ACCEPTABLE MANAGEMENT PRACTICES

A REVIEW OF VERMONT LOGGING PRACTICES AND THEIR EFFECTS ON WATER QUALITY AND FLOODING

Prepared by

FB Environmental Associates

for

Standing Trees

August 2025

TABLE OF CONTENTS

LIST OF TABLES

LIST OF FIGURES

Executive Summary

The *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont*, or AMPs, are rules to protect Vermont's water quality from pollutants. The State of Vermont updated these in 2015 and 2018, with the latest updates used in part to show compliance with the Lake Champlain phosphorus Total Maximum Daily Load, an EPA approved plan to protect the lake. The Vermont Department of Environmental Conservation (DEC) made quantitative phosphorus removal performance claims of AMP effectiveness to support the TMDL and gain approval for the Worcester Range Management Unit (WRMU) Long Range Management Plan (LRMP). This report evaluates those performance claims and the literature they were based on closely.

The claimed performance was found to be not well supported by the cited literature and likely overstated. In many cases, the cited research occurred in conditions so different from those in Vermont that they do not provide a reliable assurance of AMP performance. Vermont's steep terrain and thin glacial soils are likely to result in more severe erosion than those in the southeastern US where several studies were conducted. Vermont's cold climate and thin soils, especially in high elevations, will likely slow down vegetative recovery after forest harvest. Finally, the AMPs are less stringent than the rules applied in the cited studies. The AMPs allow greater disturbance within stream buffers, steeper roads and trails, and do not require re-seeding of disturbed areas. Taken together, these factors all strongly suggest that the AMPs will achieve a lower phosphorus reduction performance than that found in the DEC cited research.

Using the research cited by DEC, along with a case study of New Hampshire logging rules, this report proposes further revisions to the AMPs to improve their water quality protection performance and better ensure compliance with Lake Champlain phosphorus reduction targets. These include:

- Setting a quantitative limit to the amount of cutting within a forested stream buffer, as is done in New Hampshire's Basal Area Rule or as was done in several studies, ranging from no forestry activity within the buffer to a maximum of 36% basal area removal.
- Expanding the no-vehicle-activity distance from 25 feet to 50 feet from streams and other surface waters, except as minimally required for unavoidable stream crossings.
- Prohibiting at-grade fords for stream crossings.
- Setting a truly conservative AMP performance assumption of 50% or less, in accord with Arthur et al. (1998), which was conducted in steep Appalachian Mountain terrain more similar to Vermont's than most of the other studies.
- Prohibiting any harvest activities within Hydrologic Reserve Zones based on multiple factors such as steep slope, soils, and proximity to surface waters, as proposed in Optimal Conservation Practices by Underwood and Brynn (2015).
- Some of the above may be accomplished by transforming guidelines in *Acceptable Management Practices Manual for Logging Professionals* (Wilcox & Sabourin, 2019) into enforceable rules.

This report also recommends comparing the phosphorus reduction performance of the AMPs to a no-forest-harvest option. Harvesting areas which have not been harvested for many years—even if improved AMPs were to be put in place and scrupulously adhered to—would cause long-term sediment yields to streams to greatly increase.

LAKE CHAMPLAIN PHOSPHORUS TMDL CONTEXT

The Lake Champlain Phosphorus Total Maximum Daily Load (TMDL) is an EPA-approved plan to reduce phosphorus pollution to levels where Lake Champlain is no longer impaired (by phosphorus) for its intended uses. In the TMDL, EPA required that phosphorus runoff from forestry in the Winooski River watershed be reduced by 5%. EPA based its modeling on 1) the balance and distribution of land uses and phosphorus inputs at the time of its analysis, and 2) EPA's professional judgment as to the most efficient or practical manner to achieve overall phosphorus reduction goals (personal communication with Eric Perkins, retired EPA). The assignment of load reduction goals per phosphorus source or watershed was not exclusively determined based on the relative proportion of that particular input, but was rather a professional determination based on a range of factors, including but not limited to political and economic considerations and the confidence in the effectiveness of the types of practices used to achieve reductions from each source category. Of critical importance to this analysis, modelers did not anticipate that large areas presently out of timber production (such as the Worcester Range Management Unit) would enter into timber production. Accordingly, the expectation in the TMDL that implementation of AMPs throughout the watershed could achieve the 5% phosphorus reduction assumed a relatively constant amount of forest land would be harvested each year. Harvesting of large new parcels not already part of the regular harvesting rotation throughout the watershed was not contemplated in the TMDL (personal communication with Eric Perkins, retired EPA).

Photo: Zack Porter

CRITIQUE OF VT DEC (2022) WORCESTER RANGE RESPONSES

Overview

In its responses to public comments received on the draft Worcester Range Management Unit (WRMU) Long Range Management Plan (LRMP), the Agency of Natural Resources referred to Department of Environmental Conservation (VT DEC, 2022) to support the claim that the AMPs reduce phosphorus transport by 80% (see Comment theme 66). Specifically, pages 26 through 31 of VT DEC (2022) address estimated phosphorus-load reductions when AMPs are applied. This section evaluates the sources cited in those pages.

Citations

Edwards & Williard, 2010 and associated references

> On Page 26, VT DEC (2022) states: "*Controlled watershed studies in forested watersheds that measured the effectiveness of BMPs on phosphorus reduction have found that a comprehensive application of forest management BMPs in harvest areas has resulted in an 85 – 86% reduction of phosphorus loads (Edwards and Williard, 2010)*."

The citation refers to a USDA publication by Edwards and Williard (2010), who conducted an "exhaustive literature search" and identified three paired-watershed studies as the basis for estimating sediment and nutrient reductions from forestry BMPs: Kochenderfer & Hornbeck (1999) in the unglaciated Allegheny Plateau of West Virginia, Wynn et al. (2000) in the coastal plain of Virginia, and Arthur et al. (1998) in the Appalachian Mountains of Kentucky. These studies were selected because they represent a rare subset of paired-watershed studies including a comparison of watersheds harvested with BMPs to those harvested without them, rather than the more common design of only comparing harvested to unharvested watersheds. The scarcity of formal, published studies on BMP effectiveness found by Edwards and Williard (2010) despite their exhaustive search is an indication that the research into percent reduction of sediment loading from forestry BMPs is not particularly robust, and results should be viewed with caution.

A more significant and key limitation of VT DEC's Department of Forests, Parks and Recreation (FPR) reliance on this source is that **none of the three studies were conducted in the Northeastern United States, nor were they conducted on glacially derived soils as in Vermont.** Environmental and climatic conditions in Vermont differ significantly from those in the southern Appalachian region. Notably, Vermont experiences substantial spring snowmelt, and its glacially derived soils are generally younger and thinner than the deeper, clay-rich soils common in the southern Appalachian region (Ciolkosz et al., 1989). Substantial snowmelt can combine with spring rain events to create runoff of much greater volume and intensity than would be expected in the southeast. Greater storm runoff intensity equals greater erosive power, and BMPs which work in lower intensity environments may not perform as well under those conditions. Thinner soils are likely to be less resilient to erosive forces from skidding and motorized traffic, because once eroded they are likely to support reduced vegetative regrowth due to the much smaller or absent soil coverage. The reduced regrowth leaves those soils and the downhill landscape more vulnerable to soil erosion due to increased stormwater volumes, reduced canopy protection from rain hitting the ground, and reduced root network which holds the soil together. Thinner soils also have less subsurface soil volume before a limiting factor such as bedrock, and therefore have less reactive capacity than deeper soils, generally. Finer soils also tend to have greater phosphorus sorption capacity due to greater surface area of the particles, though chemical composition of the soils also plays an important role. For example, a review by McCray et al. (2005), which focuses on wastewater disposal in soils, finds that the median reported maximum phosphorus sorption capacity of sands is ten-times lower than that of sandy loam soils. Retention of phosphorus in the soils is also dependent upon the presence of iron and aluminum oxides (in acid soils) (Fink et al., 2016) and exchangeable calcium (in alkaline soils) (Ige et al., 2005). While the specific soil characteristics vary in Vermont, they are quite different from those in the cited research, none of which were on thin, young glacial till soils.

A study by Wynn et al. (2000) occurred in sandy loam soils and very low slopes given its coastal plain location; therefore, its conclusions cannot be relied upon to apply to steep, mountainous terrain typical of state-owned Vermont lands under consideration for forest harvest. Long, steep slopes occurring in mountainous terrain such as the Appalachians have greater capacity to generate longer paths of higher velocity runoff than flat coastal plain areas. High velocity runoff has much greater erosive power than slower, shorter runoff paths.

