RIPARIAN AREA MANAGEMENT PRINCIPLES AND PRACTICES:
WORKSHOP SUMMARY REPORT

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INTRODUCTION

This report summarizes the background material presented at a staff workshop on riparian area management held in Prince Albert, Saskatchewan on June 19th and 20th, 2000. The workshop was organized by the Forest Ecosystems Branch of Saskatchewan Environment and Resource Management (SERM). Senior staff members from the Fish and Wildlife Branch and Environmental Quality Branch also participated. The primary goal of the workshop was to review and discuss salient scientific literature and operational experience as a foundation for the development of 20 year forest management plan approval conditions. This information also will contribute to the improvement of riparian area management standards in Saskatchewan.

The extent of scientific literature and field experience with riparian area management in the boreal forest in general, and Saskatchewan in particular, is somewhat limited. Fortunately, there are a wide range of studies and case examples elsewhere in North America from which valuable data, information, and technologies can be reasonably transferred. Naturally, differences in climate, forest type, disturbance regime, and timber harvesting operations must be taken into account. Nevertheless, the conservative combination of basic ecological principles, time-tested practices, and professional judgement can yield an approach that balances the demand for wood fibre with the stewardship of other forest values and resources.

This report has five major sections: (1) a background discussion, (2) a summary of the structure, function and values of riparian forest ecosystems, (3) a summary of timber harvesting and fire effects on nutrient cycling, (4) examples of protection and management strategies, and (5) a summary discussion of management options for Saskatchewan.

BACKGROUND

To frame the discussion of the state-of-the-science and examples of riparian area management policies, it may be useful to briefly consider some starting premises.

1. Forests, water, and people are inextricably connected.

2. The nature and importance of these connections can change in relation to ecological, social, and economic conditions.

3. The value and vulnerability of these connections are usually underestimated by people—including resource managers and decisionmakers. The opportunities and full suite of values generated by active management are usually underestimated as well.

4. Connections between forests, water, and people strongly influenced the genesis of the Conservation Movement and the profession of forestry throughout the 20th Century—they will be *at least* as important during the 21st Century.

5. Because water and aquatic ecosystems are vital components of forested landscapes and resource-dependent economies, reactive or custodial approaches are, over the long-term, much more costly (economically *and* ecologically) than proactive conservation and stewardship. In other words, preventive measures are a "pennies-on-the-dollar" strategy in comparison to restoration costs.

6. Focused plans and sustained efforts are the foundation of long-term success for an adaptive management approach.

An Historical Perspective

During the last two centuries, management of natural resources in North American has run the gamut from overt exploitation …to "wise use" …to complete protection. Complete protection—if such an approach is possible, let alone advisable, since forest ecosystems are constantly changing—corresponds to a preservationist philosophy. Although "wise use" is a value-laden phrase that can mean many things to many people, in general, it corresponds to a conservationist philosophy. By contrast to protected or carefully managed systems, evidence of exploitive resource use on degraded sites usually persists until deliberate restoration efforts are completed. In most cases, this is a very expensive proposition. It also is very difficult to bring about the in-kind replacement of a degraded forest ecosystem.

In his landmark 1912 report (summarized in 1911 testimony) to the U.S. Senate entitled, "*Forests and water in light of scientific investigation,*" Dr. Raphael Zon (1927), then Director of the U.S. Forest Service Lake States Forest Experiment Station and a Russian emigré, respectfully offered the following admonition.

> *"A national policy which, though considering the direct value of forests as a source of timber, fails to take full account also of their influence upon erosion, the flow of streams, and climate, may easily endanger the well-being of the whole people."*

This sober and well-founded statement contrasted sharply with the tone of the Weeks Bill debate in the House of Representatives (West 1992:41-43) during which the Honorable Joseph G. Cannon (1836-1927), Speaker of the House, acidly declared *"…not one cent for scenery!"* Thankfully, common sense prevailed and the passage of the Weeks Act (after several failed attempts beginning in 1905) led to the appropriation of funds to purchase land for the U.S. National Forest system.

Clearly, a conservation philosophy applied to *all* resources is an obvious choice along a spectrum bounded by preservation and exploitation. Devising a forest management strategy that balances the needs and values of people with the productive capacity of the forest is the central challenge for SERM and leaseholders. To achieve this goal fibre production must be kept in balance with the resistance and resilience of the forest ecosystem *as a whole*. Although it is very difficult to arrive at a consensus definition of sustainability, it is a relatively straightforward task to identify management practices that generate chronic or acute stresses on forest ecosystems and are, therefore, unsustainable.

Forest Management Strategies

Decades of research and operational experience have demonstrated the benefits and costs—ecological and economic—of various forest management strategies. The deliberate replication of natural patterns and processes, to the extent it is operationally feasible, has become a central tenet of most contemporary management strategies.[1] The spatial and temporal scale of timber harvesting and the characteristics of silvicultural systems may, however, vary substantially. For example, small harvest units (10s of hectares) scattered across large areas may be used to simulate gap dynamics, insect and disease damage, beaver activity, etc. with time scales of years to decades. This approach influences stand-level attributes of the forest. By contrast, large-scale (100s to 1,000s of hectares) harvesting attempts to mimic low frequency disturbances such as wildfires, severe storms (ice damage or windthrow), and acute insect and disease outbreaks. This approach can influence landscape-level patterns and processes for many decades. Most large industrial operations are combining both approaches in order to accommodate variations in forest conditions, production requirements, transportation costs, and community preferences. Like an investment portfolio, common sense argues for a diverse range of holdings and diligent performance monitoring.

[1] Species or forest type conversions (*e.g.*, northern hardwoods to Norway spruce in the Adirondacks ca. 1900; central hardwoods [oak-hickory] to eastern white pine in Massachusetts ca. 1930, etc.) were unsuccessful attempts to transplant German and French forestry techniques to North America. Some contemporary approaches to intensive forest management are much more successful and widely accepted (*e.g.*, southern oaks to yellow pine plantations in the southeastern United States) or show promise in for the future (*e.g.*, agricultural land on the prairie-forest fringe to hybrid poplar plantations) as a supplemental wood supply.

FUNCTIONS AND VALUES OF RIPARIAN AREAS

Riparian areas are transition zones between terrestrial and aquatic ecosystems in a complex and dynamic landscape of upland forests, wetlands, streams, and lakes. Their functions and values may be ecological, social, or economic. Although a wide range of functions and values are, of necessity, listed and discussed in series in this report, their inter-related nature should be noted and considered.

Ecological Functions and Values

Although it may comprise a relatively small part of most watersheds, riparian areas can have a disproportionate influence—either positive or negative—on the quantity and especially the quality of water in forest ecosystems. This influence directly affects aquatic ecosystems and, as a result, human uses and values.

Regulation of Microclimate

A canopy of trees and shrubs arches over headwater streams in forest ecosystems. They also shade near-shore areas of lakes, larger streams, and rivers during a portion of each day. Their height and aerodynamic roughness also influences wind velocity and direction over the water surface. These cumulative effects on the energy balance can produce substantial changes in a key attribute—water temperature. It is a key attribute because dissolved oxygen concentration is *inversely* proportional to water temperature; decomposition, biochemical reaction, and metabolic rates are *directly* proportional to water temperature. Hence, as water temperature and biochemical oxygen demand *increase*, there is a concurrent, sometimes marked, *decrease* in the supply of oxygen available to aquatic organisms. This can impose severe stress on insect and fish populations. Chronic stress can slowly, yet visibly, alter aquatic ecosystems. Acute stress can lead to algal blooms, fish kills, and other abrupt, undesirable changes.

Riparian vegetation has the greatest proportional influence along headwater streams. The microclimate effect decreases moving downstream as the width of the stream, river, or lake increases relative to the height of the riparian vegetation. It should be noted, however, when water flowing from headwater areas has a low ambient temperature this ecological benefit is transferred downstream. When the reverse is true—there are few opportunities for cooling—an abrupt water temperature increase often signals the start of adverse cumulative impacts.

Organic matter

Leaves, needles, and wood supply energy—carbon—to headwater streams. The shade that regulates water temperature also limits the opportunity for aquatic plants, ranging from algae to floating and rooted aquatic vegetation, to supply food [primary production of *autochthonous* carbon] and generate oxygen for microbes, insects, and fish. Hence, the foundation of the food web is largely the [*allochthonous*] carbon generated by riparian vegetation and deposited into the stream. Leaves are subject to rapid decomposition and may persist for only a few weeks or months. By contrast, a large, decay resistant log may last for decades. Like microclimate effects, the relative importance of carbon inputs from riparian vegetation decreases as the receiving water becomes larger. However, the inflow of dissolved and particulate carbon from headwater areas remains an important supplement to *in situ* primary production by algae and other aquatic plants in creeks, rivers, and lakes.

Woody debris

In addition to being a persistent source of carbon, woody debris (ranging from small twigs to branches, boles, and entire trees) forms critical structural features for stream ecosystems. As woody debris lodges and jams along the banks and bed of the stream it provides a matrix to capture leaves and other small organic matter that is drifting downstream. These leaf packs retain carbon that would otherwise be lost from headwater areas, at the same time avoiding enrichment of downstream waters. Woody debris and leaf packs also increase the variation of flow velocity—pools, glides, and riffles—in headwater streams. Quiet water and eddies behind debris jams induces the deposition of sediment. As flow accelerates around or between debris, localized scour can occur. This pattern of deposition and scour leads to the formation of alternating pool and riffle sections in headwater streams and adds essential spawning, rearing, feeding, hiding, and overwinter habitat for fish, amphibians, and invertebrates.

Structural support

The interlocking roots of riparian vegetation anchor streambank, floodplain, and lakeshore soils and increase their resistance to erosion and scour. Flood events and spring breakup in streams and rivers and wave action in lakes concentrates erosive forces at the water's edge. Without root support, saturated soils along streambanks and lakeshores are prone to sheet erosion or slumping. Eroded soil, now sediment, is carried downstream or off-shore before settling to the bottom in low velocity areas. Insect and disease outbreaks or wildfires can cause extensive mortality and lead to the loss of root support and subsequent instability. Root support and floodplain vegetation are essential contributors to the dynamic equilibrium of stream channel (Brooks et al 1997; Heede 1980; Rosgen 1994) and lakeshore systems.

Evapotranspiration

During the growing season, riparian vegetation returns massive amounts of water to the atmosphere via evapotranspiration[2] and thereby increases the thickness of the unsaturated zone above the water table. Consequently, available storage for rain, snowmelt, and upland inflow is maximized as is the residence time of water passing from the uplands as subsurface flow to streams, rivers, wetlands, and lakes. As soil water content decreases as a result of ET, there also is a corresponding increase in the frictional resistance to surface and mass erosion.

