, switching to rotational grazing is expected to produce $54.72 in annual benefits per acre, in addition to the one-time groundwater recharge benefit.

Figure 2: Rangelands in the Blue River Basin



SOURCES: US Census Bureau, USFS, USGS, Mapbox
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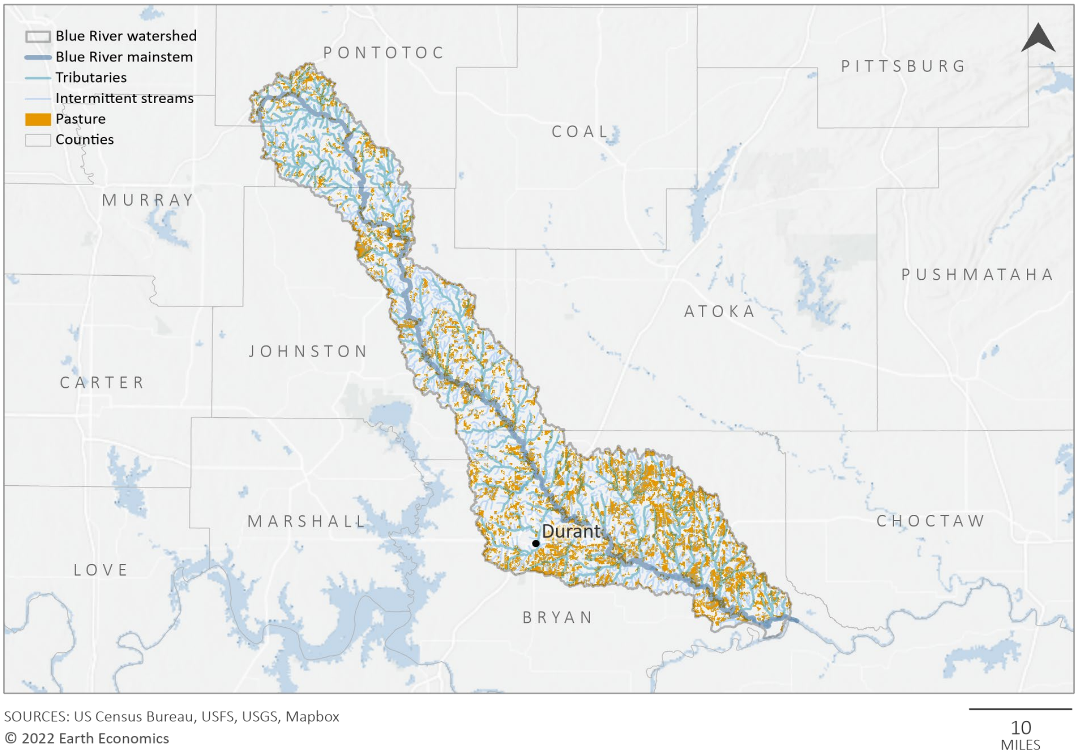
[4] An acre-inch is a variation on acre-feet, a common measure of water volume. One acre-inch is the equivalent of 27,154 gallons per acre.

Figure 3: Pasture in the Blue River Basin



SOURCES: US Census Bureau, USFS, USGS, Mapbox
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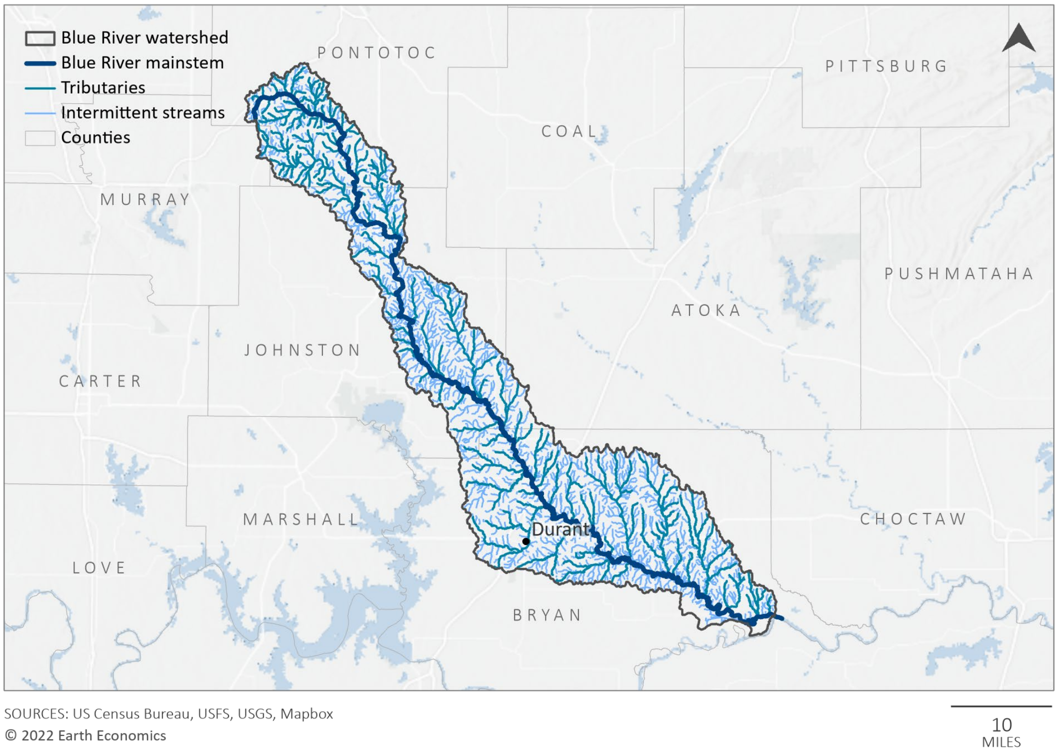
Riparian Buffers

