Indiana Department of Natural Resources
Division of Forestry

Effects of Forest Management on Water Quality: Focus on Monroe Lake Watershed, Indiana

Abstract

Forests are the source for the highest quality and most sustainable water resources (Neary, et al. 2009). Forested land cover, even multiuse forests that include timber production, have been found to be positively correlated to good water quality. In the United States after mass deforestation during the settlement and post-settlement periods, forest cover is generally increasing steadily. Indiana has gained 20% in forest cover since the 1920s, an increase of 4.6 million acres (McCoy 2005, Sobecki & McCoy 2017). While forests provide clean water, activities that occur in the forests can contribute to nonpoint source pollution (NPS). This paper will focus on how silvicultural practices can affect water quality and on the practices commonly used to reduce or eliminate these possible effects, focusing on the Monroe Lake Watershed in south-central Indiana.

Forests soils & Water quality

For centuries forests have been noted for their ability to provide high-quality water for civilizations. In 1215 King Louis VI of France announced "The Decree of Waters and Forests," which noted the connections and relationships of water and forests. In 1342 the first European watershed protection forest was set aside in Switzerland (Kitterage 1948). A total of 322 more forests would become protected watershed preserves in the next 400-plus years. The U.S. National Forest System was created in 1891, primarily for watershed protection. In the early to mid-20th century, 441 paired watershed studies were created in the continental U.S. to establish the scientific connections of forests, water, soils and nutrient cycling (Ice & Stednick 2004). Many of these studies are long-term and ongoing. Numerous paired watershed studies have successfully proven that reduction in forest cover increases water yield, afforestation reduces water yield and that nitrate nitrogen (NO_3-N) does not significantly increase in streamflow after partial or complete clear-cutting (Neary 2016). These are just a sampling of the conclusions that scientists have definitively drawn from these studies.

The paired watershed studies, in which at least two similar watersheds were studied with control and treatment watersheds, were designed to test and learn a variety of things about forested watersheds. Study topics include, but were not limited to, nutrient cycling, atmospheric deposition, climate change, hydrologic budgets, subsurface and surface flow, stream habitat and biota, and water quality and quantity. These are based upon a variety of land manipulations including but not limited to clear-cuts with and without best management practices (BMPs), selective single tree cuts, and shelter wood cuts (Elliot & Vose 2009, Arthur, et al. 1998, Neary 2016). The impact of fire, invasive species and disease have also been subjects of paired watershed studies (Stednick 2008, Ice & Stednick 2004, Neary et al. 2009).

NPS pollution occurs to surface waters when runoff from precipitation moves pollutants (manure, soil, nutrients, chemicals, oils, etc.) from the varying land uses to surface waters, such as streams, lakes and wetlands. Therefore the land use/land cover that runoff moves across has direct impacts upon surface-water quality. Forests in watersheds have been shown to drastically reduce the need for drinking-water treatment, thus reducing water costs (Stolton & Dudley 2007, Gray 2003, Fiquepron, et al. 2013). Agricultural and urban lands have been shown to cause the most NPS pollution (Tasdighi, et al. 2017), this same study showed no significant or strong correlation of forests to nutrient loads and concentration. Runoff from primarily agricultural watersheds has been shown to be nine times higher in nutrients, total phosphorus and total nitrogen than from watersheds that are primarily forested (Omernik 1977). Gianessi et al. 1986, Brown & Binkley 1994, found that national sediment loading rates into streams from cropland was more than five times higher than from forested lands.

Eastern forest cover has increased after the land was cleared during settlement times (Foster, et al. 2003). Indiana's pre-settlement forest cover is estimated to be 85%. By the early 1900s that number had plummeted to 7% (McCoy 2005). In the last 100 years, the amount of Indiana's forested lands has increased 4.6 million acres. Now, 27% of Indiana is covered by forests, an increase of 20% (Sobecki & McCoy 2017). Land that was previously used for pasture, mining and row-crop agriculture has since been converted to forest; however, the soils of these areas still reflect the legacy of previous land uses (Yesilonis, et al. 2016, Foster et al. 2003).

