Concepts about Forests and Water

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ABSTRACT: *Six concepts concerning forests, forestry, and water resources are discussed: (1) the role of the forest canopy in erosion control; (2) the impact of disturbance on soils; (3) the variability of natural water quality; (4) the impact of harvesting on water quality; (5) the role of extreme experiments; and (6) the effectiveness of forestry best management practices (BMP). The literature shows that the forest floor, not the canopy, protects soils from erosion. Harvesting can be conducted in ways that limit compaction and essentially confine overland flow to areas of exposed mineral soil on roads, trails, and log landings. Overland flow from these areas can be controlled and converted to subsurface flow before it reaches streams and lakes. Thus, effects to watershed hydrology are small. Undisturbed watersheds tend to have better quality water than highly disturbed watersheds, but the undisturbed character of a catchment does not assure high-quality water. Undisturbed forests vary greatly in sediment and chemical exports that are controlled by variables such as streamflow, soils, geology, air pollution, and land use history. Conversely, timber harvesting does not necessarily have measurable or biologically meaningful negative effects on water quality. Forestry BMP have proven effective in controlling adverse changes to in-stream sediment and water chemistry. Many studies that have reported large changes in water quality often represent extreme treatments not associated with typical forest operations, or they have not employed BMP. Properly and adequately used forestry BMP protect watershed resources while allowing the removal of wood products.* *North. J. Appl. For. 23(1):11–19.*

Key Words: Soil compaction, erosion and sedimentation, overland flow, BMP, water quality, timber harvesting.

In a paper about watershed folklore, Richard Sartz (1969) began by stating: "The field of forest watershed relations can lay claim to many widely held misconceptions." Over the past several decades, the public has become much more aware of environmental issues, but many people still harbor misconceptions about the interrelationships of forests and water. This problem often is exacerbated by inaccurate information included in popular publications as scientific fact, and by inaccurate presentations of scientific findings in documents meant to provide technology transfer to the public. Although science still has much to discover about forest and water relationships, there is a substantial knowledge base that scientific and lay communities can use to better manage and protect watersheds and water bodies.

The purpose of this article is to discuss and clarify six watershed concepts. Data are included on typical forestry operations in the northeastern United States to show the range of baseline conditions and the impact of harvesting. The northeastern states share similar hydrologic regimes and are well represented by research results from experimental watersheds from which we have drawn much of our information.

Concept 1: The Role of the Forest Canopy

Some watershed guides credit the forest canopy with protecting forest soils from excessive erosion. But it is the presence of an intact forest floor on the soil surface, not the forest canopy, that protects soil (Satterlund and Adams 1992). The forest floor is composed of the litter layer, underlying organic layer (humus), and fibrous roots. Hornberger et al. (1998) credited the roots of forest vegetation for keeping the "soil porous and highly permeable" and Reinhart (1964) correctly stated that most of the beneficial hydrologic attributes of forestland are present where the forest floor remains intact even when aboveground portions of trees are removed.

The litter and humus protect the mineral soil from raindrops by absorbing the impact energy of droplets. Once on the forest floor, water can move through it and into the mineral soil below. In the absence of an intact forest floor, raindrops that hit exposed mineral soil have sufficient force at the surface to compact the soil slightly. Tiny particles also become dislodged and then fill in the pores around neighboring soil particles. The combination of direct raindrop

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compaction and pore filling reduces infiltration rates and increases overland flow, possibly leading to erosion.

Throughfall drops (water droplets falling from the canopy) have a greater average size than rain falling in the open. Before they fall from a leaf, throughfall droplets usually run across the leaf in response to wind or gravity, coalescing with other droplets to form a larger droplet. When these larger droplets fall to the ground as throughfall, their greater mass provides a greater amount of kinetic energy (Table 1) that dislodges additional soil particles where mineral soil is exposed.

