The Economic Connections Between Forests and Drinking Water

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A summary report by the Center for Watershed Protection

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Forests have a natural capacity to store and cleanse our water supply; yet, the economic valuation of these ecological services that benefit humans is lacking at a watershed scale. For decades, technology has replaced, to some extent, the services provided by forests but at a high price. Billions of dollars are invested in the construction and upgrade of water treatment plants to clean our public water supply that has been degraded by pollution as a result of industrialization and urban development. In fact, water utilities spend 19 times more on water treatment chemicals every year than the federal government invests in protecting lakes and rivers from pollution in the first place (Frost & Sullivan 2004; Gross 2003; EPA 2009a; EPA 2009b; EPA 2009c; EPA 2009c). In some communities, new water supplies need to be found as the water source is too diminished to fulfill the public water demands. Although the ecological services provided by forests are widely accepted in the scientific community, they have not really been translated into the language that most often drives planning and land use decisions at the local level: dollars. Local government officials often make tough decisions about growth at the expense of natural resource conservation, and they must make these decisions without the benefit of economic data that measures the costs of development and values of natural resources.

The Forest Service estimates that nearly 1 million acres of American forest were converted to developed uses each year in the 1990s, and by 2050, an additional 23 million acres of forests may be lost due to development (Stein et al., 2005). Areas experiencing the most forest loss are often suburban and urbanizing communities where municipal staff struggle to keep up with the growth and may not have adequate tools to manage it. How does this loss of forest cover translate to costs incurred by communities for sustaining quality, long term water supply? The answer to this question is largely unknown as few communities track increases in drinking water treatment costs (or other community services) with the loss of forest land or evaluate these possible impacts prior to approving new developments.

To address this gap, the Center for Watershed Protection (the Center) completed a research study to identify the specific economic connections between forests and drinking water, based on the available science, to provide a basis for forest conservation as an economical means to ensure reliable safe drinking water supplies. The scope of the study was limited to surface water supplies and drinking water quality, and the research included two major elements:

1. **Literature Review.** The Center compiled and summarized existing research on the costs and benefits of forests for protecting drinking water quality.

2. **Pilot Study.** Using the Linganore Creek Watershed in Frederick County, Maryland as a pilot watershed, the Center collected new data to evaluate the costs and benefits associated with conserving forests for drinking water protection. The results will be used to develop recommendations for local planners to integrate forest conservation and water supply planning into long term planning efforts and land development decisions.

This report presents the results of the literature review and pilot study to illustrate the cost of forest loss and its impact on water treatment costs. The ultimate goal is to use this material to: a) advance planning for water supply and forest conservation and place it at the forefront of community planning issues, b) make the economic case for forest conservation to protect drinking water, c) encourage the use of incentives for forest conservation and reforestation that are more reflective of their true value, and d) encourage communities to factor in the costs of drinking water supply and treatment when evaluating development alternatives.

Literature Review

The Center completed a literature review of research related to the following questions:

- What services do forests provide related to drinking water and how does forest loss affect drinking water?
- What is the value of these services and what are the costs associated with forest loss?

Numerous studies exist that quantify the ecological benefits provided by trees, such as the ability to filter pollutants from both air and rainfall, cooling effects as a result of evapotranspiration, provision of wildlife habitat and migratory corridors, among many others. Yet, limited research exists to directly relate forest benefits to drinking water treatment costs at a watershed scale. Two national studies were found that investigated watershed forest cover and drinking water treatment costs and both found significant relationships between land cover and drinking water treatment costs (Ernst 2004, Freeman et al., 2008).

The first was a survey of 27 water suppliers conducted in 2002 by the Trust for Public Land and the American Water Works Association. They found that operating treatment plant costs decreased as forest cover in the source area watershed increased. This relationship is illustrated in Figure 1, which shows that for every 10 percent increase in forest cover, treatment and chemical costs decreased approximately 20 percent, up to about 60 percent forest cover. Not enough data were obtained on drinking water watersheds with more than 60 percent forest cover; however, the study authors suggest that treatment costs level off when forest cover is greater than 70 percent. About 50-55 percent of the variation in treatment costs was explained by the amount of forest cover in the watershed. The other 50 percent was attributed to the varying treatment practices used, the size of the treatment facility, and the characteristics of development and agricultural land in the watershed, including use of best management practices (BMPs).

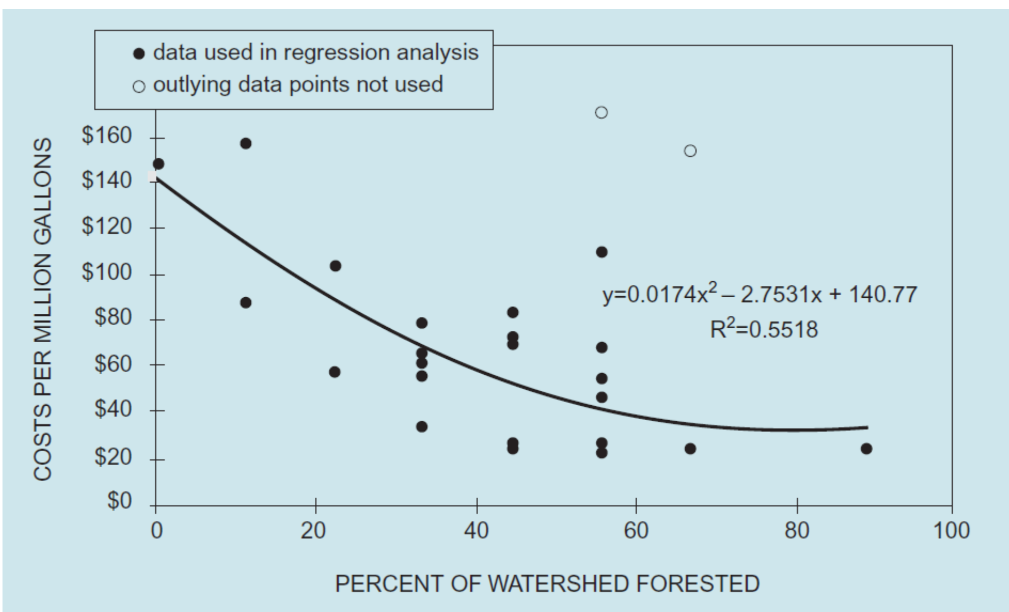


Figure 1. Relationship between Watershed Forest Cover and Drinking Water Treatment Cost (Ernst, 2004)

The second study was conducted by the Trust for Public Land (Freeman et al., 2008) and summarized raw water quality data, forest cover data, and drinking water treatment cost data for 60 water treatment plants across the country. This study found that there were significant relationships among percent land cover, source water quality, and drinking water treatment costs. Decreased forest cover was significantly related to decreased water quality, while low water quality was related to higher treatment cost. The variability associated with the potential treatment costs given a change in watershed land cover precluded the development of a statistical model to predict treatment costs with certainty.

The Trust for Public Land found that operating water treatment plant costs increased as forest cover in the source area watershed decreases due to the associated decline in water quality

A summary of the relevant literature follows to provide qualitative evidence supporting the connections between forests and drinking water treatment costs. This includes: forests and individual trees' ability to reduce runoff and pollutants through the processes of rainfall interception, evapotranspiration and infiltration; modeling and monitoring studies that document increased runoff, sediment and other pollutants when forest land is converted for other land uses; and sediment impacts on drinking water treatment costs. These study results have been integrated below.

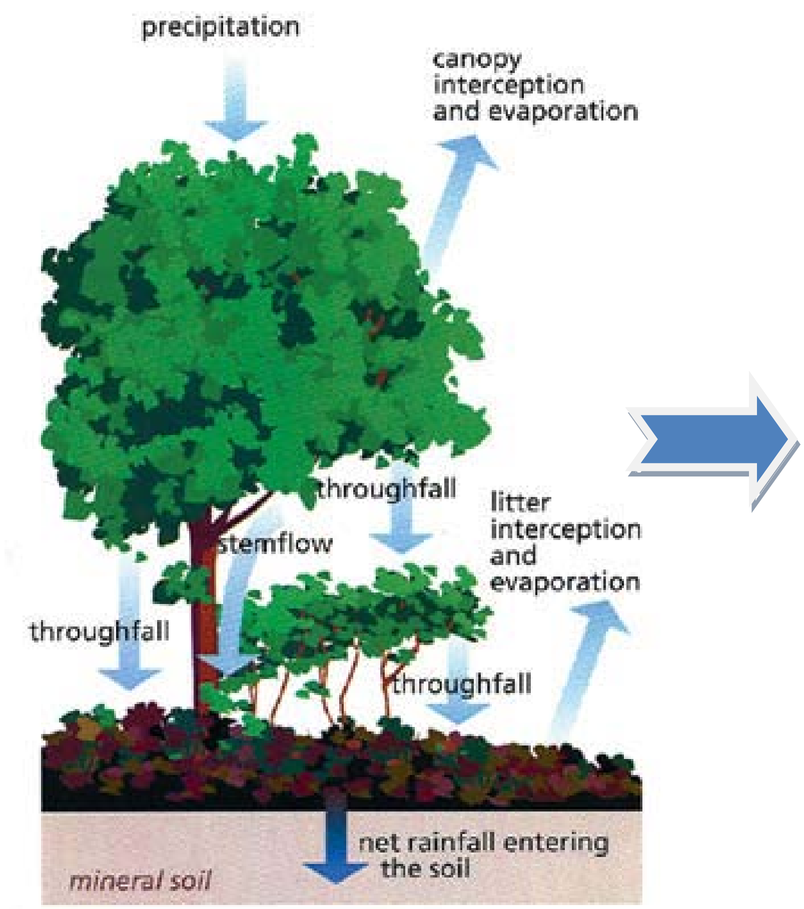
WHAT SERVICES DO FORESTS PROVIDE RELATED TO DRINKING WATER AND HOW DOES FOREST LOSS AFFECT DRINKING WATER?

The specific processes by which forests protect and improve drinking water quality can best be described as part of a cycle of inter-related components (Figure 2). When rain occurs, forests capture rainfall in their canopies (**rainfall interception**). Intercepted rainwater is either evaporated directly into the atmosphere (**evaporation**), absorbed by the canopy surfaces, or transmitted to the ground via stems, branches, and other tree surfaces (**stemflow**). The water delivered to the base of trees penetrates the soil rapidly (**infiltration**) by following interconnected pathways in the soil formed by large roots. Leaf litter and other organic matter, soil macropores, and small depressions in the forest floor all work to slow runoff, hold water and further promote infiltration. Forests uptake water from the soil through tree roots and release moisture in the form of water vapor from leaves (**transpiration**). This increases soil water storage potential, effectively lengthening the amount of time before rainfall becomes runoff. Increased infiltration helps to replenish groundwater supplies (**recharge**).

