



Effect of Forest Cover on Drinking Water Treatment Costs

A Project funded by the American Water Works Association and the U.S. Endowment for Forestry & Communities Inc.

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Acknowledgements

Thanks to Pam Froemke of the USFS Rocky Mountain Research Station for providing GIS support and Linda Hills of The Cadmus Group, Inc. for technical support on drinking water treatment characterization. In addition, we would like to thank Randy Easley of Central Arkansas Water and Nancy Toth of Eugene Water and Electric Board for their contributions to the case studies for this project. Furthermore, we would like to express our gratitude for the sponsorship from the American Water Works Association's Technical and Educational Council and the U.S. Endowment for Forestry and Communities, which make this effort possible. Finally, a special thanks to all participating water utilities, members of the AWWA Source Water Protection Committee, Kelley Hart of the Trust for Public Land, and Kami Johle Butt, Ken Mercer, and Dawn Flancher of AWWA for their support.

Abstract

This paper explores the relationship between forest cover and drinking water treatment costs using results from a 2014 survey by the American Water Works Association (AWWA) that targeted utilities in forested ecoregions in the United States. On the basis of the data collected, there is a negative relationship between forest cover and turbidity, i.e. as forest cover increased, turbidity decreased. However, the relationship between land use and total organic carbon (TOC) is not statistically significant. Within the bounds of the collected data, a conversion of 1% of a watershed from forested to developed land is associated with an increase in turbidity by 3.9%. Because water treatment needs are impacted by both TOC and turbidity, increase in either parameter will result in an increase in chemical costs. The lack of a strong relationship between land use and TOC has weakened the influence of land use change on water treatment cost.

Introduction

This paper explores the relationship between forest cover and drinking water treatment costs. Over the past decades, water utilities in the United States have spent millions of dollars on protecting and improving their water sources as part of a multiple barrier approach to ensure the delivery of safe drinking water. Given the complex nature of watershed protection and governance, however, it is difficult to directly quantify the benefits associated with various protective measures. While a definitive measure of the value of watershed protection has been elusive, the pieces of the puzzle are nonetheless coming together.

Forested lands are the source of over half of the surface water supplies in the 48 contiguous United States (Brown et al. 2008) and provide drinking water to approximately 212 million Americans through public and private water systems (EPA, 2011). Nearly all of the US's forests are facing pressures from urbanization and agriculture (Riitters et al., 2002), pressures that are expected to increase leading to even greater loss and forest fragmentation (Stein et al. 2007, Johnson and Beale 2002, Radeloff et al 2005). This loss of forests is diminishing the landscape's ability to provide key ecosystem services, particularly services related to the provision of safe drinking water (Foley et al 2005, Smail and Lewis 2009).

That there is a relationship between water quality and treatment costs is generally taken as a given, as evidenced by the EPA's drinking water treatment unit cost models which can estimate the costs for most modern treatment technologies (EPA, 2014). Regional variations in costs associated with turbidity have been shown by Moore and McCarl (1987), who found a one percent reduction in turbidity reduced water treatment costs by 0.67 percent in northwestern Oregon; Forster, Bardos, and Southgate (1987), who reported a 10 percent reduction in soil erosion in Ohio's corn belt could reduce treatment costs by four percent; and Dearmont, McCarl, and Tolman (1998) who found a one percent reduction in turbidity led to a 1/4 percent reduction in treatment costs in Texas. Using data from a 1986 national survey of water treatment plants by the American Water Works Association (AWWA), Holmes (1988) found a one percent increase in turbidity led to a 0.07 percent increase in operating and maintenance costs; most utilities in this dataset with raw water turbidity levels above 10 NTUs (Nephelometric Turbidity Units) used conventional treatment methods, indicating a possible

threshold for water quality at which direct filtration methods are either not effective or not economical.

Literature linking loss of forests to diminished water quality focuses on two relationships. First, non-forest land uses tend to add more pollutants to water than undisturbed forests, and second, forests have the ability to remove pollutants from the water flowing through them (Hill, 1996). Lenat and Crawford (1994) showed that among forested, agricultural, and urban land uses in the North Carolina Piedmont, water from agricultural lands had the highest levels of nutrients. Tong and Chen (2002) found total nitrogen, total phosphorous, and fecal coliform levels in Ohio streams had strong positive relationships with commercial, residential, and agricultural land use upstream; whereas, levels of these same pollutants were negatively related to forested lands. Similar results were found in a comparative analysis of all US watersheds by Hascic and Wu (2006). Tong (1990) and Bolstad and Swank (1997) showed first flush storm events in urban areas and high storm events immediately following changes in land use have particularly strong negative impacts on downstream water quality, which are more pronounced in areas that contain headwater streams, because in general, headwater streams generate much of the streamflow in downstream areas (MacDonald and Coe, 2007).

Studies directly linking land use to water treatment costs primarily reside in non-peer reviewed reports and white papers. The most widely cited work is from a 2002 survey of 27 water suppliers by the Trust for Public Land (TPL) and AWWA (Ernst et al. 2004). The study found a negative relationship between treatment costs and percent of the watershed in forest cover. Freeman et al. (2008) expanded the 2002 survey to 40 treatment plants and found both turbidity and total organic carbon (TOC) decrease with forest cover, and that treatment costs increase with TOC. No significant effect of turbidity on treatment costs in these watersheds was reported.

Two key goals of this current work are to update the data used in Holmes (1998) and Freeman et al. (2008), and to further explore the role of forests on water treatment costs. With those goals in mind, this paper proceeds as follows: The next section describes methods and data used in the analysis, including a survey administered by AWWA for this study. We then present results showing that forest cover affects water quality and that water quality affects

costs. Specific cost savings and implications of the results are presented in the discussion section, followed by concluding remarks.

Methods and Data

The effect of land use on the cost of water treatment was modeled using a two-step process. In the first step, it is taken that land use affects water quality through an ecological production function. In the terminology of Keeler et al. (2012), water quality is the ecological end product, or “valued attribute”, often modeled or measured by biophysical assessments. The second step of the model relates water quality to treatment costs through an economic benefits function that estimates avoided chemical costs for water treatment associated with forest cover in the watershed.

Ecological production function

Raw water enters treatment plant i after flowing through the watershed upstream of its intake. The quality Q_i of that water is determined by a vector of characteristics called STRESSORS_i . STRESSORS_i include land development, roads, and agriculture that take place in the watershed. We focus on two measures of water quality relevant to water treatment: turbidity, measured in NTUs, and the level of total organic carbon (TOC), measured in mg/L. The basic hypothesis is that under normal conditions water from forested lands has better water quality (e.g., lower turbidity) than water originating from land used for other purposes. Forests have been shown to directly remove pollutants from water, stabilize surrounding soils to reduce sediment runoff, and limit exposure to pollutants by limiting human activity within the watershed. This study considered six land use types: forest, rangeland, developed area, agricultural area, water, and barren land. The variable LANDUSE_i gives the percentage of each land use in the watershed, with forests serving as the reference land use.

Intakes of water treatment facilities are located either on rivers or reservoirs. Reservoirs provide an opportunity for solids to settle out and so they will remove some of the sediment before the raw water enters the treatment plant, therefore, in general, lower turbidity is expected at intakes in reservoirs when compared to intakes in rivers. For this study, the binary variable RIVER_i is set to 1 if the intake is on a river.

This study used a multivariable regression model where the response and continuous STRESSORS variables are log transformed as described in the following:

$$\log(Q_i) = \beta_0 + \beta \text{ LANDUSE}_i + \gamma \log(\text{STRESSORS}_i) + \delta_i \text{ RIVER}_i + \varepsilon_i$$

where Greek letters represent regression coefficients; β_0 is the intercept term, β is the marginal effect of a change in land use in the watershed, γ is a vector of coefficients for the independent variables, δ is the marginal effect of a river intake on water quality, and ε is an error term.

Economic benefits function

Water utilities strive to minimize their operating costs while meeting all drinking water standards. Utilities must choose treatment technologies appropriate for their water sources; potable water treatment typically includes adding chemicals to remove impurities and disinfect the water. The respondents to the 2014 AWWA survey are associated with four types of treatment trains, namely:

- Unfiltered/disinfection only – Unfiltered systems provide only disinfection. Unfiltered systems are required to provide at least two forms of disinfectants (e.g., ozone and chloramine).
- Direct – Direct filtration systems use coagulation, flocculation, filtration, and disinfection. These systems do not have a sedimentation step.
- Conventional – Conventional filtration systems use coagulation, flocculation, sedimentation, granular media filtration (e.g., sand, anthracite) and disinfection.
- Advanced – Advanced filtration systems first use pretreatment for solids removal followed by membrane filtration for particles (via microfiltration or ultrafiltration) or dissolved constituents (via nanofiltration or reverse osmosis).

Common water treatment chemicals include alum for coagulation and flocculation, sometimes augmented with various polymers; lime and caustic soda for pH adjustment; and chlorine, chlorine dioxide, and chloramines for disinfection. Some systems also add potassium

permanganate as an oxidant and for taste and odor control, polyphosphates for corrosion control, and fluoride for dental benefits. Ozone and UV may also be used for primary disinfection.

The economic benefits function is expressed as:

$$\log(\text{COST}_i) = \beta_0 + \beta_Q \log(Q_i) + \beta_{pop} \log(\text{SIZE}_i) + \beta_{dr} \log(\text{DRAINAGE}_i) \\ + \beta_c \text{CONVENTIONAL}_i + \beta_d \text{DIRECT}_i + \beta_a \text{ADVANCED}_i + v_i$$

where Greek letters represent regression coefficients; β_0 is the intercept term, β_x are the regression coefficients associated with various independent variables. Average chemical treatment cost (COST_i) is measured in dollars per million gallons treated. We, therefore, control for total daily volume of water produced (SIZE_i) measured in million gallons per day. DRAINAGE indicates the size of the watershed in square kilometers. CONVENTIONAL, DIRECT, and ADVANCED are dummy variables indicating the type of treatment plant; unfiltered plants serve as our reference case. The random variable v_i is assumed to be normally distributed with mean zero and constant variance.

Data

Data from a 2014 AWWA survey was used as the basis for this study. The survey targeted AWWA member utilities in forested ecoregions in the United States and collected their chemical costs of water treatment. These survey results were combined with raw water qualities and data on watershed conditions collected through this study to estimate the effect of forest cover on turbidity and TOC, and the effect of turbidity and TOC on chemical use in treatment.

American Water Works Association survey

AWWA, established in 1881, is the largest nonprofit, scientific and educational association dedicated to managing and treating drinking water. In early 2014, the AWWA Technical and Education Council, in partnership with the U.S. Endowment of Forestry and Communities, supported a study to examine the value of watershed protection as it relates to reducing the cost of water treatment. To reduce the confounding impacts associated with making comparisons between drastically different ecoregions, this study focused on utilities with intakes in forested ecoregions. In general, water utilities located in Eastern Temperate Forest and Northwestern Forested Mountains were targeted for this study (Grey area in Figure 1).

Figure 1. Ecoregions of survey respondents. Grey areas indicate the Level III Ecoregions targeted for the survey.