Kinetic energy also increases with an object's maximum or terminal velocity (Table 1). Terminal velocity for a raindrop is achieved at a height of approximately 8 m (25 ft) (Satterlund and Adams 1992). Because the bottoms of tree canopies are more than 8 m above the ground in many forests, particularly mature ones, the maximum velocity can be achieved even in the presence of a forest canopy.

Each year, a portion of the forest's litter decays and becomes humus, especially in warm, moist climates. Humus is incorporated into mineral soil continually by the actions of soil animals and insects. As a result, the canopy is essential in providing sources of leaves, other organic debris, and fibrous roots to regularly replenish the forest floor.

Application of the concept: The forest floor is an important hydrologic attribute of forestland. Every effort should be made to protect the forest floor during harvesting operations by considering the season of operation and using an efficient skid trail/road system.

Concept 2: The Impact of Disturbance on Soils

The concept that normal harvesting damages soils fails to recognize the durability of the forest floor. Most forests soils are highly porous because they sustain microorganisms, soil insects, soil animals, and dense root systems. These organisms constantly move soil and create voids of various dimensions and configurations, keeping forest soils porous and highly permeable to precipitation. If the forest floor is intact and the surface is not compacted, precipitation generally infiltrates through the soil surface and then percolates fully into underlying mineral soil. Thus, only extremely intense rainfall rates exceed the infiltration rates of intact forest soils and result in overland flow. In Maine, Hornberger et al. (1998) found that 150 mm of water fully infiltrated into a forest soil in 1 h.

Simply removing the canopy by harvesting does not nullify the hydrologic function of the forest floor. Following harvesting, the forest floor remains largely intact and although studies have found a reduction in the forest floor following harvesting (Yanai et al. 2003), these changes do not necessarily lessen the hydrologic function of the forest floor. In West Virginia, even when herbicides were used over several years to prohibit regeneration, there was sufficient organic material on the soil surface to allow infiltration and prevent overland flow (Troendle et al. 1974).

In the humid East, revegetation occurs rapidly, especially following clearcutting. Many tree species common to northeastern forests regenerate from root and stump sprouts, and seeds buried in the litter can remain viable for many years until sufficient solar radiation is available for germination. Consequently, reestablishment of a new forest progresses rapidly during the first growing season after harvesting. Although plant size and species composition of these new stands initially may differ dramatically from what was harvested, the regrowing forest provides substantial and sufficient organic inputs during leaf fall to protect the soil.

During harvesting, heavy equipment is the primary cause of disturbance and compaction in forests. Compaction reduces the sizes and number of soil pores, which limit the entry of water into soil. The result can be an accumulation of water at the soil surface and overland flow. Where mechanized equipment is used on the soil, it is important to maintain intact forest-floor layers to help reduce overland flow as organic layers and roots cushion the soil during heavy equipment use (Adams 1998).

Bulldozed roads, trails, and log landings are the most common areas of soil compaction (Case and Donnelly 1979; Kochenderfer 1977) and overland flow. Here, the forest floor is removed and increased loads and vibration compact the soil. Proper planning and layout of roads, trails, and landings before forest operations begin are essential to control overland flow and associated erosion. Also, locating roads and other areas of soil compaction well away from water bodies and limiting heavy equipment traffic to these predefined routes will limit the net effects of compaction.

Even if a substantial area is disturbed during harvesting, compaction may not result in meaningful overland flow. For example, Martin (1988) characterized nine types of disturbances and elevation changes in the soil surface due to each at three New England sites (Connecticut, New Hampshire, and Maine) that were whole-tree harvested. He reported that some soil disturbance, e.g., scarification and mounds, could benefit vegetation regrowth. More extreme types of disturbance, e.g., rutting, using heavy equipment on nondesignated roads and trails, and extensive mineral soil exposure can reduce site productivity, and potentially result in overland flow.

Application of the concept: Harvesting plans should consider Martin's (1988) recommendations to limit the degree of disturbance and area affected by the more severe types of disturbances.