Soil physical and hydraulic properties

The presence of perennial woody vegetation in the riparian zone leads directly to the development and maintenance of favorable soil physical and hydraulic properties. Periodic additions of organic matter undergo decomposition and are mixed with the

[2] Evapotranspiration is the sum of (1) evaporation from soil and open water, (2) interception by and subsequent evaporation of water from the plant surfaces, and (3) transpiration – water extracted from the soil by plants and returned to the atmosphere via the leaves.

mineral soil by microbes and invertebrates. These physical and biochemical processes reduce bulk density thereby increasing porosity (storage capacity), infiltration capacity (the rate of water movement *into* the soil), and permeability or hydraulic conductivity (the rate of water movement *through* the soil). Water retention characteristics also are enhanced by the addition of organic matter. The growth, senescence, and death of fine roots, along with the tunneling action of invertebrates and small mammals typically produces a complex system of macropores that augment the permeability of the soil matrix. Collectively, these soil properties maximize the likelihood that rain, snowmelt, or overland flow from adjacent uplands will pass beneath the soil surface and travel as subsurface flow through the riparian zone. In addition, hummock [mound] and hollow [pit] microtopography, woody debris, herbaceous plants, and leaf litter on the forest floor combine to produce a hydraulically rough surface that impedes overland flow if and when it occurs.

Overland flow control and sediment deposition

Water holding capacity resulting from evapotranspiration, infiltration capacities that typically exceed rainfall and snowmelt rates, and a hydraulically rough surface combine to efficiently convert overland flow into subsurface flow. Sediment and other suspended materials are deposited on the surface when overland flow seeps into the soil. Dissolved and colloidal (e.g., clay) materials become a part of the soil solution are less likely to reach nearby streams, rivers, or lakes.

Nutrient uptake and assimilation

Nutrients (particularly nitrogen, phosphorus, and potassium) are used by organisms ranging from soil bacteria to overstorey trees to fuel growth, development, and biomass accumulation. When mobile forms such as nitrate (NO_3^-) are sequestered from the soil solution and incorporated into plant tissue, the pathway of flow to the receiving water (stream, wetland, or lake) comes to an abrupt halt. When the plant biomass re-enters the nitrogen cycle as a fallen leaf, branch, or entire tree, decomposition processes slowly convert particulate nitrogen back into several more mobile forms. Hence, there are new opportunities for other plants to use these resources and add more time along the path to the aquatic ecosystem.

In addition to macro- and micro-nutrients, a host of biogeochemical reactions can transform such unlikely candidates as metals, hydrocarbons, and pesticides into more benign forms. Obviously, there are limits to the assimilative capacity of the riparian zone. However, even in densely populated urban areas and adjacent to intensively managed agricultural land they exhibit a surprising capacity to ameliorate contamination. They are a *buffer* in many senses (biological, physical, and chemical) of the term. The next major section of this report discusses timber harvesting, fire, and nutrient cycling.

Transitional habitat

The complex and varied characteristics enumerated above are evinced in a diverse, sometimes unique, community of plants and animals that are linked to the riparian zone. This link may be ephemeral such as a deer pausing for water at stream. It may be obligate for organisms such as beaver, herons, or waterfowl. It may change over time for amphibians or migratory birds. Whatever the individual life history, it is clear that upland and aquatic species interact in the riparian zone. At the transition between upland and aquatic ecosystems, riparian areas have the "best of both worlds."

Social Values

The social functions and values of riparian areas are as varied as the people and communities interested in their conservation and stewardship. Although the following list is not exhaustive, it includes some of the most significant human dimensions of these ecosystems. Market-valued goods and services are discussed in the section on economic values.

Aesthetics

Riparian areas are often regarded as some of the most striking and picturesque parts of the landscape. Aquatic ecosystems and riparian areas present a diverse range of colors, textures, patterns, sounds, and movement found nowhere else on the landscape.

Trees, shrubs, and herbaceous plants reflected by the adjacent water, soil and stone exposed by streamflow or lakeshore wave action, open vistas highlighted by sun and shadow, and opportunities to observe many types of wildlife all contribute to the richness of the scene. People have a natural affinity for the water's edge as a place for recreation and relaxation. As a case in point, urban parks and greenways with rivers or lakes are invariably more popular than monotypic upland landscapes.

Cultural Resources

Native people have used waterways and riparian areas for thousands of years. They have served as travel routes and especially productive areas for hunting, fishing, and gathering foods and medicines. Lakes and rivers linked family, clan, and tribal groups in summer and winter. The first contact with Europeans was made by water when Saskatchewan entered the global economy in the late-1700s via the fur trade. Seasonal camps, canoe routes, and portages are timeless features of the northern landscape. Settlements, trading posts, rendezvous sites, traplines, and cabins mark the transition from traditional to contemporary lifeways. Many of these cultural resources occur in riparian areas and warrant particular care and respect.

Spiritual Values

The combination of ecological, aesthetic, cultural, and historical values endows riparian areas with special significance. In the northern forest, streams, lakes, and riparian areas can be a retreat, a source of inspiration, and place to appreciate the beauty and complexity of the natural world. The vast expanse of the Saskatchewan's boreal forest amplifies their wild beauty.

Economic Values

The ecological and social values of riparian areas and aquatic ecosystems also generate a wide range of direct and indirect economic benefits. The goods and services emanating from the lakes, streams, and forests of Saskatchewan are an important part of the regional and national economy.

Wood Fibre

Soil and site characteristics combine to make riparian areas some of the most productive components of the landscape. As a result of well-watered conditions and fertile soils trees such as white spruce (*Picea glauca*) can reach unusually large sizes.

In boreal mixedwood stands, careful harvesting of dominant and large co-dominant white spruce releases advance regeneration by creating small openings and increasing understorey light levels. White spruce seedlings and saplings and woody shrubs quickly add vertical (understorey and mid-storey) structure in mature closed canopy stands. This structural diversity expands the range of hiding, thermal, travel, and nesting cover available to many wildlife species.

Single tree selection, small group selection, patch cuts, or a two-pass shelterwood system can favorably alter nutrient cycling by replacing a limited number of older trees with a large number of rapidly growing young trees dispersed throughout the stand. Nutrient uptake and assimilation increases in proportion to rates of biomass accumulation. This is an economic value inasmuch as it represents nonpoint source pollution damage *avoided* in association with harvesting. Harvesting some high-value mature trees before they succumb to windthrow, storm damage, insects, disease, or fire limits economic losses to mortality. In the context of forest management lease agreements made to supply mills with wood fibre, this is another form of natural resource damage or loss avoided. In most of the U.S., state-level forest cutting practices acts (and associated regulations) typically allow the removal of up to 50% of basal area in the riparian zone once every ten years. This does not include the trees within 5 to 10 meters of stream banks.The 10 year time interval is not a silvicultural prescription. Rather, it ensures adequate natural regeneration by setting an operational minimum.

Wildlife

Saskatchewan is widely known for the quality of traditional hunting and fishing opportunities. Major sporting goods retailers in the U.S. (e.g., Cabela's, Orvis, Dunn's, etc.) offer package trips to Saskatchewan as a select destination for white-tailed deer and black bear hunting and fishing (lake trout, northern pike, walleye pike). First Nations communities, outfitters, resort owners, and the hotel-restaurant-travel industry, and the

Province (via license fees and tax revenue) all benefit from the sustained interest of sportsmen. In addition to hunting and fishing revenues, increasing interest in ecotourism by people from eastern Canada, the U.S., Japan, and Europe, often centered on viewing and photographing wildlife, provides important opportunities to diversify the northern economy and increase tourism. Clearly, aesthetic values and cultural resources are important, if not essential, assets.

Fisheries

As noted in the earlier section on ecological functions and values, fish-bearing streams provide critical spawning and rearing habitat for a wide range of species. As a result, the direct links between riparian areas and aquatic ecosystems are nowhere more apparent than in the biointegrity of fish and macroinvertebrate populations. If riparian area management plans and on-the-ground activities maintain key functions and attributes such as microclimate regulation, streambank stability, large woody debris recruitment, and ambient water quality, the stream and lake fisheries of northwestern Saskatchewan will remain largely unaffected by forest harvesting activities. In fact, road-stream crossings can have a more substantial influence on water quality, channel stability, and fish migration. They also pose substantially greater management challenges and costs.

Recreation

In addition to hunting, fishing, bird-watching, and ecotourism, riparian areas offer attractive sites for camping, hiking, and relaxation. Clearly, the quality of canoeing, kayaking, float trips, and other water-based recreational experiences also depends upon the condition and appearance of water and riparian areas. In this light, an example from the northeastern U.S. is noteworthy.

During the 1980s in the northwestern section of the state of Maine, forest products companies were compelled to retain very large riparian setbacks (1 ~ 2 km) along popular canoe routes such as the Allagash, Androscoggin, and Penobscot Rivers as well as large lakes (*e.g.*, Moosehead Lake). This mandate followed years of public complaints, regulatory inaction, and studied indifference by the forest products companies (who owned the land).

In many cases, the effectiveness of these 1 or 2 km setbacks was negated when the whine of grapple skidders could still be heard on the water and very large clearcuts and clouds of dust were visible on higher terrain beyond the setback from the lakes and rivers. This resource use conflict could have been avoided without the imposition of large setbacks and the current movement to ban clearcutting altogether. A common sense-based combination of (1) scheduling for winter operations (rather than July and August at the peak of holiday use), (2) harvest units with irregular boundaries, patch and vertical structure retention, and (3) rapid and effective natural regeneration could have prevented, or at very least minimized, the problem.

TIMBER HARVESTING, FIRE, AND NUTRIENT CYCLING[3]

Timber harvesting and nutrient cycling

The type, intensity, and areal extent of timber harvesting operations can substantially influence changes in water yield, nutrient cycling, and nutrient output as well as the duration of disturbance effects. Although harvesting effects are further confounded by variations in weather conditions some useful generalizations can be made.

Timber harvesting typically removes the merchantable portion of trees, leaving the tops (<10 cm diameter) and most of the nutrients on the site. After the trees are cut, several associated changes take place that accelerate nutrient mobilization. Removing all or part of the forest canopy increases the amount of rain and snow that reaches the soil surface and root zone (net precipitation). Harvesting mature trees reduces plant biomass and effective rooting depth (the zone of active soil water depletion). This, in turn, decreases the demand for soil moisture by plants (transpiration). Evaporation of soil moisture from the litter layer, O and A horizons (upper 20 to 30 cm) is commensurate with the increases in solar radiation, humidity (vapor pressure gradient), wind speed, air temperature, and soil temperature. Evaporation increases notwithstanding, the increase in net precipitation coupled with decreased total evapotranspiration generates an increase in water yield. This water yield increase (via shallow subsurface flow through the root zone) coupled with reduced plant uptake leads to increased nutrient output even if nutrient concentrations in soil solution do not change appreciably.