Riparian buffers produce multiple benefits, including removing nitrogen and phosphorus from surface runoff, reducing soil erosion, sequestering carbon, and improving air quality. To identify total nitrogen and phosphorus loads, we applied EPA state-level estimates (2002), and those from a 2010 USGS study for Oklahoma's Eucha-Spavinaw basin (Esralew and Tortorelli). These showed that Oklahoma nitrogen and phosphorus runoff loads ranged from 3.79 to 12.61 pounds of nitrogen and 0.097 to 0.47 pounds of phosphorus per acre per year. According to Rempel and Buckley (2018), riparian buffers can efficiently remove 36–90 percent of total nitrogen and 36-70 percent of total phosphorus. They estimated costs of $4.48 to $64.96 to remove one pound of nitrogen, and $27 and $447 to remove one pound of phosphorus. Assuming these costs remain constant throughout the project lifetime, we estimated that each year, an acre of riparian buffer can efficiently remove between $6 and $372 of nitrogen, and $5 and $89 of phosphorus.

Rempel and Buckley (2018) also estimated that riparian buffers can reduce between 0.1 and 0.5 tons of soil erosion per acre each year. Combined with the cost of erosion reported in Pimentel et al. (1995), we estimated that riparian buffers provide erosion control benefits between $2 and $6 per acre per year. They also estimated that riparian areas can sequester from 10 to 18 tons of carbon per acre, each year. Applying the SCC from Wang et al. (2019), this translates to $1,207 to $1,680 of atmospheric carbon per acre per year. Finally, Rempel and Buckley estimate that each acre of riparian buffers can improvements in rural air quality valued between $3.36 and $7.84 per year (2018). In total, we estimate that an acre of riparian buffer can produce between $1,223 and $3,082 in benefits every year.

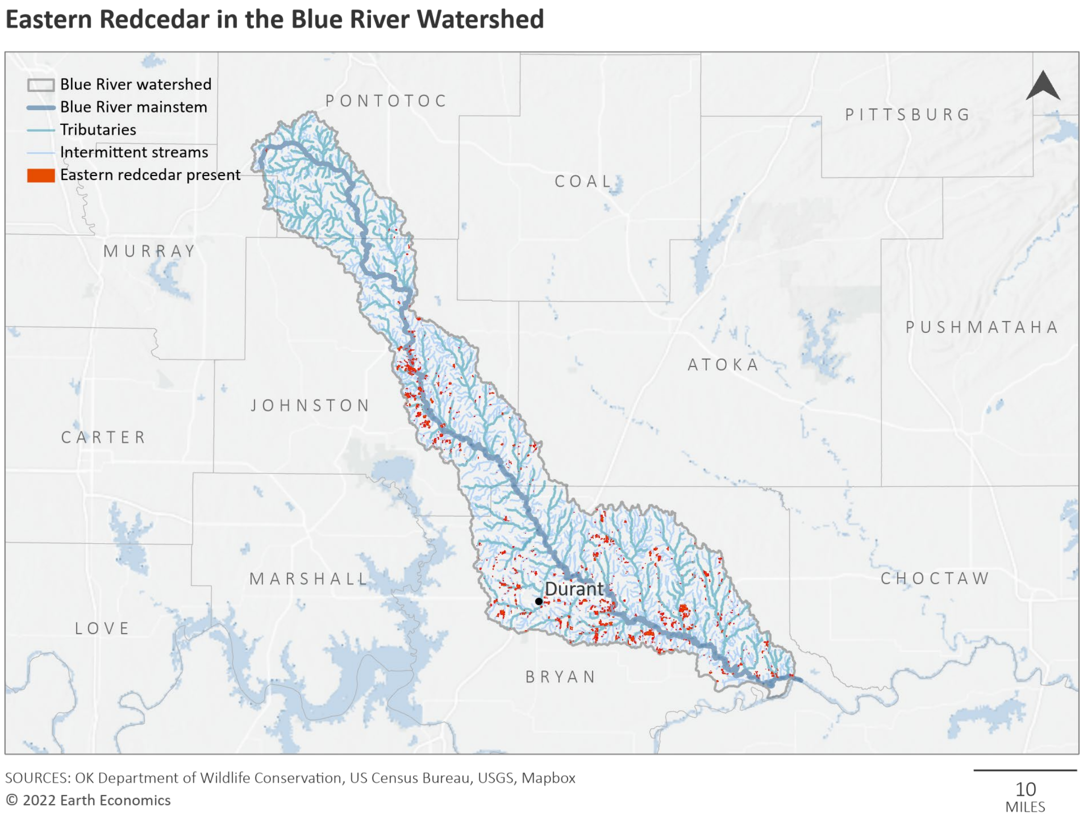
Figure 4: 100-meter riparian buffer zones in the Blue River Basin



Eastern Red Cedar Removal

Literature estimating the value of removing the Eastern Red Cedar is limited. However, the Oklahoma Natural Resources Conservation Service (NRCS) estimated the avoided costs for all lands with more than 50 Eastern Red Cedar trees per acre within the state. Based on losses due to wildfire, reduced rangeland forage, loss of wildlife habitat, loss of recreational opportunities, and reduced water yield, they estimated that Eastern Red Cedars caused $447 million in damage in 2013. Statewide, there are 12.6 million acres of such Eastern Red Cedar lands, or an average avoided cost of $35.48 per acre per year.

Figure 5: Eastern Red Cedar Woodlands within the Blue River Basin



A summary of the estimated per acre, per year economic benefits of each BMP is presented in Table 4, below.