Concept 3: The Variability of Natural Water Quality

The concept that undisturbed forest watersheds provide water that is suitable for all uses ignores the range of environmental factors that affect water quality. There are many constituents that are associated naturally with surface waters draining forested lands. They have a wide range of concentrations and annual loadings (e.g., Clark et al. 2000, Mulvihill 1999, Martin et al. 1986, Sweeney et al. 1999), some of which are within ranges suitable for a particular use such as irrigation, but unsuitable for other uses such as drinking water.

Many people believe that muddy (turbid) water occurs only in streams draining watersheds that have been disturbed by humans. It is true that for a given set of storm characteristics, stream water from forested watersheds tends to be clearer and have lower levels of suspended sediment than that from other land uses. However, forest streams exhibit wide natural ranges of suspended sediment (Table 2), including periods of high turbidity.

Several factors contribute to variations in sediment in forest streams. Streamflow, or discharge volume, is a primary factor in determining whether water is turbid or clear. Streamflow volumes (and energy) are greater during storms and snowmelt events than during baseflow (nonstorm) periods. As a result, a greater amount of within-channel sediment can be dislodged and carried by stormflow. Erosion and sediment delivery from areas of exposed mineral soil also increase during precipitation and snowmelt. Streamflow during flood events dislodges and conveys the highest concentrations and loadings of sediment. Catastrophic floods dominate annual sediment loadings (Beasley 1979, Edwards and Owens 1991, Kochenderfer and Edwards 1991) such that a single flood can yield sediment quantities that exceed normal sediment yields summed over several years (Kochenderfer et al. 1997).

In general, the larger the flow, the greater the amount of sediment suspended in stream water and the higher the resulting turbidity, though other factors control sediment in forest streams. Thus, increases in turbidity and suspended sediment levels are not identical for storms with similar precipitation or discharge characteristics. In forests, particularly headwater forests, sediment tends to be source-limited rather than energy-limited; that is, once all the available sediment is suspended in streamflow, turbidity and suspended sediment levels do not increase even if discharge increases. This explains why turbidity and suspended sediment values often reach maximum values before peak discharge (Figure 1).

The timing of stormflow also controls sediment relationships. If multiple storms occur repeatedly over a fairly short period (e.g., days), streamflow during the later storms often is clearer than during the first several storms because the supply of immediately available sediment is flushed out by the initial stormflows. Conversely, if weeks or months have elapsed between storms, a relatively small streamflow event can have unusually high turbidities and suspended sediment levels.

Previous land uses and catastrophic events, e.g., agriculture and wildfire, may have contributed sediment to channels that continues to affect stream-water quality in what today appear to be undisturbed forested watersheds. In fact, historically delivered sediment can be stored in stream channels for decades or even hundreds of years (Milius 1998); it is redistributed or flushed from the watershed periodically during stormflows. Kochenderfer and Helvey (1989) found residual elevated sediment loads in a forested watershed stream that had been farmed decades earlier. Harding et al. (1998) found that aquatic invertebrate and fish biodiversity in the 1990s had been modified by sedimentation from agricultural activities that occurred during the 1950s.

Although sediment is the most common natural impairment in undisturbed forest streams, it is not the only impairment that can exist. Other water quality parameters affect and limit beneficial uses, and their concentrations can be affected by season, geology and soil chemistry, past land use, severity of erosion, air pollution inputs, streamflow levels and sources, and types and age of vegetation present. In some areas, pH and toxic-metal levels in naturally acidic water are so high that fisheries cannot be supported (Hunter 1991). In other areas, acidity and metal toxicity are functions of air pollutants and conditions toxic to fish occur only during stormflow or snowmelt events (Baker et al. 1996). In the past, many scientists hypothesized that nitrate levels in stream water draining from undisturbed forested watersheds should be near zero because forests were considered nitrogen deficient. However, more recent research has shown that nitrate concentrations in forest streams can be quite high (Williard et al. 1999), and increasing nitrate outputs from a watershed that has remained undisturbed for nearly a century have been attributed to decades of elevated air pollution deposition (Edwards and Helvey 1991). Stand age also can contribute to nutrient losses as older forests sometimes lose more nitrogen to stream water than younger ones that have higher nutrient demands and uptake (Leak and Martin 1975).