Note: North America has been divided into ecological regions (ecoregions) that provide the broad backdrop to the ecological mosaic of the continent. At level I, there are 15 broad ecological regions in North America. There are then 50 level II ecoregions that have been delineated to provide a more detailed description of the large ecoregions nested within the level I ecoregions. Level III mapping

describes smaller ecoregions nested within level II regions. At level III, the continent currently contains 182 ecoregions that enhance regional environmental monitoring, assessment and reporting.

A list of all zip codes falling within the chosen ecoregions was compiled and matched to the AWWA membership list. Email requests were sent to utilities inviting their participation. An initial “long version” of the survey asked respondents to characterize their treatment processes and all chemicals used (typically alum or other coagulants, polymers, copper sulfate, corrosion control chemicals, and disinfection chemicals). Systems were asked to identify the quantity of each chemical used during the survey period, the cost per unit (gallon or pound), and the total cost of that chemical for that survey year. The summed chemical costs were then normalized to a cost per gallon by dividing by the gallons produced by the plant for the year. The survey also asked for information on the following water quality variables for each water system: minimum, median, and maximum raw water turbidity in NTUs during the most recent calendar year for which water treatment plants had data; minimum, median, and maximum raw water TOC in mg/L during the most recent calendar year for which water treatment plants had data; intake location; and raw water source (reservoir or river). A second round of data was collected via a shortened version of the survey, focusing only on chemical costs and raw water quality, and dropping many of the specifics about what chemicals were used and in what amounts.

The final dataset contains 37 responses at the water intake level; any responses that were either unclear or seemed incorrect based on knowledge of the treatment plants’ watersheds and treatment processes were confirmed via phone call. Based on the results of the survey and phone calls, each water system was classified into 1 of 4 types of treatments. Of the 37 treatment plants in the dataset, 26 treatment plants used conventional treatment, 7 treatment plants used direct treatment, 2 treatment plants used advanced treatment, and 2 treatment plants had no treatment except disinfection.

Watershed data

Survey respondents provided the Public Water System Identification (PWSID) number for each of their water treatment plants, and these were used to match the treatment plant with its watershed based on locations from the EPA’s Safe Drinking Water Information System (SDWIS). Percentages of land cover in each category were based on the 10-digit hydrologic unit

code (HUC) watershed containing the intake using the 2011 USGS National Land Cover database (NLCD). Data from the NLCD included watershed drainage area in square kilometers, percent of land in forest, water, rangeland, developed, agriculture, and barren use. Data on stressors were taken from Brown and Froemke (2012), who examined the spatial distribution of nonpoint source threats for over 15,000 10-digit HUC watersheds throughout the US. Data from Brown and Froemke included watershed population, kilometers of roads in each watershed, and animal units in each watershed.¹

Descriptive statistics

Table 1 presents descriptive statistics for the survey and watershed data. Because the majority of the sample is treatment plants with conventional treatment (26 out of 37 observations), descriptive statistics for this subsample were also provided.

The average median turbidity reported by respondents is 8.1 NTU, with a standard deviation of 16.3 NTU. These statistics are influenced by 1 outlier in the dataset with a median turbidity of 100 NTU. If we exclude this observation (it is not included in the statistics of conventional treatment), the average turbidity level is 5.5 NTU with a standard deviation of 5.1 NTU. Excluding this outlier has little effect on the ecological production function but does reduce the significance of coefficients in the economic benefits function. Compared with turbidity, TOC levels are less variable. The average of the median TOC from all treatment plants is 2.6 mg/L, with a standard deviation of 1.7 mg/L.

¹ An animal unit is a normalization that accounts for differential impacts of livestock on the land; weights are chosen so one cow equals one animal unit.

Table 1 - Summary Statistics

Variables	All treatments (N=37)				Only conventional treatment (N=26)			
	Mean	St. dev.	Min	Max	Mean	St. dev.	Min	Max
Min turbidity (NTU)	1.52	1.66	0.07	10	1.40	0.83	0.07	3.2
Max turbidity (NTU)	92.03	167.8	0.68	825	96.56	165.98	1.42	825
Median turbidity (NTU)	8.07	16.34	0.30	100	6.66	5.41	0.52	23
Min TOC(MGL)	1.66	1.08	0.33	6	1.75	1.15	0.33	6
Max TOC (MGL)	4.66	4.51	1	25	5.23	5.08	1.25	25
Median TOC (MGL)	2.55	1.68	0.65	7.36	2.78	1.74	0.65	7.36
Forest area (%)	60%	18%	5%	86%	57%	19%	5%	86%
Developed area (%)	14%	13%	1%	48%	17%	14%	1%	48%
Agriculture area (%)	3%	4%	0%	19%	3%	5%	0%	19%
Water area (%)	2%	2%	0%	11%	2%	2%	0%	11%
Barren area (%)	0%	0.9%	0%	5%	0%	1%	0%	2%
Rangeland area (%)	21%	12%	6%	61%	21%	9%	6%	43%
Watershed drainage area (km2)	494	203	197	981	457	185	197	920
Watershed population (2000 census)	81,334	95,980	5,319	348,824	101,788	106,998	5,737	348,824
Roads density (km/km2)	2,295	1,141	937	5,996	2,535	1,265	937	5,996
Animal Units per watershed (weighted average)	4,802	4,587	533	20,113	4,275	3,422	533	13,489
Chemical treatment costs (\$/MG)	105.32	92.36	4.96	493.37	106.23	101.73	9.64	493.37
Water production (MGD)	48.5	179.00	0.06	1,100	24.08	24.07	0.06	90

Note: The statistics for TOC are estimated only with 35 observations for all treatments, and 25 observations for only conventional treatment. Turbidity and TOC are associated with the source water, not treated water

Average water production in our study dataset is 48.5 MGD with a standard deviation of 179 MGD. This statistic is skewed by one outlier treatment plant with 1,100 MGD of water production. Eliminating this outlier lowers the average water production to 19.3 MGD with a standard deviation of 3.7 MGD. The models were evaluated with and without this outlier and minimal changes in coefficients and significance levels were observed.

Chemical treatment costs vary from a minimum of \$4.96 per million gallons (MG) treated to a maximum of \$489.87 per MG treated. The average cost is \$105.3 per MG with a standard deviation of \$92.4 per MG. These values are fairly similar to values reported in Freeman et al (2008) in which they reported a mean of \$94.4, standard deviation of \$76.4, minimum of \$14.3, and maximum of \$391.4.

Differences in treatment costs were observed when comparing the water quality from rivers and reservoirs, as well as between plants using conventional treatment and plants using other types of treatment. Fourteen of the 37 responses have intakes on rivers. These 14 systems were found to have higher and more variable average levels of turbidity. TOC levels are not statistically different between intakes on rivers and intakes on reservoirs (see Table 2).

In comparison to the rest of the dataset, the conventional treatment plants have lower values for median turbidity, larger watershed populations, and fewer animal units in their watersheds. The average chemical cost for conventional treatment plants, however, is not significantly different than that for the whole dataset. Direct treatment, on average, has the highest chemical costs followed by conventional and advanced treatment (Table 3). The extremely low costs for plants without filtration show the benefits of filtration waivers for treatment plants in watersheds with raw water quality. Not surprisingly, population density, developed area, and road density are highly correlated with each other (Table 4). Road and population densities were therefore excluded as explanatory variables in the models to avoid problems with multicollinearity.

Table 2 - Differences in Median, Max and Min of Turbidity and TOC by Source

	Turbidity			TOC		
	Median	Min	Max	Median	Min	Max
River	14.3	2.0	169.8	2.4	1.6	5.6
Reservoir	4.3	1.2	44.7	2.6	1.7	4.1
p-value	0.035	0.072	0.013	0.622	0.669	0.187

Table 3 - Summary Statistics for Costs by Type of Treatment in \$/MG

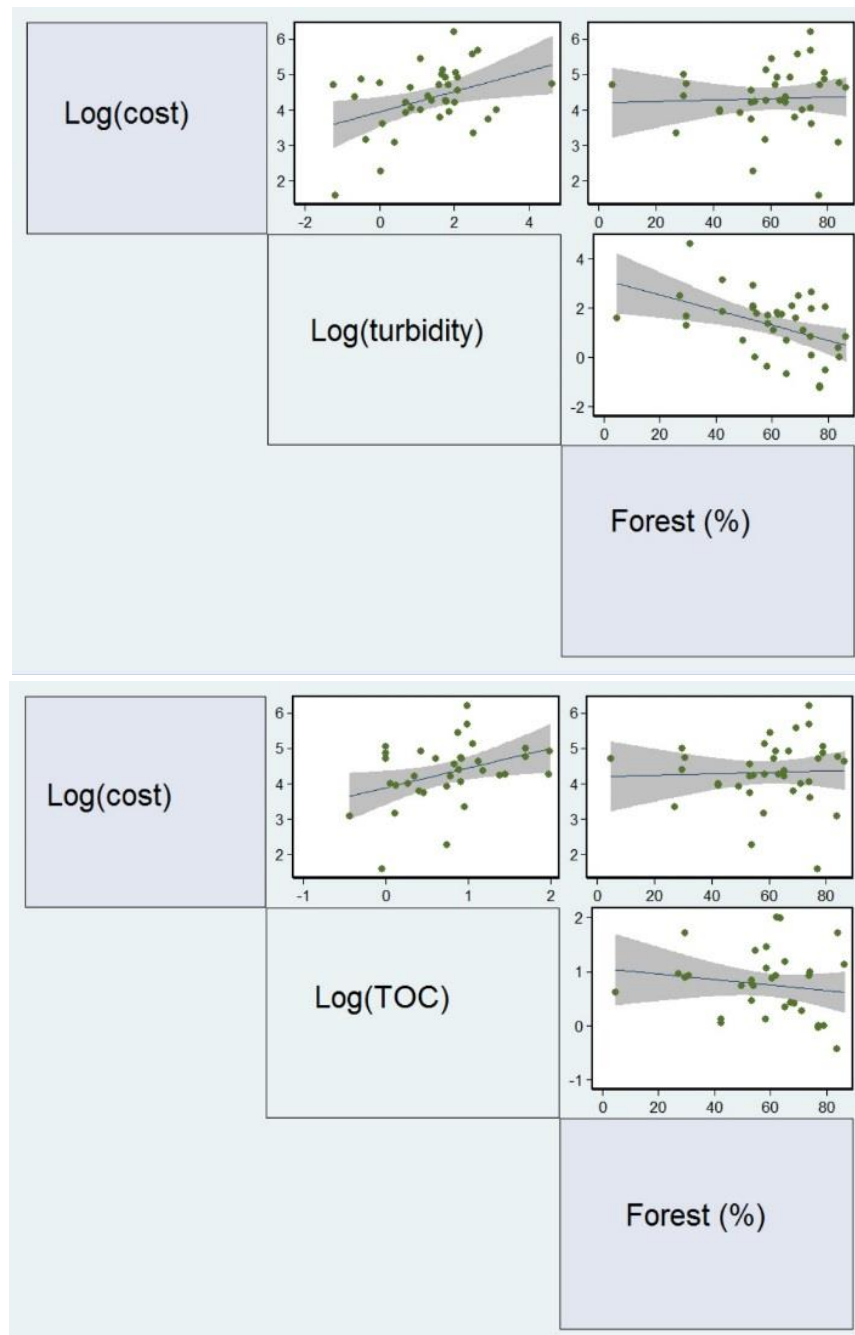
	Obs.	Mean	St. Dev.	Minimum	Maximum
Disinfection only/No Filtration	2	20.8	22.4	5.0	36.7
Conventional Treatment	26	106.2	101.7	9.6	493.4
Direct Treatment	7	133.7	63.3	23.5	229.9
Advanced Treatment	2	78.6	49.2	43.8	113.4

Table 4 - Correlation of Regressors

Correlations	Forest area (%)	Dev. area (%)	Water area (%)	Ag area (%)	Barren area (%)	Range area (%)	Road density (km/km2)	Pop density (pop/km2)	Animal units density (AU/km2)
Forest area (%)									
Dev. area (%)	-0.67								
Water area (%)	-0.25	0.26							
Ag area (%)	-0.49	0.04	0.21						
Barren area (%)	-0.08	0.14	0.09	-0.14					
Range area (%)	-0.58	-0.14	-0.19	0.33	0.08				
Road density (km/km2)	-0.51	0.94	0.18	-0.08	0.12	-0.26			
Pop density (pop/km2)	-0.63	0.97	0.21	0.003	0.11	-0.14	0.96		
Animal units density (AU/km2)	-0.05	-0.21	-0.07	0.38	-0.24	0.21	-0.26	-0.26	

Figure 2 shows scatterplots of the data. Initial evidence suggests a positive relationship between treatment costs and both turbidity and TOC and a negative relationship between forest cover and both turbidity and TOC. Relationship between forest cover and treatment costs are less clear. These figures explain, in part, why finding meaningful relationships between forest cover and water treatment costs have been elusive even when relationships between the components seem apparent.

