Forest Management and Water Quality
In Indiana

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Abstract

Forests cover about one-third of the land in the United States, yet they produce about 80% of the freshwater resources (Sedell et al., 2000). With the majority of that forest in private ownership, often economic forces drive their destiny to either be managed as an economic resource, to be converted to a more economic land use, or to be sold.

Timber management has a unique relationship with water quality in that there can be both positive and negative correlations. By managing timber, there is a positive impact in that forests are the producers of the cleanest surface and ground water when compared to other land uses, and wood products contribute to the national gross product.

When timber is harvested, there can be negative impacts by increasing sediment, nutrients, pesticides, and other pollutants depending on the management system and practices utilized. Often, many of these negative impacts are minimal when compared to other land uses and the pollutants they produce, but can still be prevented or mitigated by using Forestry Best Management Practices.

This discussion will include general practices and systems both silvicultural and harvesting, their possible impacts to water quality, how or when these practices are used in Indiana, mitigating practices that can be employed, and how all of these subjects come together in Indiana's forests and state forest properties.

I. Introduction

In pre-settlement times Indiana was approximately 23,157,000 acres in total area and approximately 85%, or 19,683,450 acres were forested. By 1900, the forested acreage of Indiana had been literally cut down to an estimated 7%, or 1,620,990 acres. Since 1900 legislation in Indiana and the United States has helped Indiana get to an estimated 20%, or 4,553,800 acres, forested through programs to help landowners plant and manage their private forests, and by public entities buying or keeping abandoned land and managing it as forest (Miles, 2004; Verry et al., 2000; Tormoehlen et al., 1998).

The management of forests is called silviculture, and silviculture is defined on the University of Missouri-Columbia's School of Natural Resources webpage as "the science, art and practice of caring for forests with respect to human objectives." In carrying out silviculture on the State Forests of Indiana, for which they were legislated in Indiana Code 14-23-4 (Indiana Legislative Services Agency, 2005a), the forests are managed for watershed protection, recreation, wildlife, and timber. Management of these objectives: recreation, wildlife, or timber requires manipulation of the ecosystem through silviculture, which may have an impact on water quality, although minor when compared to other land uses (NCASI, 1999; Patric, 1995; Welsch, 1991).

In the 1890's Gifford Pinchot believed forests should be valued because their effect upon climate, floods, runoff, and erosion. Pinchot was convinced of the positive impact of forests upon streams. He was quoted as saying "The connection between forests and rivers is like father and son. No forests, no rivers" (Todd, 2001). In 1897 the National Forest Commission recommended establishment of 13 forest reserves for timber, water supply, and flood prevention (NCASI, 1999).

When trees are harvested, machinery must move the trees from the place in which they stood to the place where they are processed. Trails must be constructed and maintained for travel and recreation, as well as vistas opened and lawns mowed. Different species of wildlife need different habitats in which they thrive, so each particular habitat must be managed to meet the requirements of different species. All of these objectives require silvicultural prescriptions that can have an impact on a site's soil and water resources, which then can impact water quality.

It is the scope of this paper to focus on the impacts that a specific silvicultural practice, timber harvesting, can have on water quality, and relate their use on Indiana State Forest properties. Today, state forest properties have approximately 148,650 acres of land, of which 20,000 acres do not have timber management as one of the objectives at this time. When timber management requires that harvesting be carried out, a site specific infrastructure is needed to facilitate the movement of people, machinery, logs and trucks.

II. Nonpoint Source Pollution

The Federal Water Pollution Control Act, better known as the Clean Water Act (CWA), had as its objective "to restore and maintain the chemical, physical, and biological integrity of the Nation's waters." In the bill Congress directs the United States

Environmental Protection Agency (USEPA) to meet these objectives by evaluating both Point and Nonpoint sources of pollution. A point source is defined in the CWA as

> any discernible, confined and discrete conveyance, including but not limited to any pipe, ditch, channel, tunnel, conduit, well, discrete fissure, container, rolling stock, concentrated animal feeding operation, or vessel or other floating craft, from which pollutants are or may be discharged. This term does not include agricultural stormwater discharges and return flows from irrigated agriculture (US Congress, 2002).