Application of the concept: Although forests usually provide better quality water than other land uses, water quality is affected by local geology, vegetation, and land use history, and it should not automatically be considered suitable for all uses.

Table 1. Characteristics of precipitation and throughfall drop sizes and associated kinetic energies, assuming terminal velocity is reached.

Droplet diameter[a] (mm)	Droplet mass[b] (g)	Terminal velocity (cm s^{-1})	Kinetic energy (erg)
1.66	0.002	578	334
3.00	0.014	700	3,430
3.84	0.030	874	11,458
4.00	0.034	900	13,770
5.00	0.065	909	26,854

[a] Rainfall drops vary in size depending on rainfall intensity. Average diameter ~3 mm; throughfall droplets generally are 3 to 4 mm in diameter.
[b] Assumes spherical droplets.

Concept 4: The Impact of Timber Harvesting on Water Quality

The concept that normal harvesting is accompanied by negative consequences, including degradation of water resources is a frequent public concern. Often this concern stems from a belief that present-day logging is just as abusive and exploitive as that at the turn of the 20th century. However, today's responsible forestry and logging operations bear little resemblance to historical logging in environmental consequences. Today, BMP generally are used to protect resources

Table 2. Baseline suspended sediment exports from relatively undisturbed watersheds in the northeastern United States.

Location	Load			Reference
	Maximum	Minimum	Mean	
	...kg ha^{-1} yr^{-1}...			
Hubbard Brook, NH				
WS1 (16 yr)	141	6	54	Martin and Hornbeck 1994
WS3 (24 yr)	71	3	25	Martin et al. 2000
WS5 (9 yr)	134	12	57	Martin et al. 2000
WS6 (28 yr)	95	1	23	Martin et al. 2000
Fernow, WV				
WS4 (8 yr)	216	26	56	Kochenderfer and Helvey 1989
National Forest, WV				
Clover (3 yr)	326[a]	262	284	Kochenderfer and Helvey 1989
Haddix (3 yr)	418[b]	49	173	Kochenderfer et al. 1997
Normal range, managed eastern forest land	224	112		Patric 1976
Monongahela Nat. For., WV	425	19		Edwards et al. 2004

[a]Attributed to farming history on the watershed.
[b]Maximum occurred during a 1985 flood event.

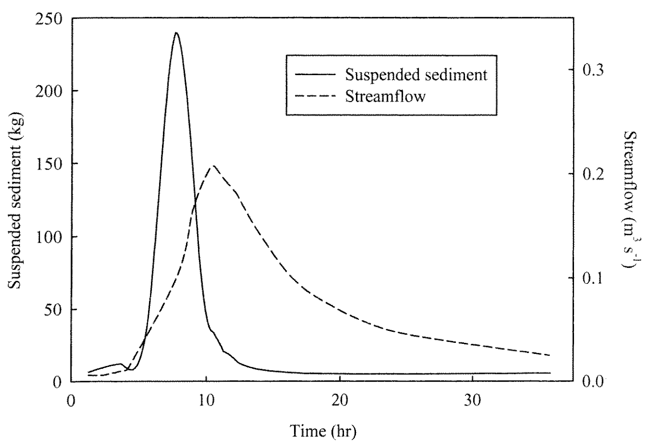

Figure 1. Characteristic timing responses of suspended sediment and discharge during a storm in a forested watershed that is sediment-source limited (Unpublished data, Fernow Experimental Forest).

(Edwards and Stuart 2002) and are critical for controlling erosion and sedimentation (Tables 3 and 4).