Of the three studies cited by Edwards and Williard (2010), Kochenderfer & Hornbeck (1999) is arguably the most relevant, which studied similarly mountainous terrain as in Vermont with average slopes of 40% in both watersheds, though lacking glacial-derived soils. Despite these similarities, the Kochenderfer & Hornbeck (1999) study was not a conventional paired-watershed study, which would assess the effectiveness of different treatments in two similar watersheds at the same time. The BMP and non-BMP harvests were separated by 30 years, and although precipitation levels were near average during harvest years, post-harvest precipitation was well below average in both cases, raising concerns that the post-harvest phosphorus loading understates typical phosphorus loading.

Another important consideration is that the climate context has changed since the studies were conducted. In Vermont, the frequency and intensity of spring and summer storms have increased in recent decades, increasing runoff intensity and erosion and potentially reducing the relevance of past BMP performance data under current or future conditions. A strict precautionary approach based on climate science is warranted, in which any landscape modifications subject to mass erosion from intense storms (i.e., a culvert washing out) should be prohibited in the steepest and most vulnerable areas. Across the Northeast, extreme precipitation from 1996 to 2014 was 53% higher than the 1901–1995 average, and total annual precipitation from 2002 to 2014 was 13% higher than the 1901–2001 average (Huang et al., 2017). High-resolution climate models developed for the Northeast show a sharp rise in extreme precipitation since the mid-1990s and project that by 2100, very extreme events (>150 mm/day, or >5.9 inches/day) could become six times more likely than in the early 21st century (Jong et al., 2023). Such events can have outsized impacts: for example, Ross et al. (2019) found that Tropical Storm Irene in 2011 released as much sediment and phosphorus into Vermont's Mad River subwatershed in a single rainfall event as would typically accumulate over an entire year.

Further, only two of the three studies, Wynn et al. (2000) and Arthur et al. (1998), measured phosphorus reduction directly. Kochenderfer & Hornbeck (1999) measured sediment but not phosphorus. In Wynn et al. (2000), flow and automated water quality samplers were installed pre-harvest (two years), during harvest, and post-harvest (three years) for three watersheds (uncut, cut with BMPs and cut without BMPs); nutrient water quality before, during, and after storm events were monitored. Wynn et al. (2000) found significantly more nutrient loading in the no-BMP watershed, while the BMP and uncut watersheds were similar in loading. In Authur et al. (1998), three watersheds (uncut, cut with BMPs, and cut without BMPs) were monitored before (18 months), during (10 months), and after (17 months) for flow, sediment, and nutrients. Authur et al. (1998) found only a 50% reduction in nutrients between the non-BMP and BMP watersheds during forest harvest. Thus, the 85–86% phosphorus reduction figure cited by VT DEC (2022, pp. 26 and 30) appears to be based heavily on a single study, conducted in Virginia between 1991 and 1997, in relatively broad and flat coastal terrain. These conditions are not present in Vermont, where the soils and terrain are likely more susceptible to erosion after timber harvest.

Another question is the comparability of the suite of BMPs applied in these studies to the AMPs used in Vermont. For instance, Wynn et al. (2000) implemented a pre-harvest plan, limited cutting to 36% basal area in a 50-foot streamside management zone, installed water bars on skid trails following harvest, and seeded landings to establish groundcover. Arthur et al. (1998) included more rigorous BMPs, such as 50-foot uncut riparian buffers, roads built at <10% grade, seeding of disturbed areas, broad-based dips, and limited skidding to minimize soil disturbance. Kochenderfer & Hornbeck (1999) applied even more extensive measures, including siting roads at least 100 feet from streams (except at crossings), installing permanent culverts and ditches, enforcing wet-weather hauling restrictions, and post-harvest stabilization with grass seeding, slash and waterbars. Generally, these studies found that minimally or non-disturbed stream buffers were highly effective at reducing sediment transport.

While there is overlap between some of these BMPs and the Vermont AMPs, the AMPs are clearly more permissive. The AMPs allow vehicle activity to within 25 feet of streams (and at stream crossings) which is more permissive than the 50-foot uncut riparian buffers in Arthur et al. (1998) and the 100-feet stream setback in Kochenderfer & Hornbeck (1999). The AMPs allow "partial cutting" (unspecified amount) within riparian buffer areas, not allowed in Arthur et al. (1998) or Kochenderfer & Hornbeck (1999). The AMPs do not contain any wet-weather restrictions as in Kochenderfer & Hornbeck (1999). The AMPs allow short sections of forest roads and skid trails to exceed 10% in slope, which was not the case at least in Wynn et al. (2000). Finally, the AMPs do not require re-seeding of disturbed areas as described in Wynn et al. (2000), Arthur et al. (1998), and Kochenderfer & Hornbeck (1999). Even if soil, climate, and slope conditions were all equivalent (and they are not), sediment and nutrient loading resulting from the more permissive Vermont stream buffer AMPs would be expected to be higher than that described in the research cited by VT DEC.

Edwards & Williard (2010) acknowledge that the Kochenderfer & Hornbeck (1999) study was not a traditional paired-watershed study. The BMP and non-BMP harvests were separated by 30 years, and although precipitation levels were near average during harvest years, post-harvest precipitation was well below average in both cases. This raises concerns about whether the same level of BMP performance would have been observed under wetter conditions. Furthermore, the non-BMP harvest methods reviewed by Kochenderfer & Hornbeck (1999) were severely degrading to water quality, including long lengths of forest roads directly adjacent to streams with no erosion control whatsoever, resulting in extremely high sediment concentrations within the streams during rain events, an important point as the authors note:

> *The proximity of roads to streams is probably the single most important attribute that determines whether streams will be adversely impacted by timber harvesting operations. The importance of providing minimally disturbed protective zones between disturbed areas and streams has been recognized for a long time.*
>
> -Kochenderfer & Hornbeck (1999)

In the forest harvest without BMPs, roads were unplanned, with almost half the total road length exceeding 20% slope. By contrast, only 2% of the BMP forestry watershed had planned roads over 20% slope. The authors note:

> *It is far more difficult to control erosion on steep roads, and they have less residual value for other uses once logging is completed. Roads of gentle grades, that are properly located and maintained, protect soil and water resources while providing effective access for many forest activities.*
>
> -Kochenderfer & Hornbeck (1999)

Thus, in Kochenderfer & Hornbeck (1999), comparing modern BMP harvesting techniques to such exceptionally damaging forestry methods from the 1950s likely provides an overly rosy view of BMP effectiveness.

Finally, Arthur et al. (1998) reported that even with BMPs applied, streamflow increased by 123% in the BMP watershed during the first 17 months post-harvest. Although this is lower than the 138% increase observed in the non-BMP watershed, it still represents a substantial increase compared to the unharvested condition. The difference between 123% and 138% is also unlikely to reflect a true difference given environmental variability and standard error. Elevated water yields persisted for eight years post-treatment, which has implications for downstream flooding. **Additionally, suspended sediment loads in the BMP watershed were 14 times higher than the uncut watershed during harvest and four times higher in the 17 months following harvest.** Note that Arthur et al. (1998) was conducted in steeply sloping Appalachian terrain in Kentucky, arguably the most similar geography to Vermont among the VT DEC citations. Harvesting even with BMPs will thus increase sediment and nutrient loads to Lake Champlain tributaries, while the total area that is harvested in each Lake Champlain basin will determine whether TMDL compliance occurs in each basin. This paper clearly shows that refraining from timber harvest in steep terrain would provide far lower phosphorus loads to Lake Champlain than harvesting those areas with BMPs.

Similarly, **Kochenderfer & Hornbeck (1999) observed higher peak flows (35-70% higher, or an increase in water volume by about a third to more than two-thirds) in both the BMP and non-BMP watershed persisting 5-6 years post-harvest.** These may be relatively modest increases in peak flows in many areas, especially if harvesting occurs in a small portion of a larger watershed; however, as noted by the National Research Council (NRC, 2008), small percentage increases in very large floods because of forest harvest may be quite large in absolute terms and may affect many people.

To summarize, VT DEC (2022) supports a precise claim of 85 – 86% reduction of phosphorus loads from BMPs by citing a single source (Edwards and Williard, 2010), which in turn describes reports of three paired watershed studies. Upon review, all three of the cited studies were conducted under soil, slope, and/or climatic conditions that diverged in major ways from those on state-owned Vermont lands under consideration for forest harvesting. It is therefore reasonable to question the 85 – 86% phosphorus reduction claim with the understanding the studies cited by FPR are not reliable indicators of likely phosphorus runoff in the Worcester Range and other Vermont state-owned lands. Finally, any harvesting-with-BMPs scenario should be compared to the likely much lower impact no-harvest scenario for a complete understanding of water quality outcomes and TMDL compliance. The performance of specific BMPs are discussed further in the Citations section below.