Nonpoint Source (NPS) pollution is defined by the Environmental Protection Agency (USEPA, 2005) to be "any source of water pollution that does not meet the legal definition of *point source* in section 502(14) of the Clean Water Act of 1987." Pollution is defined in the CWA as "the man-made or man-induced alteration of the chemical, physical, biological, and radiological integrity of water." Through the CWA, states were directed to identify and evaluate the NPS pollution from each listed contributor, which included, but was not limited to, agriculture, mining, and construction as well as silviculture, and to develop Best Management Practices (BMPs) for each contributor that would reduce the resultant pollution as much as possible (US Congress, 2002).

The USEPA and others have identified sediment as the pollutant of greatest concern from forestry activities. Other pollutants such as, nutrients, temperature, toxic chemicals and metals, organic matter, pathogens, and pesticides are of concern as well, but to a lesser degree (USEPA, 2005; NCASI, 2001; Binkley et al., 1999; NCASI, 1999). As forestry BMPs were developed in Indiana, they focused on sediment as the pollutant of concern, but addressed the others as well. The focus was on sediment because pesticides and other chemicals are not commonly used in abundance as in the Deep South, streams are commonly left with a number of trees to shade them, and the other pollutants have not been identified as pollutants from forest activities in Indiana.

With CWA grant money through the Indiana Department of Environmental Management (IDEM), the Department of Natural Resources Division of Forestry (DoF), in cooperation with the Woodland Steward Institute, took on a statewide project to develop an aggressive program to implement voluntary forestry BMPs. The forestry BMP guidelines were completed in 1996 and the first edition of the Forestry BMP Field Guide was published in 1998. The BMP monitoring program, which monitors public and private timber harvest sites, has evolved a great deal since the guidelines were produced in 1996. The DoF has monitored BMPs in five official rounds; 1996, 1997, 1999, 2000, and 2005 and monitored BMPs on every timber harvest on state forest properties from July 1, 1999 through 2003 at which time the DoF began to evaluate the effectiveness and efficiency of monitoring every timber sale and moving to a sampling method (Sobecki and McCoy, 2005).

The focus of this paper will parallel that of the Indiana Forestry BMPs'. It will look mainly at sediment, but will also identify and discuss other pollutants that are important to the water quality situation in Indiana.

III. Forest versus Other Land Uses

In Indiana there are many land uses that fit in the categories of NPS contributors to include; mining, construction/urbanization, agriculture, and silviculture. In the 1997 Natural Resource Inventory (NRI), soil loss through sheet and rill erosion was estimated at 2.9 tons per acre per year from all cropland, which was estimated to have 10,915,700 acres, not including Conservation Reserve Program (CRP) that had a different erosion rate, which results in an estimated 31,655,530 tons of sediment in 1997 from cropland alone. The 1997 NRI also estimated CRP land would add 59,970 tons of sediment and another 519,610 tons of sediment from pastureland. From cropland, there is another soil loss through wind erosion, which is not lost from CRP, pastureland, or forest because they have continuous ground cover; which adds another 0.5 tons per acre per year of which some amount ends up as sediment, some as atmospheric dust, and the remainder comes to rest on another place. The total average soil loss from cropland in Indiana adds up to 3.4 tons per acre per year across the cropland acreage multiplies to 37,113,380 tons. In the NRI there is no estimate of soil loss from forestland, but that is not to say soil erosion does not happen on forested soils (NRCS, 1997). Hood et al. (2002) recorded 0.14 tons per acre per year lost from the control plot and Patric (1980) (cited from Hood et al., 2002) estimated 0.1 tons per acre per year from responsibly managed forestland