As stated earlier, erosion is generated and sediment is delivered primarily from roads, trails, and log landings on which mineral soil has been exposed, compaction has occurred, and water has been concentrated. Best management practices reduce erosion and in-stream sedimentation through careful planning and location of roads, trails, and landings, minimizing their length and surface area as well as the number of stream crossings within the road system, and using stream-crossing systems (culverts, bridges etc.) that are appropriate for the area's physical conditions and discharges; using proper road-surfacing techniques and materials at stream crossings and water-control areas; providing sufficient numbers and sizes of water-control features, for example, cross-drainage culverts and broad-based dips to divert water from roads in small quantities so that erosion is controlled; retaining forest filter strips (i.e., the natural forest floor) between streams and roads, trails, and landings to trap soil eroded from those areas; and prohibiting machine operations where soils are wet and vulnerable to compaction and erosion.

Increases in nutrient concentrations and loadings often are observed during the first year or for several years after harvesting, although rarely to levels that adversely affect water quality (Stednick 2000). The public often is concerned that nitrogen and phosphorus levels may increase from forestry operations. However, nitrogen concentrations usually remain below the 10 mg L^{-1} standard for public water supplies (Table 5), and phosphorus concentrations generally remain unchanged by harvesting (Table 6).

By contrast, chemical loadings or outputs can increase, but these loading increases usually are a function

Table 3. Sediment exports during and several years after harvest.

Location	Load			Reference
	Maximum	Minimum	Mean	
	...kg ha^{-1} yr^{-1}...			
Hubbard Brook, NH				
WS4 (10 yr) Strip cut	146	3	50	Martin et al. 2000
WS5 (7 yr) Whole-tree clearcut	208	6	83	Martin et al. 2000
National Forest, WV				
Clover (4 yr)	584[a]	194	386	Kochenderfer and Helvey 1989
Haddix (5 yr)	123	22	70	Kochenderfer et al. 1997
Leading Ridge, PA (2 yr)	56	42		Lynch and Corbett 1990

[a]Maximum occurred during a flood event.

Table 4. Turbidity values for Fernow Experimental Forest watersheds harvested with different levels of BMP; roads were closed after harvesting in all watersheds.[a]

Site	Treatment	Maximum turbidity (JTU)		
		Year 1	Year 2	Year 3
WS1	Liquidation sale, no BMP	56,000	5,000	170
WS2	Diameter limit harvest, no BMP during harvest, skid roads water barred after harvest	5,200	150	8
WS5	Selected trees harvested BMP used were: no skidding in streams, roads limited to 20%, water barred after harvest	210	25	6
WS3	Selected trees harvested BMP used were: no skidding in streams, filter strip between roads and streams, 10% limit on grades, limited stream crossings, roads closed and stabilized after harvest	25	≤5	55
Control	None	15	8	≤5

[a]Year 1 data from Reinhart et al. (1963); unpublished data for years 2 and 3.

Table 5. Reported annual nitrate-nitrogen concentrations and loadings in precipitation and stream water from harvested and baseline watersheds.