Edwards et al. (2016) and Witt et al. (2011)

> VT DEC (2022, P. 27) states: "*A synthesis compiled by Edwards et al. (2016) indicated that Witt et al. (2011) found an 84% efficiency for portable bridges and a 77% efficiency for temporary culverts.*"

Witt et al. (2011) investigated the effectiveness of BMPs in reducing sedimentation into ephemeral streams in Kentucky. While their study measured turbidity and total suspended solids (TSS), it did not include total phosphorus. There are several limitations in applying their findings to Vermont's AMPs:

- The study was conducted in Kentucky, where climatic, hydrologic, and soil conditions differ significantly from those in Vermont, as described above. These environmental differences can influence erosion, runoff, and BMP performance.
- The results pertain specifically to ephemeral streams. While the study contributes valuable insight, particularly given that ephemeral and intermittent streams are often overlooked in forestry BMP research, it is important to note that the findings may not directly translate to perennial streams.
- Turbidity and total suspended solids were measured only after the stream crossings had been retired, as low rainfall and streamflow during the harvest period prevented sampling during active operations. As a result, the findings clearly do not fully reflect the impacts of harvesting on ephemeral streams during storm events occurring in the harvesting period.

While not cited by VT DEC in this instance, another important discrepancy between Edwards et al. (2016) and claims made based on the study is relevant, because the AMPs revision of 2018 was used to show (in part) Vermont's compliance with the TMDL. The *Appendix B: Crosswalk between the Vermont Phase 1 Implementation Plan and EPA's BMP scenario identifying achievable phosphorus reductions* (EPA, 2016b) of the *Phosphorus TMDLs for Vermont Segments of Lake Champlain* (EPA, 2016a) cites a BMP efficiency for grassed swales ranging from 73 to 100% in Edwards et al. (2016). Kaighn and Yu (1996), which was cited in Edwards et al. (2016) as supporting those values, was not publicly available; a summary within Weiss et al. (2010) is reviewed below in lieu of the original publication. Weiss (2010) states that Kaighn and Yu (1996) found only a 33% reduction of total phosphorus due to vegetated swales at slight slopes (2% or 5% grade) which does not support the sediment reduction efficiencies ranging from 73 to 100% for vegetated swales with check dams specified in the Lake Champlain TMDL.

Packer (1967)

> VT DEC (2022, P. 27) states: "*The efficiencies of forest buffers between forest roads and waterbodies have not been well studied, but Packer (1967) calculated that forest buffers from 9 to 46 meters could retain 85% of sediment flows from cross drains*."

Similar to the previous citations, this study was conducted in a different geographic region, the northern Rocky Mountains in the northwestern U.S. Key differences include drier summers and deeper, well-drained soils compared to Vermont. The research agrees with many others that forest buffers are effective, but it does not necessarily support an 85% sediment retention everywhere in Vermont's forests regardless of terrain, soils, and other conditions. Rather, the width of a forest buffer needed to control 83.5% of sediment depends on the spacing of water bars, berms or cross-drains in the road, soil type, and the composition of the buffer strip such as the presence of logs, rocks, trees and stumps, slash and brush, or only herbaceous vegetation (see Table 4 in Packer, 1967). The 720 logging road study sites assessed were limited to segments between two drainage structures where sediment from the lower structure "*must have been stopped on the slope before reaching a stream channel, a downslope road, or a major topographic barrier, such as a bench*." In other words, the forest buffers were not interrupted by stream crossings, skid roads, truck roads, or log landings. Road grades ranged from 0 to 15%, with approximately one-third of segments exceeding a 10% grade. The study only assessed truck roads and not skid roads.

Damian (2003)

> VT DEC (2022, P. 27) states: "*Damian (2003) found broad-based dips at approaches to water crossings to be 50% effective in modeling studies*."

This interpretation of Damian's M.S. thesis appears to oversimplify the findings. Damian (2003) used road ditch models to predict the optimum placement of the final culvert in a series of ditch-relief culverts before a stream crossing, aiming to minimize sediment transport to the stream. The study highlights a trade-off: culverts placed too far upslope allow sediment to accumulate in road runoff below this final culvert—delivering it directly to the stream below—while culverts placed too close to the stream offer limited opportunity for sediment filtration by vegetation.

The modeling, which was specific to road segments in Tahoma State Forest in Washington, found that siting the final culvert approximately 50–60 meters from the stream crossing could reduce sediment delivery by up to 50% compared to suboptimal placements. However, the study does not specify that the culvert in question is a broad-based dip, as implied by VT DEC (2022). Furthermore, the 50% reduction is a modeled estimate based on specific assumptions, including road grade, stream crossing angle, and sediment production rates, rather than an empirical measurement of culvert efficiency regardless of context. Note that the AMPs specify at 25-foot distance between a stream crossing and the final ditch turnout—a suboptimal placement according to Damian (2003).

Damian (2003) discusses various other limitations with the model results:

- The accuracy of flow-path and stream generation from digital elevation models (DEMs) is heavily influenced by raster cell size; coarse resolutions (e.g., 10 m or 30 m used in this study) limit precision, especially for short road segments.
- The CULSED model is tailored for in-sloped roads with continuous side ditches, making it unsuitable for road networks lacking consistent ditch features, or for crowned or out-sloped roads.
- Sediment estimates rely on region-specific models from Northwestern U.S., which may not generalize well to different conditions or support fine-scale, culvert-by-culvert analysis.

Cristan et al. (2019)

> Cristan et al. (2019) is one of two USDA summary reports cited by VT DEC (2022) on page 29: "*In comparing published data, Cristan et al., (2019) determined that standard BMP implementation reduced estimated sediment load by 75% compared to low BMP implementation levels. High levels of BMP implementation were estimated to potentially remove nearly all forest operation produced sediment. This study does note, however, that the reduction estimates were based on limited data and address only one year following harvest*."

As with other studies referenced in VT DEC (2022), the findings of Cristan et al. (2019) are based on research conducted outside the Northeast, specifically in the southern Piedmont region ranging from Virginia to Alabama. The review by Cristan et al. (2019) does not include areas such as Vermont where heavy rainfall frequently occurs during snowmelt and when freeze-thaw cycles may have loosened soil substrate. Furthermore, the Vermont state lands under consideration for forest harvest include large areas of steep slopes which allow higher velocity runoff with greater erosive power than conditions prevailing in the low, rolling hills of the southeastern US Piedmont region. Absent research from mountainous northern New England areas, the specific and quantitative BMP effectiveness claims made by VT DEC (2022) are not supported by Cristan et al. (2019). In addition to the geographic limitations noted by VT DEC, the cited authors acknowledge that sediment reduction estimates are based on BMP categories that vary between states, estimated operations, and limited published sediment delivery ratios. It is reasonable to expect that specific BMP requirements determine the level of phosphorus removal efficiency; one example being exactly how much and what kind of disturbance is allowed within a protective vegetated stream buffer (undefined in the AMPs). Cristan et al. (2019) also highlight that the study does not address the multi-year effects of harvesting on sediment yields, which typically decline within 3 to 8 years post-harvest when appropriate BMPs are applied. The high elevations and alpine climate combined with thin glacial till soils in large sections of state-owned areas in Vermont will experience shorter growing seasons and slower vegetative growth compared to the more southern and lower elevation areas reviewed by Cristan et al. (2019); thus, the sediment yields may remain elevated for a significantly longer time span in Vermont.

Nolan et al. (2015)

> This study is cited alongside Cristan et al. (2019) on page 29 of VT DEC (2022) in the section on total phosphorus load reduction efficiency for Vermont's Use Value Appraisal (UVA) Program: "*The total phosphorous (TP) reduction efficiency values representing each level of proper BMP utilization and implementation are conservative estimates based on existing United States Department of Agriculture (USDA) Forest Service reports and published erosion and sediment research summarized in Cristan et al., (2019) and Nolan et al., (2015).*"

Nolan et al. (2015) assessed numerous truck road and skid trail stream crossings in the southern Piedmont region using three levels of BMPs: BMP–, BMP-standard and BMP+. This aligns with the categories used by VT DEC (2022) for the Use Value Appraisal Program. The study is generally useful for estimating costs and effectiveness in upgrading BMPs, though as with the other studies, caution should be used when extrapolating beyond the study region. As described under Cristan et al. (2019), large areas of the Vermont lands under consideration have steeper slopes, harsher climate with shorter growing season, thinner and poorer soils which slow vegetative regrowth, experience freeze-thaw action which loosens soil, and seasonally experience high intensity rain-over-melting-snow runoff. Combined, these factors suggest that applying similar BMPs in Vermont as those used in the cited study areas is not a conservative approach. While some level of protection is expected, quantifying that level of protection requires research from mountainous northern regions similar to Vermont. Additionally, no fords were used for any of the observed crossings; they were either culverts, portable bridges, permanent bridges or pole crossings. The Vermont AMPs allow at-grade fords for truck roads and skid trails under specific conditions. At-grade fords can directly load sediment into streams by rinsing off soil from tires, vibrating and loosening sediments from the streambed and banks, direct path over bare soil to the stream on both sides for runoff to follow during rain events, plus the direct soil disturbance impacts from construction and potentially removal of the ford. Since at-grade fords are sometimes allowed by the Vermont AMPs but they were excluded from the research cited by VT DEC (2022), the phosphorus reduction values in the citation cannot be relied on.