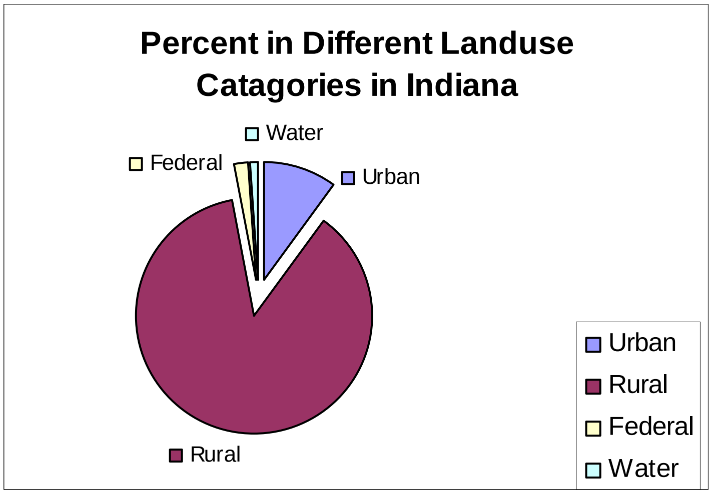


Figure 1. Produced from Table 1 of the NRI Data (NRCS, 1997)

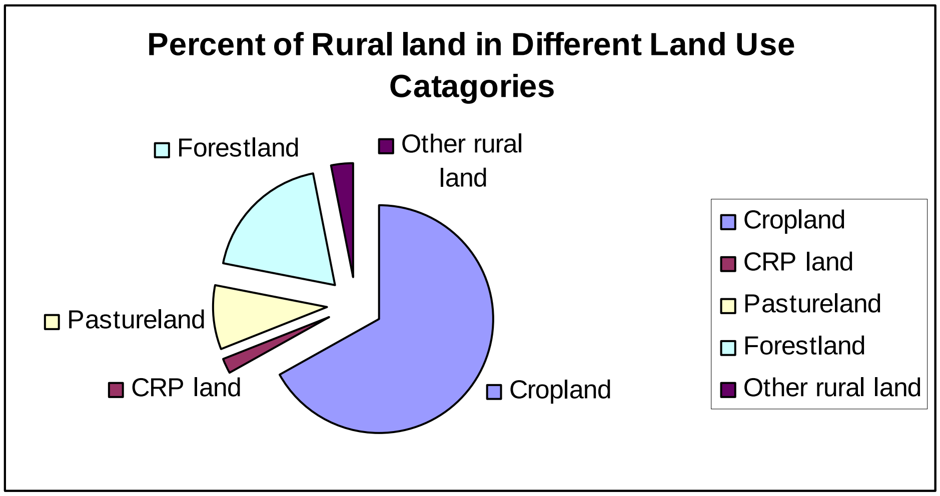
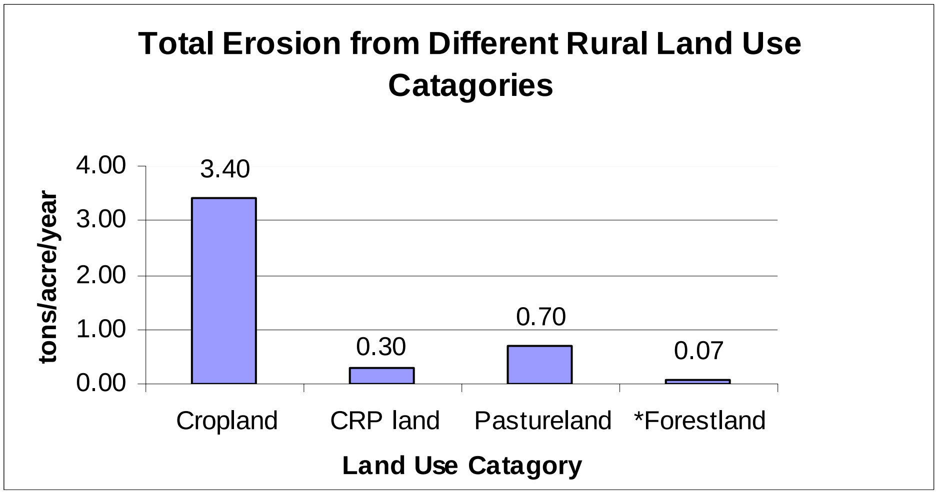


