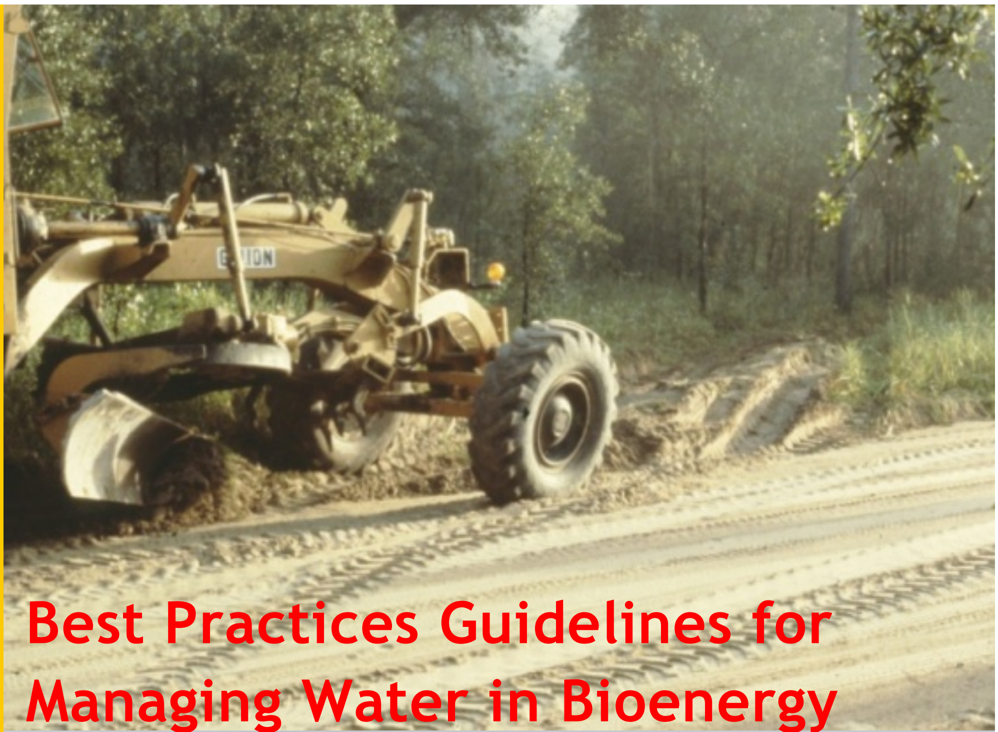
Best Practices Guidelines for Managing Water in Bioenergy Feedstock Production



This report presents comprehensive information regarding the management of water in the production of feedstocks for bioenergy. This report details the role of “Best Management Practices” in ensuring sustainable biomass production systems and preventing environmental degradation.

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BEST PRACTICES GUIDELINES FOR MANAGING WATER IN BIOENERGY FEEDSTOCK PRODUCTION

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Summary report

KEY MESSAGES

Best Management Practices (BMPs) have been developed and implemented since the early 1970s to ensure that land management for wood fiber and agricultural crop production can be conducted with minimum impact on the environment, particularly water quality. Although BMPs were originally designed to minimize water quality impacts, they can be used for a variety of environmental concerns. The use of BMPs is widespread in developed countries and it varies from mandatory to voluntary.

The development and application of BMPs is not a static process, but one that relies on a continual cycle of application, assessment and monitoring, and refinement. Although some countries have "national standards", the complex matrix of forest and agricultural ecosystems, climates, soils and topography, crop establishment and tending systems, and harvesting systems requires on-going assessment, monitoring, and refinement to craft BMPs to best suit local conditions.

The rationale for BMP usage is multifaceted. Reasons include:

(1) State and National environmental regulations,
(2) Agency regulations and goals,
(3) Private land management objectives,
(4) Land manager desires to seek certification for marketing purposes,
(5) Corporate/individual commitment to sustainability goals,
(6) Recognition of the productivity benefits of BMPs,
(7) Desire to integrate multiple ecosystem services into land management,
(8) Cultural and religious legacy,
(9) Personal conservation heritage, and
(10) Desires to emulate successful examples of good natural resources management.