Soil O and A horizons were reduced and in some cases even completely depleted during these activities, increasing surface flow and accelerating erosion. Gullies formed from severe erosion due to previous land uses fill with organic material after afforestation, encouraging soil formation. But these gullies can be reactivated in forests, especially during disturbance, either from man's activities on the land or when natural disasters strike.

Jackson, et al. 2005 determined that 60-80% of current sediment in export in the South Carolina Piedmont Region was from stream down, cutting erosion from unstable soils due to past agricultural uses on highly erodible areas. However, soils are reforming on abandoned agricultural and mine lands. Van Lear 1995 showed that slowly, at a rate of a few centimeters in a half century, new A horizons are re-establishing in the Piedmont. As forest soils reform, sediment delivery has declined, nutrient flux has been reduced and stream flow is less volatile (Jackson, et al. 2005).

Southern Indiana forests show this pattern of forest regrowth on previously farmed or mined lands. Many sediments coming from stream-bank erosion could be due to stream channel back cutting and bank erosion from forest/stream hydrogeomorphology that is still in the process of reaching equilibrium after the trauma of past overuse and abuse. In the southern Appalachians, researchers found that the diversity and composition of fish and macroinvertebrates in streams were best predicted not by current forest cover but by watershed land use more than 50 years before (Harding, et al. 1998, Maloney, et al. 2008). Effects of past land uses on recovering forest soils and streams is an area that is under-researched, especially in the Midwest. It is not currently known if the effects of these past land abuses are still affecting the land and waters of southern Indiana, where the large majority of afforestation occurred in the state.

Impact of Forestry BMPS

Logging may affect water quality (Stednick 2008, Brown 1979). The severity is determined by a variety of factors, including slope, harvest type, harvest equipment used, weather conditions during and after harvest, use of BMPs, and many others. Typically, the impacts are short-lived due, in large part, to the rapid natural re-vegetation of sites in the Midwest (Sobecki & McCoy 2017).

Research has shown that, typically, a two-year increase in sediment and associated nutrients is recorded after a harvest, with delivery of these pollutants quickly returning to pre-harvest levels shortly thereafter (Croke et al. 2001, Megahan 1974, Friedricksen 1970, Hewlett 1982, Brown & Binkley 1994). Multiple paired studies have also shown the difference between logged watersheds with and without forestry BMPs employed during and after the harvest (Edwards & Willard 2010, Arthur et al. 1998). Litschert & MacDonald 2009, examined areas below 200 timber harvest units in the California Cascade Mountains to identify sediment and water movement over land in the form of rills and sediment plumes. A total of 19 features were found, 15 rills and four sediment plumes. Only six rills, no plumes, made it to a stream. Soil and water movement was largely attributed to skid trials (N=16) while three were from clear-cuts. Authors attribute the low number of incidence to the current BMP practices used in that region.

Forestry BMPs have been found to be efficient at reducing sediment and nutrient delivery to surface waters (Arthur et al. 1998, Edwards & Willard 2010, Hornbeck & Reinhart 1964, Stewart & Edwards 2006). Edwards & Willard 2010 showed an efficiency rate of 53-94% for sediment removal the first year after harvest. Particulate and sediment bound forms of nitrogen (60-80% removal rate) and phosphorus (85-86% removal rate) were quite responsive to implementation of forestry BMPs. However, soluble nitrogen only had a 12% removal rate, showing that BMPs are effective only for surface-water pollution control.

Forest roads and trails, and resulting stream crossings have been indicated as the source of most pollutants at a harvest site (Croke et al. 2001). Streams can be crossed in a variety of ways. Simple fords or culverts are often used. Bridges and bridge mats are used less often but are effective crossing structures. A study in the Piedmont region of North Carolina looked at sediment yields above and below stream crossings and found that two were wood bridges, three steel-bridge mats, and one culvert was installed. Sediment loads did not significantly increase total suspended sediments (TSS) at any sites before, during or after the harvest (Boggs et al. 2017). Sediment loads above the crossings averaged 82 kg/ha/year and 80 kg/ha/year below the crossings. This indicates that if proper BMPs for each crossing were employed, that sediment delivery would likely be minimal, even on the most vulnerable parts of the harvest.