Figure 2. Produced from Table 2 of the NRI Data (NRCS, 1997)

Soil erosion is a natural process often referred to as geologic erosion, in which the detachment and movement of soil particles by wind, water movement above or below the surface, freeze-thaw processes, or some kind of mechanical process (glacial movement or activities of organisms). Soil erosion in natural systems occurs at variably low rates depending on watershed conditions (Spence et al., 1996; USDA, 1993). Indiana's pre-settlement soil erosion rates were low depending on the local topography, weather, parent material (glacial till, limestone, etc.), and the activity of the local organisms. Since settlement of Indiana, erosion increased with farming and development. In recent years there has been a decrease in erosion rates as conservation practices and NPS mitigation programs have become more active. An example of this decrease is evident in the NRI, in which cropland was losing an average of 4.7 tons/acre/year in 1982 and has decreased to the 2.9 tons/acre/year in 1997 referenced above.



* = No Indiana specific data found, eastern forest average soil loss (Patric, 1976).
Figure 3. Produced from Tables 10 and 11 of the Indiana NRI data (NRCS, 1997).

Manipulating soils and their local environment to meet management objectives can affect the hydrologic cycle for that area, essentially changing the amount of water that will take its different paths once at the vadose zone, which is the zone from the soil surface to the water table. The main paths of water at the vadose zone include overland flow, subsurface flow, evaporation, and evapotranspiration. An example would be if all the trees in a forest were cut, but not moved, forest soil moisture content would likely increase due to a net reduction in forest evapotranspiration (ET) and a reduction in interception by vegetation allows more precipitation to reach the soil, organic matter recruitment (leaves, needles, wood) for stream channels could increase, but could move back toward original levels as the vegetation recovers (Rockefeller et al., 2004; Putz et al., 2003).

In different land uses the soil and its environment is manipulated differently, but all have similar affects to differing degrees, such as areas with lower infiltration rates, mineral soil exposure, vegetative manipulation or removal, smooth surfaces, and others. These manipulations create pollutants such as sediment, larger and quicker peak flows, and temperature if there is less vegetation covering the waterbodies.

Urbanized areas have high amounts of impervious surfaces that raise water temperature and increase runoff, fertilized lawns and gardens that increase N and P, roads with metals and petrochemicals, waste water treatment plants, septic systems, and pets that increase coliforms, and a myriad of other sources and pollutants (Coulter et al., 2004; Long and Plummer, 2004; Murray et al., 2004; Welsch, 1991). In looking to meet USEPA drinking water standards at their intakes, New York City was looking at an $8 billion water filtration project, and instead spent $500 million to put in conservation practices and riparian buffers to have the same effect and to this day, the New York City Watershed is a model for others to follow (Gray, 2003).

Areas under construction remove most vegetative cover, large amounts of soil are removed, moved, and compacted, drainage patterns are manipulated, all of which produce increased levels of overland flow and peak flows, water temperature, sediment, and nutrients. Once construction is complete these urbanized areas become highly dissected with impervious surfaces that have high rates of overland flow and high temperatures, lawns that are often fertilized with nutrients, and all wash directly into storm drains. All of these impacts are maintained in an urbanized area, so their impacts are sustained for the long term (Schueler, 1994).