Figure 2: Scatter plots of data. Simple visual inspection of the data shows univariate relationships between water quality and costs and between water quality and forest cover are not straightforward. The two-step connection between costs and forest cover, therefore, are likely to be even more complicated. The first panel shows the relationships between cost and TOC, between TOC and forest cover, and between cost and forest cover. The second panel shows the relationships between cost and turbidity, between turbidity and forest cover, and between cost and forest cover. Grey areas indicate 95 percent confidence intervals around the blue linear trend line.



Results

Ecological production function

Table 5 gives results for the ecological production functions. Five models were used to test the relationship between forest cover and water quality. Columns (1) to (3) give results for the models using turbidity measures for water quality. Column (1) gives results using the full dataset; column (2) omits an outlier with extremely high turbidity; and column (3) gives results for the subset of data that only includes conventional treatment plants. Columns (4) and (5) provide results for the models using TOC measures for water quality. Because the dependent variable is logarithmic and the independent variables are linear, the coefficients need to be transformed to interpret them. If the estimated coefficient for a land use in this regression is b_x , a z percent change from forest cover to that land use will indicate a $e^{z*b_x} - 1$ percent change in water quality.

Table 5 -Ecological production functions

Dependent variable:	Log(median turbidity)			Log(median TOC)	
	(1)	(2)	(3)	(4)	(5)
Developed area (%)	0.038*** (0.012)	0.039*** (0.013)	0.033** (0.014)	-0.003 (0.008)	-0.012 (0.01)
Agriculture area (%)	-0.093** (0.041)	-0.082* (0.043)	-0.11** (0.045)	-0.010 (0.028)	-0.001 (0.035)
Rangeland (%)	0.061** (0.015)	0.049** (0.020)	0.052** (0.022)	0.016 (0.010)	0.018 (0.017)
Barren area (%)	-0.40** (0.18)	-0.38** (0.18)	-0.28 (0.36)	-0.038 (0.12)	0.29 (0.27)
Water area (%)	0.007 (0.08)	0.002 (0.076)	-0.0023 (0.075)	0.065 (0.052)	0.027 (0.056)
Source (River =1; Reservoir = 0)	0.74* (0.32)	0.69** (0.33)	0.43 (0.33)	-0.20 (0.22)	-0.11 (0.26)
Animal units density (AU/km2)	0.031 (0.028)	0.039 (0.030)	0.025 (0.030)	0.01 (0.02)	0.001 (0.025)
Constant	-0.60 (0.49)	-0.47 (0.52)	-0.038 (0.62)	0.36 (0.34)	0.56 (0.47)
Obs.	37	36	26	35	25
R-squared	0.56	0.46	0.41	0.18	0.24
Regression characteristic:	All observations	1 outlier eliminated (100 NTU)	Only conventional treatment	All observations	Only conventional treatment

Notes: *** p-value<0.01; ** p-value<0.05; * p-value<0.1.; Std. errors are in parenthesis.

In general, there is a negative relationship between forest cover and turbidity. Converting 1% of the forested land in a watershed to developed area increases turbidity by $\exp(0.038) - 1 = 3.9\%$ (with ± 1 standard deviation (SD) = 2.6% to 5.1%). Converting 1% of the forested land to rangeland increases turbidity by $\exp(0.061) - 1 = 6.3\%$ (with ± 1 SD = 4.7% to 7.9%).

Agriculture and barren land decrease turbidity in the model, but there is not enough of either land use in the dataset to make this definitive. The median amount of agricultural land in the watersheds we studied is 3%, with a maximum of 19%. The treatment plant with the largest amount of agriculture in its watershed draws water from a reservoir filled with water diverted from a mountain creek 16 miles away. The reservoir is surrounded by a well-maintained park and so is not likely to experience direct agricultural runoff. The treatment plant with the second largest percent of its watershed in agriculture draws its water from Lake Ontario. If both of these observations are eliminated from the dataset, no significant effect from agriculture is observed. Animal units have no measurable impact on turbidity, and it should be noted that the level of animal units in the watersheds is also low. While the intuition would point to a position association between agricultural land use and turbidity of the receiving water, because of data limitation, it does not appear to be a concern for this study in general. A study with an agricultural land use focus, in contrast to a forestry focus, can be conducted to quantify the relationship between agricultural land use and water quality. As noted earlier, we have found that water from river intakes has much higher turbidity levels than water from reservoir intakes.

No relationship was found between land use and TOC level. TOC in source water comes from decaying natural organic matter (e.g., decaying leaves from deciduous trees) and agricultural activities (e.g., crop residuals after harvest) in the watershed. Lack of large scale agriculture in the study dataset could explain the low variability in TOC levels, and therefore, the lack of significance of coefficients in our analysis of TOC.

Economic benefits function

Table 6 provides results for the economic benefits function. Chemical costs are reported in dollars to treat one million gallons of raw water, which was estimated by dividing annual

chemical costs by average annual amount of water produced. Column (1) gives results using the full dataset; column (2) omits the outlier with extremely high turbidity; and column (3) gives results for the subset of data that only includes conventional treatment plants. Because the dependent variable is logarithmic, coefficients for log transformed variables are interpreted as the percentage change in the cost resulting from a percentage change in turbidity, TOC, and size of treatment plant. Interpreting the effects of treatment type dummy variables requires transformations as discussed above for log-linear models.

We find positive and significant effects of turbidity and TOC for costs in the full model, with TOC having a larger effect than turbidity. A one percent increase in turbidity increases costs by 0.19 percent (with +/- 1 SD = 0.08% to 0.30%); a one percent increase in TOC increases costs by 0.46 percent (with +/- 1 SD = 0.27% to 0.65 %). There is 1 outlier for turbidity in the sample (100 NTU) that could be influencing the results, so the same regression was made without this outlier (column 2). The coefficient on turbidity becomes insignificant when this outlier is omitted, though it does not change in magnitude.

The size of the treatment plant, measured in million gallons of water treated per day, reduces average cost of treatment. This result is consistent with other findings that economies of scale exist for water treatment, related to both cost savings from larger infrastructure and from market power when negotiating chemical costs. Not surprising, other types of treatment methods are more expensive than those that provide disinfection only (no filtration). Among the other types of treatment, chemical costs are lowest for advanced treatment plants, followed by conventional treatment, then direct treatment. These results are consistent with economic intuition – unit variable costs should be inversely related to the fixed capital costs required to operate the plant. Advanced treatment plants have higher fixed costs than conventional treatment plants, which higher fixed costs than direct filtration plants.

Table 6 - Economic Benefits Function

	All types of treatment	All types of treatment	Only conventional treatment
Dependent variable:	Log(cost)	Log(cost)	Log(cost)
	(1)	(2)	(3)
Log(turbidity)	0.19* (0.11)	0.19 (0.13)	0.22 (0.15)
Log(TOC)	0.46** (.19)	0.46** (0.19)	0.51** (0.22)
Log(million gal / day)	-0.19** (.07)	-0.19** (0.08)	-0.2** (.08)
Conventional (Conventional treatment =1; Otherwise = 0)	1.89** (0.73)	1.91** (0.75)	
Direct (Direct treatment =1; Otherwise = 0)	2.5*** (0.70)	2.51*** (.71)	
Advanced (Advanced treatment =1; Otherwise = 0)	1.48 (0.91)	1.45 (0.97)	
Constant	2.19*** (0.65)	2.19*** (0.66)	4.03*** (0.39)
Obs.	35	34	25
R-squared	0.59	0.59	0.43
Regression characteristic:	All observations	1 outlier eliminated (100 NTU)	Only conventional treatment

Notes: *** p-value<0.01; ** p-value<0.05; * p-value<0.1.; Std. errors are in parenthesis.

Discussion

The data presented show potential increase in the cost of chemicals for water treatment resulting from loss of forest cover. However, it should be noted that the analyses for this study are limited by a relatively small dataset (n=37), lack of randomization, and highly variable data values. The average watershed in our sample is 60% forested area. The effect of loss of forest on source water turbidity and associated cost increases were estimated first. Then, because the effect of forest loss on TOC is not statistically significant, the effect of increases in TOC on costs were estimated without connection to forest loss. It should be noted that this two-stage modeling process does not propagate errors associated with fitting the TOC or turbidity models to the cost models. Therefore, no statements can be made on the statistical significance and confidence intervals for the estimates calculated in this section, the difficulty of which is demonstrated in the scatter plots in Figure 2.

It was estimated that converting 10 percent of the average watershed from forest to developed area would increase chemical treatment costs from \$2.52 to \$20.48 annually per million gallons treated (i.e., +/- 1 SD).

While no relationship was found between land use and TOC levels in this dataset, increases in TOC were shown to increase treatment costs, specifically, a one percent increase in TOC in the average watershed increases costs by 0.46 percent (with +/- 1 SD = 0.27% to 0.65%). A one percent increase in TOC would increase costs by from \$0.28 to \$ 0.68 (+/- 1sd) annually per million gallons treated. [Note: The chemical costs associated with the treatment plants in the survey range from \$6,000 to \$3,519,000 after the exclusion of the outlier mentioned above.]

Freeman et al. (2008) found that a 1% increase in forest cover reduces turbidity by 0.5 NTUs (with a sample mean of 3.4 NTU, that reduction is equal to an 18% decrease in turbidity) and reduces TOC by 0.6 mg/L (with a sample mean of 3.3 mg/L, that reduction is equal to a 16% decrease in TOC). For this study, the effect of development in the sample watersheds on turbidity is less than this, and the current study did not find a statistically significant relationship between TOC and forest cover. Both the Freeman and current studies did find a statistically significant relationship between TOC and chemical costs. Using the means and the most conservative value for TOC level for the average treatment plant (\$94 per million gallons in chemical costs), a 1% increase in forest cover would reduce chemical costs related to TOC by about 0.14%; this is reasonably close to the results of this study.