Conclusion Regarding AMP Performance Claims

In summary, VT DEC (2022) relies on studies conducted outside of the Northeast to support its methods for tracking sediment and phosphorus load reduction. These studies are used to provide specific percent efficiency or percent pollutants retention values in response to comments on the Worcester Range Management Unit LRMP. While the research cited by VT DEC (2022) generally indicates that BMPs provide real and significant benefits to water quality during forest harvest compared to no BMPs, none of the cited research support DEC's specific and quantitative conclusions on efficacy of Vermont's AMPs. The DEC describes its claims as "conservative" (i.e., potentially underestimating the benefit), but the differences in climate, slope, elevation, and soils between the study areas and the mountain ranges of Vermont all point to higher erodibility, harsher precipitation events resulting in greater erosive power, and slower recovery from forest harvest in Vermont, meaning the BMP efficiency claims are more likely to be overstated than understated.

Critically, VT DEC failed to assess or cite any research on an unharvested watershed baseline for comparison. A recent study in a steep, forested western Maine watershed with glacially-derived soils indicates that sediment yields due to logging are three times higher than background (pre-logging) conditions (Cook et al., 2020). BMPs would clearly be expected to offer some improvements over no BMPs, though there is uncertainty in quantifying the improvement. There is no evidence provided by VT DEC to support a conclusion that BMPs are an improvement over, or even be equivalent to, a "no harvest" scenario. This is especially relevant in a landscape like the Worcester Range Management Unit where there is little recent history of timber harvest, where proposed logging activities represent a significant change in watershed management compared to existing conditions, and where an existing TMDL requires a net reduction in phosphorus loading from forested land cover.

CRITIQUE OF VERMONT ACCEPTABLE MANAGEMENT PRACTICES

Vermont's Acceptable Management Practices

Measures to protect water quality from logging operations were adopted in Vermont in 1987 as the *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont*, with amendments in 2015 and 2018. These rules were updated in 2018 with the goal of protecting Vermont's water quality from sediment, petroleum, and organic pollutants. The updates to the AMPs are cited within Lake Champlain phosphorus TMDL documents as an important step toward approval and successful implementation of the TMDL (e.g., 2020 EPA Lake Champlain TMDL Phase I implementation report card). The Acceptable Management Practices (AMPs) outlined in the rules regulate practices to be used during and immediately after logging and specifically focus on truck roads, skid trails, stream crossings, equipment and materials, log landings, and the forest buffer.

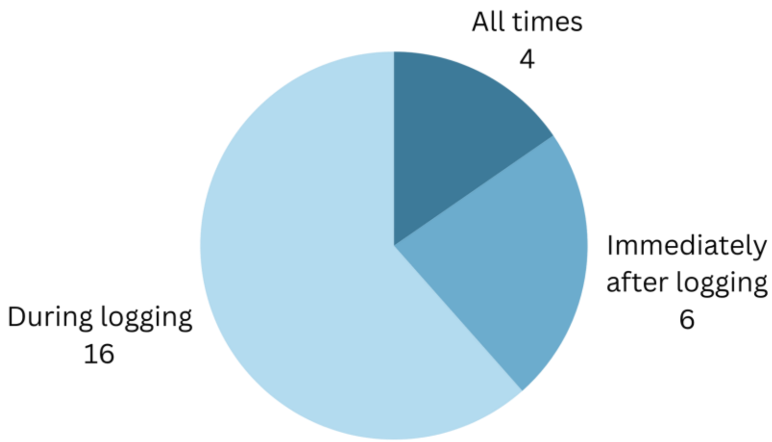

Figure 1. Circle chart showing which part of the logging timeline each AMP regulates. AMPs regulate forestry practices during active logging, immediately after logging, or always.

There are twenty-six subsections of the AMPs that regulate logging practices. Most AMPs (~60%) focus on practices that need to be in place while logging is occurring; the rest apply to the time immediately following logging or are general practices that should be always followed. AMPs to be followed immediately after logging focus on the use of water bars for stormwater diversion, re-seeding bare soil areas within 50 feet of a stream channel, and removing temporary culverts or other measures to stabilize and restore stream channels.

The AMPs do not cover post-construction activities besides removing temporary structures, repairing ruts in roads, and stabilizing soil near streams as discussed above. Post-construction activities beyond what is required in the AMPs could include tree re-planting, decommissioning roads and skid trails, restoring altered hydrology, or soil stabilization (seeding) in all areas exposed. Adding these measures would strengthen the AMPs.

The AMPs provide seeding and mulching standards in Table 3 of the document, with the most detail pertaining to application rates for hay or seed mixes. In particular, the AMPs mandate the use of one of the following options: annual ryegrass, winter rye, soil conservation seed mix, or hydroseeding with native grasses or weed-free seed mix. Winter rye and ryegrass are common cover crops used for stabilizing soil and promoting nutrient cycling, however they are non-native grass species. Conservation seed mixes are typically comprised of a diverse mix of native grasses, legumes, and wildflowers. The referenced seed mixes are non-specific (i.e., the recommended species within "conservation seed mix" and "weed-free seed mix" are not specified) and many commercial products with a variety and varying degree of native species composition exist; a list of native grasses or required species is not provided in the AMPs. **The AMPs could be improved by requiring native grass, legume, and wildflower seeds be utilized in addition to the annual ryegrass or winter ryegrass; this would allow for rapid establishment and soil stabilization by the non-native grasses in the initial growing season but provide opportunities for native species to grow in subsequent years, enhancing species and vegetative structural diversity.**

An alternative is to place more emphasis on utilizing the conservation seed mix or native grasses mixes over the non-native grass seed. In either case, a list of suitable native species to be incorporated into the mixes should be added to the AMPs. In addition, **all** soils exposed during and due to forestry activities should be stabilized. The AMPs require bare soils within 50 feet of a stream channel to be seeded and stabilized; however, all exposed soils have the potential to erode and mobilize through stormwater. The AMP manual merely recommends seeding exposed soils within forest buffers, at waterbody crossings, and “other sites” and to take into consideration the use of fertilizers in proximity to waterbodies and especially avoid direct application or discharge into any waterbody. Those two actions should be required rather than recommended. **Incorporating these recommendations into the AMPs would improve water quality protections and strengthen ecological integrity.**

Vermont’s logging AMPs regulate various activities aimed to reduce stormwater quantity and protect water quality. Eight of the AMPs focus on preventing stormwater drainage ditches from terminating directly into a stream by diverting stormwater into filter areas, using drainage structures such as water bars, turnouts, and broad-based dips. These stormwater control measures must be spaced apart according to Table 1 of the document. The distance between each drainage structure depends upon the type of measure used, the type of road, and the slope of the road. The required distances in Table 1 are generally higher (more spaced apart) than is recommended for similar slopes in other nearby states such as New Hampshire. Having more spaced apart drainage structures reduces overall cost but increases the volume of stormwater that is able to accumulate before stormwater is diverted, which relates to a higher erosion potential. New Hampshire also accounts for the erosion risk of the underlying soils; areas with sandy or silty soils have a higher erosion risk than rocky or clay soils and therefore are required to have drainage structures placed closer together. Vermont’s AMPs do not consider the erosion potential of underlying soils.

These types of drainage structures reduce the stormwater volume accumulating on the road surface and road ditches, allowing it to infiltrate into the soil. Beyond preventing the stormwater from entering surface waters directly through the drainage ditch, these measures also reduce erosion potential of road ditches by reducing stormwater velocity and volume, thus greatly reducing sediment and phosphorus loading to the stream. Diverting stormwater into filter areas also allows for pollutant attenuation if erosion had occurred uphill.