Farming manipulations are commonly broken into classes of cultivation and grazing. Cultivated soil is manipulated several times across a large area with heavy equipment causing surface and subsurface compaction, macropore dissemination, and smoothing the surface, only specific vegetation is grown, and the area is usually left bare for some part of the year. Most cultivated vegetation does not completely cover the soil with a canopy or a cover of organic matter that can intercept precipitation before reaching the soil. Precipitation can mechanically disassemble surface colloids into individual soil particles, which decreases pore size at the soil surface lowering infiltration. Nutrients, such as nitrogen and phosphorus are added to the soil, which move with soil colloids and water flow above and below the surface, eventually making into surface waters. Vegetation on grazed soils is manipulated to grasses, and animals walk the area despite soil moisture content causing surface compaction, decreasing infiltration and increasing overland flow. All of these impacts are maintained in the agricultural system, so their impacts are sustained for the long term (Long and Plummer, 2004; Bharati et al., 2002; Mitsch et al., 2001; Spence et al., 1996; Welsch, 1991).

In a ground based timber harvesting system, machinery must move the trees that are felled, but traffic is often concentrated onto trails covering variable amounts of the area being harvested, depending on the equipment operators and the silvicultural prescription utilized (Kreutzweiser and Capell, 2001; McNabb et al., 2001). Also, there can be several years between harvests to allow natural or planted vegetation to grow and help those areas return to pre-harvest conditions in 1 to 5 years (Lister et al., 2004; Putz et al., 2003; Hood et al., 2002; Patric, 1996, Patric, 1995a) depending on the amount of compaction, local topography, and soil properties.

In comparing grazed pastures, cultivated fields, and forested riparian buffers of silver maple, Bharati et al. (2002) found that precipitation’s ability to infiltrate soil was best under the silver maple, and the grazed fields and the cultivated areas had little difference between them. Some of the reasoning behind lower infiltration was increased soil sealing due to a lack of vegetative cover and little canopy, increase in bulk density, and a decrease in soil uptake.

IV. Impacts of Timber Harvesting and Regeneration

There are several silvicultural prescriptions that can be used when having a timber harvest, and each has its own level of intensity to determine the number of trees to be removed and the system in which the subsequent generation of trees will grow. There are several systems that may be utilized to facilitate the removal of the trees being harvested, each with its own common impacts. Once trees are removed and the harvest is complete, there are several methods for the regeneration of a tract and the impacts that they can have. Many of these different methods and their impacts are discussed.

“Silvicultural systems are long-range harvest and management schemes designed to optimize the growth, regeneration, and administrative management of particular forest types” (Young, 1982). The two most general silvicultural systems are even aged or uneven aged management. Even aged management is when all of the trees in the stand are managed to be of the same age and usually employs one or some combination of three methods; clearcutting, seed tree, and shelterwood. Uneven aged management is when the trees are managed so that there can be a distribution of different ages represented in one stand, which is accomplished by selecting single trees or groups of trees to be removed to maintain a distribution of age classes (USEPA, 2005; Kreutzweiser and Capell, 2001; Kellison and Young, 1997; Young, 1982).

In order to manage these differing silvicultural systems, or combination thereof, often trees need to be removed to meet the objectives. Clearcutting is usually the most intense and famous of these silvicultural prescriptions, in which all of the trees in the stand are removed or killed because the desired species of trees to grow in the next generation are shade intolerant. Whichever silvicultural system is chosen, there are different harvesting systems that may be employed to cut, process, and move the trees. Most harvesting systems generally include; hand or machine felling; drag, carry, cable, or aerial removal to landing; hand or machine bucking whether at the stump or on the landing; and removal of the logs by trucks from the landing to the processing plant. Each of these harvesting systems impact the remaining resources in different ways. The timber harvesting industry in Indiana uses, almost exclusively, ground based drag systems utilizing cable skidders in 95.6% of the timber harvests monitored. Other drag systems include horses, ATV's, tractors, and backhoes. There are harvesting systems that are not drag systems, such as forwarders, that carry the logs rather than dragging them, and they have appeared on timber harvests in Indiana, but their use at this time is limited and has appeared on only one monitored site thus far. Grapple skidders are employed in Indiana, but the monitoring has not differentiated between grapple or cable skidders (DoF BMP unpublished data).