Location	Treatment type	Average annual nitrate-nitrogen		Reference
		(mg L^{-1})	(kg ha^{-1})	
Across United States	Baseline	<0.01–0.77	<0.01–5.80	Clark et al. 2000
Hubbard Brook Experimental Forest, NH	Precipitation		5.0	Martin et al. 2000
WS6 (27 yr)	Baseline discharge		2.3	Martin et al. 2000
WS4 (3 yr)	Strip cut		7.3	Martin et al. 2000
WS5 (3 yr)	Whole-tree clearcut		10.6	Martin et al. 2000
WS101 (3 yr)	Block clearcut		19.8	Hornbeck et al. 1987
Upper Mill Brook, White Mountains, NH	Baseline	0.23–0.27		Stuart and Dunshie 1976
(3 yr mean)	Clearcuts	0.39–0.96		Stuart and Dunshie 1976
	Thinning	0.45		Stuart and Dunshie 1976
	Downstream	0.23		Stuart and Dunshie 1976
Bowl Natural Area, Leading Ridge, PA	Old growth	0.49–1.07		Leak and Martin 1975
WS1 (8 yr)	Baseline	0.01		Lynch and Corbett 1990
WS3 (4 yr)	Clearcut	0.05		Lynch and Corbett 1990
Fernow Experimental Forest, WV				
WS4 (4 yr)	Baseline (mature)	0.13	1.9	Aubertin and Patric 1974
WS3 (34 months after)	Clearcut	0.24	5.7	Aubertin and Patric 1974
North central WV				
Fernow WS4 (11 yr)	Baseline (mature)	0.75	5.31	Kochenderfer et al. 1997; loadings from unpublished data
Haddix (4 yr)	Diameter limit cut	0.41	2.90	
Nashwaak Experimental Watershed, New Brunswick	Precipitation		1.89	Jewett et al. 1995
	Baseline		1.15	Jewett et al. 1995
	Clearcut		5.47	Jewett et al. 1995
New England				
ME	Baseline		~0	Pierce et al. 1993
	Whole-tree clearcut		1.36	Pierce et al. 1993
NH	Baseline		0.68	Pierce et al. 1993
	Whole-tree clearcut		2.04	Pierce et al. 1993
CT	Baseline		~0	Pierce et al. 1993
	Whole-tree clearcut		4.29	Pierce et al. 1993

of increasing streamflow rather than a change in a constituent's concentration. Loadings are the product of concentration and streamflow (streamflow × concentration × conversion factors). Harvesting more than 25 percent of the basal area on a watershed generally increases annual streamflow in the East (Hornbeck et al. 1993), and streamflow increases proportionally to the amount of timber harvested in a watershed (Reinhart et al. 1963). Because the streamflow component of the loading calculation is much greater than the concentration value, streamflow dominates the final loading value (Swistock et al. 1997). As a result, outputs can increase after logging due to the increase in streamflow. This was the case for phosphorus (Jewett et al. 1995).

There can be wide variation in nutrient changes among sites during forest operations. Concentrations and/or loadings of some constituents increase, whereas others decrease or do not change, but in all cases where logging, including

Table 6. Reported phosphorus concentrations and loadings in precipitation and stream water from harvested and baseline watersheds.

Location	Treatment type	Average annual phosphorus ($mg\ L^{-1}$)	($kg\ ha^{-1}$)	Reference
Across United States	Baseline	<0.10–0.20	<0.01—0.82	Clark et al. 2000
			0.02	Richardson 1988
Hubbard Brook Experimental Forest, NH	Precipitation		0.04	Hornbeck et al. 1987
Upper Mill Brook, White Mountains, NH	Baseline discharge		0.02	Hornbeck et al. 1987
(3 yr mean)	Baseline	0.012–0.024		Stuart and Dunshie 1976
	Clearcuts	0.018–0.026		Stuart and Dunshie 1976
	Thinning	0.018		Stuart and Dunshie 1976
	Downstream	0.014	0.124	Stuart and Dunshie 1976
Fernow Experimental Forest, WV				
WS4 (4 yr)	Baseline (mature)		0.06	Aubertin and Patric 1974
WS3 (2 yr)	Clearcut		0.09	Aubertin and Patric 1974
Nashwaak Experimental Watershed, New Brunswick	Precipitation		0.248	Jewett et al. 1995
	Baseline		0.084	Jewett et al. 1995
	Clearcut		0.112	Jewett et al. 1995

clearcutting, and related activities are conducted carefully, changes in stream water chemistry are small or of short duration. Typical harvesting activities do not elevate ionic concentrations above acceptable levels for drinking water. Even in the northern hardwood forest type of New Hampshire, where changes in stream chemistry from harvesting are the most dramatic, increases in the concentrations of all measured constituents, including nitrogen, were below the highest concentrations in uncut, reference watersheds (Martin et al. 1984). Although it is desirable to minimize adverse human effects to forest ecosystems, natural baseline concentrations of stream-water constituents vary greatly from year to year and storm to storm.