The maximum soil moisture and water yield increases typically occur in first year after cutting, while the maximum rate of nutrient output usually occurs in the second year. It takes some time for the logging slash to settle into contact with the soil surface and become subject to microbial decomposition, wetting and drying, and freezing and thawing. As a new plant community of tree seedlings, shrubs, grasses, sedges, and other herbaceous plants becomes established, nutrient uptake and assimilation fuels new growth. Because growth rates increase exponentially after the establishment phase of

[3] This section is a synthesis of more detailed reviews by Barnes and others (1998), Brooks and others (1997), and Satterlund and Adams 1992.

tree seedlings or sprout clumps, rates of water use and nutrient cycling rapidly approach pre-harvest conditions. As the plant canopy develops (in clearcuts or patches) or closes (in single tree selection or strip cuts), net precipitation quickly decreases. The concurrent increases in biomass and leaf area rapidly reduces the difference between inputs and outputs to the pre-harvest equilibrium in about 5 to 10 years.

In sum, timber harvesting temporarily accelerates natural patterns and processes of organic matter input, water balance changes, decomposition, nutrient cycling, and nutrient output in relation to size and intensity of the operation. For example, a light, low thinning that only removes suppressed trees may have no measurable effect. In comparison, a whole tree chipping operation during the growing season may remove or mobilize massive amounts of nutrients (Silkworth and Grigal 1982). It follows that the net effects of other silvicultural systems (e.g., single tree selection, two-pass shelterwood, partial overstorey retention, block clearcuts, etc.) will vary in relation to biomass removal, microclimate changes, regeneration success, growth rates, and host of operational (e.g., equipment type, scheduling, supervision, processing of slash, etc.) and site-specific characteristics (e.g., soil type, soil surface condition, the road network, hydraulic connections to nearby streams, etc.).

Forests fires and nutrient cycling

Throughout much of the 20th century, fire was reviled as a destructive agent with few, if any, beneficial effects (CCC 1937). This was an understandable response when massive forest fires destroyed rural communities and the fledgling forestry profession was pledged to prevent the recurrence of these disasters. Over the last several decades, research in forest ecology, soils, silviculture, fire management, and ecosystem restoration has slowly changed perceptions about this complex phenomenon. Operational successes with prescribed fire and operational gaffs inadvertently caused by the assiduous exclusion of fire and the subsequent accumulation of fuels (e.g., the 1988 Yellowstone National Park Fire) have clearly illustrated the central role of fire as a key disturbance mechanism in many forest ecosystems. At the same time, the ecological impacts and economic efficacy of fire salvage operations have been reconsidered. In many respects, fire salvage operations are a vestige of early-1900s “waste not, want not” and 1950s-vintage “maximum utilization” forestry paradigms. Because forest and aquatic ecosystems are in a fragile condition, both fire suppression and fire salvage operations can cause serious—albeit unintentional or inadvertent—damage.

The enormous range of natural variation of forest fire intensities—in comparison to timber harvesting using different silvicultural systems—and site conditions makes it much more difficult to generalize about on-site and downstream effects. Clearly, a high intensity crown fire (with an energy output of up to 150,000 $kW \cdot m^{-1}$) will have drastically different effects than a surface backfire (burning into the wind and generating 100 to 800 $kW \cdot m^{-1}$).

Fire reduces organic matter to water vapor, carbon dioxide, nitrogenous gases, and ash containing mineralized nutrients. When rain or snowmelt leaches nutrients from the ash into the soil there are increases in pH, microbial decomposition rates, and mineralization rates. These processes and conditions combine to increase the availability of nutrients to plants. This is evinced by the rapid “green up” of herbaceous vegetation during the first growing season after most fires. This pathway—uptake and transformation—can slow or effectively stop the off-site transport of nutrients. However, the same characteristics that enhance availability to plants (small particle sizes and high solubility) simultaneously increase nutrient concentrations in soil solution, shallow subsurface flow, and overland flow (if it occurs) and the consequent likelihood of off-site transport.

The water balance and microclimate changes caused by the effects of fire on overstorey, understorey, herbaceous vegetation, and the litter layer influence the rate and volume of nutrient and sediment inputs to adjacent streams, lakes, and wetlands. The highly variable character and condition of post-fire forest structure and weather patterns has a direct effect on nutrient cycling. For example, low or moderate intensity fires do not substantially alter overstorey vegetation (or net precipitation) or infiltration capacity (the rate at which water passes through the soil surface). Nutrients and cations (e.g., Ca^{++}, Mg^{++}, Na^{+}) mobilized by the fire may only move a few centimeters before they are assimilated by plants or microbes or bound on exchange sites in the soil. By contrast, a severe crown fire incinerates virtually all forest vegetation, leaf litter, and the O horizon exposing the mineral soil (A horizon). Surface temperatures may be so high (>400 °C) the soil is literally baked or fused and infiltration capacity is substantially reduced. In extreme cases, the soil may be rendered hydrophobic. Under these conditions, the quantity of overland flow generated by subsequent rainstorms or snowmelt will simply equal the rainfall intensity or snowmelt rate minus infiltration capacity—like stormflow off a compacted agricultural field or forest road. Another notable effect of severe fires is the destabilization of stream channels caused by abrupt increases in stormflow and sedimentation. This can be especially severe if the fire sweeps through the riparian zone.

As for harvested sites, the rate of revegetation and biomass accumulation will dictate the time required to for the stand or landscape to return to an equilibrium condition. In cases where post-fire species composition is markedly different (e.g., a dry site mixed wood stand is replaced by pure jack pine), the water balance, microclimate, soil chemistry will not return to the pre-fire equilibrium conditions. Naturally, the adjacent aquatic ecosystems will reflect these differences as well.

Relative effects of fire and timber harvesting

A comparison of the most extreme forms of wildfire and timber harvesting is germane to the development and evaluation of riparian area management guidelines. The antecedent conditions that generate severe forest fires (decades of fuel accumulation, extended drought, and/or tree mortality from insects or diseases) can preordain several outcomes. First, the total and contiguous area of severe forest fires (100,000s of hectares in Saskatchewan) can exceed years, even decades, of harvesting operations. Second, severe fires can burn through muskeg, riparian areas, and uplands with equivalent intensity. As a result, the effects of a severe fire on landscape-scale water and energy balances can exceed the effects of clearcut logging. As a result, soil erosion, sediment transport, and nutrient mobilization rates in burned areas could routinely exceed those in clearcut areas. It follows that the net ecological effect, in both severity and duration, of a severe fire can surpass the cumulative impacts of clearcut logging. The validity of this assertion may, however, be questioned or refuted if a system of Conservation Management Practices (CMPs) for timber harvesting is not applied with due diligence.

On the other hand, the validity of this assertion could be amplified if fire suppression and fire salvage operations further destabilize a fragile post-fire landscape.

Summary

Because variability is rule rather than the exception, substantial differences in site characteristics, fire conditions and effects, and harvesting systems make it difficult to generate straightforward comparisons between natural and anthropogenic disturbances. The combined efforts of SERM, the forest products industry, and local communities have, however, produced consistent and noteworthy improvements in the design, implementation, and monitoring of harvesting operations. The introduction of patch retention, irregular harvest unit boundaries, variable width buffers, retention of large woody debris, partial cuts, and a host of new technologies have helped foresters to emulate fire effects. Improvements notwithstanding, the old refrain *…more research and monitoring is needed* …is particularly relevant to this complex set of ecosystem patterns and processes.

PROTECTION AND MANAGEMENT STRATEGIES

Several riparian area and soil and water conservation strategies, regulations, and programs are summarized and discussed in this section. The chronology begins in the early-1970s and describes changes during the ensuing 30 years. I use two northeastern U.S. case studies, with which I have first-hand experience, to compare and contrast different approaches to riparian area management. Massachusetts has general statewide standards and guidelines supplemented by site-specific prescriptions and review by foresters and others in the field. New York City's (Catskill Mountain region) watershed management strategy has a long list of riparian setback[i4] requirements in a voluminous Memorandum of Agreement reached with rural communities. In many respects, this is a comparison of "bottom-up" versus "top-down" regulatory and resource management approaches. They also might regarded as "field-based" [Massachusetts] versus "office-based" [New York City] approaches.

Filter Strips – First Generation Riparian Protection

When the Environmental Movement of the late-1960s and early-1970s, along with pressure from the public at large, finally generated the political will to control air and water pollution, a long series of federal laws and state analogs were enacted. The [U.S.] National Environmental Policy Act required an environmental impact statement (EIS) for most construction projects as well as extractive uses of natural resources. The Clean Water, Clean Air, and Safe Drinking Water Acts originally focussed on point source industrial and municipal pollutant discharges. Amendments to all three laws have extended regulations to nonpoint sources of pollution. In addition to the laws and regulations noted above, the National Forest Management Act and Endangered Species Act had immediate impacts on timber harvesting and road construction, particularly in the western U.S.

[4] Setbacks are fixed width strips within which no timber harvesting or other active resource use is allowed. By contrast, riparian forest buffers may allow, if not encourage, some timber harvesting with special precautions to avoid soil compaction, overland flow, and nonpoint source pollution.

In virtually all cases, a federal agency (e.g., the Environmental Protection Agency) has primacy with respect to the development and implementation of rules and regulations. Primacy may be transferred to counterpart state agencies when a state law equals or exceeds the breadth and rigor of the federal law. The federal agency must also be confident in the ability of the designated state agency to consistently meet policy and program goals and objectives.

In the early-1970s, the states of Oregon, Washington, and California were the first in the U.S. to adopt forest practice acts. They were developed to impose regulatory controls on the exploitive practices then common in the Pacific Northwest. The post-World War II building boom, increasing mill capacity, larger and more powerful heavy equipment, and a skilled workforce all contributed to the increase in the scope and scale of timber harvesting. Checkerboards of 640 acre block clearcuts were an unfortunate artifact of the U.S. Government Land Survey system (as in western Canada, 1 square mile sections referenced to north-south meridians) combined with outdated area regulation harvest scheduling methods. Skidding with crawler tractors was a common and highly destructive practice. Fire laws and access requirements for artificial regeneration led to logging slash being windrowed (by tractors fitted with root rakes, slotted blades) and burned. Douglas fir (*Pseudotsuga menziesii*) seedlings were planted at high densities (6 x 6 feet). If a stream happened to traverse the cutblock it was often laid bare and sometimes used as a skidway. The cumulative effects on fish populations were devastating.