Forestry BMPs in Indiana

For more than 20 years, the Indiana Division of Forestry (DoF) has carried out a Forestry BMP program and employed a team of professionals that are dedicated to education, research, monitoring, enforcement, data analysis and reporting of practices to reduce NPS pollution associated with timber harvests and other forest-management activities. Every harvest site on State Forest properties is monitored for application and effectiveness of BMPs to reduce NPS pollution to surface waters and protect soil health during and after the harvest.

The five main areas of a harvest are examined. These include access roads, log yard, skid trails, stream crossings and riparian management zones (RMZs). All State Forest harvests in Indiana, which are monitored for compliance and effectiveness, are internally required to employ BMPs. BMPs are considered at every stage of the harvest. While marking the harvest, foresters designate areas to avoid, where to place water diversions and crossings, and the location of sensitive areas and RMZs.

These practices are discussed in pre-harvest conferences between the forester and the loggers before every harvest. Consultations between a professional forester and loggers before a harvest have been shown to enhance BMP implementation (Cristan et al. 2016). Foresters monitor the site during the harvest for compliance of BMP standards. The forester also works with the loggers to ensure the correct BMPs are implemented at closeout. Sometime after the closeout of the harvest is complete, typically within two years or less, the administering forester and (a) member(s) of the monitoring team look over the entire site, with special focus on the five main areas of the harvest discussed previously. Every year, data from all of the sites monitored in that year are analyzed and a report is compiled. A total of 588 state sites monitored across those 20 years have an 86% BMP application rate and a 92% effectiveness rate (Sobecki & McCoy 2017),

Figure 1. Not only does DoF monitor State Forest harvests, since 2009, a total of 10% of reported Classified Forest harvests were monitored and reported on yearly as well, comprising 452 sites (Sobecki & McCoy 2017), Figure 1. In the past years, 122 non-industrial private forest (NIPF) owners and a handful of other land ownership types have been monitored after timber harvests as well. Since the beginning of the BMP monitoring program in 1996, more than 1,172 sites and counting have been monitored (Sobecki & McCoy 2017), Figure 1. Application rates for the 20 years of monitoring is 86% and effectiveness rate is 91%, Figure 2.