These AMPs identify certain drainage structures by name, including water bars, broad-based dips, and turnouts. Additional structures not named in the AMPs such as check dams may also be useful for reducing stormwater volume and velocity. The AMPs also specify that stormwater must be diverted into filter areas but does not specify how these filter areas should be constructed or maintained, or whether they are simply undisturbed forest duff or native soils. For example, filter areas could include vegetated filter strips, level spreaders, sediment basins/plunge pools, or engineered systems. These filter areas should be stabilized with either vegetation or crushed stone. The AMPs do not currently specify how filter areas should be stabilized, nor set a defined maintenance schedule which is critical for effective treatment. Filter areas can become overwhelmed by sediment, thereby reducing their effectiveness.

Erosion control is addressed in three AMPs, with a focus on repairing ruts in skid trails that could become gullies and seeding exposed soil within 50 feet of stream channels. **Erosion control AMPs do not require stabilizing soil in areas outside of the 50-foot buffer zone. Additional actions could include re-seeding disturbed areas greater than 50 feet from the stream channel (such as skid trails to be**

abandoned) or requiring road crowning or grading to prevent gullies from forming in gravel road surfaces. The AMPs also do not require road ditches to be stabilized. Road ditches can easily erode during storms of any size and could be stabilized with crushed stone (rip rap) or seeded.

Four of the AMPs regulate stream crossing parameters which include requirements about the location and alignment, type of structures, and the sizing of permanent and temporary stream crossings installed along truck roads and skid trails. The AMPs also require permanent stream crossings along perennial streams be designed in compliance with the Vermont Agency of Natural Resources Stream Alteration Rule and General Permit. The Vermont Stream Alteration Rules include the equilibrium and connectivity performance standards which establish standards to ensure activities along perennial streams preserve the ecological integrity of streams; don't compromise aquatic ecosystems, water quality, or adjacent property; and maintain or restore dynamic equilibrium in streams to minimize fluvial erosion hazards. Stream crossing types include bridges, culverts, and at-grade crossings. Table 2A and 2B of the AMPs provide reference on the minimum culvert and bridge sizes for temporary and permanent stream crossing installations. The infrastructure size is based on a stream's drainage area at the crossing location. This method of culvert and

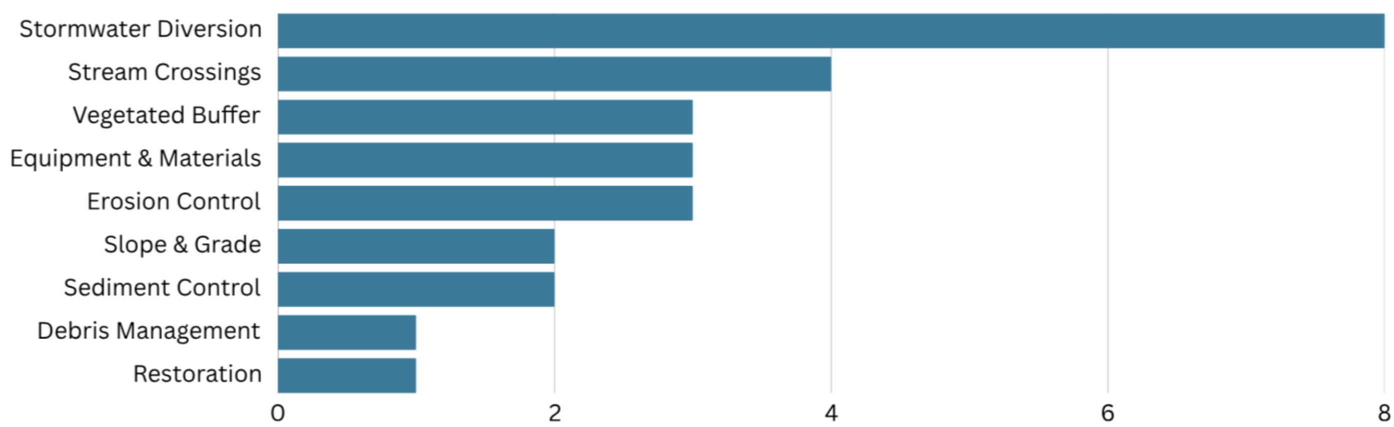

Figure 2. Bar chart showing the most common topics addressed by the AMPs. AMPs covering more than one topic were counted once for each topic.

bridge sizing is not informed by storm volumes (typical flows versus peak or high flows) nor factor in climate change and the higher precipitation events Vermont and New England are facing. In NH, permanent stream crossings along truck roads are required to, at a minimum, be designed to adequately handle a 25-year flood, the peak flow that statistically would occur once in 25 years (Smith et. al., 2024). Additional consideration should be given to whether the minimum culvert size will sufficiently convey high-volume storms and align with the stream's geomorphic conditions. Additionally, the wording about stream crossing alignment in AMP 6.5.2 could be improved to provide better clarity. At-grade crossings are allowed along truck roads when streams have low banks, stable streambed material, and gradual approaches. Consideration should be given to prohibiting at-grade stream crossings, particularly at perennial streams. If at-grade crossings are to be allowed, they should be limited to intermittent streams and only under specific conditions. Allowing machinery to regularly cross perennial streams at truck roads or skidder trails poses significant risks to water quality and stream habitat integrity. At-grade crossings pose a risk to natural stream processes; they can disrupt streambed and channel features, increase the risk of erosion and sediment deposition, alter stream flow velocity, disrupt in-stream habitat connectivity, and introduce debris or chemicals from vehicle traffic.

The slope of logging roads also relates to stormwater diversion and erosion control as steeply sloping areas tend to produce more runoff and thus higher velocity stormwater due to the acceleration due to gravity and the limited opportunities for stormwater to infiltrate into the ground. Large volumes of stormwater moving at a high velocity have the largest erosion potential and can easily overwhelm stormwater control measures. The AMPs prohibit the construction of permanent or temporary truck roads in areas with >10% slope and skid trails in areas with >20% slope. The AMPs provide exceptions for cases in which it is not possible to avoid steeply sloped areas and stipulate that sections of steeply sloped logging roads may not exceed 300 feet in length and generally should be the minimum length possible. Slope is used in Tables 1 and 4 to determine the required distances between drainage structures and the forest buffer width.

The AMPs also regulate maintaining a forested buffer along streams and the distance a truck road, skid trail, or log landing can be constructed in proximity to streams. The width of a forest buffer is established based on the topography of the site; the slope measured from a stream's top of bank to the desired location of a truck road, skid trail, or log landing, detailed in Table 4 of the document, determines the forest buffer width. The steeper the slope, the wider the forest buffer width. Partial cutting within the buffer is allowed but is not defined in the AMPs; specifying maximum allowable harvesting within the buffer would strengthen this AMP. Forested buffers prevent erosion, provide wildlife habitat, and protect stream temperature and aquatic life, and is widely supported in the literature. Limited harvesting within forested buffers is described in some sources, with somewhat mixed results:

- Wynn et al. (2000), describes allowing 36% basal area harvesting within 15 meters of perennial streams, though in the Virgina coastal plain study area slopes are shallow. Water quality protection was good.
- Stafford, C., M. Leathers, and R. Briggs. (1996) reports Lynch et al. (1985) [original paper not found] as stating that buffers can greatly reduce sedimentation to rivers, but allowing even selective cutting of high value trees within buffers can increase windthrow, resulting in "small increases in turbidity."

Therefore, stronger requirements in the AMPs for the amount and location of clearing that can be done within a forest buffer is critical. The guidance document suggests that "ground disturbance and areas of exposed soil within forest buffers" be kept to a minimum and that a harvesting plan should be adopted that provides "continuous forest cover along streams and other bodies of water for shade" consistent with 60-70% crown cover or B level stocking (Wilcox & Sabourin, 2019). In New Hampshire, forestry activities must follow The Basal Area and Slash Laws. The Basal Area law requires that healthy, living trees be retained along town and state roads, streams, and water bodies following a timber harvest. Specifically, no more than 50% of the basal area can be removed within 150 feet of a road, great pond, and 4^{th}-order (or larger) stream or within 50 feet of a perennial stream. Additionally, the Slash Law restricts the location and limits of slash within the forested buffer to no slash placed in any river, stream, or brook unless authorized through a wetlands permit or within 25 feet of perennial 4^{th}-order streams or less or within 50 feet of a great pond, public highway, or railroad. Better quantifying and increasing limitations and criteria for work within the forest buffer would strengthen the Forest Buffer AMPs.