In response to this reckless damage and disregard for “non-timber” resources, 50 foot (15 m) filter strips were required to shade streams and, as importantly, serve as an obstacle for heavy equipment. Despite their limited, fixed width (< ¼ of mature tree heights in the Pacific Northwest), they were surprisingly effective in mitigating the worst impacts of large-scale block clearcut logging. They were, however, subject to windthrow, opening shock, and other forms of mortality.

The term “filter strip” was coined to describe—albeit incorrectly—their expected function of filtering or sieving sediment from “runoff” [overland flow]. The realization that road-stream crossings, mass erosion, and accelerated channel erosion impacts completely overshadowed the net sediment input from flow across the strips was years away from being common knowledge. Erroneous descriptions of the streamflow generation process, namely that limited infiltration capacity produced "surface runoff" led directly to the perceived, perhaps even hoped for, function of filter strips. Unless rills or gullies breached the filter strip, it was much more likely for rain or snowmelt to reach the stream via shallow subsurface flow through the root zone. Despite their biophysical and semantic shortcomings, filter strips were, as noted above, an important first step away from exploitation towards renewed conservation ethic.

The Massachusetts Forest Cutting Practices Act

By the mid-1980s, forest practice acts were in place throughout most of the U.S. Forest conditions and operations in the southern New England differ substantially from western U.S. and Canada. Therefore, the Massachusetts Forest Cutting Practices Act (Chapter 132) differs as well. It also is the most stringent in New England. Nevertheless, a strong tradition of town government (Board of Selectmen, local commissions, annual town [open] meeting) has resulted in some communities enacting "no cut" ordinances. Although most are found unconstitutional (a violation of private property rights) when challenged, they are generally accepted as a part of the sociopolitical landscape of southern New England. Consulting foresters, loggers, and small sawmills simply look elsewhere for landowners who are willing to sell stumpage.

Chapter 132 regulates most aspects of timber harvesting in Massachusetts. Notably, the silvicultural system or regeneration method is *not* regulated. A moderate climate, plentiful seed sources, and many species capable of sprouting virtually ensures full stocking with one or more tree species in two or three growing seasons. Whether or not these species are appropriate or desirable for the site is sometimes debatable. Many in the forestry community are urging the state extend Chapter 132 to include a prohibition on "high-grading" valuable hardwood species such as northern red oak (*Quercus rubra*), sugar maple (*Acer saccharum*), and yellow birch (*Betula alleghaniensis*). Predictably, some property rights groups and coalitions of small sawmills and log buyers (who export to Europe) are actively opposing more regulation.

Although the legislation is broad in scope, specific on-the-ground details are delegated to harvesting contractors, public lands or private consulting foresters, and service foresters.[5ii] Road design and construction, road-stream crossings, wetland crossings, skid trails and landings, riparian forest buffers, and slash and waste handling are regulated. In addition, statewide Wetlands Protection and River Protection Acts supplement Chapter 132 and related federal legislation. The people involved with the process include:

1. landowner(s),
2. abutting landowners,
3. forester (private or public sector, licensed to practice in Massachusetts),
4. logging contractor(s) (licensed to practice in Massachusetts),
5. DEM Service Forester,
6. Inland Wetlands, Planning and Zoning, and Conservation [Town] Commissions, and
7. biologists with the Massachusetts Natural Heritage (threatened and endangered species) Program.

A cutting plan must be filed for all timber sales greater than 25,000 board feet (~60 m^3). This effectively exempts landowners and contractors who cut small quantities of firewood. Once the cutting plan is filed, a copy is forwarded to the Natural Heritage Program for cross-referencing with statewide maps of habitat characteristics. If a state-listed or federally-listed species occurs, or *may* occur, in the vicinity, the service forester is alerted to this contingency and alterations to the cutting plan (e.g., location, silvicultural system, scheduling, road locations, etc.) may be required. The service forester inspects the proposed sale (new road and skid trail centerlines are flagged or painted) and requests modifications as needed (e.g., alignment, stream crossing method, schedule, etc.). The forester and logging contractor(s) revise the cutting plan, if necessary, then begin work. Harvesting proceeds with periodic unannounced inspections by the service forester. Adjustments are made with respect to soil, site, and weather

[5] Service foresters are employees of the Massachusetts Department of Environmental Management, Bureau of Forestry. There are 12 service foresters each with a district that generally corresponds to major river systems and their watersheds. They report to a regional forester, five statewide, and the supervising service forester in the Boston office. The Bureau of Forestry has about 60 employees in total. A group a management foresters has responsibility for 300,000 acres of public land statewide.

conditions when needed. The service forester may suggest some voluntary alterations or simply mandate changes. Failure to comply with mandatory changes needed to comply with Chapter 132 triggers a Stop Work order and a fine. Repeated violations result in license revocation for the logger and/or forester. Most foresters and loggers work to comply with Chapter 132 and reasonable requests and suggestions by the service foresters with due diligence. Naturally, some people try to skirt the rules (e.g., a series of 24,999 board foot sales along the same forest road, etc.). After a few years and a string of incidents, they either go bankrupt or are brought to bay by irate banks, landowners, and/or town commissions.

The provisions of Chapter 132 and the Best Management Practices (BMP) field manual (Kittredge and Parker 2000) that guide the design and implementation of riparian forest buffers are a substantial improvement over fixed-width filter strips. The default minimum width of riparian forest buffers is 50 ft. (15 m) on each side of intermittent and perennial streams and around lakes, wetlands, and vernal pools[6] [iii]. The width of the riparian buffer is increased in proportion to slope based upon a simple table in the BMP manual (Table 1). This can be implemented in the field with a clinometer to determine gradient and a hip chain or pacing for distance.

TABLE 1 – Riparian buffer width in relation to slope (adapted from Kittredge and Parker 2000)

% slope	Buffer width (m)*
0	15
10	27
20	40
30	52

* converted from 50, 90, 130, 170 feet, respectively

If the adjacent slope exceeds 30%, the riparian buffer is extended (if more than 50 m) to the top of the slope. It is important to note that the field application of table 1 results in landform-based, variable width buffers on most timber sales.

6 Vernal pools are small (< 0.5 ha) temporary ponds that fill during spring snowmelt and again during October and November rains. They are obligate breeding and overwinter habitat for several species of amphibians. They also may support unique plants with specialized site requirements.

Chapter 132 allows for harvesting within riparian buffers. Up to 50% of the total basal area can be removed with a minimum of five years between cuts (most sites of are fully stocked with natural regeneration within 2 or 3 growing seasons). The re-entry is expressly intended to prevent clearcutting and/or high grading of the buffer by cuts occurring in two or more consecutive years. In general, service foresters strongly discourage the cutting of streamside trees. In order to prevent disturbance of the litter layer, soil compaction, and rutting, no equipment is allowed in the 15 metre riparian buffer. Most logging contractors in the region use rubber-tired, cable skidders. Directional felling and winching is used to retrieve trees from the buffer while minimizing damage to the residual stand. Some larger operations now use track-mounted feller-bunchers and rubber-tired forwarders. The feller-buncher can reach into the riparian buffer (~5 meters; these are smaller machines than are typically used in Saskatchewan) to harvest trees then stack them within reach of the forwarder.

In summary, and by contrast with 1970s-vintage fixed-width filter strips, the riparian area management strategy and attention to road-stream and wetlands crossings has substantially decreased the short-term impact of harvesting operations in Massachusetts. A widely acknowledged strength of the Chapter 132 implementation strategy is the use of basic guidelines or "boundary conditions" coupled with enough flexibility for site-specific application and adaptation. The start-to-finish involvement of the DEM Service Foresters provides continuity and enhances accountability at all levels. Loggers quickly learn what is, and is not, acceptable practice. If the program has a weakness it is related to the variability with which service foresters interpret and apply the regulations. As such, there will always be a least common denominator somewhere in the state.

The Quabbin Watershed Forest "Add-on"

The Quabbin Reservoir (completed in 1939) is the principal source of drinking water (~ 225 million U.S. gallons per day) for the city of Boston and 60 surrounding communities. The 22,270 ha (55,000 acre) forest that surrounds the reservoir is intensively managed by the Massachusetts Metropolitan District Commission (MDC).

Barten and others (1998) and the 1995-2004 Quabbin Watershed Management Plan (MDC 1995) describe the system and approach in detail. The MDC is the wholesaler of water; the Massachusetts Water Resources Authority (MWRA) retails the water to consumers through a complex distribution system and collects and treats wastewater (at the new, $6 billion Deer Island Wastewater Treatment Plant at the east side of Boston Harbor).

Metropolitan Boston's drinking water is disinfected with chlorine (to be converted to ozonation in 2003) but remains one of the few large unfiltered supplies in the U.S. As such, there is little or no margin for, or tolerance of, errors leading to source water contamination. In order to minimize the potential for nonpoint source pollution caused by timber harvesting, the MDC-Quabbin forestry and natural resources staff has developed a system of checks and balances and additional BMPs to supplement Massachusetts Chapter 132 requirements (the Quabbin Forest is still subject to DEM Service Forester oversight).

The primary additions include (1) harvest planning that occurs one year in advance of field operations, (2) forest-wide mapping of "Areas with Special Management Restrictions (ASMRs), and (3) a systematic internal review process. The Quabbin Watershed Forest management plan calls for the gradual conversion of largely even-aged mixed oak, eastern hemlock (*Tsuga canadensis*), and eastern white pine (*Pinus strobus*) stands to uneven-aged stands with greater species and structural diversity. In addition, about 4,000 acres (1,620 ha) of 1930s-era red pine (*Pinus resinosa*) and Norway spruce (*Picea abies*) plantations have be regenerated to native species or clearcut and mowed every two to three years to maintain some large patches of early successional vegetation. The Quabbin Forest is divided into five blocks or districts—Pelham, New Salem, Petersham, Hardwick, and Prescott Peninsula—of approximately 4,050 ha (10,000 acres).

As noted earlier, block foresters develop harvesting plans at least one years before the stands are scheduled for treatment. After review by the chief forester (the equivalent of a private sector operations manager), the plans are forwarded to a natural resources specialist (the functional equivalent of a private sector planning manager), a wildlife ecologist, the environmental [water quality] staff, and an archaeologist [cultural resources specialist]. After internal reviews are completed and revisions are made as needed, the cutting plan is submitted to the DEM service forester and Massachusetts Natural Heritage program per the standard Chapter 132 process. Again, revisions or modifications may be required. Decades of intensive management and public scrutiny have demonstrated the value of:

1. showing the sale to prospective contractors (bidders) and emphasizing key terms and conditions;
2. a detailed timber sale contract with stringent soil, water, and biodiversity conservation clauses, work schedules, schedule change protocols (for adjustments in relation to inclement weather or maintenance shut-downs), *and* performance bonds;
3. active supervision by MDC-Quabbin foresters in relation to the skill level and dependability of the contractor(s) (for some, twice a day, for others, once every two weeks); and
4. third-party Forest Stewardship Council (FSC) certification for quality control and quality assurance that is credible with the public, other government agencies, and not-for-profit environmental groups. The MDC-Quabbin forest management program was the first (1995) public land to be certified in the U.S.