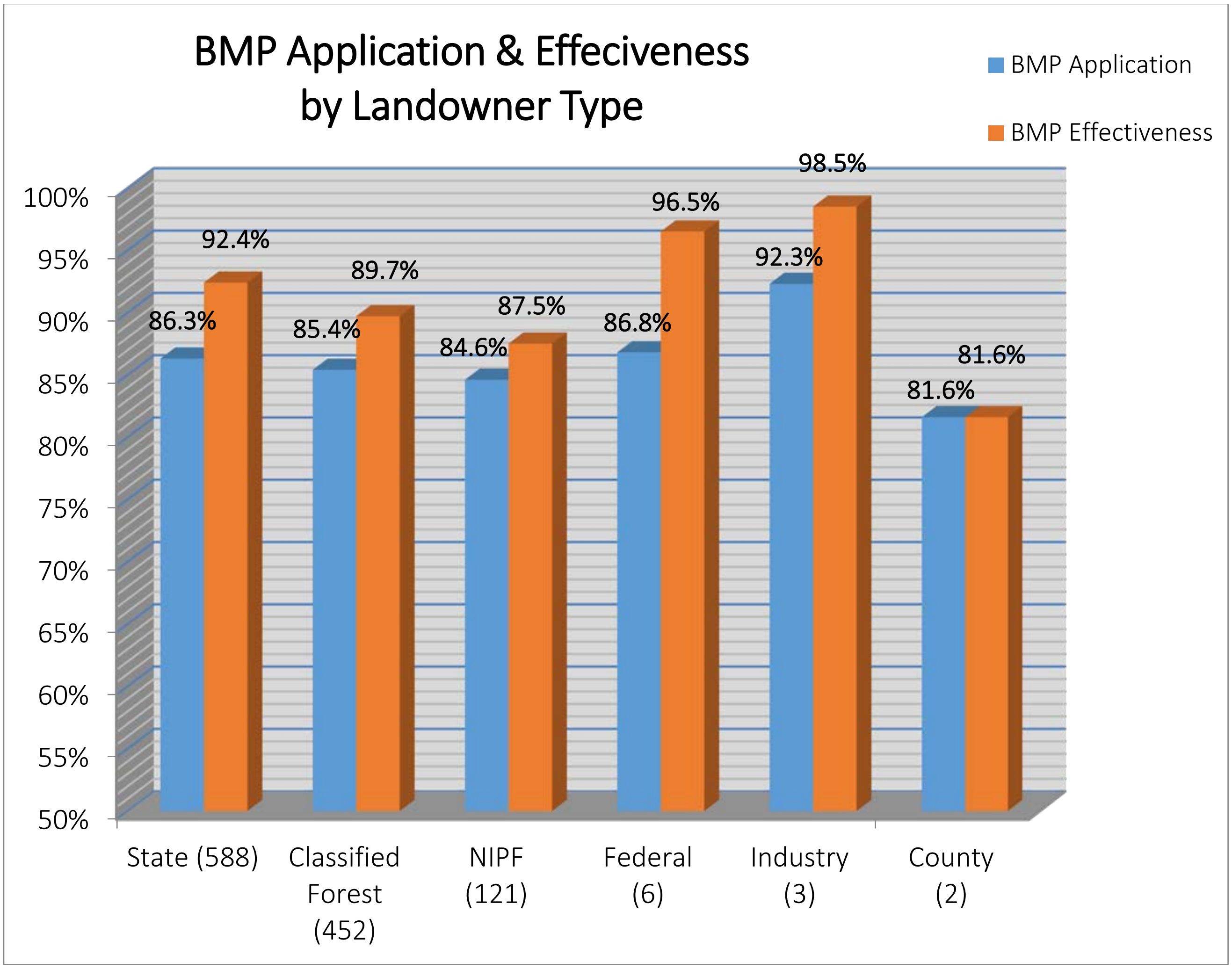

Figure 1. Indiana Forestry BMP application and effectiveness percentages for all landowner types and all sites monitored in the 20-year history of the program (Sobecki & McCoy 2017)