Freeman et al. (2008) did not find a relationship between turbidity and chemical costs, and the relationship for the sample in this study becomes insignificant when one outlier with high turbidity levels is not included. Intuitively, higher turbidity levels should lead to higher costs. Perhaps treatment plants are responding to higher turbidity levels with capital improvements and well-placed reservoirs upstream of treatment – decisions that are not included in this study's data. This relationship warrants more research.

Ernst et al. (2004) found a negative, nonlinear relationship between forest cover and chemical costs. In their estimation, a 1% increase in forest cover was associated with a 2% decrease in chemical treatment costs for water systems located in watersheds with 50% of forested cover. Our results are lower, but of the same magnitude. Ernst et al. (2004) also failed

to find significant cost savings associate with increased forest cover in watersheds with more than 60% forest cover. In our sample, 21 out of 37 water systems have forest cover higher than 60%. In the study by Ernst et al., only 2 water systems had forest covers higher than 60%. Roads, deforestation, and initial conversion of forests to other uses have been shown to be the largest contributors of sediment in forested watersheds, exacerbated by increased runoff and greater variation in flow associated with these activities (Bormann and Likens, 1979; Knapp and Matthews, 1996; Richards, Johnson, and Host, 1996; Sidle and Sharma, 1996). Proportional increases in sediment are therefore larger when development takes place in a highly forested watershed than when the same amount of development takes place in a highly developed watershed.

Case Studies

As a part of this project, we worked with two water utilities to learn about their efforts in monitoring and protecting their source waters. These utilities are Central Arkansas Water (CAW) in Arkansas and Eugene Water and Electric Board (EWEB) in Oregon.

For CAW, the water quality of Lake Maumelle (the source water reservoir for the case study) is very good in general but has degraded slightly over the past two decades. Chlorophyll a, total organic carbon (TOC), and turbidity have all increased from 1994 to 2014. Without proper land use management in the watershed, future water quality conditions could exceed source water quality criteria that might threaten public health and/or require costly added treatment. Over the past decade, CAW has been implementing various parts of their Lake Maumelle Watershed Management Plan. In addition, CAW has increased its monitoring efforts of the watershed and lake water quality to gauge the outcomes of their source water protection efforts. A more detailed description of CAW's source water protection program is included as Appendix A of this document.

For EWEB, their comprehensive Drinking Water Source Protection Program was developed in 2001 to address the multiple threats to their valuable resource from urban runoff, agricultural activities, forest management activities, hazardous material spills, development and septic systems. EWEB's program involves working with a variety of partners to engage McKenzie watershed landowners and stakeholders using voluntary approaches. EWEB spends over \$700,000 annually on its source protection program, which includes 2.75 staff. EWEB's

source protection staff is working with management to enact a watershed stewardship fee on the utility's bill to provide a more predictable and sustainable source of funding for source water protection going forward. EWEB recognizes that the McKenzie watershed is an extremely valuable asset. Although the natural services that it provides are not financially accounted for in traditional economic models, new methods are being developed to place a value on this 'natural capital.' In 2010, EWEB conducted a watershed valuation, which estimated the annual value of McKenzie watershed ecosystem services at between \$248 million to \$2.4 billion. Services include things such as water supply, flood mitigation, soil erosion control, etc. A more detailed description of EWEB's source water protection program is included as Appendix B of this document.

Concluding Remarks

Evidence was found that forest cover reduces the cost of treating water by improving water quality at the intake. The clearest link found is between forest cover and turbidity. A relationship between forest cover and TOC levels was not observed, though the link between TOC and treatment costs is clear. These results are in line with the literature that healthy (i.e., forested) watersheds reduce treatment costs. Of course, there are many confounding factors that complicate these relationships. Atmospheric deposition of nitrogen species, weather, soil or geology characteristics, agricultural practices, pesticide application, water hardness, and presence of naturally occurring organic matter (e.g., fallen leaves and decaying wetland plants) all affect treatment costs. Costs to water treatment plants are also affected by sudden extreme events, like wildfires and landslides. No one study can generally address all these site-specific issues, but this study provides additional supporting evidences that improving ecosystems services of forests contribute to the multiple barrier approach to water treatment.

It is acknowledged that some treatment plants are less reliant on chemical addition than others. For example, plants that use membrane filtration are more likely to have higher capital costs and use more energy, but may have lower chemical costs than a conventional or direct filtration plant, even though they may be treating lower quality water. Similarly, systems that use UV disinfection will have a lower disinfection chemical cost than those that use only

chemical disinfection but will likely have higher energy costs. The results of this study are consistent with this potential tradeoff between capital investments and operational costs.

Finally, the provision of safe drinking water is but one ecosystem service forests provide. Additional benefits would accrue from enhancements in wildlife habitat and recreation opportunities. The results of this study should be taken as a lower bound for the value of forest protection.

References

- Bolstad, P. V., and Swank, W. T. (1997). Cumulative impacts of landuse on water quality in a southern Appalachian watershed. *Journal of the American Water Resources Association*, 33(3), 519-534.
- Bormann, F. H., and Likens, G.E. (1979). Catastrophic disturbance and the steady state in northern hardwood forests: A new look at the role of disturbance in the development of forest ecosystems suggests important implications for land-use policies. *American Scientist*: 660-669.
- Brown, T.C., Hobbins, M.T., and Ramirez, J.A. (2008). Spatial distribution of water supply in the coterminous United States. *Journal of the American Water Works Association*, 44(6): 1474-1487.
- Brown T. C and Froemke, P. (2012). Nationwide Assessment of Nonpoint Source Threats to Water Quality. *Bioscience*, 62(2): 136-146.
- Dearmont, D, McCarl, B., and Tolman, D. A. (1998). Costs of water treatment due to diminished water quality: a case study in Texas. *Water Resources Research*, 34(4): 849-853.
- EPA (U.S. Environmental Protection Agency). (2014). Work breakdown structure-based cost models for drinking water treatment technologies, available online at <http://www.epa.gov/dwregdev/drinking-water-treatment-technology-unit-cost-models-and-overview-technologies>.
- Ernst C., Gullick R., and Nixon, K. (2004). Protecting the Source: Conserving Forests to Protect Water. *American Water Works Association*, Vol. 30, No. 5.
- Foley, J.A., DeFries, R., Asner, G.P., Barford, C., Bonan, G., Carpenter, S.R., Chapin, S., Coe, M.T., Daily, G.C., Gibbs, H.K., and Helkowski, J. H. (2005). Global consequences of land use. *Science*, 309(5734), 570-574.
- Forster, D. L., Bardos, C. P., and Southgate, D. D. (1987). Soil erosion and water treatment costs. *Journal of Soil and Water Conservation*, 42(5): 349-352.
- Freeman, D., Madsen, R., and Hart, K. (2008). Statistical analysis of drinking water treatment plan costs, source water quality, and land cover characteristics. *Trust for Public Land*.
- Hascic I. and Wu, J. (2006). Land Use and Watershed Health in the United States. *Land Economics*, 82(2): 214-239.

- Hill, A. R. (1996). Nitrate removal in stream riparian zones. *Journal of environmental quality*, 25(4), 743-755.
- Holmes, T. P. (1988). The offsite impact of soil erosion on the water treatment industry. *Land Economics*, 64(4): 356-366.
- Johnson, K. M., and Beale, C. L. (2002). Nonmetro recreation counties: Their identification and rapid growth. *Rural America* 17:12-19.
- Keeler, B. L., Polasky, S., Brauman, K. A., Kris A. Johnson, J. C., O'Neill, A., Kovacs, K., et al. (2012). Linking Water Quality and Well-being for Improved Assessment and Valuation of Ecosystem Services. *Proceedings of the National Academy of Sciences of the United States of America*, 18619-18624.
- Knapp, R. A., and Matthews, K. R. (1996). Livestock grazing, golden trout, and streams in the Golden Trout Wilderness, California: Impacts and management implications. *North American Journal of Fisheries Management*, 16(4), 805-820.
- Lenat, D. R., & Crawford, J. K. (1994). Effects of land use on water quality and aquatic biota of three North Carolina Piedmont streams. *Hydrobiologia*, 294(3), 185-199.
- MacDonald, L. H., & Coe, D. (2007). Influence of headwater streams on downstream reaches in forested areas. *Forest Science*, 53(2), 148-168.
- Moore, W. B., and McCarl, B. A. (1987). Off-Site Costs of Soil Erosion: A Case Study in the Willamette Valley. *Western Journal of Agricultural Economics*, 12(1): 42-49.
- Radeloff, Volker C., Roger B. Hammer, and Susan I. Stewart. Rural and suburban sprawl in the US Midwest from 1940 to 2000 and its relation to forest fragmentation. *Conservation biology* 19.3 (2005): 793-805.
- Richards, C., Johnson, L. B., & Host, G. E. (1996). Landscape-scale influences on stream habitats and biota. *Canadian Journal of Fisheries and aquatic sciences*, 53(S1), 295-311.
- Riitters, K. H., Wickham, J. D., O'Neill, R. V., Jones, K. B., Smith, E. R., Coulston, J. W., ... and Smith, J. H. (2002). Fragmentation of continental United States forests. *Ecosystems*, 5(8), 0815-0822.
- Sidle, R. C., & Sharma, A. (1996). Stream channel changes associated with mining and grazing in the Great Basin. *Journal of Environmental Quality*, 25(5), 1111-1121.

Smail, R.A., and Lewis, D.J. (2009). Forest land conversion, ecosystem services, and economic issues for policy: A review. General Technical Review of USDA Forest Service, Pacific Northwest Research Station, PNW-GTR-797, available online at <http://www.fs.fed.us/openspace/fote/pnw-gtr797.pdf>

Stein, S. M., Alig, R. J., White, E. M., Comas, S. J., Carr, M., Eley, M., Elverum, K., O'Donnell, M., Theobald, D.M., Cordell, K., Heber, J. & Beauvais, T.W. (2007). National forests on the edge: development pressures on America's national forests and grasslands.

Tong, S. T. (1990). The hydrologic effects of urban land use: a case study of the Little Miami River Basin. *Landscape and urban Planning*, 19(1), 99-105.

Tong, S. T., and Chen, W. (2002). Modeling the relationship between land use and surface water. *Journal of Environmental Management*, 66, 377-393.

Appendix

Appendix A

Case Study: Central Arkansas Water

Source Water Treatment

Central Arkansas Water (CAW) governs and manages Lake Maumelle, Lake Winona and Jackson Reservoir, which provide drinking water to approximately 388,000 residents in Central Arkansas. By 2050, the population served by CAW is expected to exceed 575,000 residents (Tetra Tech 2007). Lake Maumelle and Lake Winona are the principal water supplies, serving an estimated 65% and 35% of the daily water demand, respectively (CAW 2015a). Jackson reservoir serves primarily as an emergency backup system and is not further discussed in this case study.

Ozark Point is the primary treatment plant for water from Lake Winona and the Jack H. Wilson Plant is the primary treatment plant for water from Lake Maumelle. Average daily production at the Ozark Point Treatment Plant is 10.5 million gallons per day (MGD), though the plant is seasonally rated to treat up to 24 MGD (CAW 2015a). Average daily production at the Wilson Treatment Plant is 53 MGD, though the treatment plant is seasonally rated to treat up to 133 MGD (CAW 2015a).