Utilizing a ground based dragging system, usually with skidders or clambunks, can affect the soil profile in many ways and the amount of disturbance correlates with the concentration of traffic and soil conditions with the most soil compaction occurring within the first three times an area is traveled over, due to compacted soil particles having a greater capacity to resist further mechanical compaction (Block et al., 2002; McNabb et al., 2001; Startsev and McNabb, 2001). Traffic affects on the soil constituents are immediate and determined by several factors such as moisture content at the time of traffic, soil physical properties, and location in the soil profile. The closer soil moisture is to field capacity or greater, the higher likelihood of compaction, puddling, or displacement, each negatively impacting infiltration and conductivity of water and gasses through degradation of soil aggregates causing a reduction in porosity. The soil constituents deeper in the soil profile are less likely to be mechanically impacted as the gravimetric force diminishes with depth (Miller et al., 2004; Block et al., 2002; McNabb et al., 2001).

Dragging the logs moves or removes the organic material from the O horizon of the soil commonly known as the forest floor, mixing with the A and E horizons, or exposing the mineral soil to sunlight and precipitation. The humus layer of the forest floor may be characterized by a 7 class humus index, which describes the interaction of the organic material over the mineral soil and the A horizon which is a mix of decomposing material and the inorganic material (Ponge et al., 2002). Soil quality, soil productivity, and landscape processes often have the humus index or the O horizon thickness as a character in its description (Wander et al., 2002; Block et al., 2002), and can be included in the Universal Soil Loss Equation (USLE) as part of the variable for soil cover "C" (Hood et al., 2002; Dissmeyer and Foster, 1984). Powers et al. (1998) state the USFS' monitoring measures compaction, ground cover, soil displacement, and organic matter abundance and then set independent standards within each USFS Region that can cause a 15% decline in soil productivity.

The Indiana DoF carried out a 319 grant through IDEM in 1999-2001 in which the DoF cost-shared with loggers 75% of their BMP expenditures up to $650. In this grant the DoF was required to estimate the amount of acreage that was disturbed and exposed throughout each timber harvest area in order to derive the estimated soil savings in carrying out the BMPs. In this the DoF found that, out of 13 timber harvest sites with a total of 1368 acres, a total of 39.478 acres (2.9%) of the harvest areas were disturbed and exposed by the harvesting equipment (DoF, 2001). Kochenderfer (1977) found on logging sites in West Virginia, with a mix of silvicultural systems, some clearcut and others with single tree selection, on sites that utilized skidders, they had 10.3% of the harvest area in roads and landings. There are technologies now being tested in which applied research could better estimate the total disturbed areas across a timber sale (McDonald et al., 2002).

Other pollutants can be generated from harvesting, impacting water quality. Water temperature increases can occur when the water surface receives direct sunlight due to a loss in vegetative cover, which can affect Dissolved Oxygen (DO) content and aquatic communities (Verry et al., 2000; Binkley and Brown, 1993). Organic sediment may increase given the amount of timber removed, its proximity to water, and how much organic matter might be felled into the water and can have both positive and negative impacts to water quality and aquatic communities (Kreutzweiser et al., 2004; Verry et al., 2000; Binkley and Brown, 1993). Pesticide application is a licensed practice requiring training for the proper use and distribution in Indiana in which all applicators must recertify on a regular basis under Indiana Administrative Code 357 (Indiana Legislative Services Agency, 2005b), and are addressed in the BMP Field Guide, which takes a large step in protecting water quality and is regularly reviewed for new findings or information to improve said protection (Michael, 2004).