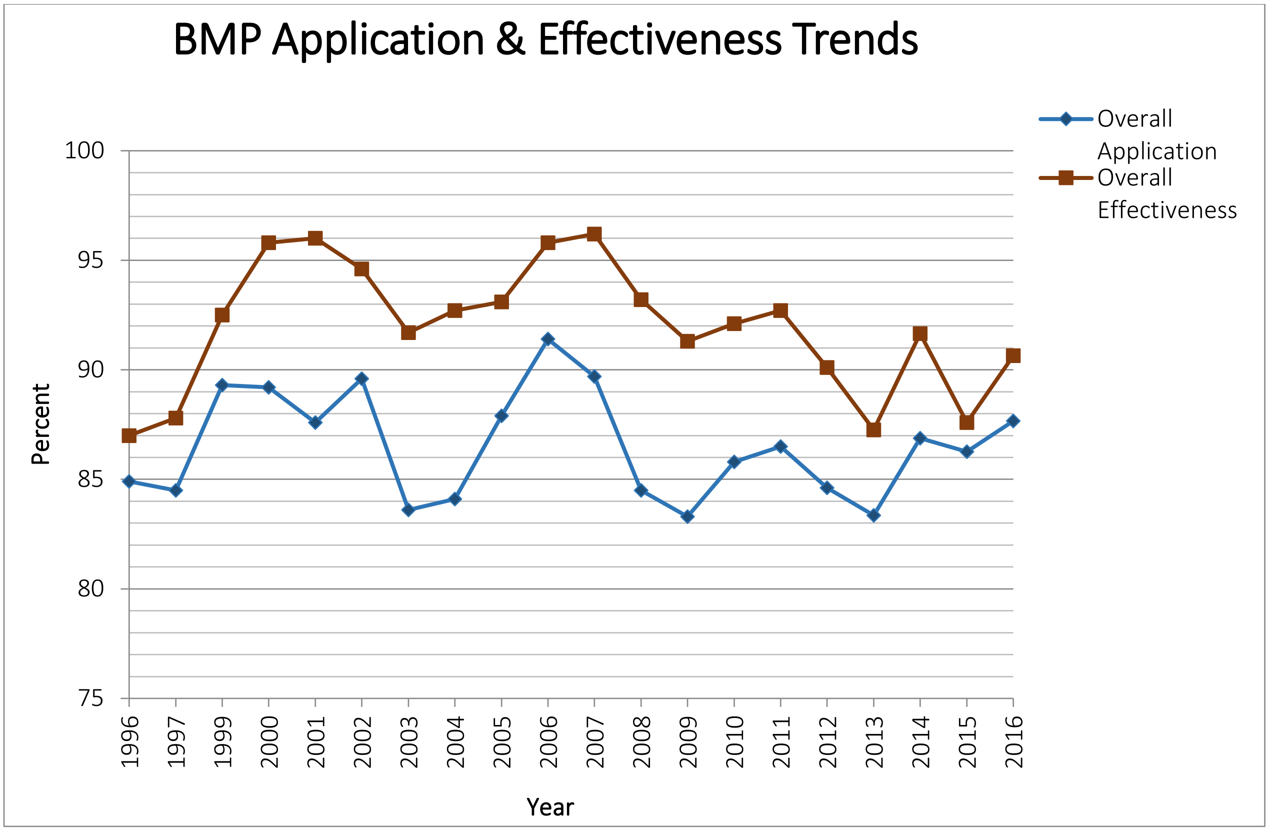

Figure 2. BMP application and effectiveness yearly trends for all sites throughout the 20-year history of the Indiana Forestry BMP Program (Sobecki & McCoy 2017).

Not only are these sites monitored, but any significant impacts on the site are noted, and mitigation of these breaches is strongly suggested on state sites and suggested on private sites. BMPs in Indiana are voluntary for private timber harvest sites, except sites where the Flood Control Act and Clean Water Act are violated. Some common departures and suggested mitigations on state and private harvests are logging debris in streams, the need for water diversions on roads or trails, usually water bars, and the need for bank stabilization at stream crossings. These impairments are easily mitigated by cutting or pulling out logging debris, putting in diversions and applying straw and seed to areas that need stabilization (Sobecki & McCoy 2017). The process of continual monitoring, data analysis and reporting allows the DoF staff to respond quickly to BMP issues that may arise and increase research and/or education efforts. It also allows for earlier detection of any positive or negative trends that may emerge.

Ice et al. 2010 found that the national average of overall BMP implementation was 89%. These rates are rising due to changes in legislation, regulation, certification (SFI®, FSC®, etc.) and public pressure. Indiana BMP implementation was the highest of any state in our area at 88% at the time of Ice's 2010 paper. Kentucky's was the lowest in our area, at 68%. Ohio, [1]Illinois, and Michigan were at 84% implementation. Increasingly, the public is demanding products that are sustainably produced. Certification groups like the Sustainable Forestry Initiative® (SFI) program and Forest Stewardship Council® (FSC) conduct audits to ensure these standards are upheld after a group earns certification status. The land management program on Indiana State Forest properties has been certified by both SFI and FSC (FSC-C012858) since 2007 (IN DoF 2017). The Classified Forest & Wildlands Program has also held certification status with FSC (FSC-C071226) since 2008 (IN DNR DoF 2017). Classified Forest landowners decide if they want to participate in certification.

Monroe Lake Watershed and Effects of Logging

The Monroe Lake watershed located in south-central Indiana is Indiana's largest reservoir. It measures 10,750 acres, and drains a 277,000-acre watershed of mixed land usage and ownership. However, there is a large amount of forest within this watershed. A total of 82% of the Monroe Lake Watershed is forested (Purdue 2017), Table 1. Many of these forested sites on private lands also have houses located on the tract.