Tree roots stabilize the soil and tree canopies reduce the impact of raindrops, both of which reduce soil erosion (**soil stabilization**). Forests in the riparian zone help to reduce stream channel erosion by stabilizing the soil with their root systems and by adding a protective layer of organic matter. Upland forests indirectly reduce stream channel erosion by reducing the volume and velocity of runoff that could otherwise contribute to scour of downstream channels.

Forests improve soil and water quality through uptake of soil nutrients by plants and soil microbes, and filtering of sediment and associated pollutants from runoff (**pollutant removal**). Certain trees also have the potential to remove highly toxic and carcinogenic chemicals such as pesticides, solvents, explosives such as TNT, crude oil, and polycyclic aromatic hydrocarbons (PAHs) from soil and groundwater, and are sometimes used to remediate contaminated sites (i.e., phytoremediation). Very little of the nutrients in forests are delivered to water bodies because they are cycled through these various processes and locked up in live and dead biomass (e.g., leaves), as well as soils. Note that there are many other benefits provided by forests, such as removal of air pollutants, wildlife habitat, and improved health and well-being; however, this review is limited to the benefits to water quality.

Figure 2. Forest Influences on Drinking Water Quality (adapted from FISRWG, 1998)



- **reduced runoff volume and velocity**
- **reduced erosion**
- **reduced pollutant inputs**

The processes described above are well-accepted in the scientific community; yet, it is very difficult to design a study that effectively quantifies the contribution of each element to downstream drinking water quality given the complexity of the system, its interactions, and the wide variability of factors within a watershed such as forest type, age and condition, climate, soils, and location in relation to the drinking water supply. Some results from the literature are provided in Table 1 as examples of study results that quantify a single element of this system.

Forests reduce the amount of rainwater that becomes runoff and filters the water so that harmful pollutants don't reach streams and enter groundwater

Table 1. Forest Effects on Rainfall Interception, Evapotranspiration, Water Storage and Pollutant Removal

Function	Research Results
Rainfall interception	• A single mature tree with a 30-foot crown can intercept up to 4,600 gallons of water per year (Portland BES, 2000). • A mature deciduous tree intercepted 760 gallons of rainfall per year in its crown in one California study, while an evergreen tree was estimated to intercept 4,000 gallons annually (CUFR, 2001). • A study in California found that a mature deciduous tree intercepted 15% of gross precipitation in winter, while an evergreen intercepted 27% of gross precipitation (Xiao, et al, 2000). • Canopy interception in a natural forest ranges from 15 to 40% of annual precipitation in conifer stands, 10 to 20% in hardwood stands and can be greater than 59% for old growth forests (Xiao, et al, 2000). • A 32-foot tall tree intercepted rainfall and reduced stormwater runoff by 327 gallons (Wolf, 1998). • Studies of rainfall interception by forests estimate that between ten and 40% of rainfall is intercepted by forest canopy (Watershed Science Center, 2000).
Evapo-transpiration	• A single tree can transpire up to 100 gallons of water a day on a sunny summer day (Metro, 2002; EPA, 1992). • Poplar trees can transpire between 50 and 300 gallons of water out of the ground in one day (EPA, 1998). • An open grown hardwood tree will consume from 1.2 to 1650 gallons of water per day, depending on the size of the tree and the evapotranspiration (ET) rate (Perry, 1994). • A mature, properly watered shade tree with a 30 foot crown can evapotranspire up to 40 gallons of water a day (Heat Island Group, 1996). • A mature bald cypress can absorb 880 gallons per day, depending on the soil type and saturation (Keating, 2002)
Water storage	• Once wet, forest floors can hold between one and five times their own weight (Kittredge, 1948).
Pollutant removal	• Pollutant removal rates for phytoremediation technologies vary greatly, but one study estimated that one sugar maple growing along a roadway removed 60 mg of cadmium, 140 mg of chromium, 820 mg of nickel, and 5,200 mg of lead from the environment during a single growing season (Coder, 1996). • Riparian forest buffers can reduce 30-90% of nutrients and sediments (CBP and EPA, 1999) • Riparian buffers serve as important sinks for the removal and long-term storage of nutrients coming from agricultural drainage (Lowrance, 1992) • Buffer widths of 30 meters can remove nearly 100% of nitrate (Fennessy and Cronk, 1997).

The data in Table 1 is challenging to summarize in a way that land managers can use to assign a single numeric or dollar value to the services provided by forests. One reason is the extent to which forests or individual trees intercept rainfall, evapotranspire water, promote storage of water in the soil, and remove pollutants varies widely with factors such as the species and size of trees, forest condition, climate, rainfall characteristics, soil characteristics, tree health and management practices, to name a few. However, an example of how this data might be translated into policy can be taken from the City of Pine Lake, Georgia where stormwater credits are given to developers for conserving trees on development sites using the following system: 10 gallons/inch credit for trees < 12" (diameter at breast height or DBH) and 20 gallons/inch credit for trees > 12" DBH. To put this into perspective, conserving three 24" DBH trees on a site reduces the same amount of runoff generated by a 500 ft^2 concrete or asphalt driveway during a peak rain event of 6 inches/hour, according to the calculations in the ordinance. These credits were developed based on a review of the literature on tree evapotranspiration rates but are conservative given their wide variability. Overall, the studies in Table 1 illustrate the immense capacity trees have to intercept, store and remove pollutants. As trees and forest cover are removed from the landscape, the ability of the watershed to intercept, store and remove pollutants is severely diminished.

As forests are cleared for agriculture, certain forms of silviculture or urban development, the immediate result is at the ground level where soils once held together by roots and organic material are exposed to erosion by both wind and rainfall. Many studies have quantified the increased sediment loads from construction sites and or/ forested sites that have been clearcut (Table 2). For example, sediment export from uncontrolled construction sites was 1,000- 2,000 times greater than comparable forested sites (Weiss, 1995). Others researchers found lower yet still significant sediment export in the range of 2-200 times greater from construction sites compared to rural or forested sites (Wolman and Schick, 1967) and upstream monitoring stations (Walling and Gregory, 1970).

Clearing forests increases erosion and sediment loading to streams, even with the use of management practices.

Table 2. Sediment Loads from Land Clearing

Source	Research Results
Wolman and Schick (1967)	Sediment loads from construction sites ranged from 2-200 times greater than loads from comparable areas in a rural or wooded condition
Walling and Gregory (1970)	Reported 2- to 100-fold increases in suspended sediment concentration below construction sites
Weiss (1995)	Sediment loads are 1,000-2,000 greater in uncontrolled construction sites than forested sites
Montgomery County DEP (2007)	In a paired watershed study, stations under construction showed clear decline during construction as shredders declined from 47% of the community to 11% of the community, collectors increased to over half of the community (53%), and the dominant taxon changed from a pollution intolerant organism to the more pollution tolerant and less sensitive Chironimidae family.
McBroom et al. (2003)	This paired watershed study evaluated the effects of forest practices on pollutant load and found sediment losses up to 224.77 kg/ha for an intensively cleared watershed and 41.85 kg/ha for a control. Nitrate loss was estimated at 2.77 kg/ha on an intensively cleared watershed vs. 0.2 kg/ha loss on a control. Likewise, total P losses were quantified at 0.28 kg/ha on an intensively cleared watersheds vs. 0.01 kg/ha loss on a control.

Even construction sites with erosion and sediment control (ESC) management measures have a measurable impact on downstream water resources. A paired watershed study in Montgomery County, Maryland showed that even though ESC controls were generally effective at decreasing sediment concentrations in runoff leaving the structure, the structure and function of macroinvertebrate communities downstream of the construction sites showed clear signs of degradation during the construction period (Montgomery County DEP, 2007). In addition, these communities did not recover after a drought as the undisturbed streams did. Although water quality was not measured in this study, it can be inferred that the decline in the aquatic community is related to water quality decline, as macroinvertebrates are highly sensitive to changes in water quality.

Conversion of forest to urban land may compact the soil to such an extent that even 'pervious' areas act like impervious cover.

In terms of forest clearing for silviculture purposes, studies have documented that sediment loss may be as much as five times greater from watersheds that have been clearcut than that of control watersheds (McBroom et al., 2003). However, McBroom (2008) found that the use of BMPs can significantly reduce the impacts of clearcutting in terms of runoff and nutrient loads from the watersheds. Increased sediment loads from forest clearing can have significant impacts on drinking water treatment costs in terms of reducing the capacity of the reservoirs or the need for additional chemicals to treat the water. Costs associated with sediment load are presented later.

Besides increasing erosion, construction-phase activities also change soil properties which can result in increased runoff and pollutant concentrations long after the construction activity is complete. Construction practices that grade the site to accommodate roads, sewers and buildings remove the topsoil, reducing soil fertility while increasing its compaction, which is measured by soil bulk density. Compacted soils have lower infiltration rates, reduced water-holding capacity and greater runoff potential (Table 3). Altered soil structure and compaction can affect root penetration and modify the soil's capacity to transport chemicals and nutrients (Price and Watters, 1989). Several studies have quantified the differences in soil properties for disturbed and undisturbed soils. For example, the bulk density of most undisturbed soils ranges from 1.0 to 1.5 grams per cubic centimeter (g/cc) and increases to values of 2 for disturbed soils, approaching bulk densities associated with impervious cover (Randrup 1998; Smith 1999; Schueler 2000). In a North Carolina study, Kays (1982) found that infiltration rates decreased two orders of magnitude for land uses with disturbed soil conditions compared to native forest conditions.