After a timber harvest is complete there are two generally accepted practices to facilitate the regeneration of the stand and they are natural and artificial. Natural regeneration is allowing the seedlings or understory to grow as the next generation, whereas artificial regeneration uses different methods to facilitate or accelerate the process through site preparation, plantings, scarification, or other methods (Young, 1982). As with harvesting, the regeneration methods manipulate the soil to differing degrees which can affect soil physical and chemical properties, exposure, subsurface water, etc. (Miller et al., 2004; Prevost, 2004; McNabb et al., 2001, Wynn et al., 2000). In a random selection of 87 sites in Indiana to look at seedling survival Jacobs et al. (2004), all the sites had previously been either cropland, pasture, or riparian buffers and not forest suggesting that most regeneration practices in Indiana following a timber harvest are natural, which requires the least amount of soil manipulation. State forest properties use natural regeneration as a common practice, except in special cases and in small acreages.

V. Mitigation of Water Quality Impacts through Forestry BMPs

With the establishment that forest harvesting practices may impact water quality, we can look to the practices that have been designed to prevent or mitigate these possible impacts, BMPs. BMPs are management practices put in place to protect surface waters during and after timber harvesting activities. When used properly BMPs can protect general water quality, water temperature, nutrient balance, habitat diversity, and hydrologic processes (USEPA, 2005; Arthur et al., 1998, Patric, 1995; Patric, 1977). In Indiana BMPs were designed to address different parts of the timber harvest area, give guidelines for practices to implement, and evaluate each part for implementation and effectiveness in protecting the water resource (Sobecki and McCoy, 2005).

Research turned to finding practices that would minimize timber harvesting impacts to water quality long before the CWA amendments of 1972, so that the forest community already had 40 years of data on how to harvest timber and protect water quality (NCASI, 1999). Through CWA amendments, all states have been given the ability to build a voluntary or regulatory BMP program and Indiana, along with many other states, developed a voluntary program (Sobecki and McCoy, 2005).

BMPs are important from the planning of a harvest, through harvest initiation, and until the vegetation has reclaimed the area when maintenance of structures is no longer needed. Planning is essential to identify problem areas such as wetlands, steep slopes, and other areas to protect in minimizing the potential impacts to water quality, how to mark them for easy recognition, and how to work around them or to implement practices when having to go through them, such as a stream crossing. The tools needed for planning a timber harvest are maps of soils, topography, waterbodies, knowledge of the equipment to be used and their abilities and limitations, and the ability to walk the land to confirm what you see on the maps or to find things maps may not show, such as seeps, sinkholes, etc. (USEPA, 2005; Sobecki and McCoy, 2005; DoF, 1999). With the information the planner assembles, the ability to mark areas of concern, appropriately lay out the harvest infrastructure for minimal disturbance, and debrief equipment operators is more easily attained.

Forest roads have often been the cited as the chief contributor of sediment from timber harvest areas by being impacted, and can be impacted three major ways; compaction, puddling, and displacement (Miller et al., 2004; Block et al., 2002; Hood et al., 2002; Startsev and McNabb, 2001; Corner et al., 1996, Lockaby et al., 1994; Patric, 1978), each of which impacts a soil's infiltration rate possibly causing overland flow. Closing out the roads when the harvest is complete can help the site recover and return to pre-harvest conditions within a few years (Hood et al., 2002; Verry et al., 2000, Patric, 1995; Binkley and Brown, 1993). Practices, such as water diversions, redirect overland flow off of roads and onto the forest floor where the sediment and water can be absorbed, while others, such as seeding and mulching can establish vegetation to decrease bulk density of the topsoil, decrease and slow overland flow, protect and hold soil particles in place, and allow natural regeneration to begin (USEPA, 2005; Schuler and Briggs, 2000; DoF, 1999; Patric, 1977).