Table 4: Annual economic benefits of Best Management Practices, per acre (2021$)

BMP	Benefits	$/acre/year (2021$)		
		Low	Average	High
Cover Crops	Reduced Erosion	$296.72	$351.71	$406.69
	Nitrogen Savings	$17.75	$26.63	$35.50
	Reduced Herbicides		$26.83	$26.83
	Grazing Fee Income		$52.83	$52.83
	Carbon Sequestration		$97.88	$87.88
Conservation Tilling	Reduced Erosion	$170.15	$461.68	$753.21
	Reduced Fuel Consumption	$12.23	$16.33	$20.42
	Reduced CO2 Emissions	$1.37	$1.83	$2.29
Grazing Management	Reduced Erosion		$14.32	$14.32
	Increased Forage Harvest		$22.76	$22.76
	Increased Water Infiltration		$500	$500
	Carbon Sequestration		$3.59	$3.59
	Recreation		$14.05	$14.05
Riparian Buffers	Nitrogen Removal	$6.12	$371.66	$737.20
	Phosphorus Removal	$4.54	$88.89	$173.23
	Reduced Erosion	$2.07	$6.22	$10.37
	Carbon Sequestration	$1,207.22	$1,680.32	$2,153.42
	Air Quality	$3.36	$5.60	$7.84
Red Cedar Removal	Aggregated Annual Benefit		$35.48	$35.48

To estimate the value of BMPs across the basin as a whole, these total annual per acre benefits are scaled by the total extent of the landcover relevant to each BMP. We assume that cover crops and conservation tilling will be implemented on lands designated as agricultural or croplands. The USDA categorizes croplands as those with row crops, close-grown crops (e.g., hay), or rotations including them (2022a). We assume grazing management will be implemented on lands categorized as rangelands or pastures. We assumed all riparian buffers to be 100 meters from the edges of the mainstem and its contributing tributaries and intermittent streams. Finally, Eastern Red Cedar removal will take place on the relevant woodlands identified by Oklahoma's Department of Wildlife.

Costs

Next, we reviewed the literature on implementation and operation and maintenance (O&M) costs per acre for each BMP. Many BMPs have multiple strategies for implementation and O&M activities, each producing different total cost estimates. To capture this variation, we again report the low, average, and high cost estimates. The following sections describe our key assumptions when forecasting the cost of implementing each BMP.

Cover Crops

The direct costs of cover cropping include seed purchases, planting methods, and machinery costs (Swanson et al., 2018; SARE 2019). Given the inevitable variability across farms, we rely on cost ranges ($31–$67 per acre, per year) reported for Midwest farms (SARE, 2019). While costs may be higher where cover cropping is substantially different from past practices, we follow Swanson et al. (2018) in assuming that overall pesticide and tillage practices would not change following cover cropping.

Conservation Tilling

No-till systems require different types of machinery and varying levels of inputs of fertilizers, herbicides, and insecticides than conventional tillage practices (Epplin et al., 2005). Additionally, due to economies of scale, the total size of the farm can dramatically change the per-acre costs of no-till practices. Epplin et al. (2005) surveyed Oklahoma wheat farmers and farm equipment dealerships to find costs for both conventional tillage and no-till systems. Based on the machinery and other inputs required for no-till systems, the price per acre is highest for small farms (320 acres) and lowest for large farms (1,280 acres); we use their mid-range estimate of $158 per acre per year. These annualized cost estimates include the fixed cost of investing in new machinery, O&M maintenance, and operation costs. We assume these will occur each year and will remain constant throughout the project's lifetime.

Grazing Management

Rotational grazing systems require limited inputs such as fencing and the installation and maintenance of alternative water sources. Site-specific factors can significantly affect these costs. Key considerations are pasture size, the number of cattle, forage species and growth rates, desired recovery time between grazing, labor availability and costs, and the type of fencing installed (Undersander et al., 2002). We assume that both high-tensile electric and electric polywire would be used, but since the actual number of paddocks and fencing types are unknown, we use a range of likely values reported by Undersander et al. (2002) and Edwards (2012). Undersander et al. (2002) found that installing paddock fencing cost between $46 and $107 per acre. Yearly O&M costs will depend on the type of fencing used and the cost of labor; we use Edwards' (2012) range of $1.78 to $2.46 per acre per year. Lastly, fencing is assumed to have a lifetime of 20 years. To reflect this within our model, we assume that every 20 years after initial implementation the fencing will need to be replaced (Edwards, 2012).

Riparian Buffers

The cost of riparian restoration varies significantly, as it can mean simply reseeding or replanting native species, or more intensive practices such as stream bank stabilization. Costs can also vary based on location. Based on studies by NRCS (2002) and the Army Corps of Engineers (USACE, 2015) we find that restoration costs within Oklahoma can range from $925 to $20,872 per acre. For simplicity, we assume that all initial restoration will occur within the first year. Again, the riparian buffers extend 100 meters inland from the mainstem and its tributaries.

We also assume that fencing will need to be installed to prevent livestock from using the river as a water source. Barb wire fencing costs between $1.78 to $4 per foot to install (Austin, 2022; Edwards, 2012), accounting for both material and labor inputs. To account for annual O&M, we use Edwards' (2012) estimates of $0.0059-$0.007 per foot. To estimate total fencing costs, we multiplied both implementation and O&M costs by the total perimeter of the riparian buffers. Again, we assume that fencing will have a 20-year lifetime and that new fencing will be installed in years 1, 21 and 41.

Finally, we assume that croplands and pasturelands within the buffers will be taken out of production. According to Oklahoma's 2021 Agricultural Statistics, the wheat and hay are the dominant crop produced in the counties within the basin. The average wheat yield in Oklahoma is 40 bushels per acre, valued at $3.50 per bushel (NASS, 2021); hay yields average 1.9 tons per acre, valued at $109 per ton. Based on these assumptions, we expect the opportunity cost of fallowing croplands in riparian buffers to be between $140 and $207 per acre, per year.