Table 3. Properties Associated with Disturbed and Undisturbed Soils

Source	Research Results
Schueler (2000)	The surface bulk density (a useful indicator of soil compaction) of most undisturbed soils ranges from 1.1 g/cc to 1.4 g/cc, while many urban soils have bulk density of 1.5 g/cc or greater
Pitt et al. (2002)	For storm events less than 1-inch, Curve Number (CN) values for a residential site approached 98, which is the CN associated with impervious cover
Kays (1980)	Infiltration tests conducted across a North Carolina watershed on various land types found that a medium aged pine-mixed hardwood forest condition had a mean final constant infiltration rate of 12.42 in/hr. When the forest understory and leaf litter was removed, the resultant lawn condition had a mean infiltration rate of 4.41 in/hr. Suburban development on an old cultivated agricultural field produced a 1.88 in/hr. mean infiltration rate. Four land types of disturbed conditions (e.g., fill soils, compacted soils, soils with the topsoil removed) all had infiltration values around two orders of magnitude less than that for the native forest conditions

The reduced infiltration capacity of the soil combined with the addition of impervious cover with development greatly increases the amount of runoff generated at the site. Site designers usually try to move this water off the site as quickly as possible. This means putting runoff into storm drainage pipes and installing curbs and gutters along streets. The runoff is then moved swiftly and efficiently off the site into the storm drainage system, which in most cases ultimately discharges into a local stream. These changes all contribute to changes in stream hydrology, including increased runoff volume, increased peak discharge, increased frequency of bankfull flow, and diminished baseflow (CWP, 2003). This in turn creates a cycle of active channel erosion and greater sediment transport in streams.

Pollutant concentrations in runoff from forest land are generally much lower than runoff from urban or agricultural uses

Stormwater runoff washes pollutants from urban lands into local streams. Concentrations of pollutants, such as sediment, nutrients, metals, hydrocarbons, bacteria and pesticides in urban streams are often significantly higher than in streams found in forested watersheds. Agricultural streams also have greater concentrations of pollutants than forested ones. An example set of studies that document the link between water quality and land use is provided in Table 4.

Table 4. The Link Between Water Quality and Land Use

Source	Research Results
Boyer et al. (2002)	Total nitrogen inputs to a catchment area were negatively correlated with the fraction of land area in forest, whereas nitrogen inputs increased directly with the fraction of land in agriculture.
Houlahan and Findlay (2004)	This study found a negative correlation between stream nutrient levels and forest cover and these effects were detectable out to 2,000 meters from the stream.
Omernik (1977)	Agricultural land uses can have nutrient concentrations nine times higher than forested watersheds.
Hurlihy et al. (1998)	One study of 346 watersheds found that watersheds with a higher proportion of forest area generally have lower concentrations of nitrates than do similar watersheds with less forest area
Forster (2002)	Conversion of farmland to developed land affects turbidity and therefore water treatment costs; a 10% increase in non-farmland in a watershed causes an estimated 20% increase in turbidity.
Pimental et al. (1995)	Soil erosion rates from agricultural land in the U.S. average about 17 tons/hectare/year whereas soil erosion rates from undisturbed forests range from .004 to .05 ton/hectare/year.

In order to assign specific values to forest services that are useful from a watershed management perspective, it is necessary to integrate data from multiple studies and make some simplifying assumptions given the gaps and variability documented in each research study. As an example, the pollutant load generated between different land cover types can be compared to illustrate the impact forest services may have within a watershed. Information from source area monitoring studies provides an average nutrient concentration in runoff from forests, turf, and impervious cover. This information in conjunction with runoff coefficients (which represent the proportion of rainfall that is converted to stormwater runoff) can be used in the Simple Method (Schueler, 1987), a widely accepted pollutant loading model, to estimate the annual nutrient load from forest, turf and impervious cover (Table 5).

Table 5. Effect of Land Cover on Runoff and Nutrient Loads

Runoff and Nutrient Characteristics		Land Cover		
		Forest	**Turf**	**Impervious**
Runoff Coefficient		0.05[1]	0.10[3]	0.95[5]
Nutrient Concentrations (milligrams/L)	Total Nitrogen	1.5[2]	9.7[4]	1.9[6]
	Total Phosphorus	0.25[2]	1.90[4]	0.40[6]
Nutrient Loads[8] (pounds/acre/year)	Total Nitrogen	0.6[7]	7.9[7]	14.7[7]
	Total Phosphorus	0.1[7]	1.6[7]	2.8[7]

[1]Measured runoff coefficient from Mostaghimi et al. (1994)

[2] From Mostaghimi et al. (1994) and USGS (1999)

[3] Average for B and C soil types from Legg et al. (1996) and Pitt (1987)

[4] Grand mean of Garn (2002), Waschbusch et al. (2000), Steuer et al. (1997), and Bannerman et al. (1993)

[5] Regression of 40 sites nationally in Schueler (1987)

[6] Grand mean of all reported impervious cover source area monitoring data in Table 19, page 59 of CWP (2003)

[7] As computed by the Simple Method (Schueler, 1987), assuming 40 inches of annual rainfall

[8] Forest and impervious nutrient loads are within range of measured loadings from Gardner et al. (1996); Mostaghimi et al. (1994); Blackburn and Wood (1990); McClurkin et al. (1985); and Schueler and Caraco (2002)

As shown in Table 5, an acre of turf is calculated to produce approximately 15 times more nutrients than an acre of forest cover, while an acre of impervious cover produces over 25 times more nutrients than forest. This type of data could be used in a management scenario by determining the average cost to reduce a pound of nitrogen or phosphorus and establishing a program whereby owners of critical forest lands are paid for the nutrient reduction services provided by their lands as long as they continue to manage them as forests. This does not begin to truly compensate forest landowners for all the environmental services they supply, but is likely to be more financially appealing than the typical tax incentives for forest conservation.

What is the Value of These Services and What are the Costs Associated with Forest Loss?

Economic valuation of environmental services is an attempt to assign a quantitative and monetary value to goods and services provided by environmental resources. In the case of forests and drinking water, we are primarily interested in the following services: reduced runoff volume and velocity, soil stabilization, and pollutant removal.

Recharge is also important; however, our study was limited to the effects of forests on the *quality* of surface water supplies.

The economic valuation methods that are relevant to drinking water services include valuations based on people's willingness to pay for specific services and estimated costs of avoided damages. Some difficulties with the willingness-to-pay approach include controversy over whether people would actually pay the amounts stated in the interviews, and that when people are not aware of the link between the environmental resource and the benefit to them personally, the value will not be reflected in the price. In our literature search, we found a handful of willingness-to-pay studies related to drinking water services to include:

Table 6. A Literature Summary of Willingness-to-pay for Drinking Water Studies

Source	Research Results
Jordan and Elnagheeb (1993)	Residents of Georgia expressed a willingness to pay $5.49 to $7.38 per month to improve the quality of drinking water in their state, even though most rated their water quality currently as very safe, safe, or fair.
Sun et al. (1992)	Another survey of Georgia residents found they were willing to pay $641 per household annually for a program that would protect groundwater supplies.
Schultz and Lindsay (1990)	Citizens of Dover, New Hampshire, were willing to pay $40 per household annually for a groundwater protection plan.
Crutchfield et al. (1997)	A survey of citizens from Indiana, Nebraska, Pennsylvania, and Washington indicated a willingness to pay nearly $55 per month to remove all nitrates from their water supplies.

Numerous studies have documented the avoided costs of constructing filtration plants associated with watershed protection (Table 7). These studies illustrate that significant financial burdens may be avoided by communities that adopt watershed protection measures to protect water supplies. It is important to note that results of economic valuation studies using the avoided cost method do not represent the true value of all the services provided by the resource.

Table 7. Avoided Costs of Constructing Filtration Plants Through Watershed Protection[1]

Metropolitan Area	Avoided Costs Through Watershed Protection	Source
New York City, NY	$1.5 billion spent on watershed protection over 10 years to avoid at least $6 billion in capital costs and $300 million in annual operating costs	NRC (2000)
Boston, MA	$180 million (gross) avoided cost	*US vs. Massachusetts Water Resources Authority* (2000)
Seattle, WA	$150-200 million (gross) avoided cost	Flagor (2003)
Portland, OR	$920,000 spent annually to protect watershed in avoiding a $200 million capital cost	Reid (2001)
Portland, ME	$729,000 spent annually to protect watershed has avoided $25 million in capital costs and $725,000 in operating costs	Reid (2001)
Syracuse, NY	$10 million watershed plan is avoiding $45-60 million in capital costs	ECONorthwest (2004)
Auburn, ME	$570,000 spent to acquire watershed land is avoiding $30 million capital cost and $750,000 in annual operating costs	Ernst (2004)

[1] Adapted from Postel and Thompson (2005)

Indirect methods may also be used to measure the financial impact of forest loss related to drinking water supply. One of the biggest costs associated with forest loss is related to the removal of the increased sediment load to the water treatment plant. Sediment is a major water-quality concern because of its ability to transport harmful substances, such as metals and nutrients, and its impacts on the cost of drinking water treatment (USDA, 2000). The costs of treating municipal water supplies increase as sediment and other pollutants input to surface waters increase (Table 8). Holmes (1988) indicates there may be a sediment-related water quality threshold above which requires additional investment in water treatment infrastructure. If the raw water quality is high, treatment plants may be able to bypass certain treatment processes such as flocculation and sedimentation (Holmes 1988). Plants may need to add more chemicals like disinfectants, pH adjusters and coagulants as water quality degrades (Dearmont, et al, 1998).

In addition to avoided costs of enhanced drinking water treatment, other costs that could be avoided by conserving forests in drinking water watersheds include reservoir dredging. Increased sediment inputs to streams and lakes increases the rate at which lakes and reservoirs are filled, costing communities millions of dollars to remove deposited sediment and prolong the reservoir’s useful life. However, these sedimentation rates can be highly variable geographically. One study from the Midwest evaluated 42 reservoirs in Iowa, Nebraska and Missouri and determined that 1.4 to 1.5 million acre-feet of reservoir and lake capacity were permanently filled each year with sediment (Clark and others, 1985). In addition, nearly a million acre feet of additional storage capacity, at a construction cost of $300 to $700 per acre-foot, was needed to capture and store this sediment (Clark and others 1985). Nationwide, sedimentation of water storage facilities costs communities nearly $1.1 billion annually (1983 dollars) (Ribaudo, 1986).

Table 8. The Relationship between Turbidity and Water Treatment Costs

Source	Research Results
Holmes (1988)	A 1 percent increase in turbidity is associated with 0.07 percent increase in operating and maintenance expenditure.
Dearmont et al., (1998)	A 1-percent reduction in turbidity from an average level of 13.05 NTUs to 22.82 NTUs reduces chemical costs by $0.20 per million gallons.
Forster et al. (1987)	A 10 percent reduction in cropland soil erosion in Ohio would reduce water treatment costs by 4 percent.
Forster (2002)	A 10% decrease in the amount of conventional tillage in watersheds draining to drinking water supplies would lessen turbidity by 13% and reduce chemical costs by $6,750 annually at an average treatment plant. In addition, a 10% increase in non-farmland in a watershed causes a $10,000 increase in water treatment costs at an average plant due to the associated increase in turbidity.