Both plants are conventional treatment plants. Chlorine dioxide, lime, and aluminum sulfate (a coagulant) are added to the raw water immediately upon entry to the plants, followed by flocculation, sedimentation, and filtration. The filter media used at Ozark Point is Granular Activated Carbon, whereas the filter media at the Wilson Plant is anthracite and sand. The filters at the Wilson Plant are approximately twice the size of those at Ozark Point. The water is finished by adding lime, fluoride, and sodium hypochlorite (for disinfection), and then sent to clear wells before distribution to consumers. Prior to 2010, CAW used chlorine gas for disinfection, which was delivered to both plants as pressurized liquid in one-ton cylinders. For safety reasons, CAW has since switched to sodium hypochlorite for disinfection (Weindorf 2010). Since January 2014, the plants also disinfect with chlorine dioxide to meet federal disinfection byproduct regulatory requirements and improve overall water quality.

Watershed Overview

Lake Winona and Lake Maumelle are well-protected water supplies with relatively high quality water. Lake and watershed maps are available on CAW's website.² Lake Winona is a 1.9 mi² reservoir that was formed after a dam was completed in 1938 on the Alum Fork of the Saline River (CAW 2007). The Lake Winona watershed (43 mi²) is predominantly within the Oauchita National Forest; therefore, the majority of the land within the watershed is managed by the United States Forest Service (USFS) and is minimally developed. Lake Winona is available for limited recreational use, including boating and fishing (CAW 2007).

Lake Maumelle (13.9 mi²) is located approximately 18 miles to the west of Lake Winona (CAW 2010). Lake Maumelle's 137 mi² watershed is predominantly forested (i.e., 90%), approximately 8% open meadow or pasture, and 2% developed road or commercial and residential land use (Tetra Tech 2007, CAW 2010). Lake Maumelle is primarily used as a water supply, but is also used for fishing and boating and serves as a wildlife sanctuary.

Source Water Protection Activities

Developing an Action Plan

In the early 2000's urban development within the watershed was recognized as the primary threat to Lake Maumelle's water quality. In 2004, CAW convened a Task Group for Watershed Management comprised of governmental and non-governmental organizations. The Task Group found that the watershed plan in place at the time would not adequately protect the lake's water quality. In response, CAW contracted with Tetra Tech in 2005 to study the watershed and prepare a Lake Maumelle Watershed Management Plan (hereinafter "the Watershed Management Plan"). To help guide development of the Watershed Management Plan, a 22-member Policy Advisory Council (PAC) was formed. Stakeholders represented in the PAC included community groups, ratepayers, elected officials, a member of the CAW Board, property owners, environmental and recreational organizations, and a realtor. Preparation and development of the Watershed Management Plan included the following key aspects (Tetra Tech 2007):

² Maps of Lake Winona and Lake Maumelle: <http://www.carkw.com/water-source-info/watershed-management/watershed-maps/>

1. Establishment of Source Water Protection Goals. Before developing the Watershed Management Plan, the following goals were established: (1) maintain a long-term source of high quality drinking water for the community, and (2) share the costs and benefits of the lake protection efforts, equally.
2. Public Participation. The importance of buy-in and involvement from the public and private sectors was recognized early on as key to successful implementation of the Watershed Management Plan. Therefore, in addition to forming the PAC, a Technical Advisory Council was formed, public meetings were held, and the public was provided Web and library access to information and data produced throughout development of the Watershed Management Plan (e.g., meeting summaries, memos, and presentations).
3. Development of Water Quality Targets. The Watershed Management Plan identified lake water quality target values for chlorophyll a (i.e., a measure of algae), total organic carbon (TOC), Secchi depth (i.e., a measure of water clarity), and fecal coliform bacteria. The purpose of the target values was to maintain the lake's high quality.
4. Assessment of Baseline Conditions. An analysis of existing watershed and lake water quality conditions was conducted to determine potential impacts of possible future build-out scenarios.
5. Development of the Site Evaluation Tool. The modeling tool was developed to evaluate the effects of various development scenarios and management activities on pollutant loading to the lake. The Tool was also applied to determine acceptable annual average loading rates that would achieve the lake water quality target values. See further discussion in the section County Ordinances and State Regulations.

Based on Tetra Tech's review of land use, ownership, and land development at the time, approximately 53% (i.e., 46,500 acres) of the watershed was developable (Tetra Tech 2007). Findings from the baseline analysis indicated that under existing management regulations and policies, the lake would exceed the water quality targets for chlorophyll a, TOC, and turbidity. A

key recommendation from the Watershed Management Plan was to focus on limiting new development and wastewater discharges, which were the primary sources of phosphorus, TOC, sediment, and pathogens within the watershed (Tetra Tech 2007).

Plan Implementation

Since development of the Task Group for Watershed Management and the Watershed Management Plan, CAW has been working with municipalities and counties within the Lake Maumelle and Lake Winona watershed to implement the Plan and maintain high water quality in both lakes. The Make Maumelle watershed has been the primary focus of their efforts.

Watershed Land Acquisition

Acquiring developable land within the watersheds has been CAWs primary focus for protecting water quality. Since the 2007 Watershed Management Plan was adopted, CAW has acquired 1,781 acres within the Maumelle Lake Watershed (Wallace Roberts & Todd, LLC et al. 2012). To increase the amount of land acquired for conservation, in 2009 CAW adopted a 45¢ fee per customer account to purchase and protect property within the Lake Maumelle and Lake Winona watersheds (Wallace Roberts & Todd, LLC et al. 2012). To date, CAW has acquired approximately 2,500 acres in both watersheds, primarily within a quarter mile of each lake (R. Easley, CAW Director of Water Quality and Operations, personal communication, May 5, 2015).

According to a CAW official, the amount of developable land within the Lake Maumelle watershed has changed minimally since the 2007 Watershed Management Plan was published. With the economic downturn, many developers pulled back on projects, buying time for CAW to acquire more land for conservation, and for Pulaski County to develop watershed protection ordinances (see next sub-section on County Ordinances and State Regulations) (R. Easley, CAW Director of Water Quality and Operations, personal communication, May 5, 2015).

County Ordinances and State Regulations

A key recommendation from the Watershed Management Plan was for local governments to adopt ordinances intended to protect the lake's water quality and the watershed (Tetra Tech 2007). In response, the Pulaski County Planning and Development

Department (PCPDD) adopted the Pulaski County Subdivision and Development Code, which prohibits wastewater discharges to surface waters that are not permitted under the National Pollutant Discharge Elimination System (NPDES) stormwater discharge program (PCPDD 2009). The Pulaski County Subdivision and Development Code also sets surface runoff loading rate limits from new developments within the Lake Maumelle Watershed portion of the county for total phosphorus (0.30 lbs/acre/yr), total sediment (0.110 tons/acre/yr), and TOC (44 lbs/acre/yr) (PCPDD 2009). Similarly, to Pulaski County's ordinance, Regulation 6 of the Arkansas Pollution Control and Ecology Commission prohibits any non-NPDES permitted surface water discharges of wastewater in the Lake Maumelle watershed. The state regulation was passed unanimously in May, 2010 (Arkansas Pollution Control and Ecology Commission 2010).

To achieve the loading targets set in the Watershed Management Plan, PCPDD prepared a Stormwater Management and Drainage Manual for the Lake Maumelle Drainage Basin (PCPDD 2010a) as well as a companion Erosion and Sediment Control Field Guide (PCPDD 2011). In tandem, the documents establish erosion and sediment control best management practices (BMP) for construction and development activities and provide guidance to construction operators on BMP installation and maintenance. A companion tool, the Site Evaluation Tool, assists developers and engineers in designing projects that limit impacts to water quality and achieve the loading rates established in the County's Subdivision and Development Code (PCPDD 2010b).

Land Use Planning

Pulaski County has prepared a Comprehensive Land Use Plan to complement the Site Evaluation Tool and the Subdivision and Development Code. The objectives of the Land Use Plan include striking a balance between watershed protection and landowner's development rights; ensuring that the Land Use Plan is consistent with the county's ordinances; and ensuring that the Land Use Plan is flexible, and simple to understand and administer (Wallace Roberts & Todd, LLC et al. 2012). Among other recommendations, the Land Use Plan incentivizes increased lot density to preserve contiguous open space, and treatment of wastewater outside of the watershed.

While the focus of the Land Use Plan is on the portion of the watershed within Pulaski County, a land cover database has been created for the entire watershed area. The database is comprised of 2009 aerial photographs, which serve as a baseline for land use and land cover (CAW 2011). The database is being used to assess temporal and spatial changes in land use and land development, and also to identify roads with the most potential for erosion within the watershed (CAW 2015b).

Comprehensive Water Quality Monitoring Program

Implementing a comprehensive water quality monitoring program is a crucial component of source water protection, as it allows for an assessment of baseline conditions, and analyses of temporal and spatial changes and trends in water quality. Water quality monitoring within the Lake Maumelle Watershed includes (1) in-lake water quality, (2) real-time water quality, and (3) biological monitoring. U.S. Geological Survey (USGS) streamflow and lake quality monitoring have been ongoing since 1989. Currently, USGS samples at 6 locations (i.e., 4 in-lake and 2 streams) at daily to monthly interval and during storm events. The two real-time, continuous USGS monitoring stations in the watershed collect data on water temperature, specific conductance, pH, turbidity, and dissolved oxygen) every 15 minutes. These sites are also used for storm flow sampling. Attempts are made to collect samples during six storm events throughout the year. If more than six major events occur during a year, attempts are made to collect additional storm event samples. These samples are analyzed for nutrients, turbidity, and suspended sediment. Lake water quality samples are analyzed in laboratory for: nutrients (total phosphorus, dissolved orthophosphorus, dissolved nitrite plus nitrate, ammonia, ammonia plus organic nitrogen), dissolved and total iron, dissolved and total manganese, silica, total and dissolved organic carbon, suspended solids, turbidity, chlorophyll-a, and fecal coliform and E. coli bacteria. Field parameters associated with in-lake samples are: water temperature, dissolved oxygen, pH, and specific conductance. Pesticides and mercury are sampled in late spring/early summer. Data collected by USGS are maintained and stored in the publically available USGS National Water Information System database.

Two intake sites provide continuous water quality monitoring data. The Environmental Sensing Platform (ESP) provides 5-minute data for dissolved oxygen and temperature near the

intake. A multi-parameter probe provides 5-minute data at the intake for: dissolved oxygen, temperature, pH, turbidity, specific conductance, oxidation reduction potential, and total dissolved solids.

For biological monitoring, CAW collects data on fisheries (i.e., trends in populations and health indices), larval fish (i.e., trends in reproduction and abnormalities), benthic macroinvertebrates (i.e., trends in population density and species), algal populations (i.e., direct cell counts, identification of species under a microscope, and measuring the amount of chlorophyll).

In 2004, USGS published a water quality assessment report of Lake Maumelle and Lake Winona using water quality data collected during the 1991 to 2003 period (Galloway and Green 2004). USGS also publishes mini-water quality reports annually for CAW. In USGS' most recent 2014 report on the lakes – “Water-Quality Monitoring Work Plan – Calendar Year 2015” – USGS recommends updating the 2004 USGS report and including information on tributary loads and yields, as well as water quality trends in the lakes and inflows (USGS 2014).