The installation and maintenance of sediment and erosion control best management practices along truck roads, skid trails, landing pads, and limits of forest harvesting are imperative to prevent degraded water quality and impacts to wildlife, wetland, and stream resources. Only two of the AMPs mention sediment and erosion control measures and specifically call out the proper installation of BMPs at log landings. Implementation of erosion and sediment control best management practices such as silt barriers, mulch berms, check dams, etc. should be applied to all earth moving activities exposing soils, dredging material, grubbing stumps, or bringing in fill material. In addition, the AMPs should address and require inspection and maintenance of erosion control BMPs installed throughout a site. The control measures are only effective if they are installed properly and maintained.

Additional factors not addressed by the AMPs include the consideration and coordination on potential impacts and effects of forestry on threatened or endangered species habitat, creating or exacerbating habitat fragmentation, the ecological effects the roads, trails, and machinery traffic have on the forest and water quality.

Acceptable Management Practices Enforcement

In Vermont, the AMPs are enforced by the Agency of Natural Resources (ANR) Department of Forests, Parks, and Recreation. If logging operations are done in compliance with the AMPs, it is presumed that the operations are in compliance with the Vermont Water Quality Standards as well and the work is exempt from applying for a discharge permit, stream alteration permit, stormwater permit, and Vermont wetland rules. Enforcement is typically through a state or federal agency that has oversight over a project through an issued permit which outlines requirements that must be upheld. However, since forestry activities are exempt from permitting if the AMPs are followed, this enforcement mechanism is weak. It fully relies upon the AMPs being followed and that the AMPs sufficiently address the requirements and standards in the discharge, stream alteration, and stormwater permits and wetland rules. Exempting forestry activities from state-level permitting reduces the effectiveness of state-level enforcement. Without agency oversight and enforcement through an issued permit, it leaves the forester and crew to self-regulate and monitor their harvesting activities and be knowledgeable of the AMPs and state water quality standards.

Because no permits are required for forestry operations, regulatory enforcement of the AMPs appears to only occur if an individual issues a complaint to the ANR; these complaints are summarized in annual statewide reports. The ANR takes action on all complaints it receives, which includes visiting the site, documenting areas where stormwater is discharging directly to streams, and recommending solutions for the loggers to implement. These complaints only result in enforcement or penalty if site investigations find that there was a substantial failure to comply with the AMPs, remediation is unsuccessful, or the logger has a history of non-compliance with the AMPs. The ANR has received 26-34 complaints per year since the new AMPs were adopted in 2018. No violations are found to occur in most (54%) of these cases. Of the cases with discharges found, 80% were able to be fully resolved using the AMPs. In the other cases, temporary measures were used to stabilize the site until more robust actions could be taken. Enforcement was only pursued in a single case since 2018.

Since water is the main conduit of pollutants from logging roads into streams, excessive pollutant loading from logging operations should not be occurring if stormwater from logging roads does not enter the stream. However, this enforcement mechanism fails to account for other violations of the AMP, including abiding by the culvert sizing/buffer/distance between drainage structures requirements in the AMPs, streambank erosion, equipment & hazardous materials handling, and others.

Loggers can also request technical assistance from the ANR for support in abiding by the AMPs. The ANR has received an average of 21 requests per year since 2018. Most of these requests relate to stream crossings. Vermont's Forest Resource Harvest Summary from 2022 suggests that there are likely far more logging operations each year than there are complaints based on the sheer volume of wood being harvested each year. The recorded complaints and violations from the annual reports likely represent a small amount of the total logging operations occurring in Vermont, suggesting that violations are likely under-reported and technical assistance is not taken advantage of to its full potential.

Table 1. Summary of complaints and requests for assistance to ANR for each year since the revised AMPs were adopted in 2018.

Year	Complaints	Requests for Assistance	Evidence of Discharge	Resolved Using AMPs	Temporary Measures Installed	Enforcement or Penalty
2024	34	22	20	17	3	1
2023	--	--	--	--	--	--
2022	29	27	15	10	5	0
2021	26	16	9	7	2	0
2020	31	24	16	12	4	0
2019	26	17	10	8	2	0
2018	28	17	10	10	0	0
Average	**29**	**21**	**13**	**11**	**3**	**0**

Management Practices Case Study: New Hampshire

In New Hampshire, there are several state laws and requirements applicable to forestry designed to encourage responsible harvesting while minimizing environmental impacts of logging. Forestry is not exempt from state level permitting. Lower scrutiny permits are available for forestry practices that are intended for management and economic purposes that can meet the permit requirements, however higher-level permitting is required if the clearing is intended for land conversion or development. There is a significant distinction that is made between timber harvesting for forest management and timber harvesting taking place to convert land to non-forest uses such as development in New Hampshire's laws.

State oversight and guidance comes from the New Hampshire Department of Revenue Administration, the New Hampshire Division of Forests and Lands, and the New Hampshire Department of Environmental Services. State laws pertaining to forestry include the following.

- Current Use Law (RSA 79-A),
- Timber Tax Law (RSA 79),
- Basal Area Law (RSA 227-J:9),
- Slash Law (RSA 227-J:10),
- Wetlands Statute (RSA 482-A),
- Shoreland Statute (RSA 483-B), and
- Alteration of Terrain Statute (RSA 485-A:17).

The Current Use Law is a tax savings program that encourages forested lands to remain forested and is derived from the understanding that there is value and money to be made if the timberland is harvested. The Timber Tax Law acknowledges that timberlands are real estate, and that real estate is taxable, therefore the timber harvested is taxable. Forestry operations are required to complete a Notice of Intent to Cut and to file and notify the town, New Hampshire Department of Revenue Administration, and New Hampshire Division of Forests and lands. The Basal Area Law regulates forested buffers along town and state roads, streams, and bodies of water, establishing buffer widths and clearing parameters that are enforceable by the State. The intent of the Basal Area Law is to prevent erosion, provide wildlife habitat, protect stream temperature and aquatic life, and preserve the aesthetics of the landscape. The law dictates that no more than 50% of the basal area may be removed within 150 feet of a road, great pond, or 4th order stream and greater or within 50 feet from a perennial stream or waterbody less than 10-acres in size. The Slash Law restricts the placement and dimensions of slash. Slash is not permitted to be placed in any river, stream, or brook, waterbody, public highway, or active railroad bed; on someone else's property; within 25 feet of a stream or an abutter; within 50 feet of a great pond, waterbody 10-acres or larger, public highway, or active railroad bed; or within 100 feet of any occupied structure such as barns, sheds, and storage buildings. Additionally, slash cannot be more than four feet high within 50 to 150 feet of a great pond, waterbody 10-acres or larger, or public highway (Smith et. al., 2024).

A wetlands permit, referred to as a Forestry Statutory Permit-By-Notification issued by the NH Department of Environmental Services, is necessary for forestry operations proposing impacts to wetlands or stream. Impact areas are limited to permanent or temporary wetland and stream crossings necessary to access upland areas to harvest and do not permit harvesting in wetlands. And must be done in accordance with The Forestry Best Management Practices for Erosion Control on Timber Harvesting Operations document. Any permanent stream crossing must be designed to adequately handle a 25-year flood. The state's Notice of Intent to Cut Timber Certificate issued through a town's municipal assessing office and recorded with New Hampshire Department of Revenue Administration and New Hampshire Division of Forests and Lands serves as the certification and verification of an Alteration of Terrain (AoT) permit. In some cases, an AoT Permit-By-Rule is necessary but in all cases it is suggested that the New Hampshire Stormwater Manual be followed. Similar to Vermont, forestry is exempt from the Shoreland Water Quality Protection Act (SWQPA) in New Hampshire if done in accordance with the Best Management Practices, Basal Area Law, Department of Revenue Administration's Intent to Cut form, and harvesting is not associated with shoreland development or land conversion. New Hampshire's *Forestry Best Management Practices for Erosion Control on Timber Harvesting Operations* (NHDFL & UNHCE, 2016) is a guidance document similar to Vermont's *Acceptable Management Practices Manual for Logging Professionals* (Wilcox & Sabourin, 2019), however the New Hampshire guidance document is cited within state law and rule, requiring the use and implementation of the guidance (Smith et. al., 2024). Instead, the Vermont guidance document states that it contains "recommended practices but is not a part of the enforceable AMP rule."

Enforcement is carried out by town officials in conjunctions with the state agencies that hold delegated authority over these laws and regulations. Municipalities can delegate responsibility either through their code enforcement, conservation commissions, a designated forestry committee, law enforcement, or a licensed forester working for the town. The knowledge and awareness to follow these laws and regulations ultimately falls upon the landowner and forester conducting the work.

Acceptable Management Practices Effectiveness

Based on our literature review, the AMPs provide a good foundation for forestry best practices, however they could be strengthened and improved. The AMP manual takes steps to that end by providing additional guidance and recommendations, but the guidance is only recommendation and not law, rule, or requirement and therefore does not fully accomplish that end. Specifically, the AMPs could be improved in areas of post-construction stabilization, establishing revegetation standards, culvert sizing updates, forest buffer limitations, and implementing sediment and erosion control best management practices site wide.