The NASS (2021) reported that pastures within Oklahoma are primarily used for grazing cattle. Oklahoma State University's stocking rate formula shows that 4.21 to 5.88 acres are required for each animal to reach an average weight of 1,000 pounds (Redfearn and Bidwell, 2017). The average sale price in Oklahoma auctions is $64–$89 per 100 pounds of live weight (USDA, 2022b), or $640–$890 for a 1,000-pound animal. Dividing the lower sales price by the higher acreage required for a single animal (and vice versa) yields an average income of $109 to $211 per acre. For simplicity, we assume these production rates and prices as constant throughout the project period.

Eastern Red Cedar Removal

Since data on Eastern Red Cedar in the basin is limited, we assumed that all stands are too large to be eradicated by prescribed burning and will require more intensive mechanical removal. Furthermore, since the annual removal rate is unknown, we treat it as a capital expense and assume that all Eastern Red Cedar trees will be mechanically removed within the first year of the project's lifetime.[5] Bidwell et al. (2002) estimate that mechanical removal of the Eastern Red Cedar can range between $38 and $229 per acre, depending on the techniques employed. We also assume that prescribed burning will be required every five years, to prevent the stands from reestablishing. Bidwell et al. (2002) report that prescribed burning costs range from $11 to $38 per acre.

[5] Both of these assumptions produce higher, undiscounted cost estimates, which lead to more conservative (i.e., lower) benefit-cost ratios. This effect is more pronounced where higher discount rates are applied.

Study Findings

The Benefits of Best Management Practices within the Blue River Basin

Since full implementation of all BMPs throughout the basin is unlikely, we developed scenarios of 1, 5, and 25 percent implementation, in which each BMP is implemented on the corresponding proportion of relevant landcover within the basin. We then projected benefits and costs for each scenario over a 50-year project period and applied a range of discount rates (0, 1, 3, and 7 percent) to generate net present value (NPV) estimates for comparison. For a discussion of the use and significance of discount rates, please refer to the 2020 study.

To identify project cost-effectiveness, we calculated benefit-cost ratios (BCRs) for all discounted scenarios[6] by dividing all lifetime benefits by all lifetime costs. Higher ratios of benefits to costs signify more effective investments, and vice-versa. The use of NPV in a benefit-cost framework allows us to compare BMPs by their expected cost-effectiveness, while the choice of discount rates can frame these approaches against other investments, both within the Blue River basin and elsewhere.

We find that a total of 247,467 acres of the Blue River basin are appropriate for implementation of these BMPs, including 8,270 acres of croplands, 104,924 acres of pasture, 130,714 acres of riparian buffers, and 3,559 acres of Eastern Red Cedar stands. Within the riparian buffers, there are 6,803 acres of cropland and 46,057 acres of pasture. Again, we assume that cover cropping and conservation tilling will be implemented on croplands, grazing management will be applied to pastures (rangelands are often managed less-intensively), and riparian buffers are consistent throughout the basin's permanent and seasonal streams.

Based on average benefits and costs, cover cropping 1–25 percent of croplands would lead to $1.3–$32.8 million in total benefits over the 50-year period, when discounted at 1 percent. This produces a BCR of 10.81, meaning that every dollar spent on cover crops would produce $10.81 in benefits. Conservation tilling could produce between $879,000 and $22 million in net benefits within the basin (depending on the scale of implementation), with a BCR of 3.03. We estimate that grazing management could produce $1.1 to $28 million in net benefits, with BCR of 9.77. Riparian buffers are expected to produce between $67.5 million and $1.7 billion in benefits over the 50-year period, with a BCR of 2.48. Finally, removal of all Eastern Red Cedar stands would lead to net benefits between $40,000 and $977,000, and a BCR of 4.34 over the 50-year project lifetime. Overall, implementation of all BMPs on 1 to 25 percent of the relevant landcovers would produce benefits of $71 million to $1.7 billion over 50 years at a 1-percent discount rate, with a combined benefit-cost ratio of 2.29 (see Table 5 for details).

Again, we developed NPV and BCR estimates for each level of implementation and for four discount rates: 0, 1, 3, and 7 percent. These results are provided in Appendix B of this report.

[6] Because we assume unit-values (both benefits and costs) remain constant at all implementation scales, the BCRs are similarly constant, regardless of the extent to which practices are implemented. Since higher discount rates have the effect of translating future benefits or costs into lower present-day values, BCRs are affected by the choice of discount rate, but not the level of implementation.

Table 5: Net Present Value over 50 years, based on average benefits and costs, discounted at 1% (2021$)

BMP	Total Acres	$/acre/year	1% Implementation		5% Implementation		25% Implementation		
			Acres	NPV $	Acres	NPV $	Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$556	68	$1,310,939	340	$6,554,696	1,701	$32,792,758	10.81
Conservation Tilling	6,803	$480	68	$879,256	340	$4,396,279	1,701	$21,994,325	3.03
Grazing Management	46,057	$55	461	$1,117,106	2,303	$5,580,682	11,514	$27,900,986	9.77
Riparian Buffer	130,714	$2,153	1,307	$67,560,977	6,536	$337,857,667	32,679	$1,689,235,551	2.48
Eastern Red Cedar	3,559	$35	36	$39,522	178	$195,412	890	$977,060	4.34
All BMPs	193,936	$3,779	1,939	$70,954,263	9,697	$354,817,057	48,484	$1,774,062,971	2.53

Discussion: Ecosystem Services and Nature-Based Solutions—Who Benefits?