Watershed Timber Management

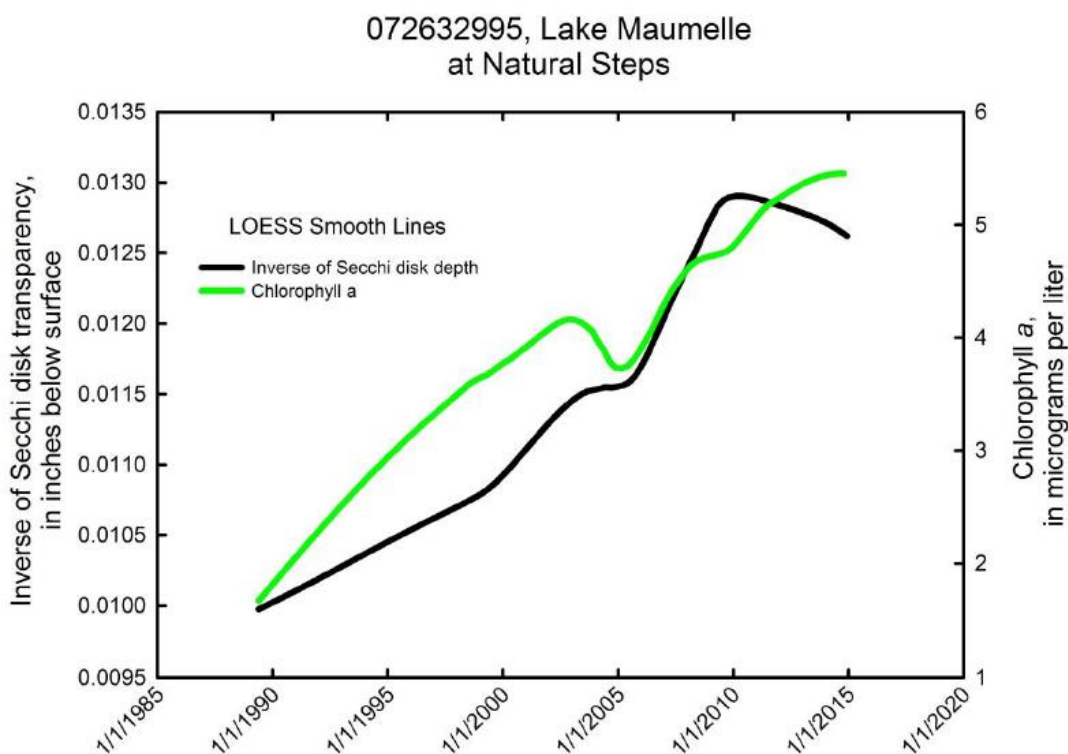
Central Arkansas Water worked with The Nature Conservancy to prepare a Fire Management Plan for the Lake Maumelle Watershed, which was published in 2013. The goals of the Fire Management Plan were to reduce organic carbon loading to the source water and reintroduce fire as a normal ecological process within the watershed (TNC 2013). Indirect benefits of controlled burns include revitalizing habitat areas and natural plant and animal communities, and reducing the potential for wildfires.

Lake Maumelle Water Quality

Water quality and streamflow have been monitored at Lake Winona and Lake Maumelle for more than 20 years by USGS and CAW. Lake Winona, which is within the Ouachita National Forest, demonstrates consistently high water quality and was recently included in an analysis of reference lakes – in terms of nutrients and nutrient-related parameters– within the Arkansas Valley and Ouachita Mountains region of the state (Justus and Meredith 2014). Water quality at Lake Maumelle also remains relatively high, though trends demonstrate a potential decline.

USGS' most recent water quality assessment report of Lake Maumelle, reports that during the 1989 to 2014 period, water clarity (as measured by Secchi disk depth) has been showing a decreasing trend, and chlorophyll *a* levels have been increasing in the downstream portion of the lake (Figure A-1).

Figure A-1. The inverse of Secchi depth and chlorophyll *a* concentrations expressed as locally weighted scatter plot smooth lines. Source: USGS (2014), Figure 6.



Annual average of chlorophyll *a* and TOC concentrations compared to the target values presented in the Watershed Management Plan are displayed in Figure A-2 and Figure A-3, respectively. The data show slight increases in chlorophyll *a* and TOC, though the R^2 values are low (i.e., 0.24 and 0.13, respectively). As expected, chlorophyll *a* and TOC are significantly positively related ($p = 0.010$). It is important to point out that these target values are not directly comparable to the annual average chlorophyll *a* and TOC concentrations for several reasons. First, the annual average values represent data from the raw water intake only, whereas the target values apply to either the mid- or lower- portions of the lake. Second, the annual average values were collected throughout the year, whereas the target values only apply during the summer months. Finally, the target values are measured as a median, rather

than an average. Annual average turbidity levels are shown in Figure A-4. Similarly to USGS' 2014 analysis of Secchi depth, lake turbidity (which is also a measure of water clarity and is the inverse of Secchi depth), has been generally increasing in the lake ($R^2 = 0.48$).

To understand the potential impacts of precipitation on chlorophyll *a*, TOC, and turbidity, annual total precipitation and snow data (i.e., total precipitation) were collected from the National Oceanic and Atmospheric Administrations, National Centers for Environmental Information (formerly NCDC) (NCEI 2015). However, total precipitation was only moderately related to turbidity ($p = 0.051$) and chlorophyll *a* ($p = 0.053$), and therefore may not be the primary explanatory variable for the trends shown in the figures below.

Figure A-2. Lake Maumelle annual average chlorophyll *a* levels compared to the target values set in the 2007 Watershed Management Plan. Note- target values are measured as summer median measurements. Data not available for 2001.

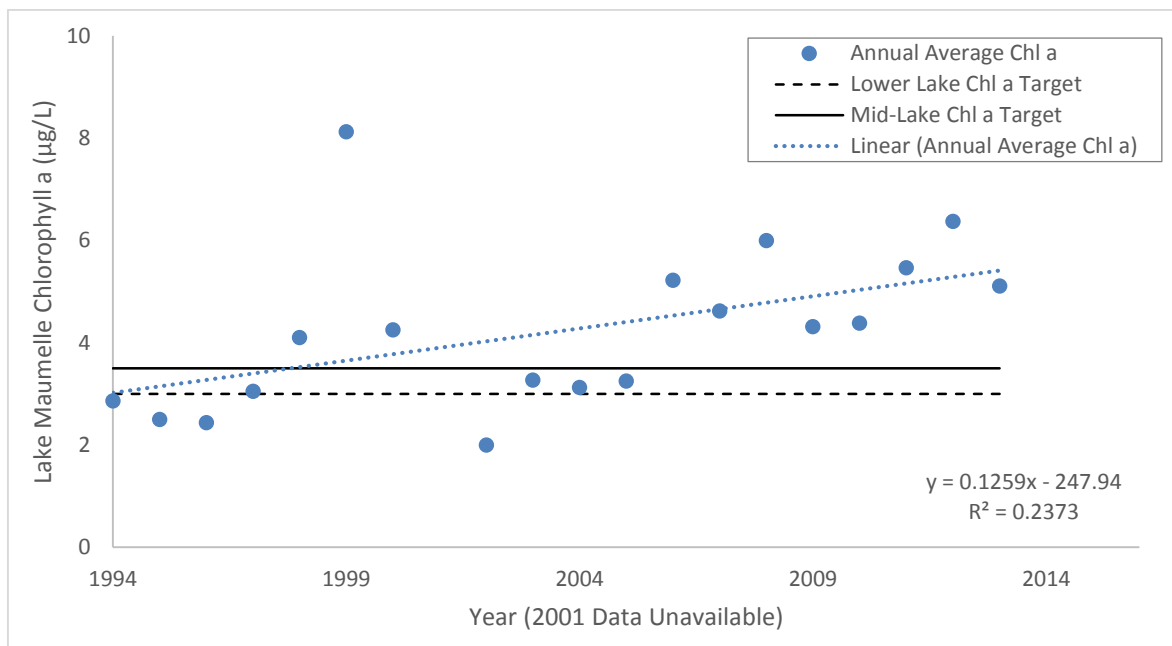


Figure A-3. Lake Maumelle annual average total organic carbon (TOC) levels compared to the target values set in the 2007 Watershed Management Plan. Note- target values are measured as summer median measurements. Data not available for 2001.

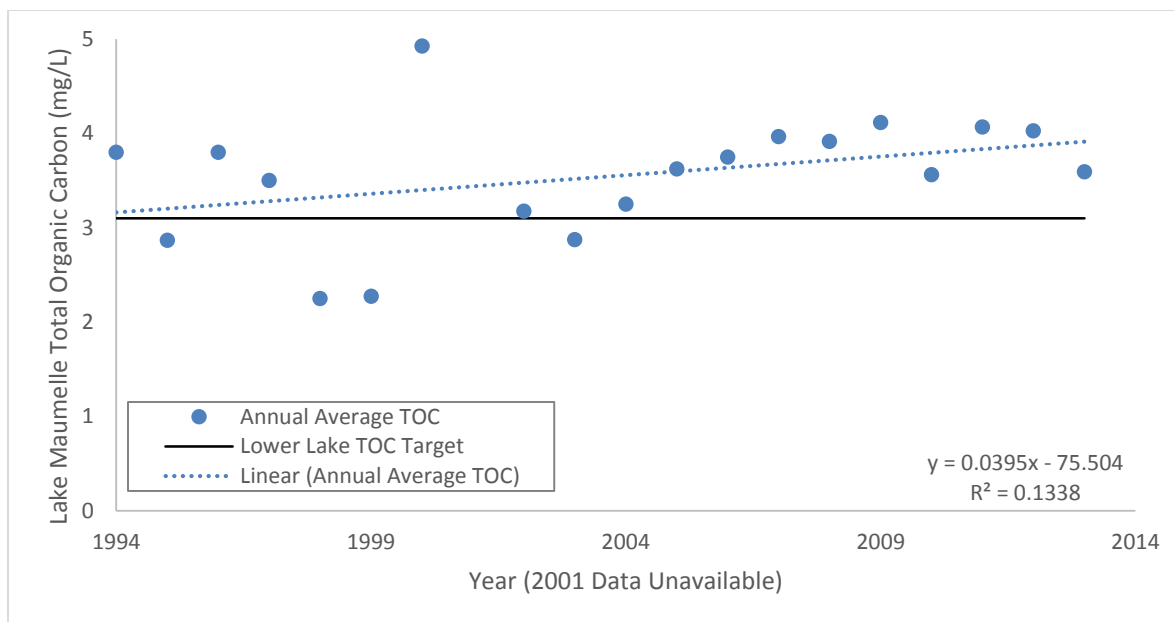
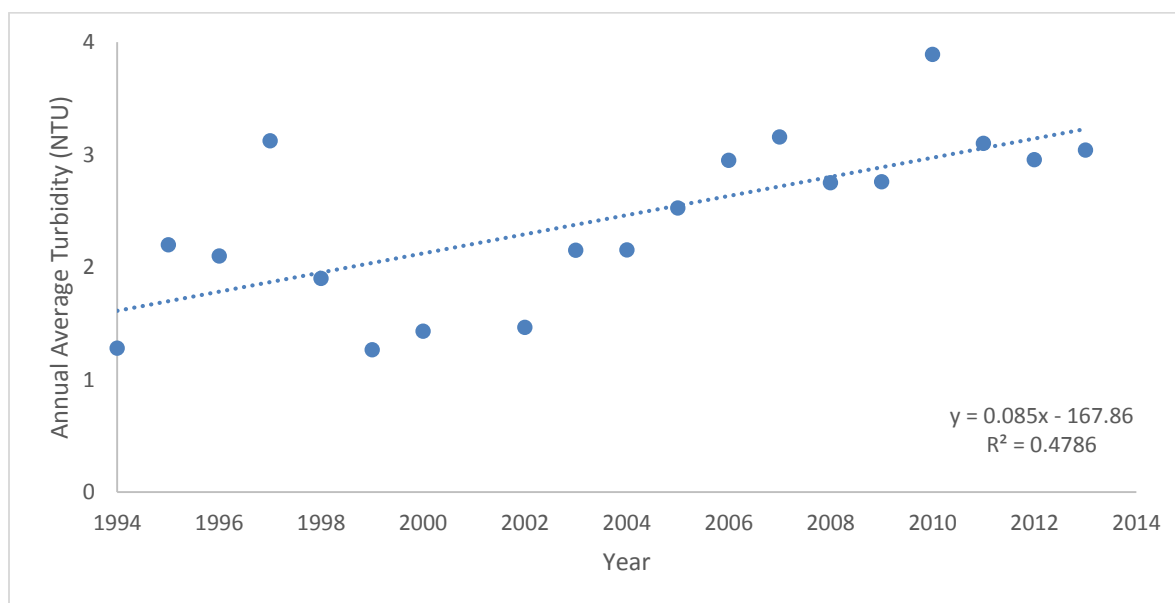


Figure A-4. Lake Maumelle annual average turbidity levels. Data not available for 2001.