Revegetation standards could specify native plant species to use in seed mixes and replanting or citing specific seed mixes or guidance documents to be followed. Requiring a growth and cover success rate, such as 75% establishment could be beneficial. Culvert sizing should consider higher volume storms and climate change. Additionally, partial clearing within the forest buffer should be well defined in the AMP using quantitative parameters of logging allowable within a forest buffer.

Optimal Conservation Practices and AMPs

Underwood and Brynn (2015) described Optimal Conservation Practices (OCPs) in *Enhancing Flood Resiliency of Vermont State Lands*. Despite the title, the report focuses on flooding *and* water quality, thus the OCPs can be viewed as an alternative or complement to AMPs. The authors mapped and assessed a sample of four representative state properties in developing the OCPs. These lands were over 90% forested and 26.5% was 2,500 feet in elevation or higher, fairly similar to state lands overall. The authors emphasize that these higher elevations receive greater and more intense precipitation and are likely to be hardest hit by increasingly intense storms due to climate change. They also mention that Vermont Forest Parks and Recreation staff indicated in interviews in 2014 that these high elevation areas which are most erosion sensitive were being included in plans for forest harvest.

Underwood and Brynn (2015) conducted a geospatial analysis of mapped soils, depth to bedrock, limited infiltration capacities, and slopes, all of which are highly relevant to AMP performance. Steep slopes and intense precipitation are frequently cited in the literature as having unconfirmed or known detrimental effects on forest harvest BMP efficiencies (see critiques of the TMDL and VT DEC documents in sections above). Furthermore, Vermont's relatively thin glacial till soils may be more susceptible to erosion than the soils in many of the literature sources used for AMPs performance assumptions. EPA's response to comments in the Lake Champlain Phosphorus TMDL acknowledge soils in Vermont are likely more erodible than central Appalachian soils in literature sources supporting the AMPs (EPA, 2016c, page 109), though EPA suggests greater soil compaction in those southern areas may offset the phosphorus loading rates (though data are lacking). Underwood and Brynn's mapping efforts designating high elevation, steep slope areas in Vermont as especially sensitive to flooding impacts and water quality impairment from forest harvesting accord well with the scientific literature.

Overall, the approach taken by the OCPs of setting aside the most hydrologically sensitive areas so they do not undergo forest harvest is based on a defensible interpretation of the scientific literature and sound precautionary reasoning. Many literature sources, including EPA in several responses to comments on what became the 2016 Lake Champlain phosphorus TMDL, highlight the paucity of hard scientific data specific to forest harvest activities in Vermont, especially in higher elevations, steeper slopes, and under the most intense storm conditions. However, one study cited by VT DEC compared an unharvested watershed to both BMP and non-BMP harvested watersheds in steep Appalachian terrain much more similar to Vermont and the Hydrologic Reserve Zone proposed in the OCPs than its other cited studies, and found that unharvested areas had much lower sediment and nutrient loading to streams: suspended sediment flux during harvest was 14 and 30 times higher on the BMP and non-BMP watersheds than the uncut watershed, respectively, and 4 and 6.5 times higher in the 17 months following harvest (Arthur et al., 1998). Cook et al. (2020) found long-term sediment yields across a mountainous Maine watershed with glacially-derived soils and no history of agriculture was over three times higher during logging (1900 to present time) than before logging, reflecting the net effect of logged and unlogged portions of the landscape on water quality.

There is certainly room to debate the specific criteria and boundaries which would define the most hydrologically sensitive areas to protect from forest harvests. The specific elevation threshold of 2500 feet used by Underwood and Brynn (2015) was selected in part based on Vermont water quality protection rules. To quote:

> *Available research for Vermont is not conclusive as to a specific threshold elevation above which sensitivity to climate change is enhanced. An elevation of 2500 feet was chosen to be consistent with Vermont Water Quality rules which require greater water quality protections for waters above this elevation.*
>
> -Underwood and Brynn (2015)

Use of Natural Resources Conservation Service (NRCS) soils datasets have a limited spatial resolution (Kimsey et al., 2020); do not account for any site-specific human activities such as excavation, fill, or disturbance (though soil altering activities would seem very unlikely in high elevation forests); and mapped soil units may have inclusions of other soils that are not mapped. The USDA (2003, revised version of 1991 report cited by Underwood and Brynn) Forest Soil Potential Study for Vermont Soils reaffirms this, stating:

> *With the exception of broad planning activities, on-site investigations are recommended when using this report…to assess variations in site conditions within a map unit delineation (i.e. stoniness, aspect, rock outcrops, wetness)… to assess the steeper portions of soil map units that range from 25 to 60 percent slopes…[and] to access the unique landscape characteristics of a map unit delineation.* (USDA, 2003)

Nonetheless, NRCS data is appropriate for this scale of planning activity, and have been widely used for that purpose, including in the Soil and Water Assessment Tool (SWAT) model in the Lake Champlain phosphorus TMDL used to estimate pollutant loads in areas where there were no water quality data. Similarly, the two slope thresholds of 15% and 35% used in the OCPs (USDA, 2003; Table 1 of that report) are cited in the original document as limiting the suitability for forest harvest to moderate and severe classifications, respectively. There is at least one report indicating BMPs were generally but not exceptionally effective on slopes of around 40% in West Virigina (Kochenderfer & Hornbeck, 1999), thus supporting a 35% slope threshold for the most restrictive OCP forestry zone. Higher slopes of 60% in the NRCS report were set as a threshold essentially barring forest harvest purely on a safety rationale (USDA, 2003).

Overall, while the AMPs provide some BMP adjustments relating to slope and hydrologic conditions, they do not consider soil erodibility or elevation, they do not address extreme storms, and they do not account for the superior benefits of unharvested and roadless areas compared to harvested areas, regardless of application of BMPs. Vermont state lands likely contain an outsized percentage of high elevation lands sensitive to all these factors compared to Vermont woodlands as a whole. The OCPs, especially the proposed Hydrologic Reserve Zone and its restrictions on forest harvests, are well supported by scientific research on individual BMP effectiveness. The scientific literature often acknowledges lack of data on BMP performance in high slopes and extreme storms and suggests BMPs in those conditions are likely more susceptibility to failure.

CONCLUSIONS

The *Acceptable Management Practices for Maintaining Water Quality on Logging Jobs in Vermont* are rules to protect Vermont's water quality from sediment, petroleum, and organic pollutants. The 2018 AMPs update were used by the State of Vermont in part to show compliance with the Lake Champlain phosphorus TMDL (see 2020 EPA Lake Champlain TMDL Phase I implementation report card), which sets a 5% phosphorus reduction target in forested areas for most lake basins. The Vermont Department of Environmental Conservation (DEC) makes quantitative phosphorus removal performance claims (VT DEC, 2022) to show the AMPs achieve compliance with the Lake Champlain phosphorus TMDL. DEC used similar claims to obtain Worcester Range Management Unit (WRMU) Long Range Management Plan (LRMP) approval.

This report reviewed those performance claims in detail by reviewing each study cited by DEC and found the claims to be not well supported and likely overstated. In some cases, performance claims in the literature simply were not found as claimed (see the section on Edwards et al., 2016 above). In many cases, the cited research occurred in conditions so different from those in Vermont that they do not provide a reliable assurance of AMP performance (see above regarding Kochenderfer & Hornbeck, 1999, in West Virginia; and Wynn et al., 2000, in the coastal plains of Virginia). To summarize, Vermont's steep terrain and thin glacial soils are likely to result in more severe erosion than those in the southeastern US where several studies were conducted. Vermont's cold climate and thin soil, especially in high elevations, will likely slow down vegetative recovery after forest harvest. Finally, the cited research all involved more stringent management restrictions than Vermont's AMPs, especially regarding allowable disturbances within stream buffers, maximum allowable road steepness, and the requirement to re-seed all disturbed areas. Taken together, these factors all point to lower phosphorus reduction performance in Vermont than achieved in the studies cited by DEC.