Fletcher et al. (2020) found that the ecosystems throughout the Blue River basin produce $927 million to $1.7 billion in ecosystem service benefits each year, directly benefiting those who travel to the basin to experience nature, and both directly and indirectly benefiting residents within the basin. This section describes in general terms how ecosystem benefits flow from the landscapes where they are produced (provisioning areas) to beneficiaries.

As living organisms interact with other biological units and an ecosystem's physical environment, they produce ecosystem functions, some of which produce benefits to human wellbeing,[vii] accruing on-site or flowing across landscapes. Soil-based ecosystem functions tend to produce highly localized benefits (e.g., soil formation, soil retention) that typically accrue to land managers. Functions associated with water may strongly influence groundwater (e.g., water storage), benefitting landowners within shared shallow aquifers, or may flow through surface waters (e.g., water capture and conveyance, water quality) to affect beneficiaries downstream. Similarly, those associated with the atmosphere are likely to follow prevailing winds (e.g., air quality), or influence local, regional, or global climates (e.g., climate stability through shading, evapotranspiration, or the sequestration and storage of atmospheric carbon). Benefits that derive their value from direct human interaction may require travel (e.g., recreation, fishing), most strongly affecting beneficiaries located nearby, including line-of-sight (e.g., aesthetic beauty). In this way, the distribution of ecosystem service benefits is influenced by topography, hydrology, meteorology, and other contextual factors, including social, cultural, and technological values and practices. There are several mechanisms through which ecosystem benefits flow from sites where they are produced to those they affect most. Table 6 describes the method and scale of ecosystem service flows, as well as the stocks that are the sources of such flows.

[vii] See the Phase I report for definitions of each ecosystem service.

Table 6. General Framework of Ecosystem Service Flows

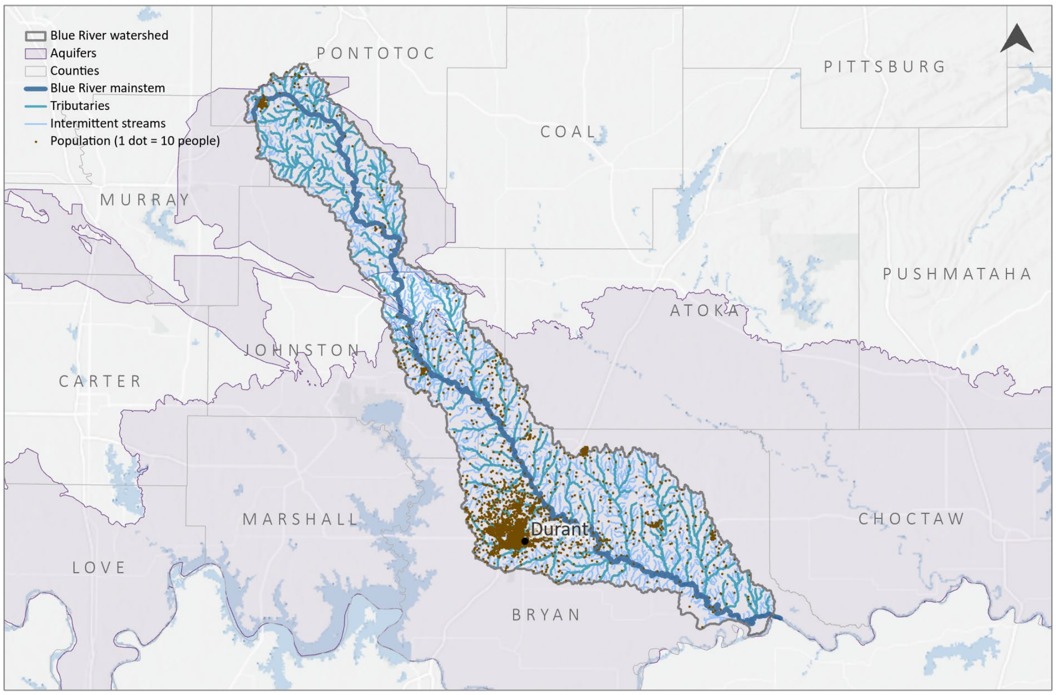
Ecosystem Service*		Stock	Flow	Distribution to Beneficiaries
Provisioning	Food	Fauna, flora, fungi	Sharing, exchange	Markets
	Medicinal Resources			
	Ornamentals			
	Energy, Raw Materials			
	Water Storage	Soil moisture, groundwater, aquifers, lakes and ponds	Local	Local use, groundwater wells, lakes and reservoirs
Regulating	Air Quality	Oxygen (ozone, particulate matter)	Air currents, particulate deposition	Local, regional airsheds
	Biological Control	Fauna, flora, fungi	Organism and population movement	Local (agriculture, habitat)
	Climate Stability	Temperature, terrestrial carbon (flora, soils, etc.)	Biomass formation, shade, evapotranspiration	Local and regional (micro and meso-climates), global
	Disaster Risk Reduction	Ecosystem presence and quality	Passive	Downstream surface waters, local and regional airsheds and climate (wildfire, drought)
	Pollination, Genetic Dispersal	Fauna, flora, fungi	Organism and population movement, air and water currents, topography	Local and regional (agriculture, habitat)
	Soil Formation	Soil	Local	Local
	Soil Quality		Local	
	Soil Retention		Local (eroded soils move with surface waters, wind)	Local (downstream surface waters, airsheds)
	Water Quality	Groundwater, surface waters	Water flows	Groundwater, downstream surface waters
	Water Capture, Conveyance, Supply	Ground- and surface water	Surface streams, canals	Local wells, surface offtakes, water utilities
	Navigation	Surface waters	Human engagement	Local waterways
Supporting	Habitat, Nursery/Refugia	Ecosystem presence	Organism and population movements	Local terrestrial and aquatic ecosystems
Information	Aesthetics	Ecosystem presence	Human engagement	Viewsheds, airsheds
	Cultural Value			Local use of ecosystems, flora, and fauna; non-consumptive benefits
	Recreation, Tourism			Local engagement with ecosystems, flora, fauna
	Science and Education			Shared knowledge through speech, text, etc.