Summary

In general, the water quality of Lake Maumelle is very good but has degraded slightly over the past 2 decades. Chlorophyll a, TOC, and turbidity have all increased from 1994 to 2014.

Without proper land use management in the watershed, future water quality conditions would exceed source water quality criteria that could threaten public health and/or require costly added treatment. Over the past decade, CAW has been implementing various parts of the Lake Maumelle Watershed Management Plan prepared by Tetra Tech (2017). In addition, CAW has increased its monitoring efforts of the watershed and lake water quality to gauge the outcomes of their source water protection efforts.

References

Arkansas Pollution Control and Ecology Commission. 2010. Regulations for State Administration of the National Pollutant Discharge Elimination System (NPDES).

<https://www.adeg.state.ar.us/regs/>

Central Arkansas Water (CAW). 2015a. Water Source Info. <http://www.carkw.com>

Central Arkansas Water (CAW). 2015b. Accomplishments to Date.

<http://www.carkw.com/water-source-info/watershed-management/accomplishments-to-date/>

Central Arkansas Water (CAW). 2011. Lake Maumelle Watershed Land Use and Land Cover February 2009. [http://www.carkw.com/wp-](http://www.carkw.com/wp-content/uploads/2011/09/LandCover_LULC.pdf)

[content/uploads/2011/09/LandCover_LULC.pdf](http://www.carkw.com/wp-content/uploads/2011/09/LandCover_LULC.pdf)

Central Arkansas Water (CAW). 2010. Lake Maumelle Brochure. [http://www.carkw.com/wp-](http://www.carkw.com/wp-content/uploads/2011/07/Lake_Maumelle_Brochure_2010_web.pdf)

[content/uploads/2011/07/Lake_Maumelle_Brochure_2010_web.pdf](http://www.carkw.com/wp-content/uploads/2011/07/Lake_Maumelle_Brochure_2010_web.pdf)

Central Arkansas Water (CAW). 2007. Lake Winona Brochure. [http://www.carkw.com/wp-](http://www.carkw.com/wp-content/uploads/2011/07/lake_winona_brochure-2007.pdf)

[content/uploads/2011/07/lake_winona_brochure-2007.pdf](http://www.carkw.com/wp-content/uploads/2011/07/lake_winona_brochure-2007.pdf)

Galloway J.M., and W.R. Green. 2004. Water-Quality Assessment of Lakes Maumelle and Winona, Arkansas, 1991 through 2003. USGS Scientific Investigations Report 2004-5182. <http://pubs.usgs.gov/sir/2004/5182/>

Justus, B., and B. Meredith. 2014. Water Quality of Potential Reference Lakes in the Arkansas Valley and Ouachita Mountain Ecoregions, Arkansas. Environmental Monitoring and Assessment. 186:3785-3800.

National Centers for Environmental Information (NCEI). 2015. Climate Data Online Search. Data obtained May 20, 2015. <http://www.ncdc.noaa.gov/cdo-web/>

Pulaski County Planning and Development Department (PCPDD). 2011. Erosion and Sediment Control Field Guide for the Lake Maumelle Drainage Basin: Pulaski County, Arkansas. <http://pulaskicounty.net/pdf/ESCFieldGuideV2.pdf>

Pulaski County Planning and Development Department (PCPDD). 2010a. Stormwater Management and Drainage Manual for the Lake Maumelle Drainage Basin, Pulaski County, Arkansas. <http://co.pulaski.ar.us/pdf/pulaskiSWmanual.pdf>

Pulaski County Planning and Development Department (PCPDD). 2010b. Site Evaluation Tool User Guidance and Documentation for the Lake Maumelle Drainage Basin, Pulaski County, Arkansas. <http://pulaskicounty.net/pdf/SETUserGuidanceV14.pdf>

Pulaski County Planning and Development Department (PCPDD). 2009. Pulaski County Subdivision & Development Code. <http://co.pulaski.ar.us/pdf/subanddevcode.pdf>

Tetra Tech. 2007. Lake Maumelle Watershed Management Plan. Prepared for Board of Commissioners Central Arkansas Water. <http://www.carkw.com/water-source-info/watershed-management/watershed-management-plan/>

The Nature Conservancy (TNC). 2013. Lake Maumelle Central Arkansas Water Fire Management Plan. August, 2013. http://www.carkw.com/wp-content/uploads/2015/01/CAW_FireManagementPlan2013.pdf

U.S. Geological Survey (USGS). 2014. Water-Quality Monitoring Work Plan – Calendar Year 2015.

Wallace Roberts & Todd, LLC, White & Smith, LLC, and Greener Prospects. 2012. Pulaski County Comprehensive Land Use Plan for the Lake Maumelle Watershed. Prepared for Pulaski County, August 12, 2011; Addendum December 7, 2012. <http://www.co.pulaski.ar.us/pdf/PulCoLUP-12072012.pdf>

Weindorf, B. 2010. Conversion from chlorine gas to sodium hypochlorite - improvements at Central Arkansas Water's Jack H. Wilson and Ozark Point Water Treatment Plants

Southwest Water Works Journal. 21(2):16-18.

http://www.swawwa.org/journal/2010_June_201006.pdf

Appendix B

Case Study: Eugene Water and Electric Board (EWEB)

Introduction

The McKenzie River, located on the western side of the Cascade Mountains, is the sole source of drinking water for over 200,000 residents in Eugene, Oregon. It is also a world-class recreational and fishing area, providing habitat for one of the last remaining native Bull Trout populations in the Pacific Northwest. Eugene Water & Electric Board's (EWEB's) comprehensive Drinking Water Source Protection Program was developed in 2001 to address the multiple threats to this valuable resource from urban runoff, agricultural activities, forest management activities, hazardous material spills, development and septic systems. EWEB's program involves working with a variety of partners to engage McKenzie watershed landowners and stakeholders using voluntary approaches. EWEB spends over \$700,000 annually on its source protection program, which includes 2.75 staff. Within the next couple of years, EWEB's source protection staff hope to work with EWEB's management to enact a watershed stewardship fee on the utility's bill to provide a more predictable and sustainable source of funding for source water protection going forward.

Geography and Land Use

The 1300 square mile McKenzie watershed stretches from the Eugene-Springfield metro area in the west all the way to the Cascade Mountain Range in the east. Elevations span from 430 to over 10,358 ft and precipitation ranges from 40 inches to 110 inches annually. The U.S. Forest Service (USFS) owns the upper two-thirds of the watershed, which benefits source protection. The middle of the watershed is largely in industrial forestry and clear cuts are common in this portion of the watershed. Finally, the lower portion of the watershed is a mixture of rural residential and agricultural land uses located along the mainstem McKenzie River and several of its larger tributaries.

EWEB's source protection program benefits greatly from the USFS ownership of the upper part of the watershed, as forested watersheds provide some of the best drinking water. In addition, unlike the private industrial forestry lower down in the watershed, Forest Service management does not employ clearcuts and herbicide sprays and abides by wider riparian

harvest buffers. Therefore, the upper part of the watershed is fairly well protected, though EWEB continues to follow and comment on proposed timber harvests to support best management practices in relation to maintaining high water quality.

The middle and lower parts of the McKenzie watershed are more in need of active source water protection for a number of reasons. EWEB owns very little land within the watershed area and has no jurisdiction over land use. There is quite a bit of rural residential development right along the river and all of the over 4,000 residents in the watershed area upstream of the drinking water intake are on septic systems. Other concerns include the removal of riparian vegetation along the riverbank for views, and application of pesticides and fertilizer along riparian areas. Although there is only a small percentage of agricultural land within the watershed, most of it is located directly adjacent to the river, and agricultural chemical runoff is a concern.

EWEB's Systematic Approach to Source Water Protection

Back in 2000, EWEB completed a risk assessment of the threats to Eugene's drinking water and developed a source water protection plan, incorporating feedback and ideas from major stakeholders in the McKenzie watershed (see <http://www.eweb.org/public/documents/water/WaterProtectionPlan.pdf>). The major threats identified upstream of EWEB's drinking water intake included urban runoff from the City of Springfield's stormwater system, hazardous material spills from transport along State Highway 126, impacts from increased development (conversion of farm and forest land to urbanized development), commercial and industrial facilities, roadside vegetation management and agriculture.

In 2001, EWEB hired a Drinking Water Source Protection Coordinator to create and implement the source water protection plan. The Coordinator developed an implementation plan that provided EWEB's management team and Board of Commissioners with a 5-year vision for how the program could be rolled out, strategies for leveraging partner and stakeholder resources and expertise, and a budget to ramp-up EWEB funding over this period of time (see <http://eweb.org/public/documents/water/SourceProtectionProgramProposal.pdf>). The implementation plan articulated EWEB's Drinking Water Source Protection (DWSP) vision as

creating the ability “to measure the balance between watershed health and human use over time and to implement actions that maintain a healthy balance for production of exceptional water quality.” EWEB strives to maintain this balance in all of the projects that it carries out and frequently works with other agencies, organizations and residents within the McKenzie watershed to achieve this vision. Because EWEB does not have jurisdictional control over activities that occur in the watershed, staff recognize that it is essential to work with landowners and other stakeholders to protect upstream water quality.

EWEB delineated its source water protection area as the entire McKenzie watershed upstream from EWEB’s drinking water intake at Hayden Bridge, encompassing over 1,100 square miles. While EWEB does consider this entire area in its implementation of the source water protection program, it also recognizes that it is an extremely large area of land. Therefore, EWEB focuses its efforts on the highest risk threats or areas of concern, which are primarily in the lower part of the watershed closest to the intake. Other priority areas include agricultural and residential development activity close to the mainstem McKenzie River. The upper portion of the watershed is U.S. Forest Service land and is not considered as large a threat to water quality as other land uses. At the same time, proper management of U.S. Forest Service land is critical to maintaining the excellent water quality in the headwaters of the McKenzie. EWEB is currently working with the U.S. Forest Service to take a whole watershed or ‘all lands’ approach that can provide resiliency in the face of climate change and other threats.