Another potential avoided cost is the construction of stormwater best management practices (BMPs) to remove pollutants from the increased runoff generated by replacing forest with developed land, as required under the Clean Water Act. The avoided costs of building stormwater BMPs to control runoff stored by urban forests have been estimated by American Forests for more than 30 cities and metropolitan areas across the country. As an example, the analysis of Montgomery, Alabama found that the urban tree canopy covered 34% of the city's area and had a stormwater retention capacity of 227 million ft^3 (American Forests, 2004). The cost to construct stormwater BMPs to manage this volume of runoff was estimated at $454 million. Similarly, an analysis of urban forests in Chicago estimated that each mature urban street tree prevents or absorbs 327 gallons of runoff per year, providing an estimated $6.70 in annual runoff control savings per tree (McPherson *et al.*, 1994).

Other avoided costs include:

- Developing a new water source if/when the quality of the existing source becomes too unreliable, contaminated or costly to treat.
- Implementation of various types of watershed restoration projects (e.g., stream restoration, stormwater retrofits, reforestation) to meet water quality objectives such as Total Maximum Daily Loads (TMDLs), as water quality declines when forest is replaced by developed land.

While administration of a willingness-to-pay survey was outside the scope of this study, the avoided costs of forest conservation were incorporated into the Linganore Creek Watershed pilot study where possible.

Summary

The key findings of this literature review are that forests protect drinking water supplies by protecting groundwater recharge, reducing the amount of rainwater that becomes runoff and filtering the water so that harmful pollutants don't reach streams and enter groundwater. Clearing forests for agriculture, silviculture or urban development initially results in significant erosion and increased sediment loading to downstream waters, even with the use of best management practices (BMPs). Conversion of forest to urban land may compact the soil to such an extent that even stabilized 'pervious' areas produce increased runoff and pollutant loads compared to undisturbed soils. It is no surprise then that pollutant concentrations in runoff from forest land are generally much lower than runoff from urban or agricultural uses.

The loss of forest land results in a decline in downstream water quality (specifically turbidity), which is associated with an increase in operating costs for drinking water treatment plants. Values associated with the drinking water-related services provided by forests have been quantified in the literature based on people's willingness to pay for clean water and by the avoided costs of constructing filtration plants (in the range of $25 million to $6 billion in gross capital costs). Other avoided costs associated with forest conservation include reservoir dredging, construction of stormwater BMPs, developing new water sources, and implementation of watershed restoration projects.

While the literature as a whole makes a compelling argument for forest conservation to protect drinking water supply, there is a lack of individual studies that quantify the economic connections between forests and drinking water supply. The literature review further underscores the need for an improved understanding about the relationship between watershed forest cover and the cost of providing drinking water in terms that are meaningful to translate into policies and action to protect forests as watersheds are developed. The second part of this study used the Linganore Creek Watershed as a case study to begin to fill in these gaps using real-world economic and land use data.

Pilot Study

Introduction

The purpose of the study was to help quantify the economic connection between forest cover and drinking water quality through analysis of real-world data from the Linganore Creek Watershed in Frederick County, MD. Data availability and insignificant changes in forest cover for the period of study limited the ability to provide a robust relationship between watershed forest cover and sediment loads to Lake Linganore using empirical methods. Due to data limitations, the study did not result in a specific drinking water protection value associated with forests in the Linganore Creek watershed. Instead, a surrogate approach using sediment as a key indicator was used to estimate the economic connection between forests and drinking water. The link between increased sediment yields in a watershed due to land cover change is well documented in the literature. The results include unit costs to remove sediment from various locations in the watershed for the purpose of providing clean drinking water. The study area, methods and results of this pilot study are presented below.

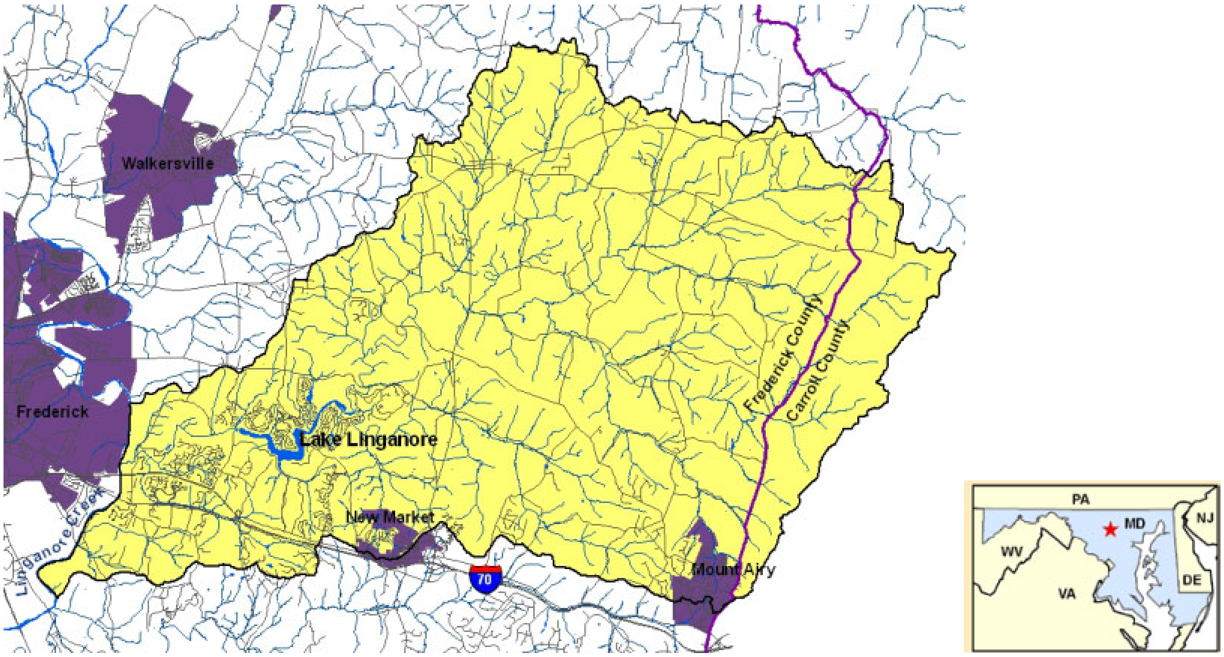
Study Area

The Linganore Creek Watershed is located in the Piedmont Region of Maryland, primarily in Frederick County, with a small portion extending into Carroll County (Figure 1). Linganore Creek has been classified by the Maryland Department of the Environment (MDE) as Class IVP, Recreational Trout Waters and Public Water Supply, and is a major tributary of the Monocacy River, a National Scenic River that is part of the Potomac River Basin and eventually drains to the Chesapeake Bay. The Linganore Creek Watershed has a drainage area of 89 square miles and contains 224 stream miles within its 20 subwatersheds. Roughly a quarter of the soils in the watershed are considered highly erodible. In some parts of the watershed, steep banks along stream corridors make erosion a bigger problem than it might be in less steep terrain.

Agriculture is the dominant land use within the watershed, especially in the northern and eastern portions; however, much of the land in the southern part of the watershed, along the I-70 corridor, is classified as low-, medium-, or high-density residential. Major centers of development within the watershed include the incorporated municipalities of New Market and Mount Airy, the unincorporated communities of New London and Libertytown, the Spring Ridge development, and several communities surrounding Lake Linganore.

The Linganore Creek Watershed is covered by 29% forest, much of which has been fragmented and is privately owned (Table 9). In 2005, Maryland's Department of Natural Resources mapped two large green infrastructure (GI) 'hubs' in the watershed, as well as several small GI hubs (contiguous interior forest) and forested corridors that are important for wildlife passage because of their ability to connect the larger hubs. A good deal of the remaining forest is located in areas having topographic constraints for farming or development such as steep slopes and stream corridors.

Figure 1. Linganore Creek Watershed



Land Use Change in Linganore Creek Watershed

While the pre-settlement vegetation in Frederick County was primarily forest, most significant forest stands were cleared for farming and charcoal production by the early 20th century. During the 1930s to 1960s, abandonment of previously farmed steep slopes and wet areas allowed for natural regeneration of stands of deciduous trees. Much of the forests that we see today were largely created during this period, and are generally considered to be low-medium to high-medium quality forests in terms of ecological health and diversity.

Frederick County began to experience significant urban development in the 1970's. Residential subdivisions proliferated throughout the county, including the Lake Linganore planned unit development (PUD). In the 1980s and 1990s, the Linganore and Spring Ridge PUDs saw increased development. Table 1 shows the changes in land use in the Linganore Creek Watershed over a 30-year period. There is a reduction in forest land use from 1973 to 1997, but a modest gain post-1997. Agricultural land use continued to decline while urban land use increased over the entire 1973-2002 time period. The majority of the urban land created during this time period was for residential use.

Table 1. Land Use Change in Linganore Creek Watershed, 1973-2002 (Source: Maryland Department of Planning)

Type of Land Use	Percent of Watershed in 1973	Percent of Watershed in 1990	Percent of Watershed in 1997	Percent of Watershed in 2002
Urban	2.6	7.7	13.6	16.4
Agricultural	67.9	65	61.3	54.4
Forest	28.8	26.4	24.7	28.7
Wetlands	0	0	0.1	0.1
Open Water	0.3	0.3	0.2	0.4
Barren/Transitional	0.4	0.6	0.1	0

History of Linganore Creek as a Drinking Water Supply

Linganore Creek has been utilized as a drinking water source for the City of Frederick since the construction of the Linganore Creek Water Treatment Plant (WTP) in 1932. The Lake Linganore Dam was constructed in 1972 by Lake Linganore Association (LLA), Inc. as a recreational lake for the Lake Linganore residential developments and to augment the flow in Linganore Creek. The Linganore Creek WTP intake is located downstream of Lake Linganore. Frederick County also withdraws water from the lake under a State water appropriation permit.