**Not every ecosystem service may be produced within the Blue River basin (e.g., as the river is not a commercial waterway, Navigation is irrelevant).*

The Blue River basin is relatively sparsely populated (fewer than 15 persons per square mile), with most residents living within the Durant city limits (see Figure 6 below). With few exceptions, population centers within the basin are located away from the mainstem; most are located along tributaries. Austin et al.

(2022) report that despite this, the Blue River is an important public water supply for more than 30,000 people in the watershed, providing about 6,100 acre-feet per year (AFY). The river is largely fed by springs originating in the Arbuckle Simpson Aquifer. As home to the Choctaw Nation headquarters and Southeastern Oklahoma State University, Durant is the largest single user, with four permits providing 90 percent of the city's water supply (BRF et al., 2019.01). As one of the fastest growing cities in the state, Durant's water demands can be expected to increase over time. Permits for public supply are over half the total allowed surface water diversions in the basin (see Table 7).

Figure 6: Population Centers within the Blue River Basin



SOURCES: Oklahoma Water Resources Board, US Census Bureau, USGS, Mapbox
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Agriculture and irrigation are the second largest permitted surface water diversions within the basin, though individual permits are relatively small, averaging less than 1 percent of total demand. Diversions for recreation, fish and wildlife are driven almost entirely by Oklahoma's Department of Wildlife Conservation's 6,445 AFY permit for the Durant State Fish Hatchery (BRF et al 2019.01), which produces about 5 million fish each year to stock public and private waters for recreation (Austin et al., 2022).

Table 7: Permitted Surface Water Diversions within the Blue River Basin as of August 2022

Use	Permits	Proportion of total permitted demand
Agriculture/irrigation	42	20.7%
Industrial/mining	2	0.8%
Public Supply	7	59.2%
Recreation, Fish, Wildlife	3	19.4%

Restoring Riparian Areas

Full restoration of 100-meter buffers along streams throughout the basin offers considerable benefits to residents of the Blue River basin. Although cropland, pasture, and rangeland within the buffers are less than 14 percent of the total basin, full implementation would produce over $5 billion in benefits over 50 years (Present Value at a 1-percent discount rate). That's nearly $130 million in benefits every year, provided as reduced nutrient and soil runoff into surface waters, as well as carbon sequestration and storage. Other benefits are also likely to follow restoration of the buffers, including improved habitat, recreational quality, and aesthetics, as well as considerable scientific and educational value. Perhaps most significant would be the cultural importance of restoring waterways throughout the Blue River basin to healthier, more natural conditions.

At the same time, full implementation of riparian buffers will present direct costs to producers, and the patchwork of property ownership and land use within the buffers would present additional challenges. Coordination and negotiation of such a complex conservation effort is likely to take significant time and resources beyond the scope of this analysis. Active agricultural uses (i.e., cropland, pasture, rangeland) extend through approximately half of the riparian areas of the basin—local research and engagement would be required to better understand the scope and scale of other uses within these buffers and to develop strategies for protecting water quality and habitat appropriate to those uses.

Table 8: Average Benefits of Restoring 100-meter Riparian Buffers (2021$)

Streams	100m buffer (acres)	% of basin	Land Cover	Acres	% of buffer	Avg Benefits $/year	Full PV (1% discount rate)
Mainstem	10,761	2.45%	Cropland	302	2.80%	$650,111	$26,131,939
			Pasture	1,351	12.60%	$2,908,278	$116,901,491
			Rangeland	1,336	12.40%	$2,875,988	$115,603,547
Tributaries	43,656	9.94%	Cropland	395	0.90%	$850,311	$34,179,192
			Pasture	6,142	14.10%	$13,221,795	$531,464,809
			Rangeland	11,453	26.20%	$24,654,707	$991,023,520
Intermittent	76,297	17.36%	Cropland	770	1.00%	$1,657,568	$66,627,793
			Pasture	16,848	22.10%	$36,268,446	$1,457,850,717
			Rangeland	21,737	28.50%	$46,792,926	$1,880,893,936
All streams	**130,714**	**29.75%**	**All**	**60,334**	**46.20%**	**$129,880,129**	**$5,220,676,945**

Conclusions

For this study, we analyzed the benefits and costs of implementing five select BMPs: cover crops, conservation tilling, grazing management, riparian buffers, and the removal of the Eastern Red Cedar. We then applied these to the relevant landcover within the basin to project benefits over the project's 50-year lifetime. As most of these benefits and costs will occur in the future, we calculated the NPV of implementing each BMP over 1, 5, and 25 percent of the relevant landcovers, using four discount rates (0, 1, 3, and 7 percent). Finally, we calculated BCRs to show the expected return on investment for each BMP and the project as a whole.

We find that the project would provide a range of benefits between \$19.9 million to \$2.3 billion using average benefit and cost values across the various discount and implementation rates. These conditions produce benefit-cost ratios ranging from 1.85 to 2.65, indicating that for every dollar spent we can assume a return of \$1.85 to \$2.65 in benefits. This suggests that the project is an effective investment, producing significantly more benefits than costs. A more detailed breakdown shows that the most efficient investment would be cover cropping, which has benefit-cost ratios ranging from 10.25 to 11.28, depending on the discount rate applied. Riparian buffers produce the largest overall benefits, ranging from \$18.6 million to \$2.2 billion. However, the significant costs associated with their implementation reduces their benefit-cost ratios. None of the BMPs produce a BCR under 1:1, indicating that all BMPs can be considered positive investments.