Table 1. Land-use percentages for the Monroe Lake Watershed. Data derived from Purdue University Department of Agriculture & Biological Engineering. (Purdue 2017). https://engineering.purdue.edu/~lthia/

Monroe Lake Watershed Land Use	% of Watershed
Forest	81.9%
Grassland/Pasture	7.1%
Open Water	4.6%
Agriculture	3.5%
Park/ Open Space	1.9%
Residential	0.2%
Commercial/Industrial/Transportation	0.0%
Shrub/Scrub	0.7%
Wetlands	0.0%
Barren Land	0.1%

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Table 2: Landownership for Monroe Lake Watershed. Data derived from internal IN DNR GIS files.

Land Ownership	% of Watershed
Private Residential/Commercial/Municipal/Water	40.00%
Hoosier National Forest USFS	24.00%
State Forest (Yellowwood & Morgan-Monroe)	18.00%
Classified Forest (Private Forestland)	10.00%
State Parks (Brown & Lake Monroe)	8.00%
Nature Preserves	0.50%

Monroe Lake is typical of the waters in this region in that it is phosphorus limited, meaning that phosphorus is the element that limits plant growth (micro and macrophytic) in the waters (Chang 1982). Phosphorus is largely delivered to waters as a sediment-bound particle. As a result, limiting erosion and sedimentation will limit phosphorus.

Monroe Lake was found to have low sediment accumulation compared to sedimentation rates for other reservoirs in Indiana at a rate of 0.03 in/yr. (Jones et al. 1997). This is in large part due to the high percentage of forested land cover in this watershed compared to the watersheds of other Indiana reservoirs. A phosphorus export model showed that 48.5% of the total phosphorus loading in the watershed comes from agricultural lands (Jones, et al. 1997), agriculture comprises about 10% of the watershed, pasture and grassland included, so that land-use percentage may be an overestimate. A total of 47.2% of the phosphorus was shown by the model to be coming from forested-land use; however, forest does make up 82% of the watershed. Also, the urban/residential contribution was thought to be underestimated—the small residences were not large enough for the GIS to resolve. The Purdue University Department of Agricultural and Biological Engineering Department has created an online watershed tool that calculates loads for various pollutants (Purdue 2017). This tool showed a very different annual phosphorus loading amount for forest at 5.3% (Table 3).

Table 3. Annual Phosphorus load as calculated by the Purdue LTHIA online tool (Purdue 2017). https://engineering.purdue.edu/~lthia/

Land use	Ave Annual Phosphorus (lbs.)	% of Annual Load
Low Density Residential 1/2acre	4329	15.74%
High Density Residential 1/8acre	268	0.97%
Commercial	374	1.36%
Forest	1459	5.30%
Grass/Pasture	171	0.62%
Agricultural	20910	76.01%

The DoF owns 18% (50,467 acres) of the area within the Monroe Lake Watershed. Most of that is forested lands. The watershed is 82% forested. A total of 24% of the watershed is federally owned by the USFS Hoosier National Forest, 8% of the watershed is owned by DNR State Parks (Monroe Lake & Brown County). A total of 10% of the watershed is held by private forest & wildland owners who have their acres enrolled in the Classified Forest & Wildlands Program. Half a percent of the watershed is owned by the DNR Division of Nature Preserves. The remainder of the watershed (40%) is held by private, commercial and various other landowners, Table 2.

The loss of forest would threaten the health of the Monroe Lake Watershed (Stolton & Dudley 2007, Anderson et al. 2012). Multiple studies have found that forests, even managed forests, provide adequate protection for drinking-water sources. Brown & Binkley 1994, concluded from in-depth research that water from both unmanaged and managed forests had the best water quality in the nation. The Monroe Lake Watershed has a mix of both unmanaged forests and managed forests (Table 2).