In December 2000, Frederick County, the City of Frederick and the LLA executed a Regional Water System Agreement. This agreement requires the LLA to release enough water from the lake to ensure that the City of Frederick can withdraw up to 6.0 million gallons per day (MGD) and also meet its Water Allocation Use Permit flow-by requirement of 4.46 MGD. The agreement also requires the County to cease all water withdrawal from the lake whenever its pool level is below the crest of the dam's spillway. This requirement effectively prevents the County from continuously relying on Lake Linganore as a source of drinking water supply. Any planned or future development in the watershed will be connected to the New Design WTP, which draws water from the Potomac River, or water will be provided through private wells. The Linganore Creek WTP is available as a secondary, back-up source.

The Linganore Creek WTP upgraded in 1954 with three additional filters with further rehabilitation in 1990 to include: flocculation and sedimentation processes, replacing media and underdrains in all six filters with complete computerized controls and instrumentation. The plant operates 24 hours a day, treating an average of 4.1 MGD. Raw water from Linganore Creek flows to a six MG pre-sedimentation pond before heading to the plant for treatment. Treatment processes consist of corrosion control, coagulation, flocculation, sedimentation, filtration, fluoridation, and disinfection. Alum and chlorine are added to two flash mix tanks. If needed, carbon lime and polymer can be added here to aid the treatment processes.

Land Use/Land Cover Impacts and Water Quality Concerns

Sediment accumulation in Lake Linganore has been accelerated due to increased sediment and phosphorus loads from land use/land cover changes in the watershed and the presence of highly erodible soils and steep slopes. Frequent nuisance seasonal algal blooms which interfere with water supply and recreational uses are attributable to excessive nutrient inputs entering the lake. Due to the excess sediment and phosphorus, the lake is included on the state list of impaired water bodies by the State of Maryland. As a result of being on this list, the state has set regulatory limits of phosphorus and sediment to the lake; these limits are known as Total Maximum Daily Loads, or TMDLs. The Lake Linganore TMDL was approved in May 2003 to reduce long-term sediment and phosphorus loadings to acceptable levels.

According to the TMDL study, 86.2% of the non-point phosphorus load and 89.2% of the non-point sediment load to the lake is attributed to agricultural land (MDE, 2002a). Developed lands generate 13.2% of the non-point phosphorus load and 8.4% of the non-point sediment load, while the remaining load is from forest land. Although agricultural land contributes the largest phosphorus load, it is unlikely that agricultural land in the watershed will increase in the future; yet agriculture will likely remain the dominant watershed land use. Therefore, reduction efforts will be concentrated on installation of Best Management Practices (BMPs) on existing agricultural lands. Of concern is that under existing local regulations, forest land and other features important for water quality in the watershed are not protected (i.e., using conservation easements or conservation zoning) and are subject to development and other land use changes. Although forest conservation is required on most development sites, a preliminary analysis of post-development forest cover in Frederick County shows that for most land use types, the majority of pre-development forest is being cleared, despite conservation requirements (developers pay into a fund instead) (Fraley-McNeal, in press).

It is estimated that a 90% reduction in phosphorus loads would be necessary to meet the TMDL for phosphorus (MDE, 2002b). Due to the propensity of phosphorus to bind to sediments, the overall strategy is to simultaneously address the water quality problems associated with phosphorus and sediments. Reduced sediment loading rates in Lake Linganore as prescribed by the TMDL are expected to result in preserving about 48%-79% of the lake's design volume over a period of 40 years (MDE, 2002a).

While only 15% of the watershed is residential according to the Maryland Department of Planning 2002 land use data, the City of Frederick Source Water Assessment Plan (MDE, 2002b) notes some areas of concern based on their size and location:

- Lake Linganore at Eaglehead, is located between I-70 and Gas House Pike and is approximately 3,730 acres. The PUD and surrounding area consist of a mixture of housing types including single family, villa and apartment units planned around Lake Linganore and five smaller lakes.
- The Spring Ridge PUD located southwest of Lake Linganore, on both sides of I-70 and west of Quinn Road. In the area north of I-70, approximately half of this housing development is located within the Linganore Creek watershed and includes a mixture of single family, townhouse and multi-family units.
- Pollution due to non-point source runoff from these large housing developments can be a major concern because of their close proximity to the lake and the City's intake, and high population density (Figures 2-3).

- Concentration of residential access roads with heavy traffic within Lake Linganore at Eaglehead and lack of proper stormwater management practices in some areas of the development can expedite further siltation of Lake Linganore.

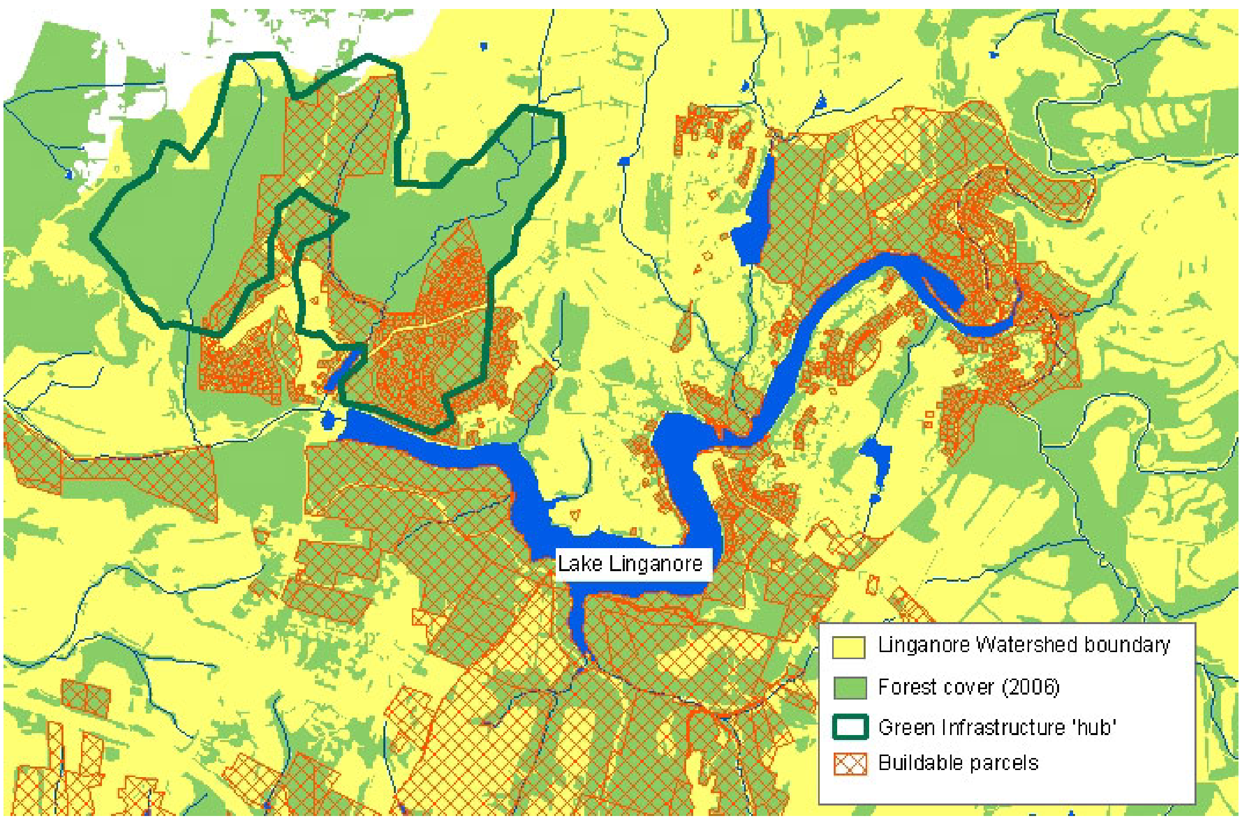
Figure 2. Typical Lake Linganore waterfront home with little forest buffer

Figure 3. Spring Ridge development in Linganore Creek watershed near the lake

Further, there is additional concern with the contribution of future development planned for the watershed to water quality problems. The County's New Market Region Plan describes the planned growth for the towns of New Market and Mount Airy and for the residential areas surrounding Lake Linganore. Three of the County's Community Growth Areas (CGAs) where residential, commercial, and employment uses will be concentrated, are located here (Linganore, Holly Hills, and Spring Ridge). Together, these CGAs have 3,982 new dwelling units in the pipeline with potential for an addition 953 units (Frederick County, 2009). Because all new development in the County with planned water service will be hooked up to the Potomac water system, this future growth should not put additional strain on Lake Linganore as a drinking water source from a supply standpoint. However, the increased sediment and phosphorus load from these new urban areas will continue to impact the lake and affect the water quality for residents who use the lake for their water supply. Specific concerns associated with the location of the planned development include:

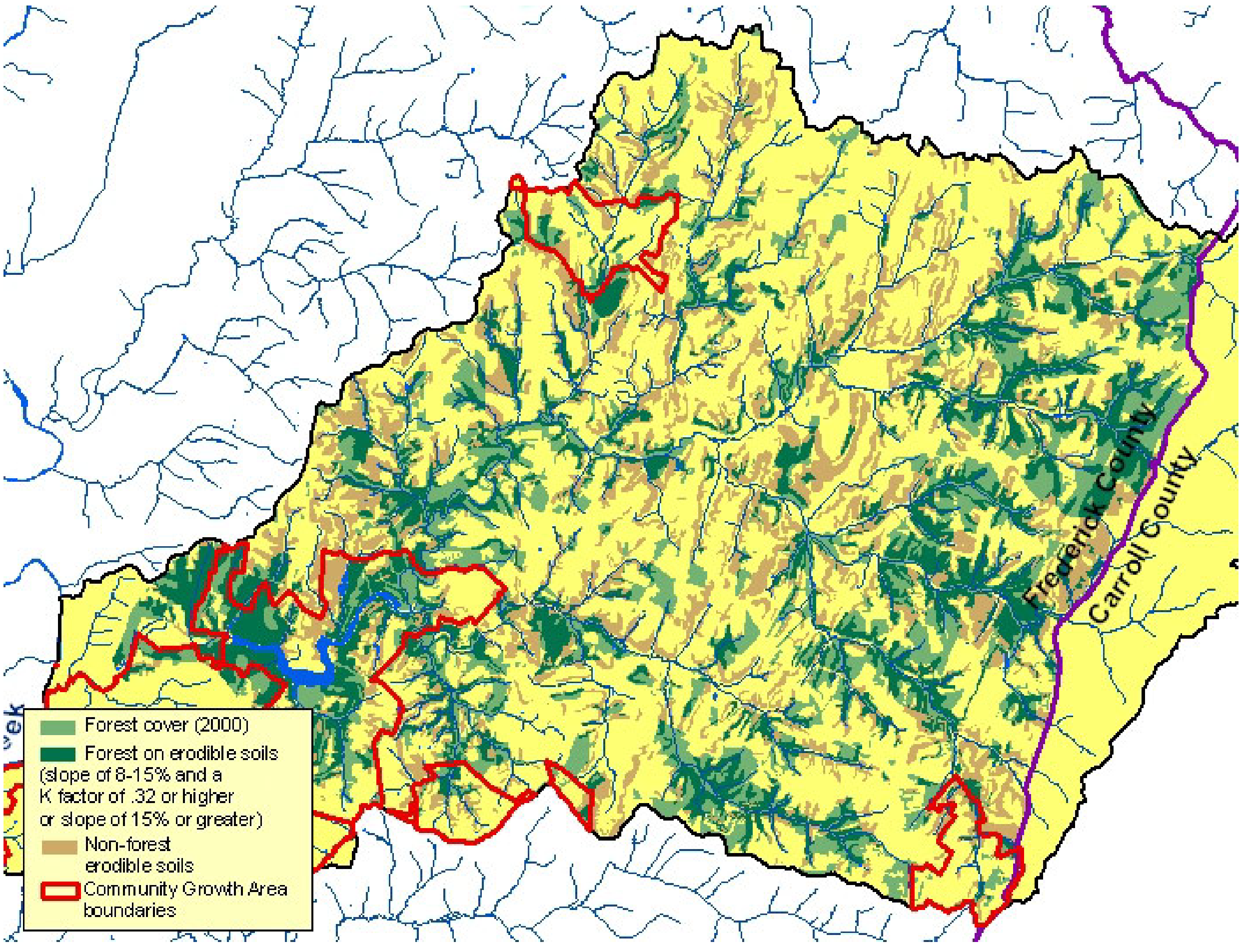
- The proximity to the lake, especially the Lake Linganore at Eaglehead development
- The potential fragmentation or loss of one of the two remaining forest hubs in the watershed (as defined by Maryland DNR, 2005), which is located within one of the CGAs (Figure 4). This property was recently re-zoned to Resource Conservation but the Board of County Commissioners is discussing future changes to allow development here.
- The location of some future growth areas on highly erodible soils (Figure 5). Approximately 19% of the planned growth areas are covered by these soil types, which can greatly increase erosion and sedimentation to the lake both during and after construction. Around 72% of the buildable portion of the forest hub described above has highly erodible soils.

Figure 4. Buildable lands and forest hubs in the immediate Lake Linganore area



These threats to water quality in Lake Linganore and its tributary streams can not only affect the source water quality and associated treatment costs, but will also make it difficult to meet the TMDL load reductions.

Figure 5. Forest and Erodible Soils in Linganore Creek Watershed



Water Supply Planning, Land Use Planning, and Forest Conservation in Frederick County

Land use decisions can have a profound impact on water resources. In Maryland, local governments control land use, while water management is predominantly a State function. Some examples of the problems created by this disconnect between water resource planning and land use planning are highlighted below:

- In some areas of the State, proposed development can proceed through the local government review and approval stages with little attention given to the availability of water until the State review process begins (Wolman, 2008).
- Many jurisdictions have not established a system to track and account for the potential water demand generated by the approval of record plats and building permits. Often, there is a lag time between

subdivision approval and actual construction. These developments that are ‘in the pipeline’ can represent a significant water demand.

- A review of the current set of Maryland water and sewerage plans and Comprehensive plans found that there are wide disparities in how current they are, their quality, and their interrelatedness (Wolman, 2008).

- According to an interview with the Linganore Creek WTP operator, the Frederick City and County WTP operators (both use Lake Linganore as a drinking water supply) do not normally interact except in the event of a spill that would jeopardize the quality of the drinking water supply. There is also limited coordination between the WTP operations and the County land use planning departments.

To strengthen the relationship between local comprehensive plans and county water and sewerage plans, and in recognition of the need to better integrate water resource issues into the local comprehensive planning process, the 2006 Maryland General Assembly enacted legislation requiring all local governments with planning and zoning authority to include a Water Resources Element (WRE) in their comprehensive plans by October 1, 2009. Frederick County’s WRE shows that, for the most part, areas where drinking water is provided or planned overlaps with the County’s CGAs. Nearly 60% of the County’s residents obtained their drinking water from community water systems in 2006 with the remaining 40% of the population relying on individual wells (Frederick County, 2009).

Preservation of land in the County is focused more on prime agricultural land rather than forest land, and is not really a consideration in terms of source water protection. The primary mechanism for forest conservation is the County’s Forest Resource Ordinance (FRO). The FRO program was adopted in 1992 to meet the Maryland Forest Conservation Act of 1991. Under the FRO, development, forest clearing, and earth disturbing activities must meet FRO requirements as follows:

- Reforestation or Conservation: replaces forest that is removed as part of the development process and conserves remaining forest, with numeric thresholds specific for different land use types.

- Afforestation: requires developers to plant trees to meet a numeric threshold of forest cover for sites that do not have much remaining forest to conserve.

Another option under the FRO for sites with limited conservation or afforestation opportunities is to pay a fee in lieu of meeting the FRO requirements. Money collected through this mitigation process is used to finance tree planting projects in the County. A GIS-based analysis of developed land in the County shows that the median forest cover remaining after development for most land use types (all but very low density residential and open urban land) is less than 4% of the parcel area, regardless of how much forest existed on the site prior to development (Fraley-McNeal, in press). This implies that the FRO has not been effective at encouraging on-site conservation, but rather, most developers choose to pay the fee-in-lieu or mitigate for forest loss off-site elsewhere in the County. The County has collected approximately $1.5 million in fees, and is in the process of allocating these funds to purchase easements from private property owners in the watershed for conservation or reforestation of riparian land.

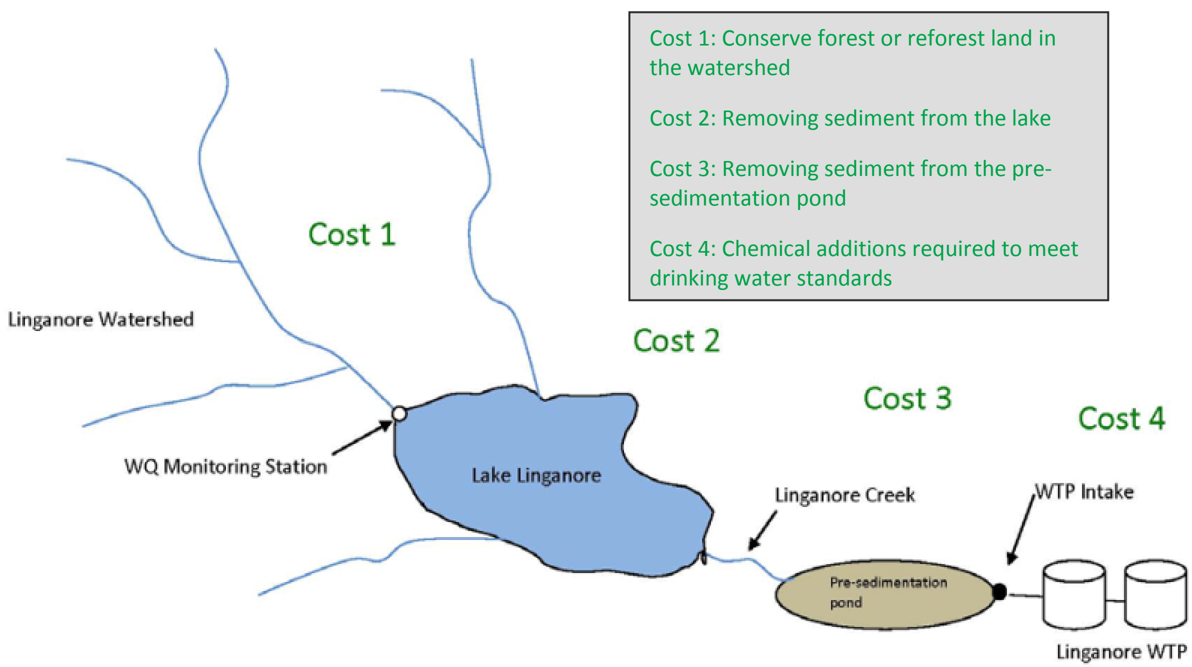
The County also has a forest banking program, which accepts voluntary FRO easements. Each acre placed into easement is a "credit" that can be sold to others who need to meet their FRO requirements. Finally, there are several state conservation programs available for landowners who wish to place conservation easements on their land; however, there is generally limited participation in these programs since they are voluntary especially for forest land owners.

METHODS

The pilot study used existing local data to determine the volume of sediment that would need to be removed from various points in the watershed in order to provide clean drinking water for residents as well as the unit costs associated with sediment removal. **The scope of this study was limited to the cost to remove sediment from water for the express purpose of drinking water supply and use**. It should be noted that there are a host of additional market and non-market values and costs that could be considered in this analysis, for example, the cost to construct urban and agricultural BMPs to reduce erosion and capture sediment, value associated with increased consumer confidence as a result of improved taste and odor of drinking water, costs associated with the effects of sediment on industrial equipment and household appliances, the environmental effects of reservoir dredging and sediment disposal, and the health and ecological impacts of other pollutants associated with sediment, to name a few. Therefore, the values estimated using this methodology likely represent a fraction of the total costs associated with forest conservation. The costs are limited to those bourne by the water utility and ultimately passed onto consumer, and do not represent the full scope of services provided by forests, but instead focus on a very limited range of benefits.

A simple modeling approach (Caraco, 2010) was used to estimate the sediment load that could be reduced (or avoided) through implementation of forest conservation or reforestation measures in the watershed. The actual per-acre cost of implementing these practices in the watershed was used to develop unit cost estimates that were compared to the cost to remove sediment from points lower in the watershed. To approximate the cost of removing or treating sediment from the water supply, three separate costs were estimated given available data on sediment removal from the drinking water supply treatment train that includes the lake, a pre-sedimentation pond and the treatment plant itself. A conceptual diagram of the four costs in the Linganore Creek Watershed is shown in Figure 6.