In addition, to the steps and program elements described above, MDC-Quabbin solicits operational support through: (1) the Quabbin Scientific and Technical Advisory Committee (QSTAC), (2) providing sites and support for a wide range of field research projects on the Quabbin Forest, (3) public involvement and outreach, and (4) monitoring.

New York City (Catskill Mountains) Watershed Management Program

The agency responsible for the metropolitan New York water supply—New York City Department of Environmental Protection (NYCDEP)—did little to proactively manage source water quality in the Catskill Mountains (~400,000 ha, 120 to 240 km NNW of New York City) since reservoir construction began in the early-1900s. This changed abruptly when, in 1989, amendments to the Safe Drinking Water Act by Congress and subsequent issuance of the Surface Water Treatment Rule by the USEPA, required all unfiltered municipal water supplies[7] to demonstrate they could meet source water standards in order to qualify for a filtration waiver. With estimates of filtration plant construction costs ranging from $6 to 12 billion, annual operating costs of approximately $400 million, and no designated site, the NYCDEP made an almost overnight conversion to watershed management. Old habits die hard, however, as evidenced by the name of their new initiative—the "Filtration Avoidance Program" [versus the Source Water Protection Program].

In 1991, by invoking a 1902 N.Y. Public Health law pertaining to the construction of the reservoir system, NYCDEP issued a voluminous set (~60 pages, single-spaced) of environmental regulations to replace the three pages of 1950s-vintage regulations. The 1950s "Sanitary Code" prohibited people in the Catskills from "butchering livestock in and around watercourses …building privies that overhang watercourses …tanning leather in watercourses" …etc. The new, improved 1991 regulations left no stone unturned. Actually, you were probably not allowed to turn any stone without a permit from NYCDEP. A complete review of the proposed 1991 regulations is not germane to this report. The background information presented herein is important to understand the development of the riparian area management strategy that forms the core of the NYCDEP approach. In my opinion, this case study demonstrates how ***not*** to develop and implement [impose] a riparian area management plan as part of a comprehensive watershed management strategy. (The interested reader is referred to the National Research Council (2000) Committee report, and a summary paper by three committee members (Platt, Barten, and Pfeffer 2000), for a comprehensive evaluation of the program).

[7] At the time this included: metropolitan Boston, New York, San Francisco, Seattle, and Portland, Oregon. Seattle has a filtration plant under construction. Portland and San Francisco are in the design phase. New York is under review by the USEPA. Boston (MWRA) just won a federal court case brought against them by USEPA Region 1 to force construction of a filtration plant. The judge found watershed management and monitoring efforts evinced due diligence and found the current program should be continued for five years.

The riparian area management provisions of the draft NYC watershed regulations and the subsequent Memorandum of Agreement (MOA)[8] contrast sharply with the Massachusetts regulations and field operations. The NYC program also diverges from the recent findings and recommendations for riparian areas by an interdisciplinary group of scientists and managers (Verry et al. 2000), to be discussed in detail in a final section of this report.

The NYCDEP's complacency about watershed management and source water protection in the Catskills can be attributed to at least four system characteristics or circumstances—a very small field staff, high ambient water quality, large forested areas, and formidable political power.

The Bureau

The organizational antecedent of the NYCDEP was the omnipotent Bureau of Water Supply (1830 to ~1980). A long succession of very capable, strong-willed, and powerful civil engineers headed this organization. Based in Manhattan, they supervised the design and construction of one of the largest and most complex water supply systems in the world. Until the first phase of the system was completed in the 1840s, cholera and dysentery epidemics and fires that burned entire city blocks wracked the ever-increasing population of New York City. The water supply system was, and still is, universally acknowledged as an engineering marvel (Evers 1982; Hall 1917; Lossing 1866). Hence, the engineers who designed, built, and operated the system were rarely, if ever, questioned about its operation. It was the one thing in New York City that *always* worked. Natrually, it was a focal point for civic pride and political speechmaking.

Nearly continual expansion of the reservoir system until 1965 ensured the age-old sanitary engineering adage *"…the solution to pollution is dilution",* could remain operationally valid. As a result, there was little attention to on-the-ground watershed management in the in the Catskills. The staff was comprised of two district engineers

[8] A 2,000+ page document negotiated by New York City, more than 50 Catskill Mountain communities, not-for-profit environmental groups [e.g., the NYC-based Natural Resources Defense Council], and the State of New York to guide source water protection, community development, and resource use in the Catskills. One of my colleagues, Prof. Rutherford Platt, described it as "the Hoover Dam of watershed agreements." It will cost about $2 billion to implement over a 10 year period. Naturally, the upstate communities fear that New York City will abandon these commitments if forced to build a filtration plant.

and their clerks, a few people to operate and maintain the waterworks, a grounds maintenance crew, and the BWS Police (whose job it was to keep local kids from swimming in the reservoirs, racing old cars along the dikes and dams, etc.). When an engineer was reassigned from headquarters in New York to the Catskill Mountains, it was, essentially, a forced exile to the Siberia of the Bureau of Water Supply. Therefore, in a bureaucracy numbering in the 1,000s, only a handful of people had first-hand knowledge of watershed conditions in the Catskills. In a sense, the operations staff in New York City and the field staff in the Catskills had unwritten "Don't ask." and "Don't tell." policies, respectively.

The new and re-allocated resources directed to the Filtration Avoidance Program, lately renamed the "Watershed Management Strategy", has increased the size of the Catskills field staff to hundreds of engineers, technicians, watershed rangers (a kinder, gentler version of the BWS Police), lawyers and real estate specialists, and even two (2) foresters. The office of the Deputy Commissioner for Water Supply also was moved north to the watershed region.

Clean Water from Pure Mountain Streams(?)

The Catskill Mountains receive about 900 to 1,200 mm of rain and snow annually. Over much of the Catskills water is naturally filtered through watershed forests and soils and held in reservoirs for months before entering the aqueducts and distribution system. Hence, its ambient quality is *usually* very high.[9] Relatively recent changes in pollutant loading (atmospheric deposition from the Ohio Valley, leaking underground tanks, etc.) and the ability to detect and trace waterborne pathogens (from livestock, failed septic systems, inadequately treated municipal wastewater, etc.) has raised concerns about source water quality. When these data are coupled with the ability to more accurately detect waterborne disease outbreaks in sensitive populations in New

[9] Biweekly water quality sampling rarely captured the effects of storm events on pollutant generation, transport , and fate. When an occasional storm event sample was collected, it was, predictably, an outlier or influential case in statistical analyses. As a result, the fixed-frequency sampling strategy led to water quality data and information that corresponded with the prevailing attitudes and beliefs. Similarly, it has been estimated that New York City's waterborne disease surveillance system would positively identify less than 10 cases out of a population of 100,000 infected patients in a city of 8,500,000 (NRC 2000).

York City (e.g., nursing homes, AIDS clinics, etc.), perceptions about the water supply's safety have been fundamentally altered (NRC 2000; Platt et al., 2000).

Forests = Clean Water(?)

Seventy-five percent of the watershed region is forested, another 15 to 20 percent is agricultural land (small dairy farms), the small remainder is residential or commercial. There are only a few industrial sites with the potential to generate point source discharges; they have been strictly regulated and carefully monitored since the early-1970s. Therefore, for the reasons noted earlier, the engineers responsible for the water supply system circumstantially equated large areas of forests and high water quality. That is, a watershed system with large forested areas, small farms, and a few scattered villages (as opposed to urbanized areas) could be expected to have high ambient water quality. This cause-effect relationship is true …to a point. However, the SDWA amendments and the SWTR ultimately subjected these assumptions—the justification for custodial management—to more rigorous analyses. As is often the case with environmental and natural resource management, *quality* [and location of forests] is more often more important than *quantity*.

Wild Forest, Forever

Destructive logging and leather tanning practices in the 1800s led to the establishment of the 385,000 acre (156,000 ha) Catskill Forest Preserve (Burdick 1985; Millen 1995). By the late-1800s, the condition of the forest, streams, and fishery were so bad, the land was protected in the New York State Constitution with the phrase *"…it shall be wild forest, forever."* Cutover land was added to the Forest Preserve when it was purchased by the State or abandoned in lieu of unpaid property taxes. The mountainous terrain limited road construction to the narrow mountain valleys. Early settlers followed roads to claim floodplain soils …the best, if not only, arable land in the region. Therefore, most of the Catskill Forest Preserve is comprised of high elevation and mid-slope parcels—not valley-bottom and riparian area parcels.

When New York City built its extensive reservoir system (1907-1965), land that was not offered for sale (at a price set by New York) was taken by eminent domain. The reservoir "takings" brought with them the everlasting enmity of Catskill residents (Steuding 1985). Hence, New York City owns approximately 10 percent of the watershed(s) in relatively narrow strips around the reservoirs and waterworks. So who owns the riparian [primary streamflow source] areas? The most critical areas of many tributary watersheds are divided into hundreds of comparatively small (<5 ha) private parcels.

The BIG Apple

In the not-too-distant-past, New York City could control the outcome of legislative and executive branch decision-making because of population demographics (i.e., the number of seats in the State Legislature and Senate and the inevitable connections between the Governor's office and New York City) and corresponding political influence. Until the court system became the primary arena for land and resource use controversies and the great equalizer of small and large communities[10], New York City enacted rules and regulations with impunity. When the Memorandum of Agreement negotiations took place, riparian area management standards and guidelines, namely setback requirements for various land and resource uses, were agreed to with little if any scientific basis; they were simply copied from other jurisdictions and increased or decreased in width during negotiations. The New York City Comptroller refused to pay for these programs until the scientific basis was reviewed by a third-party commission …the National Research Council (1997-99, published in 2000) Committee. Neither the NYCDEP nor the watershed communities were very enthusiastic about this *post hoc* assessment. They had a deal; this group of eggheads was likely to get the "wrong" results and spoil everything. Ironically, the not-for-profit environmental groups were the most strident critics of the NRC study and the need to evaluate the scientific foundation of the Memorandum of Agreement. They had already declared victory to their membership and the media.

[10] For example, the Coalition of Watershed Towns (CWT), originally named the Organization of Water Exporting Counties (OWEC) filed suit against New York City that forced them to negotiate the Memorandum of Agreement modifying the 1991 draft regulations.