Forested Riparian Buffers (RFBs) are designed to detain and absorb overland flow, nutrients, contaminants, and sediments before reaching the water body in agricultural settings where soil is lost at a rate usually exceeding the tons per acre per year from any other land use, and to uptake N and P attached to soil particles in the overland flow, and the water in groundwater flow, before it reaches a water body. RMZs in timber harvest areas are designed for the same purposes as RFBs, but usually have fewer pollutants to absorb. Many studies have shown the efficacy of RMZs in keeping sediments from reaching streams (Cavalcanti and Lockaby, 2005; Udawatta et al., 2002; Castelle and Johnson, 2000; Verry et al., 2000; Wynn et al., 2000; Welsch, 1991). In comparing silvicultural and harvesting systems Kreutzweiser and Capell (2001) concluded that single tree selection systems with up to 50% removals, and no RMZ, did not produce fine sediments in the stream, whereas the clearcuts produced sediments along with one area that was not harvested, but had a new road built.

The Indiana Forestry BMP Guidelines focus on different timber harvest areas; areas of equipment traffic and log dragging (access roads, landings, skid trails); areas adjacent to water bodies (riparian management zones, RMZs); and stream crossings and also covers harvest planning, and "non-logging" BMPs. Each area has a section in the Indiana BMP Field Guide (DoF, 1999) and a separate section of the monitoring form with its own list of questions. The BMP monitoring in Indiana is designed to assess the implementation of BMPs throughout the timber harvest area and the effectiveness in keeping soil from reaching the water (Sobecki and McCoy, 2005).

The BMP guidelines recommend planning the infrastructure of the timber harvest. Planning is also mentioned in conjunction with each area within a timber harvest, recommendations such as minimizing the amount of roads and trails, to time the harvest for the best time of year, minimize slope, and more, so that soil movement and sedimentation can be minimized. Also, the BMP guidelines recommend RMZ widths, the maximum amount of soil to be disturbed and exposed within the RMZ, and to leave at least half of the canopy remain standing well distributed throughout the RMZ (DoF, 1999).

The most recent BMP monitoring report in Indiana reports a rate of 89% compliance on State Forest Properties timber sales, which means that 89% of the 58 BMP specifications on 97 timber sales met the requirements of the BMP guidelines (Sobecki and McCoy, 2005).

Conclusion

Timber management has the lowest water quality impact of any other land use category as it is the natural vegetative cover of most soils. Water quality may be impacted by harvesting timber, but in comparison to other land uses, such as urbanization and agriculture, the impacts are slight and transitory, often moving back to pre-harvest levels within 5 years. Between silvicultural systems, the amount of impact to soils can differ because of the intensity of removal and the amount of soils disturbed.

The state forest property common silvicultural system of uneven aged management (single tree and group selection) in combination with natural regeneration which has a low area of soil disturbance per harvest, better canopy cover for streams, less likely increase in water yield, and has a short recovery time until soil movement reaches pre-harvest conditions.

Timber harvests on state forest properties are planned, and pre-harvest conferences with the harvesting crews facilitate the fruition of the plan by communicating sensitive area locations, discussing important aspects of the tract (RMZS, stream crossings), and creating a line of communication between forester and logger. All of these aspects are crucial in carrying out a successful harvest with minimal impact to water quality.

The amount of soil disturbed and exposed on the average IN state forest property timber sale is likely to be between 2% and 10% depending on site conditions, BMP planning and implementation, and harvest objectives, which leads to a much lower disturbance level than USFS standards as outlined in Powers et al. (1998) in most cases.

Forestry BMPs are designed to prevent or mitigate impacts that might occur from timber harvesting. Indiana DoF enforces BMPs on all of its timber harvests to the point of having 89% compliance.

Research looking at the impacts of forest practices on water and soil quality, in a more regional perspective, is needed in Indiana to gain a more quantitative, scientific foundation to base management decisions both on public and private forest land. The state forests provide a good, controlled environment for such research and have the potential to provide research plots for the long term.

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