Application of the concept: Well-planned and carefully conducted forest management operations usually result in only short term change to stream water chemistry that are within the natural variability in which these stream ecosystems exist and have evolved.

Concept 5: The Role of Extreme Experiments

The concept that extreme experiments represent normal harvesting is a misuse of research. Extreme experiments generally were conducted to demonstrate the effectiveness of BMP or to determine a maximum response. An example is a study that denuded a watershed on the Hubbard Brook Experimental Forest in New Hampshire and caused high nitrogen concentrations in surface water. The study examined the effects of clearfelling a northern hardwood forest in the winter, leaving the felled trees in place, and denuding the watershed of all regrowth and understory vegetation during three subsequent growing seasons with herbicides. Early articles describing or citing this experiment often stated or inferred that cutting the trees caused the dramatic nitrogen increase. However, examination of the timing of nutrient loss relative to felling and herbicide use and comparison of concentrations with those from other studies conducted at and near Hubbard Brook involving normal harvesting with no chemical treatment revealed that killing the vegetation caused most of the changes in stream chemistry. Bormann et al. (1968) reported that nitrate-nitrogen concentrations in stream water ranged from about 0.75 to 3.0 mg L^{-1} following felling. These concentrations are similar to those obtained from other harvesting-only studies in the New Hampshire area (Table 5). Concentrations of nitrate-nitrogen increased to nearly 13.5 mg L^{-1} after most of the vegetation was dead. The standard for drinking water is 10 mg L^{-1}.

Another extreme study, on the Fernow Experimental Forest, was conducted to show how sediment and turbidity could increase in the Appalachians following careless logging. In this study, a watershed was clearcut to 2.54 cm dbh. Best management practices were not used during or after the harvesting, there was no prior planning, roads were located immediately adjacent to streams, stream fording was permitted, and logs were skidded in the stream channel (Reinhart et al. 1963). Environmental protection was not considered during any of these operations, and numerous poor practices that are inconsistent with contemporary BMP were used. During harvesting, a maximum turbidity of 56,000 JTU (about 56,000 mg L^{-1}) was recorded compared with 15 JTU on a nearby control watershed. Poor road placement and skidding in the streams mobilized sediment and diverted it directly into the stream channel. The study was used to contrast with adjoining studies where BMP were properly used and where levels of suspended sediment approximated those prior to harvesting or from uncut watersheds (Table 3).

Not all forestry research represents conditions or practices that would be included in contemporary forestry operations. Often, there are other underlying questions that exclude concern about issues such as water quality. This was the case with many of the studies that used herbicides to denude watersheds throughout the East during the 1960s. Most of these investigated the potential use of intensive vegetation management to substantially augment water yields during long periods of drought. Water quality was not included as an initial objective even though these studies now are referenced almost exclusively in terms of water quality. Extreme studies do not represent effects or results from typical operations, nor are they designed to do so.

Application of the concept: When using research to estimate the effects of a given operation, one should assess the results of studies in which both the conditions and practices are comparable.

Concept 6: The Effectiveness of Forestry BMP

Questions about the effectiveness of forestry BMP have been one of the arguments for instituting new regulations or new practices. Most BMP are designed based on processes controlled by the laws of physics or chemistry, such as those involving gravity and energy, and these phenomena have not changed. Consequently, BMP are as relevant and useful today as when they were developed.

The effectiveness of BMP for protecting water quality has been evaluated in many studies. The determination of effectiveness is usually based on meeting water quality standards or avoiding harmful impacts to the biological integrity of surface waters. In some cases it is difficult to determine whether the favorable results were due to BMP effectiveness or to the relatively low impact of harvesting. The following studies illustrate effectiveness in terms of water quality:

A 1957 study in West Virginia limited skid roads to maximum of 10%, located them away from streams, provided bridges to cross streams, closed skid roads with water bars, and seeded all potential sediment sources after the sale. Only two turbidity readings were in the 11 to 25 mg L^{-1} range (Reinhart et al. 1963).