Riparian Area Management Provisions

As noted earlier, New York City's approach to riparian area management is comprised of a long list of regulated activities or resource uses and corresponding setback requirements. The width of the setbacks reflects the perceived importance of the receiving water or the perceived risk of the activity (Table 2). In light of the preceding discussion, it should be noted that riparian area protection begins at the downstream, rather than in the headwater areas, of the watersheds. The NYCDEP considers the reservoir and principal tributaries to be the most important components of the system. With respect to water conveyance and storage this is clearly true. However, in relation to the streamflow and nonpoint source pollutant, the principal tributaries and reservoirs are sinks not sources. Streamflow is generated in saturated source areas adjacent to, or connected to, hundreds of kilometers of ephemeral, intermittent, and perennial streams. When land or resource use in these riparian areas exceeds the resistance and resilience of the site, sediment, nutrients, pathogens, or other contaminants may enter the stream network at a limitless number of places. Because land ownership patterns (NYCDEP land in strips around reservoirs, Catskill Forest Preserve draped over the mountaintops, and private land along stream valleys) the riparian area management strategy affords the least protection where it is needed most. Once pollutants reach the stream system, in a matter of hours they flow right past the 1,000 foot buffer strips directly into the reservoirs. Simply put, riparian setbacks requirement are likely to be ineffective because they fail to adequately protect the most significant portions of the watershed system (NRC 2000). The preoccupation with municipal and domestic wastewater and petroleum and metals comtamination (Table 2, items 1-10) while exempting agriculture and neglecting forestry (in watersheds that are 15% agricultural land and 75% forest land) reflects an urban, point source pollution control perspective.

The primary source water quality problems faced by NYCDEP are (1) pathogens, (2) turbidity (inorganic and organic suspended solids), and (3) phosphorus (the limiting nutrient in most freshwater ecosystems and the cause of algal blooms in several reservoirs). The corresponding primary sources of these pollutants are (1) barnyards and failed septic systems (2) unpaved roads and road-stream crossings, and (3) application of fertilizers and manure to fields. Riparian setbacks or buffers can enhance the effectiveness of other conservation management practices (e.g., overland flow and stormwater controls). They cannot assimilate and transform unlimited quantities of pollutants from chronic sources. Furthermore, riparian setbacks are ***not*** the appropriate control or mitigation measure for these potential sources of contamination. Petroleum products, pesticides, metals, road salt, and landfill leachate are "conservative tracers" in the environment. They are little affected by geochemical transformation, vegetative assimilation, or soil adsorption. After flowing through the unsaturated [root] zone they mix with or float on the surface of shallow groundwater (the water table or top of the saturated zone). It may take years, but it is only a matter of time before these materials reach adjacent water bodies. The appropriate pollution prevention and control techniques for petroleum bulk storage include (1) preventive maintenance, (2) regular inspections for leaks or malfunctions, (3) accurate inventory [input, output, net storage] records, (4) provisions for spill containment, and, if needed, (5) removal and safe disposal of leaking tanks and contaminated soil. Pesticide, fertilizer, and road salt contamination can be minimized by careful control of application rates, conditions, and timing.

Two years of complex negotiations, after years of staff work and threatened lawsuits, have resulted in a labyrinth set of regulations and enforcement procedures with a very limited likelihood of success. My assessment of the most fundamental flaws of the NYCDEP approach include the following. (These conclusions are shared by the other 14 members of the National Research Council Committee, a panel of experts convened to supplement our review of the riparian setback provisions, technical reviewers of the NRC report, as well as an earlier EPA Expert Panel (Okun et al., 1993).

1. The development of watershed management standards and guidelines was a political process with a very limited scientific basis.

2. The resulting standards exhibit a mismatch between the spatial patterns of nonpoint source pollutant loading and riparian setback requirements. Private lands and primary pollutant sources are inadequately considered.

3. The watershed management strategy places excessive reliance on setbacks instead of a comprehensive system of conservation management practices.

4. The fixed width setback specifications have no provision for site-specific or activity-based adjustment. When in doubt, they simply rounded up from example regulations in other states.

5. The NYCDEP's fixed-frequency (biweekly) water quality monitoring system lacks the spatial and temporal resolution to accurately identify problems. It will clearly identify problems only when they become chronic.

I am especially concerned that when (not if) this ill-conceived system fails and NYCDEP is required to build a filtration plant under federal court order, watershed management and pollution prevention will simply be dismissed, *en masse*, as failed strategies. Instead of combining scientifically sound source water protection *and* filtration and distribution infrastructure maintenance to maximize delivered ("finished") water quality and public health, watershed management will be scuttled to pay for a behemoth filtration plant. When funding and staff resources are withdrawn from the Catskill Mountain region, the conservation and stewardship ethic that is beginning to emerge will be quickly dissipated. As uncontrolled development and inappropriate resource use accelerates so will the downward spiral of environmental quality degradation. This is a lose-lose situation in the making.

TABLE 2 – A summary of riparian setback requirements in the New York City watershed Memorandum of Agreement (adapted from Table 10-1, NRC 2000).

Regulated activity or land use	Wetlands or Watercourses†	Reservoir or Principal Tributary
	------------Setback width (ft)------------	
1. Storage of hazardous substances	100	500
2. New aboveground fuel tanks	100	500
3. New underground home heating oil tanks	100	500
4. New underground or aboveground petroleum tanks (>185 gallons)	25	300
5. Subsurface discharge from wastewater treatment plants	100	500
6. Absorption fields for new septic systems	100	300
7. New raised bed septic systems	250 (100)*	500 (300)*
8. Impervious surfaces	100 (50)*	300
9. New impervious surfaces at residences	100	300
10. Solid landfill or junkyard	250	1,000
11. Pesticide application	250	1,000
12. Forestry‡	50	100
13. Agriculture	**	**

† A "watercourse" is defined as a stream, creek, or river that appears on a 1:25,000 scale topographic map. Hence, most intermittent streams and all ephemeral streams are not mapped.

* The width in parentheses is allowable if the size and/or shape of the parcel renders the standard setbacks infeasible.

** Agriculture is exempted if the farm is enrolled in the "Whole Farm Planning" Program. An interdisciplinary team works with farmers to develop site-specific pollution prevention and mitigation plans for sediment, nutrients, and pathogens. I have visited many of the demonstration farms in the program. I have yet to see a riparian forest buffer or fencing to exclude cattle. The most benign land use I have observed have been hayfields mowed right up to the streambank.

‡ The State of New York just published a forestry BMP manual in January 2000

MANAGEMENT OPTIONS FOR SASKATCHEWAN

The delineation and management of riparian areas is an important part of a forest resources conservation plan for soil, water, and biological diversity. However, as noted in the preceding section, riparian forest buffers or setbacks will not offset damage that accrues from inattention to other critically important conservation management practices. Watershed studies and operational monitoring have shown that roads and road-stream crossings are responsible for the majority (70 to 90%) of sediment input to aquatic ecosystems (reviewed by Satterlund and Adams 1992). Many other aspects of forest management (e.g., timber sale and road construction contracts, scheduling, supervision, equipment type restrictions [e.g., forwarders vs grapple skidders], access control, road decommissioning, forest renewal, protection or avoidance of critical habitat and cultural resources, etc.) influence the net effectiveness of riparian area management efforts. The development, implementation, and refinement of a *system* of conservation management practices can yield excellent results. Because the system is only as strong as its weakest element, neglecting one or more major elements (e.g, road stabilization) can negate the positive effects of others.

As discussed in an earlier section, riparian forest buffers are critically important for microclimate regulation, carbon inputs, floodplain and channel stability, the provision of terrestrial and aquatic habitat, and other functions and values. They are designed to *prevent* pollutants (e.g., sediment and nutrients) from reaching the adjacent receiving water. A riparian buffer can do little to *remove* pollutants that have entered the receiving water somewhere upstream. When, for example, an undersized culvert fails during a storm or snowmelt event and a road fill is carried downstream, the riparian forest buffer, whether 10 or 1,000 meters, can do little or nothing to ameliorate the environmental impact. This simple example reminds us that the purpose of riparian area management at the landscape scale should be carefully considered. Furthermore, the marginal benefits and costs, both ecological and economic, of riparian forest buffers should be evaluated. Namely, would wildlife and fisheries habitat (and many other functions and values) be better protected with (1) a 1,000 m buffer and substandard road-stream crossing *or* (2) a 50 m buffer and a conservatively engineered crossing protected by a modest short-term investment in erosion control and slope stabilization? The answer to this loaded question is obvious, however, the optimal combination and configuration of management practices across vast areas of Saskatchewan's boreal forest is not so simple to determine or prescribe. Hence, the primary goal of and justification for an adaptive management approach to is to develop ecologically—*and* economically—optimal operations as quickly and efficiently as possible.

This section presents a summary of recent information about riparian areas generated in the U.S. as the foundation for scientifically-based and operationally reasonable standards and guidelines in Saskatchewan. Similar field trials and experiments are being conducted in Saskatchewan (e.g., Prince Albert Model Forest and by Mistik Management Ltd. on the NorSask Forest) and Albert (e.g., Albert-Pacific, Millar-Western Whitecourt, etc.) but have not yet been published.

USDA Forest Service Riparian Forest Buffer System

The standard "second generation" version (filter strips being the first) of riparian forest buffers is shown in Figure 1 (Welsch 1991). Originally developed by the USDA Forest Service, USDA Natural Resources Conservation Service, and university research scientists for the Chesapeake Bay Project and similar applications, it is comprised of three zones with a total width of approximately 30 meters (100 feet, the default regulatory limit throughout most of the U.S.).

◊ *Zone 1* is a strip (~ 5m) of undisturbed vegetation along the stream channel, lakeshore, or estuary.

◊ *Zone 2* is an actively managed 20 m strip. It is designed to trap sediment, foster water use by plants, assimilate nutrients, and sequester pollutants in actively growing biomass. Harvesting techniques must avoid any soil compaction, surface disturbance, or rutting and are generally limited to directional felling and retrieval using the winch on a cable skidder positioned outside of Zone 2. Alternatively, in New England and the Lake States, harvesting, skidding, and/or processing (Cut-to-Length, CTL) equipment can operate on frozen ground, a deep snowpack, or during very dry conditions late in the growing season (August and September).

◊ *Zone 3* is added when the intensity and/or spatial extent of adjacent land use leads to the generation of overland flow. BMPs adapted from agriculture (e.g., terraces, diversions, grassed waterways, and small berms to spread overland flow over a broad area) are used to prevent rill and gully formation and induce infiltration and sediment deposition in the riparian forest buffer. In some situations such as pastures on dairy farms, fencing is required to exclude cattle from the buffer and prevent trampling damage to structures in Zone 3. Periodic mowing also is required. In most timber harvesting applications, Zone 3 is unnecessary (because overland flow does not occur) and another 5 m is added to Zone 2.