Watershed studies from the Pate Hollow area of the Monroe Lake watershed have shown a lack of impacts from timber harvesting upon the water quality. Storck, 1988, conducted a graduate research project in which four small subwatersheds within the Pate Hollow watershed were studied for water-quality responses to timber harvests. Two of the subwatersheds had harvests, and two did not. The operation standards for the USFS during that time were followed, and the sites were closed with BMPs at the conclusion of the harvest. This research found that even with some mistakes made in the timber operation, little effects to water quality occurred, even with an unusually wet field season.

Moss, 1995, also looked at the same Pate Hollow sites and resulting data, and found no increase in phosphorus due to harvesting, and only recorded one instance of elevated nitrogen; however, that was not determined to be statistically significant.

Both of the researchers for the Pate Hollow study concluded that while small inputs of sediment and nutrients were recorded during and soon after timber harvesting, these amounts were too small to negatively affect water-quality. (Storch 1986, Moss 1995)

Current and past studies of the effect of logging on the water quality of Monroe Lake are lacking. From the little research that is available, it was determined environmental quality goals were not being violated by timber harvesting. In a large watershed with such diverse usage, determining the sources of NPS pollution is challenging task.

Conclusion

Monroe Lake has 82% forest cover. While this is largely beneficial to watershed water quality, many studies show the positive correlation to high water quality and high percentages of forested land cover, there are still activities within these forests that can have negative impacts. While satellite data can show forest cover, many times such data misses the activities that occur in those forests, such as grazing and residential areas with septic systems. Many private forests in the watershed now have defined, frequently used ATV tracks as well. Many of these cross or even go down stream beds, exacerbating erosion.

Logging is also occurring in the watershed, across various landowner types, including private, classified private, industry, state and federal. While state and federal agencies hold logging contractors to high standards, requiring monitoring and enforcing BMPs during and after the harvest, this is not always true for private lands, on which BMP participation is voluntary. About 10% of the Monroe Lake watershed forests are in the Classified Forests & Wildlands Program. Private forests that are certified in the Indiana Classified Forest Certified Group are required to follow current BMP guidelines. Classified Forests that are not in green certification must avoid significant erosion according to the Classified Forest & Wildlands law. Even in instances in which the logging job was not optimal in respect to BMPs, the effects are typically short-term, two years or less, and erosion rates are lower than from other land uses.

Monroe Lake provides drinking water for Bloomington, Indiana, with a population of more than 84,000, including Indiana University, which has a student population of more than 42,000. Monroe Lake waters provide an average of 15 million gallons of water per day to Bloomington residents and businesses (City of Bloomington 2017). Understanding the dynamics of this watershed, and pinpointing the main pollutants and their sources is important to the health and well-being of the entire ecosystem of the region, human population included. This review identified several research gaps for this region. Many more are yet to be seen. Some research gaps seen were historical land-use influence on current-day streams and water quality, effects of various types of timber harvesting, and effects of ATV traffic on forest soils and waters.

There have been multiple studies conducted within the watershed and lake, in part due to the watershed being near a university. In the past, several diagnostic and pilot studies have been conducted and management plans produced for the watershed (Jones et al. 1997, Willard & Primack 1996, USACE 2015). While these were thorough reports, they are either now more than 20 years old and no longer reflect current conditions in the watershed and/or focus more on the recreational uses and future planning instead of diagnostics.

The Hardwood Ecosystem Experiment (HEE) is a 100-year study at Morgan-Monroe and Yellowwood state forests now in its 11th year of collecting data and publishing results on the effects of timber management on plants and animals of the area (Meier 2015). More than 50 peer-reviewed articles and several extension publications have been published as a result of the HEE (HEE 2017). Research on water chemistry responses to even-aged stand management are in the beginning stages (HEE 2017).

The Monroe Lake watershed is large and diverse, with many different pollutant sources. If the focus is to improve water quality of this watershed, the main sources that are most detrimental to water quality should be targeted in order to have the greatest impact on water quality. Managed and unmanaged forests have long been associated with the highest water quality when compared to other land uses. Even so, Indiana's Forestry BMP program continues to monitor and improve harvesting practices to minimize the negative impacts on water and soil quality for all the watersheds in the state.

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