Variation within these estimates reflects the uncertainty of the location and scale of BMP implementation, site-level factors (e.g., biophysical conditions, current land use practices), and the specific practices chosen for implementation. For example, the benefits of cover cropping vary depending on which species are planted, with different effects on erosion control, carbon sequestration, nitrogen savings, pesticide reduction, and soil quality. Additionally, their value will depend on current landscape health and land use. Similar uncertainties surround implementation costs. For example, actual grazing management costs will vary by pasture size, pasture conditions, forage species, the number of livestock, type of fencing, and the number of paddocks. We attempted to capture this variability by reporting ranges of both benefits and costs. By including low, average, and high estimates, our results support a range of potential scenarios.

This analysis could be refined by selecting candidate sites and surveying the managers of those lands about their current practices and preferred BMP alternatives. Even with the ranges of the estimates presented here, the BCRs show each BMPs can produce more benefits than costs across a wide range of scenarios. This should go far in encouraging participation and broader adoption throughout the basin.

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Appendix A. Bibliography of Methodological References

This appendix describes the methodology, ecosystem services, and BMP applied from each study used in this report.

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Appendix B. Ranges of Total Net Present Value Estimates

Table 9: Low Estimate of Total Net Present Value by BMP with 0% Discount Rate (2021$)

BMP	Total Acres	Benefits $/Acre/Year Low	1% of Total Acres	NPV $	5% of Total Acres	NPV $	25% of Total Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$492	68	$1,531,694	340	$7,658,472	1,701	$38,314,886	15.22
Conservation Tilling	6,803	$184	68	$88,731	340	$443,653	1,701	$2,219,572	1.16
Grazing Management	46,057	$55	461	$1,411,888	2,303	$7,053,315	11,514	$35,263,510	14.44
Riparian Buffer	130,714	$1,223	1,307	$69,594,992	6,536	$348,029,025	32,679	$1,740,091,060	6.83
Eastern Red Cedar Removal	3,559	$35	36	$59,929	178	$296,316	890	$1,481,578	12.50
Total	193,936	$1,989	1,939	$72,687,234	9,697	$363,480,781	48,484	$1,817,370,606	6.72

Table 10: Low Estimate of Total Net Present Value by BMP with 1% Discount Rate (2021$)

BMP	Total Acres	Benefits $/Acre/Year Low	1% of Total Acres	NPV $	5% of Total Acres	NPV $	25% of Total Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$505	68	$1,193,703	340	$5,968,516	1,701	$29,860,132	15.06
Conservation Tilling	6,803	$184	68	$69,934	340	$349,670	1,701	$1,749,376	1.16
Grazing Management	46,057	$79	461	$1,158,636	2,303	$5,788,156	11,514	$28,938,265	14.51
Riparian Buffer	130,714	$1,223	1,307	$54,632,963	6,536	$273,207,294	32,679	$1,365,993,988	6.67
Eastern Red Cedar Removal	3,559	$35	36	$46,899	178	$231,890	890	$1,159,449	11.56
Total	193,936	$2,027	1,939	$57,102,135	9,697	$285,545,525	48,484	$1,427,701,211	6.58

Table 11: Low Estimate of Total Net Present Value by BMP with 3% Discount Rate (2021$)

BMP	Total Acres	Benefits $/Acre/Year Low	1% of Total Acres	NPV $	5% of Total Acres	NPV $	25% of Total Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$505	68	$772,858	340	$3,864,291	1,701	$19,332,820	14.69
Conservation Tilling	6,803	$184	68	$46,505	340	$232,525	1,701	$1,163,307	1.16
Grazing Management	46,057	$79	461	$843,069	2,303	$4,211,686	11,514	$21,056,601	14.67
Riparian Buffer	130,714	$1,223	1,307	$35,990,649	6,536	$179,981,291	32,679	$899,878,411	6.33
Eastern Red Cedar Removal	3,559	$35	36	$30,675	178	$151,670	890	$758,350	9.85
Total	193,936	$2,027	1,939	$37,683,756	9,697	$188,441,463	48,484	$942,189,488	6.27

Table 12: Low Estimate of Total Net Present Value by BMP with 7% Discount Rate (2021$)

BMP	Total Acres	Benefits $/Acre/Year Low	1% of Total Acres	NPV $	5% of Total Acres	NPV $	25% of Total Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$505	68	$401,255	340	$2,006,277	1,701	$10,037,287	13.84
Conservation Tilling	6,803	$184	68	$25,751	340	$128,753	1,701	$644,144	1.16
Grazing Management	46,057	$79	461	$563,290	2,303	$2,814,008	11,514	$14,068,818	14.89
Riparian Buffer	130,714	$1,223	1,307	$19,459,241	6,536	$97,311,453	32,679	$486,542,016	5.63
Eastern Red Cedar Removal	3,559	$35	36	$16,325	178	$80,718	890	$403,588	7.33
Total	193,936	$2,027	1,939	$20,465,862	9,697	$102,341,209	48,484	$511,695,852	5.61

Table 13: High Estimate of Total Net Present Value by BMP with 0% Discount Rate (2021$)

BMP	Total Acres	Benefits $/Acre/Year High	1% of Total Acres	NPV $	5% of Total Acres	NPV $	25% of Total Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$620	68	$1,833,639	340	$9,168,197	1,701	$45,867,952	8.93
Conservation Tilling	6,803	$776	68	$2,142,432	340	$10,712,161	1,701	$53,592,313	4.91
Grazing Management	46,057	$555	461	$1,311,551	2,303	$6,552,067	11,514	$32,757,488	7.39
Riparian Buffer	130,714	$3,082	1,307	$107,161,571	6,536	$535,891,644	32,679	$2,679,374,432	2.09
Eastern Red Cedar Removal	3,559	$35	36	$43,195	178	$213,574	890	$1,067,871	2.97
Total	193,936	$5,068	1,939	$112,492,389	9,697	$562,537,644	48,484	$2,812,660,056	2.13