A number of studies have quantified the effectiveness of riparian forest buffers and unmanaged setbacks. Several recent and forthcoming publications (NRC 2000; NRC in preparation; Verry *et al.* 2000) contain exhaustive literature reviews. In general, for a wide range of adjacent land uses (e.g., row-crop agriculture, grazing, timber harvesting), sediment trap efficiency ranges from 80 to 95%, nutrient removal ranges from 30 to 80%, and contaminant assimilation and transformation are highly variable. The latter varies in relation to the biochemical properties of the pollutant and the substrate as well as the time of year (soil temperature, soil water content, and biological activity).

Although the standard USDA riparian forest buffer system is a substantial improvement, both ecologically and administratively, over earlier efforts, it remains a "one-size-fits-all" approach. In complex and heterogeneous landscapes it will, at various times and places, be insufficient (e.g., steep slopes), adequate (e.g., moderate slopes, medium-textured soils), or excessive (e.g., level sites with fine-textures soils). A "third-generation" variable-width approach (Verry et al. 2000) will be discussed after a review of buffer width considerations.

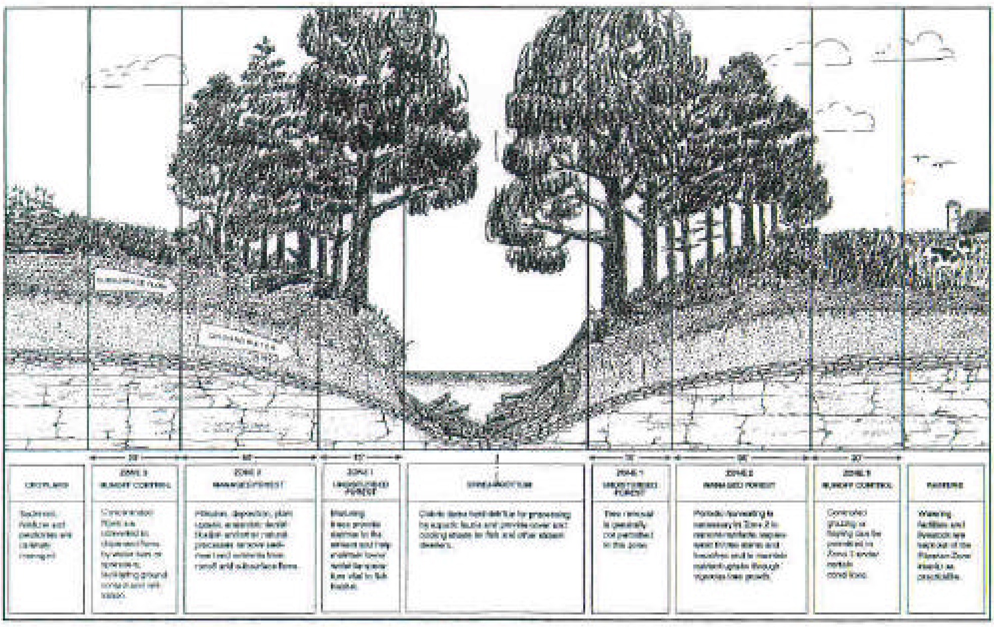

FIGURE 1 – USDA Forest Service Riparian Forest Buffer System (Welsch 1991).

Primary Considerations for Buffer Width

In a review paper prepared for a widely-cited interdisciplinary journal (*Environmental Management*), Castelle and others (1994) note there are at least four criteria that should be considered when sizing a buffer zone.

1. Resource functional value

The buffer zone may be primarily intended for pollutant removal. Alternatively, it may be focused on maintenance of terrestrial or aquatic habitat. In many circumstances, these goals or expected functional values may be linked or at least complementary. In other words, pollutant removal may be critical to aquatic habitat quality. Maintaining shade, woody debris, and bank stability is of little use if, in an urban industrial site or a fuel depot in a rural area, a toxin breaches the buffer zone and kills macroinvertebrates, amphibians, or fish.

2. The intensity of adjacent land or resource use

The quantity and quality of stormwater passing through a buffer is directly related to the scale and intensity of adjacent land and resource uses. For example, a unfenced 10 meter buffer strip between a stream and 100 hectare pasture for 2,500 sheep may accomplish little or nothing. By contrast, a 100 meter buffer strip between a stream and a 1 hectare organic garden will almost certainly fully protect the aquatic ecosystem. Timber harvesting is an infrequent disturbance (30 to 100 years between stand entries) that is deliberately distributed across the landscape. In comparison to timber harvesting, agricultural, urban, and industrial land uses can overwhelm the assimilative capacity of riparian forest buffers because pollutant inputs (1) are chronic [constant] or (2) reach toxic concentrations.

3. Buffer characteristics

Nowhere in the discussion and design of buffer strips is the complexity of natural systems more apparent than in the multiple combinations of (1) soil physical and hydraulic properties, (2) slope and landform (Fraser 1999; Fraser *et al.* 1998), (3) vegetation age, type, and condition, (4) land use history, and (5) random variations in climate that occur at the landscape scale. This is the primary reason why a prescriptive, top-down approach (e.g, New York City's Catskill Mountain region standards) is much less robust than an approach that takes site-specific characteristics into account.

The scientific uncertainty associated with riparian buffer zone structure and function clearly underscores the need for carefully designed and diligently implemented monitoring while basic and applied research strives to expand our understanding over the next 5 to 15 years. Monitoring serves the dual purpose of (1) performance evaluation for current practices and (2) data and information gathering to enhance the design of subsequent projects. Clearly, both are important aspects of adaptive management.

4. Specific performance requirements (pollutant removal efficiency)

In areas subject to many different types and intensities of land use, riparian forest buffers are being re-established to ameliorate water quality. For example, in the Chesapeake Bay (bordered by the states of Delaware, Maryland, Virginia, and the District of Columbia), nonpoint source pollution from row-crop (primarily corn) and animal (chicken and hog farms) agriculture and pollution from several large urban and suburban areas has seriously degraded water quality. As a result, the shellfish industry in many parts of the Chesapeake Bay is seriously threatened, waterfowl populations have suffered disease-related declines, pathogenic microorganisms limit recreational opportunities in some areas, and cultural resources are being degraded.

The Governors of the "Bay States" signed a compact that, as key provision, calls for the re-establishment of 2,010 miles of riparian forest buffers by 2010. The original document called for 2,000 miles by 2000 [an election year]; the goals were artfully revised after less than 200 miles were completed by 1999. Enormous sums have been appropriated, state and federal agencies have assembled large staffs, watershed associations have been formed and mobilized, all in a *reactive* effort to *restore* water quality. In many respects, 2,010 miles of "new" riparian forest buffers are intended to offset other, less efficiently controlled sources (e.g., urban stormwater and atmospheric deposition) in addition to providing *in situ* pollution control.

Variable Width Riparian Forest Buffers

In 1995, the USDA Forest Service commissioned three of its most accomplished research scientists[11] to summarize the state-of-the-art in managing riparian areas. As they state in the preface of the book they edited *"…It quickly became clear that this task was beyond the capabilities of three individuals and one organization. …Thus, we turned to a common solution to such problems and organized a conference titled 'Riparian Management in Forests of the Continental Eastern U.S.'* [New England, the Ohio Valley, the Lake States, and the northern Appalachians]." The result of the conference was a book with 49 contributing authors that will serve a seminal reference for several decades (Verry, Hornbeck, and Dolloff 2000).

In addition to the information cited earlier in this report, the book chapter by Ilhart, Verry, and Palik (2000:23-42) presents a field key to define riparian areas that is well-suited to serve as a general model or template for Saskatchewan (Figure 2). It combines landform, stream channel and lakeshore characteristics and information about riparian area structure and function to guide managers in planning and operations. The width of the riparian area is increased in accordance with landform and terrain characteristics (e.g., concave versus planar or convex slopes) and field assessments of site stability.

In a later chapter, Palik, Zasada, and Hedman (2000:233-254) discuss the ecological principles of riparian silviculture. They are very similar to principles and practices developed independently by MDC-Quabbin and QSTAC and a refinement of earlier, more general USDA Forest Service guidelines (Welsch 1991). Figure 3 (Palik et al. 2000:251) illustrates options that could be implemented in Saskatchewan. The cross-contour orientation of strips and openings implied in Figure 3 could be modified to favor the more conservative approach discussed in a subsequent chapter (Phillips et al. 2000: 273-286). Figure 4 (Phillips et al. 2000:283 after Blinn and Dhalman 1995) shows a herringbone skid trail arrangement, following slope contours, roughly parallel to the stream channel.

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[11] Dr. Elon S.Verry, Lake States Region Forest Hydrologist, Marcell Experimental Watersheds, Minnesota, Dr. James W. Hornbeck, Northeast Region Forest Hydrologist, Hubbard Brook Experimental Watersheds, New Hampshire, and Dr. C. Andrew Dolloff, Project Leader and Fisheries Biologist, Coldwater Streams and Trout Habitat Research Unit, Virginia