Figure 6. Conceptual Diagram of Relationships between Land Use, Drinking Water Quality and Sediment Removal Costs in the Linganore Creek Watershed



Cost 1: Cost to conserve forest or reforest land in the watershed

The volume of sediment reduced or avoided by conserving existing forest land or reforesting agricultural land in the watershed was estimated using pollutant loading coefficients from the Chesapeake Bay Program's Phase 4.3 model (used to develop the Linganore TMDL) (Table 2). The sediment load for reforestation was estimated by taking the difference between the agricultural and forest loading rates, while the conservation practice was taken as the difference between urban and forested land use. The costs for reforestation and conservation practices are based on the purchase price for easements and forest buffer conservation in the Linganore watershed (Wilkins, personal communication). Table 3 summarizes the data used to estimate the cost to conserve or reforest land in the watershed.

Table 2. Chesapeake Bay Program Phase 4.3 Watershed Model Sediment Loading rates

Land Use Type	Chesapeake Bay Program Phase 4.3 model loading rates (tons/acre/year)
Agricultural land	0.347
Forested land	0.024
Urban land	0.144

Table 3. Volume of Sediment Reduced or Avoided Under Conservation and Reforestation Scenarios in Linganore Creek Watershed

LULC Conversion Type	Change in Sediment Load (tons/acre/year)[1]	Unit Cost to Reduce Sediment[2] ($/ton)
Reforestation (Agriculture to Forest)	0.33	$30,960
Conservation (avoided load calculated based on a Forest to Urban conversion)	0.12	$33,333
[1]Based on annual sediment loading rates from Chesapeake Bay Program Phase 4.3 model (used to develop the Linganore TMDL) [2] Based on the current purchase price for easements in the Linganore watershed: • $10,000/acre for reforestation of buffers (includes easement purchase in addition to cost of reforestation) • $4,000/acre for conservation of existing forest buffers		

Cost 2: Cost of removing sediment from the lake

Data from a siltation and cost study in 2002 and a bathymetric survey conducted by the USGS in 2010 were to estimate the cost of sediment removal from Lake Linganore. A 2002 siltation study of Lake Linganore (Whitman, Requardt & Associates, LLP, 2002) showed that 13% of the Lake's capacity had been lost to sedimentation between 1972-1999, an estimated loss of 104.5 million gallons (MG) due to the addition of 320 acre-feet of sediment. A 2009 bathymetric survey conducted by USGS found comparable results. Sekellick and Banks (2010) estimated that **313 acre-feet of sediment** has been deposited in Lake Linganore from 1972-2009, resulting in a 16% loss of capacity. The USGS study used more reliable methods and was more recent, so these values were used and converted to a mass (for comparison with other data) using a sediment density of 1.5 g/cm^3 from Hargrove (2007). This resulted in an estimated **638,370 tons of sediment** deposited to Lake Linganore**.**

The siltation study estimated costs for two dredging scenarios at $3.5 million and $4.3 million, to remove 188 acre-feet of sediment from Lake Linganore and restore 61 MG of capacity (or $11.53/$yd^3$ to $14.18/$yd^3$). Two other options for restoring lake capacity were explored: 1) emergency excavation estimated at $6.7 million and 2) raising the water level with a 2-foot rubber dam to restore 149 MG of capacity or a 3-foot dam to restore 221 MG of capacity. The cost to install the 2-foot rubber dam is **$1.2 million** and the cost to install the 3-foot dam is **$1.5 million**. In addition, the study estimated costs to install a forebay for long-term sediment management at $580,000 for construction, and $7.00/$yd^3$ to remove 1 foot of sediment from the forebay through maintenance dredging once every two years. All cost estimates considered hauling and disposal of materials as well as engineering and permitting costs. The final recommendations were to use a combination of the forebay and rubber dam to increase the lake's capacity. Another cost related to in-lake treatment is the twice per year addition of copper sulfate to control algae at a cost of $300 per event. Algae is a primary source of turbidity in the summer months. This would add a negligible $600/year to the total cost. A summary of the data used in this cost estimate is provided in Table 4.

Table 4. Sediment Deposited in Lake Linganore and Estimated Cost of Removal

Volume of Sediment Deposited in Lake (tons)	Estimated Cost to Restore Lake Capacity	Unit Cost to Remove Sediment ($/ton)[1]
638,370 (from 1972-2009)	2-ft rubber dam: $1.2 million 3-ft rubber dam: $1.5 million Dredging: $3.5 million to $4.3 million Emergency excavation: $6.7million	$1.88 to $10.50
[1] does not include costs associated with forebay construction and maintenance dredging or cost of in-lake treatment with copper sulfate		

Cost 3: Cost of removing sediment from the pre-sedimentation pond

The Linganore WTP draws water from Linganore Creek below the dam instead of drawing directly from the Lake. The water goes to a 6 MG pre-sedimentation pond that allows sediment to settle out before being sent to the plant for further treatment. The Linganore WTP operator estimates that the 6 MG pre-sedimentation pond is dredged 3 times every 10 years and estimates the cost of dredging the pond to be $250,000 per event, with a unit cost of $0.08/gallon to remove the sludge from the pond (or $13.89/yd^3) and dispose of it (Lambert, personal communication). Using these figures, an estimated 3,125,000 gallons of sludge is removed every 3.3 years, which is converted to a mass using a sediment density of 1.5 g/cm^3 from Hargrove (2007), resulting in an estimate of **19,560 tons per event (Table 5).** This would mean that the pond is filled to about half its capacity every 2-3 years.

Table 5. Sediment Removed from Linganore Water Treatment Plant Pre-Sedimentation Pond and Estimated Cost of Removal

Volume of Sediment Deposited in Pre-Sedimentation Pond (tons)	Estimated Cost to Dispose of Sediment	Unit Cost to Remove Sediment ($/ton)
19,560 every 3.3 years	$250,000 per event	$12.78

Cost 4: The cost of chemical additions required to meet drinking water standards

As turbidity increases in drinking water influent, the variable costs of water treatment to mitigate this turbidity increase, primarily related to addition of chemicals that bond to sediment particles to promote settling, and disposing of the solids that are deposited. Some communities have even attributed the avoided costs of constructing filtration plants to conservation measures applied in the watershed. For the Linganore WTP, construction and operating costs were not available, so the costs to remove sediment from the plant's pre-sedimentation pond as well as the cost of chemical additions (primarily alum) to remove sediment from the water column were used for this analysis.

Monthly water quality reports from the WTP were obtained for a portion of 2007-2009 and evaluated them to determine the total sediment load treated at the plant for 2008. Raw water turbidity was converted to total suspended solids (TSS) using the NTU and flow data and an equation documented in USEPA (2009). The estimated TSS load treated ranges from **39,374,629 tons/yr to 108,275,600 tons/year**.

Using the monthly water quality reports from Linganore WTP, we determined the total alum additions in 2008 were 272.65 tons. We also obtained a unit cost for alum addition from the County (based on bids secured by the County in 2010) and multiplied by tons of alum to determine a total cost of **$78,988** for alum addition in 2008. It is recognized that the raw water quality and required chemical additions from 2008 may not be representative of an average year; however, our analysis had to be limited to this time period because it was the only timeframe for which we could obtain electronic records.

Results and Discussion

The combined costs of reducing or removing sediment from the Linganore Creek Watershed water supply and use is summarized in Table 6. Table 6 compares the unit costs to remove sediment (or prevent erosion) through various activities in the Linganore Watershed for the express purpose of water supply. The unit cost to remove sediment through alum addition is negligible. However, due to limited cost data available for WTP operation, this estimate is not an accurate reflection of the cost to remove sediment but was used as the only available data. Other costs that would ideally be included are: cost of additional treated water used to backwash filters, replacement cost of filters, some portion of WTP operating costs, occasional cleanout and disposal of sludge from settling basins and initial construction of the filtration plant. Further, the method used to convert NTU to a sediment load (derived from EPA, 2009) is very coarse and may require further analysis to determine its practical application. Despite the inability to provide a full cost for removing sediment, a comparison of turbidity values (a sediment indicator) for Linganore and another water treatment plant in Frederick County (Lester Dingle) in which the watershed is completely forested illustrates the impact of forest cover on water quality. The turbidity values expressed as NTU (unitless) are a fraction compared to the Linganore WTP. For example, the average NTU value at the Linganore WTP is 8.7 with a range of 2.0 to 72.7, compared to an average NTU value of 0.83 and range of 0.37 to 1.8 NTU at the Lester Dingle WTP for 2008. While qualitative in nature, this finding supports the research that shows water quality declines as watershed forest cover decreases.

Table 6. Costs to Reduce Sediment in Drinking Water in the Linganore Creek Watershed

Method of Preventing Erosion or Removing Sediment	Unit Cost to Remove Sediment ($/ton)	Benefits or Impacts in Addition to Drinking Water
Forest conservation in the watershed	$33,333	Air quality improvement, wildlife habitat, water quality goals (e.g., TMDLs), replenish groundwater, social benefits
Reforestation in the watershed	$30,960	Same as above; may result in loss of useable land for property owner
Dredging/disposal of sediment deposited in the lake or other methods to increase lake capacity	$1.88 to $10.50	Potential environmental impacts (e.g., would require wetland permits and environmental impact study)
Dredging/disposal of sediment deposited in the pre-sedimentation pond	$12.78	Possible environmental impacts to disposal area
Alum addition at the WTP	N/A*	None

* Cost of adding alum is minimal per ton of sediment treated

The unit cost to remove sediment from the pre-treatment pond is 1.2 to 6.8 times the cost to remove it from the lake through dredging, depending on which lake restoration method is selected. This is likely due to the high initial mobilization costs associated with dredging, making large-scale projects such as the proposed lake restoration project more cost-effective. The unit costs for forest conservation and reforestation are comparable to each other because, although a greater volume of sediment is reduced on a per acre basis by converting to forest from a developed land use such as agriculture or urban, the actual cost to purchase an easement on agricultural land in Frederick County is more than double the cost to purchase forested land. The reason for this price difference is to compensate the landowner for the loss of useable agricultural land associated with reforestation. Overall, the unit costs for forest conservation and reforestation are several orders of magnitude higher than the unit costs to remove sediment at the lake and WTP. The reasons for this and implications are discussed below.