Table 14: High Estimate of Total Net Present Value by BMP with 1% Discount Rate (2021$)

BMP	Total Acres	Benefits $/Acre/Year High	1% of Total Acres	NPV $	5% of Total Acres	NPV $	25% of Total Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$642	68	$1,428,175	340	$7,140,876	1,701	$35,725,383	8.83
Conservation Tilling	6,803	$776	68	$1,688,578	340	$8,442,888	1,701	$42,239,273	4.91
Grazing Management	46,057	$79	461	$1,075,575	2,303	$5,373,208	11,514	$26,863,707	7.37
Riparian Buffer	130,714	$3,082	1,307	$80,488,991	6,536	$402,508,039	32,679	$2,012,477,114	1.99
Eastern Red Cedar Removal	3,559	$35	36	$32,144	178	$158,934	890	$794,671	2.67
Total	193,936	$4,615	1,939	$84,713,463	9,697	$423,623,946	48,484	$2,118,100,148	2.03

Table 15: High Estimate of Total Net Present Value by BMP with 3% Discount Rate (2021$)

BMP	Total Acres	Benefits $/Acre/Year High	1% of Total Acres	NPV $	5% of Total Acres	NPV $	25% of Total Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$642	68	$923,344	340	$4,616,719	1,701	$23,097,172	8.62
Conservation Tilling	6,803	$776	68	$1,122,877	340	$5,614,383	1,701	$28,088,429	4.91
Grazing Management	46,057	$79	461	$781,665	2,303	$3,904,933	11,514	$19,522,969	7.35
Riparian Buffer	130,714	$3,082	1,307	$47,368,569	6,536	$236,880,211	32,679	$1,184,363,686	1.79
Eastern Red Cedar Removal	3,559	$35	36	$18,430	178	$91,124	890	$455,622	2.17
Total	193,936	$4,615	1,939	$50,214,884	9,697	$251,107,370	48,484	$1,255,527,878	1.83

Table 16: High Estimate of Total Net Present Value by BMP with 7% Discount Rate (2021$)

BMP	Total Acres	Benefits $/Acre/Year High	1% of Total Acres	NPV $	5% of Total Acres	NPV $	25% of Total Acres	NPV $	Benefit-Cost Ratio
Cover Crops	6,803	$642	68	$477,653	340	$2,388,267	1,701	$11,948,362	8.11
Conservation Tilling	6,803	$776	68	$621,757	340	$3,108,784	1,701	$15,553,063	4.91
Grazing Management	46,057	$79	461	$520,757	2,303	$2,601,525	11,514	$13,006,494	7.27
Riparian Buffer	130,714	$3,082	1,307	$17,715,003	6,536	$88,589,366	32,679	$442,932,478	1.42
Eastern Red Cedar Removal	3,559	$35	36	$6,360	178	$31,447	890	$157,233	1.51
Total	193,936	$4,615	1,939	$19,341,530	9,697	$96,719,389	48,484	$483,597,630	1.46

Appendix C. Riparian buffer landcovers

Table 17: Riparian buffer landcovers

Streams	100m buffer (acres)	% of basin	Land Cover	Acres	% of buffer	% of basin
Mainstem	10,761	2.45%	Cropland	302	2.80%	0.07%
			Pasture	1,351	12.60%	0.31%
			Rangeland	1,336	12.40%	0.30%
			Eastern Red Cedar	58	0.50%	0.01%
Tributaries	43,656	9.94%	Cropland	395	0.90%	0.09%
			Pasture	6,142	14.10%	1.40%
			Rangeland	11,453	26.20%	2.61%
			Eastern Red Cedar	334	0.80%	0.08%
Intermittent	76,297	17.36%	Cropland	770	1.00%	0.18%
			Pasture	16,848	22.10%	3.83%
			Rangeland	21,737	28.50%	4.95%
			Eastern Red Cedar	962	1.30%	0.22%
All streams	130,714	29.75%	All	61,688	47.19%	14.04%

Appendix D. Limitations and Assumptions

This analysis has been necessarily general, due to a lack of details regarding where and how BMPs will be implemented in the Blue River basin. To address these uncertainties, we report benefits and costs as ranges. With additional site-level information, the calculations we presented here could be substantially refined.

Similarly, there is uncertainty regarding future conditions within the basin (e.g., water scarcity, climate). Accordingly, we assumed that current conditions continue throughout the project timeline. There are similar issues with market prices (e.g., fuel costs). We have attempted to account for these uncertainties by applying multiple discount rates.

Of course, any analysis is limited by the availability of relevant research. Performance of the BMPs presented here are still relatively under-studied in southcentral Oklahoma. We have thus been limited in our ability to estimate the biophysical impacts of these practices within the Blue River basin.

We assumed that the full potential of both biophysical and economic impacts will be captured within the initial years following implementation. However, it can be expected that when beginning a new practice, such as these BMPs, that the full impact will not be realized until the system is established. For example, it is known that cover crops can increase soil fertility, but this benefit takes time to reach its full potential. Because research on this dynamic is limited (especially in southcentral Oklahoma), we were unable to project the “maturity period” for each BMP.

Finally, we assume that all practices will be implemented within the first year. When calculating NPV with a positive discount rate, any benefits or costs occurring in the first year are not discounted. Where initial implementation costs are considerable, this tends to produce more conservative estimates of NPV and BCRs. Each would be affected by the pace at which adoption of BMPs spreads throughout the basin.