A 1986 West Virginia study on a watershed with 40% slopes used planned skid road locations, provided forest filter strips between roads and streams, constructed roads with proper drainage techniques, generally kept roads below 10%, and seeded areas of exposed soil near streams. Increases in sediment yields were short term and within the normal range for the area (Kochenderfer et al. 1997). A study by Kochenderfer and Hornbeck (1999) contrasts the careless logging study by Reinhart et al. (1963) with this 1986 study to illustrate the value of BMP.

A 1970 block clearcut in New Hampshire produced only two turbidities in the 11 to 40 JTU range. Other changes in water chemistry did not approach water quality standards. Normal precautions were taken to prevent pollution but they were not identified. One of the conclusions was that northern hardwood forests have an "inherent resistance to erosion that can withstand cutting disturbances so long as the forest floor is not abused" (Hornbeck et al. 1987).

A 1976 Pennsylvania study evaluated the effectiveness of BMP. The lower half of a 257-acre watershed was clearcut using BMP for shade on streams, stream crossing structures, a planned main skid road and landing, and sale closure using water bars and seeding. There was no increase in turbidity during the first year, but there was a significant increase to 0.019 - 0.025 ton ac^{-1} the second and third year due to blow down in the riparian area (Lynch and Corbett 1990). However, the change was still within the range of normal sediment levels on undisturbed forestland of 0.05 to 0.10 ton ac^{-1} (Patric 1976). The authors recommended increasing the width of the shade buffer to one and one half the height of trees adjacent to perennial and intermittent stream channels to reduce sedimentation from blow down.

South Carolina evaluated the water quality effectiveness of BMP on 27 harvest areas with perennial streams that were unaffected by other land uses. Biological monitoring was used to determine effectiveness. Best management practices protected macroinvertebrate habitat and populations. In a few cases there was no impact on biology even when BMP were inadequate (Adams 1993).

A Maryland study evaluated the effectiveness of BMP on normal harvesting activities in 1997. Nearly 50% of a 330-ac watershed received treatments from clear cuts to thinning. Best management practices for truck roads, skid trails, landings, streamside management, wetlands, and stream crossings were used. Harvesting did not significantly change suspended solids, stream habitat, macroinvertebrate populations, or stream temperature (Maryland Dept. Nat. Res. and Chesapeake & Coastal Watershed Service 2000).

Forestry BMP have remained relevant because they are revised periodically. During the 1990s, nine states in the Northeast revised their forestry BMP to provide updated techniques to address new logging methods, strengthen riparian provisions, and address changing laws (Edwards and Stuart 2002). Best management practices also are evaluated using accepted research techniques. They generally have been done on "real world" logging operations involving commercial crews and techniques. Consequently, the findings are applicable to and representative of commercial situations.

Application of the concept: Forestry BMP are effective at controlling nonpoint source pollution and protecting aquatic biology when used appropriately and adequately.

Summary

The forest floor is a key watershed attribute of forested watersheds. It controls storm runoff, stream sedimentation, and nutrient loading by encouraging surface water to infiltrate into the soil. Harvesting has a small affect on water resources for two reasons: first, removing the canopy does not significantly affect the function of the forest floor; and second, the disturbance from normal harvesting does not reduce the function of the forest floor significantly, except on roads and landings. Extreme experiments designed to demonstrate the effectiveness of BMP or to maximize the output of water do not represent normal forestry. Efforts to determine the effectiveness of BMP in pollution control and the impact of harvesting on water resources must take natural conditions into account and separate the effects of harvesting from historic land uses and other current activities on the watershed. The effectiveness of forestry BMP is validated by the acknowledgment that forestry is a minor contributor of pollution to lakes and streams (US Environmental Protection Agency 2000).

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