As shown in Table 6, there are a variety of other costs and benefits associated with each sediment-reducing activity that should be considered. For example, while dredging the lake and treating water at the WTP generally do not provide other benefits to the community, forest conservation and reforestation can help the County to meet their TMDL goals and are generally more cost effective stormwater management solutions when compared to structural BMPs. Further, there are many additional benefits provided by forests that are not easy to measure but are important from a social, environmental and economic standpoint. However, when focusing narrowly on the removal of sediment for drinking water supply, it is more cost effective to dredge the lake or treat raw water at the WTP (per unit of sediment) than it is to prevent the same amount of sediment from eroding in the first place. Therefore, proposing to use these values to help provide an incentive for forest conservation and reforestation is not likely to be successful unless additional costs and benefits to the community are considered.

One goal of this study was to generate results that could be used as a basis for establishing costs for purchase of easements or fee-in-lieu payments under the FRO that reflect the cost associated with drinking water treatment in Frederick County. While we did not have sufficient data to do so because the cost of sediment removal at the WTP is likely underestimated and because the results focus solely on sediment, we propose the following as an initial (e.g., starting point) for such a cost structure. Payments made in lieu of meeting the FRO requirements are currently based on values established by the Board of County Commissioners (BOCC) and the current payment ranges from $18,730 to $23,522 per acre (depending on location) (http://www.frederickcountymd.gov). These fees could be increased to not only reflect the cost to establish forest cover elsewhere in the County to replace forest lost at development sites, but also to reflect the costs to replace other services provided by these forests, such as runoff reduction, erosion control and drinking water protection. The results of this study provide an initial *minimum* estimate of the sediment removal benefits of forests as follows:

> Cost to remove sediment from WTP (not calculated) + cost to dredge pond ($12.78/ton) + cost to install forebay ($0.91/ton) + cost to install 2-foot rubber dam ($1.88/ton) + cost of forebay dredging ($1.26/ton) * sediment kept on site through reforestation of agricultural land using fee-in-lieu funds (0.323 tons/acre) = $5.44/acre

Note that the costs of installing a forebay and 2-foot rubber dam were used because these were recommended in the 2002 siltation study as the most cost effective way to increase lake capacity. The cost of maintenance dredging of the forebay was also derived from Whitman, Requardt & Associates, LLP (2002). It is recommended that the County further evaluate available cost data to refine this estimate and fill in gaps (e.g., cost to remove sediment at the WTP, perhaps by estimating a portion of the City's water treatment budget that is attributed to Linganore WTP) and make the case to the BOCC to raise the fee-in-lieu by the resulting amount to begin to reflect the actual costs to replace some forest benefits. Raising the fee would also have the effect of further encouraging on-site conservation as intended by the FRO, which is particularly important in light of a recent study that shows that most of the forest is being cleared for development (Fraley-McNeal, in press).

Some additional suggestions are outlined below regarding further analysis of the Linganore data as well as changes to municipal programs, policies and fee structures.

- While the unit cost of forest conservation and reforestation relative to the sediment reduced is high compared to other methods of removing sediment from drinking water, the fact is that forests produce significantly less sediment and pollutants than agricultural or urban land uses and are valuable strategies to meet water quality goals such as TMDLs. TMDL implementation plans should not only include these measures but should model how the loss of unprotected forest with future development will influence watershed pollutant loads.
- Another facet of this analysis that has not been explored but would be useful is to use site-specific data to identify sites that provide a greater pollutant removal benefit (e.g., because of their position in the landscape, soils type, slope, adjacent land use, etc) and prioritize these for conservation or reforestation to make the most of limited funds. The result of the ongoing USGS sediment study in Lake Linganore should be used for this analysis.
- A true costing of the additional environmental benefits and the social and economic benefits provided by forests would help to quantify the additional benefits provided by forests as compared to dredging and WTP chemical additions to put these practices on a more level plane. Ideally, the value of these benefits and other environmental costs would be built into the purchase price of easements.
- At the County level, greater coordination and communication across departments such as watersheds (TMDL, stormwater, watershed planning) and planning (land use and forest conservation) is needed to work towards common goals and share resources.
- Better linkages are needed so that water supply planning, source water protection and WTP operations are tied into local land use planning and the process for site plan approvals.
- The County should consider revising the structure for payment of fees in lieu of compliance with the Forest Resource Ordinance to reflect the cost to reforest elsewhere as well as the cost to adequately compensate forest landowners for providing drinking water services.
- Utilities should re-evaluate drinking water cost structures and consider ones that are reflective of the true cost to provide it over the long term (e.g., include cost to remove sediment periodically). This can serve to fund source water protection projects as well as begin to educate consumers about the connection between source water protection activities and drinking water quality.

CURRENT AND FUTURE WORK

The Center conducted a buildout analysis of the Linganore Watershed to estimate forest loss with future development. The results show that the current (2010) forest cover in the Linganore Creek Watershed is 29.97%. With future buildout of the watershed, 679.45 acres of forest will be cleared, decreasing watershed forest cover to 28.65%. This represents only a 1.3% loss across the watershed, but a 14.5% loss within the growth area boundaries. We are currently using these results to recommend a forest cover goal for the LInganore Watershed, to be adopted by the County, as well as specific actions to achieve the goal. Because current forest cover and future forest loss are both relatively low, achieving a forest cover goal will have to primarily be accomplished through an aggressive reforestation effort. Since most of the land is private, this will rely heavily on outreach and education.

In addition to the buildout analysis, runoff volume and pollutant loadings were assessed using the Watershed Treatment Model (WTM) (Caraco 2010) for three scenarios – pre-development (99.7% forest), existing land use (30.0% forest), and future buildout (28.6% forest) of the watershed based on comprehensive land use plan designations. For each scenario, total annual loading rates were calculated for nitrogen, phosphorus, and suspended sediment. The analysis was conducted using GIS and 2007 land use / land cover data for Frederick County (MDP nd). While the runoff and pollutant estimates for the existing and future scenarios do not reflect absolute values because they do not account for secondary sources of pollution (i.e., non-land use factors such as road sand, septic systems, and channel erosion) or the presence of management practices to treat runoff, the results of this analysis show the relative change in runoff and pollutants associated with land use changes in the watershed. Methods and data used to derive the estimates are described in Fraley-McNeal (in press).

The results, presented in Table 7, show that pollutant loading increases as forest cover is replaced with agriculture and urban uses. Comparing pre-development to existing development reveals that total nitrogen (TN) increased 82%, total phosphorus (TP) increased 289%; and total suspended sediment (TSS) increased 30%. Comparing existing development to proposed future development reveals that TN may increase an additional 3%, TP may increase by 5%, and TSS may increase another 3%. While the increase in pollutants and runoff from the pre-development to future scenario estimates from the Watershed Treatment Model cannot be ascribed solely to the loss of forest cover (since forest loss is always associated with the addition of a new land cover), the results imply that forest conservation and reforestation measures have great potential in helping the County meet regulatory requirements for pollution reduction in the watershed.

Table 7. Estimated annual land use based pollutant loadings for the Linganore Creek Watershed

Land Cover Scenario	Annual Runoff (acre-feet/year)	TN (lbs/year)	TP (lbs/year)	TSS (lbs/year)
Pre-Development (99.5% forest cover)	3,259	122,487	9,683	4,820,210
Existing Development (30.0% forest cover)	12,296	222,665	37,712	6,275,675
Future Buildout (28.6% forest cover)	13,449	228,628	39,549	6,469,212

Because this study did not result in a definitive per-unit cost recommendation to use in valuing watershed forests and appropriately compensating landowners for the drinking water benefits they provide, we were unable to use the results in an education campaign as described in the original scope of work. However, we are currently conducting a multi-media outreach campaign focused on the Linganore Creek watershed to 1) increase tree planting within the watershed and 2) track the effectiveness of the various outreach mechanisms in encouraging landowners to plant trees. The outreach campaign includes:

1. A series of ads and articles published in the Frederick News Post and ads in local newsletters and church bulletins. The basic message of the ad is to plant a tree for clean drinking water and encourages folks to visit the Marylanders Plant Trees website to download a coupon for $25 off the purchase of a native tree from participating nurseries.
2. Radio ad(s) on local station Key 103. The basic ad was run during traffic and weather announcements for one week and focused primarily on promoting tree planting and the $25 coupon. A longer ad providing more info on why you should plant trees for clean drinking water was run during the prime listening time that same week.
3. A short (1 minute) video podcast was developed with a similar message as the print and radio ads. The podcast will be widely broadcast through various Frederick County partners as well as social media sites such as Facebook.

The Marylanders Plant Trees program tracks participants who redeem coupons at local nurseries and will provide this data to the Center so that we can determine the number of trees planted in Spring 2011 in the Linganore Creek Watershed. The coupons also require the user to note where they heard about the program. We will use this info to determine if one of the media types was more effective in encouraging watershed residents to plant trees.

CONCLUSIONS

Research conducted as part of this study revealed the need for improved reporting and accessibility of water treatment data so that a broader scale compilation and analysis can be used to elicit the relationship between drinking water and watershed forest cover. Additional research is needed to value forests on the same ‘level playing field’ as other public services. Getting public and political support for environmental initiatives can be difficult as the services provided by natural resources are not valued in the same way as other initiatives for which there are clear and quantifiable economic benefits. The field of ecosystem valuation involves estimating the dollar value of ecosystem benefits where possible, and developing non-monetary indicators of economic value where dollar measures are impossible or impractical. There are a wide variety of methods for valuing ecosystem services that should be further explored to define a more robust connection between drinking water and forests.

The limited analysis applied to the Lake Linganore watershed illustrates the economic disincentive for forest conservation (e.g., technology can meet water quality standards more cost-effectively). However, as Frederick County continues to grow, additional pressure to find and construct new water sources and WTP will increase the cost of supplying drinking water. Albeit, forestry practices alone will likely not achieve the desired load reduction to meet drinking water quality standards alone or TMDL requirements, and conservation and reforestation have multiple benefits that go beyond protecting water supplies not quantified in this report.

The results provide a baseline cost to remove sediment that has eroded as a result of land use practices in the watershed in order to provide clean drinking water. The results are preliminary and further analysis can be used to help make the case for greater (and more cost-effective) land use management practices in the watershed in order to reduce sediment inputs and treatment costs. The unit costs to remove sediment at various locations in the watershed can be compared to help guide how to best target local conservation and restoration dollars. Alternatively, communities with primarily forested water supply watersheds can use these numbers to make the case for forest conservation to prevent sedimentation of reservoirs and increased treatment costs at the WTP.

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