There are well-documented approaches which if adopted within the AMPs will improve their water quality protection performance. These include:

- Quantifying limits to cutting within forested stream buffers, as is done in New Hampshire's Basal Area Rule or as was done in several studies, ranging from no forestry activity within the buffer to a maximum of 36% basal area removal.
- Expanding the no-vehicle-activity distance from 25 feet to 50 feet from streams and other surface waters, except as minimally required for unavoidable stream crossings.
- Prohibiting at-grade fords for stream crossings.
- Setting a truly conservative AMP performance assumption of 50% or less, in accord with Arthur et al. (1998), which was conducted in steep Appalachian Mountain terrain more similar to Vermont's than most of the other studies.
- Prohibiting any harvest activities within Hydrologic Reserve Zones based on multiple factors such as steep slope, soils, and proximity to surface waters, as proposed in Optimal Conservation Practices by Underwood and Brynn (2015).
- Some of the above may be accomplished by transforming guidelines in *Acceptable Management Practices Manual for Logging Professionals* (Wilcox & Sabourin, 2019) into enforceable rules.

Improvements to the AMPs described above would be an important step toward protecting the surface waters of Vermont and complying with the Lake Champlain phosphorus TMDL. Even more important would be to assess a no-forest-harvest option alongside all proposed forest harvest activities. Forest harvest with

AMPs would likely result in a long-term tripling of sediment yields to streams in steep forested areas that have not been recently logged, putting compliance with Lake Champlain water quality requirements at risk.

REFERENCES

Arthur, M.A., G.B. Coltharp, and D.L. Brown. (1998). Effects of best management practices on forest streamwater quality in eastern Kentucky. Journal of the American Water Resources Association 34:481-495.

Brynn, D.J. and Clausen, J.C. 1991. Postharvest assessment of Vermont's acceptable silvicultural management practices and water quality impacts. *Northern Journal of Applied Forestry*, *8*(4), pp.140-144.

Ciolkosz, E.J., Waltman, W.J., Simpson, T.W. and Dobos, R.R., 1989. Distribution and genesis of soils of the northeastern United States. *Geomorphology*, 2(1-3), pp.285-302.

Cook, T.L., Snyder, N.P., Oswald, W.W. and Paradis, K., 2020. Timber harvest and flood impacts on sediment yield in a postglacial, mixed-forest watershed, Maine, USA. Anthropocene, 29, p.100232. https://doi.org/10.1016/j.ancene.2019.100232

Cristan, R., Aust, W. M., Bolding, M. C., & Barrett, S. M. (2019). Estimated Sediment Protection Efficiencies for Increasing Levels of Best Management Practices on Forest Harvests in the Piedmont, USA. Forests, 10(11), 997.

Damian, F., 2003. *Cross-drain placement to reduce sediment delivery from forest roads to streams* (Doctoral dissertation, University of Washington).

Edwards, Pamela; Williard, Karl W.J. 2010. Efficiencies of forestry best management practices for reducing sediment and nutrient losses in the eastern United States. Journal of Forestry. July/August: 245-249.

Edwards, P. J., Wood, F., & Quinlivan, R. L. (2016). Effectiveness of best management practices that have application to forest roads: a literature synthesis. Gen. Tech. Rep. NRS-163. Newtown Square, PA: US Department of Agriculture, Forest Service. 171 p., 163, 1-171.

Fink, J.R., Inda, A.V., Bavaresco, J., Barrón, V., Torrent, J. and Bayer, C., 2016. Adsorption and desorption of phosphorus in subtropical soils as affected by management system and mineralogy. Soil and Tillage Research, 155, pp.62-68.

Huang, H., Winter, J.M., Osterberg, E.C., Horton, R.M. and Beckage, B. 2017. Total and extreme precipitation changes over the northeastern United States. *Journal of Hydrometeorology*, 18(6), pp.1783-1798.

Ige, D.V., Akinremi, O.O., Flaten, D.N., Ajiboye, B. and Kashem, M.A., 2005. Phosphorus sorption capacity of alkaline Manitoba soils and its relationship to soil properties. Canadian journal of soil science, 85(3), pp.417-426.

Jong, B.T., Delworth, T.L., Cooke, W.F., Tseng, K.C. and Murakami, H., 2023. Increases in extreme precipitation over the Northeast United States using high-resolution climate model simulations. *NPJ Climate and Atmospheric Science*, *6*(1), p.18.

Kimsey, M.J., Laing, L.E., Anderson, S.M., Bruggink, J., Campbell, S., Diamond, D., Domke, G.M., Gries, J., Holub, S.M., Nowacki, G. and Page-Dumroese, D.S. 2020. Soil mapping, monitoring, and assessment.

Forest and rangeland soils of the United States under changing conditions: A comprehensive science synthesis, pp.169-188.

Kochenderfer, J.N. and Hornbeck, J.W., 1999, February. Contrasting timber harvesting operations illustrate the value of BMPs. In Proceedings, 12th Central Hardwood Forest Conference (pp. 128-136). Lexington, KY: USDA Forest Service, Southern Research Station. https://www.srs.fs.usda.gov/pubs/gtr/gtr_srs024/gtr_srs024_018.pdf

National Research Council. 2008. Hydrologic Effects of a Changing Forest Landscape. Washington, DC: The National Academies Press. https://doi.org/10.17226/12223.

National Weather Service, 2023. The Great Vermont Flood of 10-11 July 2023: Preliminary Meteorological Summary. https://www.weather.gov/btv/The-Great-Vermont-Flood-of-10-11-July-2023-Preliminary-Meteorological-Summary

National Research Council (NRC). 2008. Hydrologic Effects of a Changing Forest Landscape. Washington, DC: The National Academies Press. https://doi.org/10.17226/12223

New Hampshire Division of Forests and Lands and UNH Cooperative Extension (NHDFL & UNHCE). 2016. New Hampshire Best Management Practices for Erosion Control on Timber Harvesting Operations. https://extension.unh.edu/resource/new-hampshire-best-management-practices-erosion-control-timber-harvesting-operations

Nolan, L., Aust, W. M., Barrett, S. M., Bolding, M. C., Brown, K., & McGuire, K. (2015). Estimating costs and effectiveness of upgrades in forestry best management practices for stream crossings. Water, 7(12), 6946-6966.

Packer, P.E., 1967. Criteria for designing and locating logging roads to control sediment. *Forest Science*, *13*(1), pp.2-18.

Ross, D.S., Wemple, B.C., Willson, L.J., Balling, C.M., Underwood, K.L. and Hamshaw, S.D. 2019. Impact of an extreme storm event on river corridor bank erosion and phosphorus mobilization in a mountainous watershed in the northeastern United States. *Journal of Geophysical Research: Biogeosciences*, *124*(1), pp.18-32.

Smith, S., Anderson, D., Gagnon, M., & Roberge, S. (2024, June). Guide to New Hampshire Timber Harvesting Laws. New Hampshire Division of Forests and Lands. https://extension.unh.edu/resource/guide-new-hampshire-timber-harvesting-laws

Stafford, C., M. Leathers, and R. Briggs. 1996. Forestry-related nonpoint source pollution in Maine: A literature review. Maine Agricultural and Forest Experiment Station Miscellaneous Report 399.

Underwood, K. L., & Brynn, D. 2015. Enhancing flood resiliency of Vermont state lands (Final Draft, June 30, 2015). Prepared for Vermont Department of Forests, Parks & Recreation. South Mountain Research & Consulting & Vermont Family Forests.

US Environmental Protection Agency (EPA). 2016a. Phosphorus TMDLs for Vermont Segments of Lake Champlain.

US Environmental Protection Agency (EPA). 2016b. Appendix B Crosswalk between the Vermont Phase 1 Implementation Plan and EPA's BMP scenario identifying achievable phosphorus reductions.

US Environmental Protection Agency (EPA). 2016c. Phosphorus TMDLs for Vermont Segments of Lake Champlain: Response to Comments. July 17, 2016.

Vermont Department of Environmental Conservation (VT DEC). 2022. Standard Operating Procedures for Tracking Accounting of Natural Resources Restoration Projects.

Weiss, P.T., Gulliver, J.S. and Erickson, A.J., 2010. The performance of grassed swales as infiltration and pollution prevention practices. A literature review. Via University of Minnesota Stormwater Research Program.

Wilcox, D. and Sabourin, G. 2019. Vermont Water Quality: Acceptable Management Practices Manual for Logging Professionals.

Witt, E.L., Barton, C.D., Stringer, J.W., Bowker, D.W. and Kolka, R.K., 2011. Evaluating Best Management Practices For Ephemeral Channel Protection Following Forest Harvest in the Cumberland Plateau–Preliminary Findings. In Proceedings of the 17th Central Hardwood Forest Conference GTR-NRS-P (Vol. 78, p. 365).

Wynn, T. M., Mostaghimi, S., Frazee, J. W., McClellan, P. W., Shaffer, R. M., & Aust, W. M. (2000). Effects of forest harvesting best management practices on surface water quality in the Virginia coastal plain. Transactions of the ASAE, 43(4), 927.