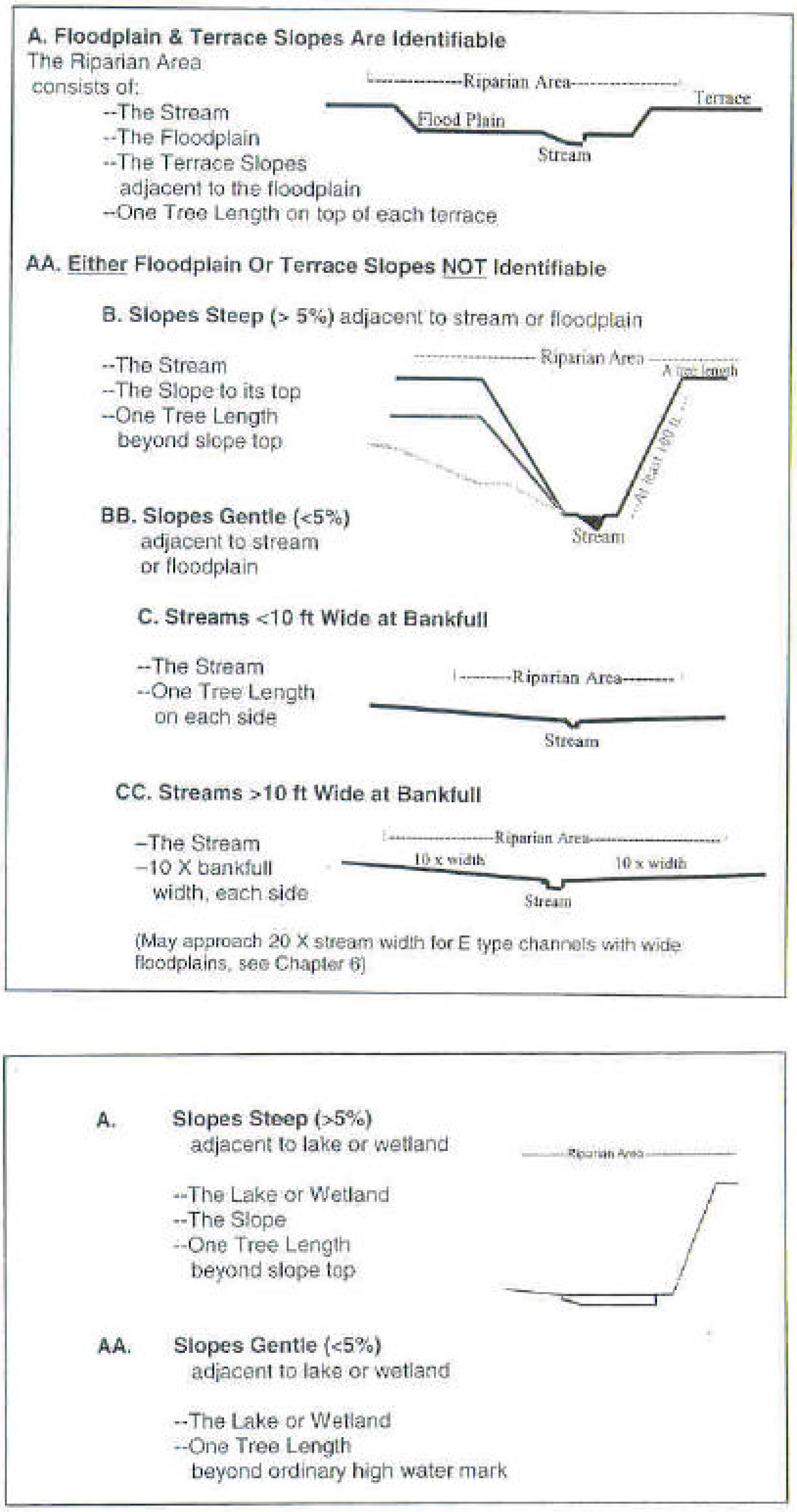

FIGURE 2 –Field key to define riparian areas for streams, lakes, and wetlands (reprinted from Ilhart *et al.* 2000:39-40)

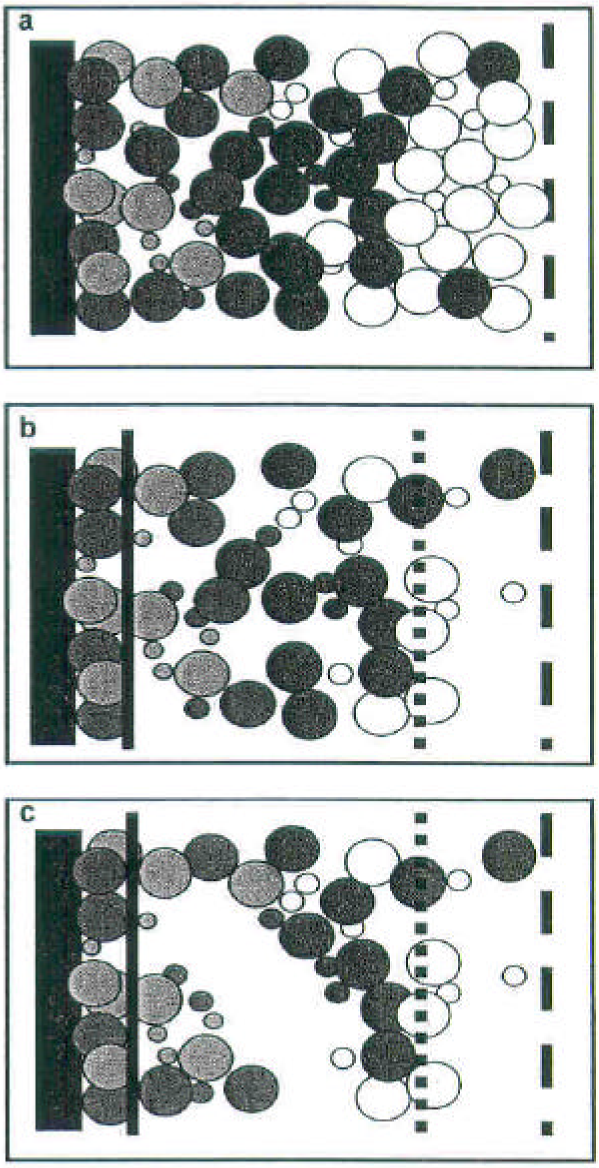

FIGURE 3 – A riparian forest showing different harvesting patterns along the riparian ecotone (upland – aquatic transition). Shaded circles show the crowns of different tree species. The thick band on the left side represents the stream channel. The uncut forest "a" showing the riparian boundary line as a dashed line (also see figures 1, 2, and 4). In "b", the riparian forest is cut along a gradient of intensity reflecting single species management on the right, mixed species management in the middle, and uncut forest adjacent to the stream. Residual basal area in the middle of the ecotone is dispersed by cutting many small gaps. In "c", the residual basal area bordered a single large gap. In both "a" and "b", mature stand structure and protection of riparian functions increase in the direction of the stream. (reprinted from Palik *et al.* 2000:251)

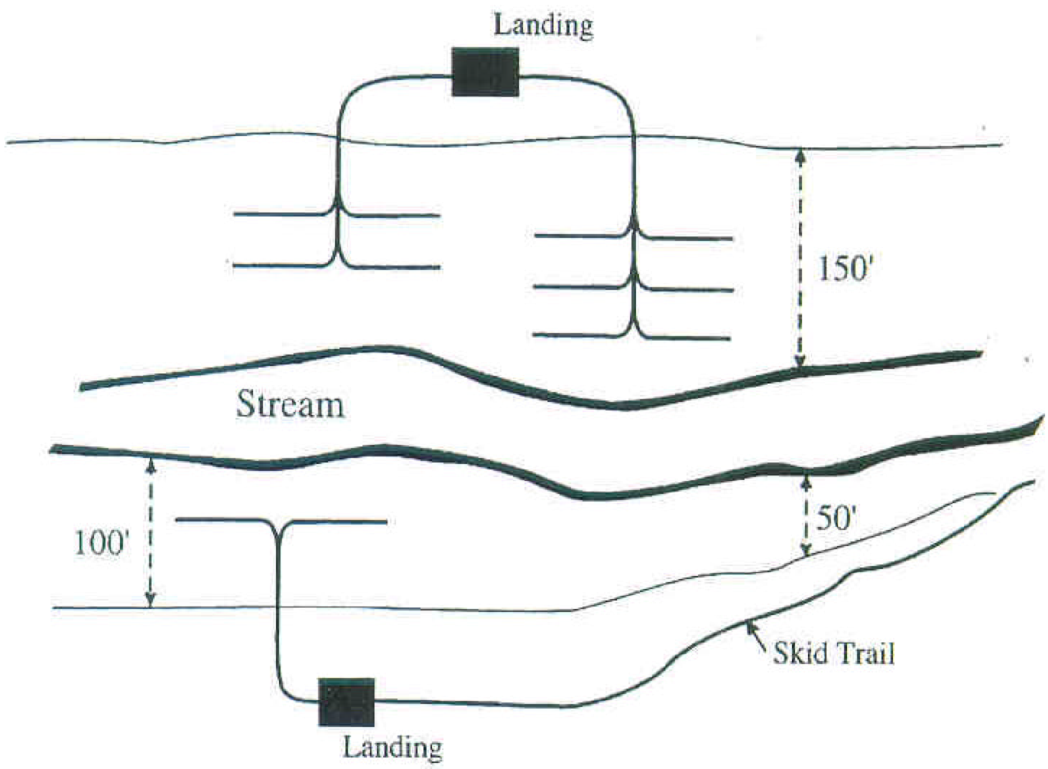

FIGURE 4 – Skid trails and landings in riparian areas. The limit of the riparian management area is noted in feet from the water's edge (reprinted from Phillips *et al.* 2000:283 after Blinn and Dahlman 1995).

Recommendations for SERM Standards and Guidelines

A proactive conservation philosophy for Saskatchewan's forests, water, and people recommends an integrative approach for riparian area management. The principal components that follow could serve as a checklist for the development, testing, and refinement of interim standards and guidelines.

- *An ecosystem-based, adaptive management approach* – The management plans submitted by major leaseholders during the last decade have adopted this approach as the basis for long-term operations in Saskatchewan's boreal forests. There is, nor should there be, no going back to philosophies and methods that focussed on wood fibre at the expense of other resources, functions, and values.

- *Riparian forest buffers (fixed-width minimum + variable width add-on)* – A two-stage approach can combine the administrative simplicity of a fixed-width buffer designed to provide minimum acceptable protection that is reinforced with additional area as guided by a short list of key attributes.

- *Riparian area functions and values* – Active consideration of the ecological, social, and economic values enumerated and discussed earlier should be used to guide the customization of basic standards to site-specific conditions and management goals. As a result, initial management objectives may need to be altered.

- *Landform* – The landform key presented by Ilhart and others (2000) is well suited for application in Saskatchewan. It encompasses all the major terrain elements encountered in the Province without generating unwieldy or burdensome numbers of categories and combinations.

- *Site conditions* – After a landform-based key is used for initial classification, key site conditions should be used to generate a riparian area management plan that is consistent with general standards and guidelines. Soil properties such as drainage class, erodibility, and trafficability and vegetation data and information (age[s], composition, structure, health and vigor, etc.) comprise this next layer or level of site-specific detail.

- *Habitat characteristics* – Although general consideration of habitat characteristics is included in the preceding steps, a site-specific assessment, and adjustment if needed, should be made. Adjustments should consider the landscape-scale disturbance patterns produced by fire as well as connectivity requirements for wildlife species ranging from amphibians to large mammals. This also allows for the application of local knowledge and a greater diversity of community values and preferences.

- *Silvicultural prescription and contract specifications* – Clearly, the site, stand, and habitat conditions and management goals discussed above should form the basis of the silvicultural prescription developed for the actively managed portion of the riparian buffer and, to some extent, the adjacent harvest unit. Equipment and schedule limitations, performance standards, and other contract specifications through which the forester and leaseholder can ensure reasonable operational control should be matched to the silvicultural prescription (and vice versa).

In summary, the design of an actively managed variable-width buffer and corresponding silvicultural prescription should be directly related to (1) riparian area functions and values, (2) landform, (3) site and habitat conditions, and (4) operational considerations. Contract specifications should ensure the silvicultural prescription is implemented in a manner consistent with ecosystem-based management goals and objectives. Throughout this process, it is expected that monitoring, assessment, and operational experience will provide the data, information, and insight needed for continuous improvement.

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