Highlights of EWEB’s Drinking Water Source Protection Program

Water Quality Monitoring

EWEB has developed a comprehensive water quality monitoring program to assess the health of the McKenzie River and identify the potential threats to drinking water. This program consists of baseline monitoring, storm event monitoring, passive sampling, split sampling with high school students, harmful algal bloom monitoring and other special projects. All water quality data is stored in a database and made available online at:

<http://reach.northjacksonco.com/EWEB/>

Several projects have been done in partnership with the U.S. Geological Survey (USGS). For example, EWEB and the USGS recently published a study based on 10-years of storm event monitoring using automated samplers that found over 40 different pesticides detected in the McKenzie Watershed. The study indicated that the largest number of pesticide detections was associated with stormwater runoff from Springfield and the greatest potential threat to drinking water quality is associated with urban areas, increased development, and agricultural pesticide applications (<http://pubs.usgs.gov/sir/2012/5091/>). EWEB uses monitoring data to do trending analysis where possible, as well as prioritize areas of the watershed on which to focus resources and programs.

McKenzie Emergency Response System (MWERS)

One of the major threats to the McKenzie River is a hazardous material spill. Highway 126 runs right alongside the mainstem McKenzie for most of its route and approximately 500 tractor trailer trucks per day travel back and forth across the Oregon Cascades. In order to address this threat, EWEB has implemented the McKenzie Watershed Emergency Response System (MWERS). MWERS is used by incident commanders to quickly gain access to crucial information, equipment and trained personnel allowing for an effective response. Watershed responders use Geographic Information System (GIS) technology to access information on a threats, critical resources, spill response strategies, equipment availability and other information needed during a crisis. This information is used to efficiently and effectively stabilize accidental or intentional chemical releases as soon as possible and avoid the initial confusion often associated with spills. EWEB and partners conduct annual drills to raise the level of preparedness among all partner agencies and practice deploying boom in challenging conditions. For more information about the McKenzie Watershed Emergency Response System (MWERS), see <http://eweb.org/sourceprotection/emergency>.

Healthy Farms Clean Water Program

The Healthy Farms Clean Water Program assists McKenzie watershed growers with agricultural chemical disposal, free soil sampling, nutrient management consultations, and

accessing local food markets among other efforts, to reduce chemical use and increase economic viability, all while protecting water quality. EWEB recognizes the value of keeping agricultural land as agricultural land, rather than seeing it carved up into parcels and sold off to developers. Development along the river can have negative impacts on water quality, including: increased pesticide/fertilizer use, loss of riparian vegetation, increased use of revetment, loss of floodplain function, increased traffic density, and a higher density of septic systems. Furthermore, keeping farmland intact in the valley ultimately benefits both the local community and the environment, especially in the face of a changing climate. EWEB has also worked closely with hazelnut farmers in the watershed to engage in nutrient management and pesticide reduction activities with help from Oregon State University researchers and funding from the Oregon Hazelnut Commission.

EWEB led an effort to establish a demonstration farm in the McKenzie watershed to showcase how sustainable agriculture can exist alongside riparian restoration in a floodplain. EWEB currently works with the McKenzie River Trust (landowner) and Cascade Pacific Resource Conservation & Development (provides staff and fiscal management support) to carry out this vision. The three central goals of the Berggren Demonstration Farm are to:

1. Protect water quality within the McKenzie River watershed by restoring habitat that maintains and enhances biological diversity and floodplain hydrology
2. Promote the development of community food systems by demonstrating sustainable and economically viable farming practices
3. Provide educational and outreach opportunities for farmers and students

See <http://berggrendemonstrationfarm.wordpress.com> for more information.

Septic System Assistance Program

On the residential side, EWEB provided over 430 free septic systems inspections and pump outs to residents in high risk areas of the watershed through a grant in 2008-2009. This project was very well-received and EWEB subsequently created a long-term septic system financial assistance program. This consists of both a cost-share and zero-interest loan program

to encourage residents to properly maintain their septic systems and repair or replace failing systems in order to protect both shallow groundwater and surface water. In the last three years, EWEB has engaged over 160 additional homeowners through this program (see <http://www.eweb.org/septic/assistance>). In addition, EWEB created a septic system maintenance brochure as part of ongoing efforts to educate homeowners about the importance of septic system maintenance to water quality. These are mailed out to participants in these programs along with a survey about the value of the program (<http://eweb.org/public/documents/water/septicSystemMaintenance.pdf>).

Urban Runoff

Stormwater runoff from east Springfield empties into the McKenzie River above EWEB's water intake via five stormwater outfalls. Two of these outfalls (42nd St and 52nd St) drain large areas of industrial and residential use and discharge into the McKenzie about a half mile upstream of the drinking water intake. EWEB received some grant funds to work with local partners to design a wetland enhancement project that will slow down flow and remove pollutants, increasing the treatment capacity for stormwater runoff before it enters the McKenzie River. This project is currently in the design phase.

Naturescaping Program

In the last several years, EWEB has worked with partners to put together and hold Naturescaping workshops for McKenzie residents to raise awareness about the impacts of chemical use along the river and to provide alternatives to pesticide use. Workshops have included information on identifying and removing invasive species, selecting appropriate native species for your property, riparian restoration, alternatives to pesticides, suggestions and technical assistance for designing a functional and attractive residential landscape. The workshops have been well-received by participants and EWEB plans to continue this program. In addition, partnering with the McKenzie Watershed Council, Upper Willamette Soil & Water Conservation District and Northwest Center for Alternatives to Pesticides has helped them in their outreach and exposure to rural residents.

Voluntary Incentives Program

EWEB is currently working to develop a new and innovative approach to engaging landowners in watershed protection called the Voluntary Incentives Program (VIP). This program is designed to reward landowners who are good stewards of their riparian property and agree to long-term protection of these areas in return for annual dividend payment or other financial incentives for maintaining the value of this natural treatment infrastructure. One of the things that makes this program unique is that it has been designed to protect land that is already in good condition, rather than paying to restore degraded land, which is often the case with other programs such as the Natural Resource Conservation Service's farmer programs, as well as most of work done by Oregon's watershed councils. The VIP places value on an acre of healthy riparian forest for its pollution filtration, flood mitigation, erosion control, shade production/water cooling and habitat services. EWEB is currently in the pilot phase of this project, with full rollout expected to occur in 2016. The Oregon Watershed Enhancement Board (OWEB) has been instrumental in helping to fund the pilot project and its transition to a fully operational program. Other Oregon utilities have also expressed interest in this concept.

There will be two main components to this program: protection and restoration. Surveyors will go out and assess landowners' properties and compare them to pre-established reference sites. For lands that are currently healthy and protective of water quality EWEB would enter into a long-term agreement with landowners to continue to protect these riparian forest areas. EWEB would fund payments to landowners as well as routine maintenance assistance through ratepayer funds. For landowners with properties in need of restoration, EWEB will enter into similar agreements. However, funding for restoration work will come from a McKenzie Watershed Fund, which will aggregate money from a variety of sources, such as private businesses (via a business sponsorship program), and other agencies (ex. the Metropolitan Wastewater Management Commission (contribute funds toward shade credit implementation), the US Forest Service (stewardship contracting retained receipts), and Oregon Watershed Enhancement Board)

EWEB is also working with Carpe Diem West (a western water nonprofit) to evaluate how best to transfer the VIP concept to other watersheds across the western United States. This will require some additional research and modifications to the program to enable it to work in watersheds with different problems, leadership and ownerships structures, partners, etc.

Ecosystem Valuation and the Economic Benefits of Source Protection

EWEB recognizes that the McKenzie watershed is an extremely valuable asset. Although the natural services that it provides are not financially accounted for in traditional economic models, new methods being developed attempting to place value on this 'natural capital.' In 2010, EWEB hired Earth Economics to conduct a watershed valuation, which estimated the annual value of McKenzie watershed ecosystem services at between \$248 million to \$2.4 billion. Services include things such as water supply, flood mitigation, soil erosion control, etc. Protecting this drinking water source ultimately helps EWEB to avoid future expenses such as increased treatment costs, new water treatment methods to deal with traditional and emerging contaminants, increased regulatory requirements, new treatment facilities, and dealing with the effects of potential hazardous material spills.

In addition, source water protection is a way of mitigating future risk. Currently, the McKenzie River exhibits excellent water quality, especially in the upper part of the watershed under USFS ownership. However, monitoring has shown that certain parameters (ex. *E. coli*, nutrients) are increasing over time, particularly in the lower portions of the watershed, and an upward trend in development poses further risks to water quality. Climate change impacts are becoming increasingly apparent and need to be taken into account in future planning. EWEB would prefer to engage landowners and other watershed stakeholders in protecting water quality now, as opposed to waiting until the problem gets worse down the road and requires more money to address. A study done by the EPA indicates that it is much cheaper to prevent pollution than to respond to it after the fact (EPA, 2012)³. Not engaging in source water

³ The Economic Benefits of Protecting Health Watersheds. United States Environmental Protection Agency, EPA 841-N-12-004. April 2012.

protection would be essentially irresponsible and shortsighted, from both a financial as well as environmental health perspective.

Finally, one of EWEB's main goals is to protect the McKenzie River as a reliable source of excellent drinking water for present *and future* generations. Drinking water source protection is by definition a long-term, future-oriented process. Increasing development and other threats are not going to go away and, if anything, will intensify. Climate change is becoming a reality that is acknowledged by more and more citizens and businesses. Drought in California, loss of snow pack in Oregon and Washington, and increased forest diseases and wildfires across the west are a few signs of these changing conditions. EWEB and its many partners understand that investments in watershed protection pay dividends in increasing community resiliency in these uncertain times while increasing economic and public health security.

Table A-1. Cost Breakdown for EWEB's Drinking Water Source Protection Program

Source Protection Program Component	Approximate Annual Budget (Based on 2014 Budget)
Water Quality Monitoring	\$169,000
Healthy Farms Clean Water	\$126,000
Septic System Assistance	\$37,000
McKenzie Watershed Emergency Response System	\$52,000
Voluntary Incentives Program	\$195,000
Education Program	\$25,000
Urban Runoff Mitigation	\$46,000
Other	\$78,000
TOTAL	\$728,000

Note: 1. These numbers include both cash resources and staff time. 2. Leveraged funds from grants and other partners vary considerably from year to year, but typically are between \$200,000-\$500,000 dollars. 3. Overall budget has increased from about \$100,000 at the start of the program in 2001.

Endnote

An attempt was made to quantify the relationship between water quality (i.e., turbidity) and coagulant used. Using available chemical use (in pounds, monthly) and turbidity data (NTU, maximum, average, and minimum, daily), adjusted by flow (MG, daily), about 58 pounds of coagulant is used per million gallon of raw water. A simple correlation equal to 0.28 is

associated with average maximum daily turbidity and coagulant used per MG at the monthly level (for data from 2007 to 2014). The simple correlation between median daily turbidity and coagulant used per MG at the monthly level (from 2007 to 2014) is 0.18. This indicates that the use of coagulant is more sensitive to high turbidity events associated with stormflows.