Research and development studies play a key part in the refinement and communication of improved BMPs. They are also crucial in validating the effectiveness of BMPs. This is especially important where local environmental conditions or operational standards are unique. Best Management Practices ensure that bioenergy programs can be a sustainable part of land management and renewable energy production.

The way forward relative to assessing soils impacts and the sustainability of biomass production systems rests with proactive proper soil management and not reactive monitoring for screening of the condition, quality, and health of soils relative to sustaining productivity. BMPs offer proactive management methods to

EXECUTIVE SUMMARY

The increase in the use of woody biomass, agricultural crops, and wood wastes as feedstocks for bioenergy production has raised questions about potential impacts on water quality. Best Management Practices (BMPs) have been developed and implemented since the early 1970s to ensure that land management for wood fiber and agricultural crop production can be conducted with minimum impact on the environment, particularly water quality. Although BMPs were originally designed to minimize water quality impacts, they can be used for a variety of environmental concerns. The use of BMPs is widespread in developed countries and it varies from mandatory to voluntary. For example, in many countries, BMPs are already incorporated in “Codes of Forest Practice” that guide forest managers through the complete bioenergy life cycle. Best Management Practices have been developed and implemented in many agricultural countries to deal with water quality problems. The development and application of BMPs is not a static process, but one that relies on a continual cycle of application, assessment and monitoring, and refinement. Although some countries have “national standards”, the complex matrix of forest and agricultural ecosystems, climates, soils and topography, crop establishment and tending systems, and harvesting systems requires on-going assessment, monitoring, and refinement to craft BMPs to best suit local conditions.

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Research and development studies play a key part in the refinement and communication of improved BMPs. These studies and monitoring projects are also crucial in validating the effectiveness of BMPs. This is especially important where local environmental conditions or operational standards are unique. Best Management Practices ensure that forest and agricultural bioenergy programs can be a sustainable part of land management and renewable energy production. There are literally thousands of BMPs so covering them all is beyond the scope of this report. The most important ones are presented and discussed in this document.

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1 INTRODUCTION

1.1 Background

In the quest to develop renewable energy sources, woody and agricultural crops are being viewed as an important source of low environmental impact feedstocks for electrical generation and biofuels production (Hall and Scrase 1998, Eriksson et al. 2002, Somerville et al. 2010, Berndes and Smith 2013). In countries like the USA, the bioenergy feedstock potential is dominated by agriculture (73%) (Perlack et al. 2005). In others like Finland the largest potential comes from forest resources. Forest bioenergy operational activities encompass activities of a continuing and cyclical nature such as stand establishment, mid-rotation silviculture, harvesting, product transportation, wood storage, energy production, ash recycling, and then back to stand establishment (Neary 2013). All of these have the potential to produce varying levels of disturbance that might affect site quality and water resources but the frequency for any given site is low (Berndes 2002, Shepard 2006, Fargione et al. 2010, Neary and Koestner 2012). Agricultural production of feedstocks involves annual activities that have a much higher potential to affect soils and water resources.

The way forward relative to assessing the soil and water impacts of bioenergy systems and the sustainability of biomass production rests with three approaches that could be used individually but are more likely to be employed in some combination (Neary and Langeveld 2013). These approaches are: (1) Utilizing characteristics that can be quantified in Life Cycle Assessment (LCA) studies by software, remote sensing, or other accounting methods (e.g. greenhouse gas balances, energy balance, etc.) (Cherubini and Strømman 2011); (2) Measuring and monitoring ecosystem characteristics that can be evaluated in a more or less qualitative way (e.g. maintaining soil organic carbon) that might provide insights on potential productivity and sustainability, and (3) Employing other proactive management characteristics such as Best Management Practices that are aimed at preventing environmental degradation.

1.2 Life Cycle Assessment

Life Cycle Assessment has been used to estimate the environmental impacts of biomass energy uses. Typically they examine greenhouse gas (GHG) emissions, CO_2 emissions, energy balance, and some indirect effects. Cherubini and Strømman (2011) reviewed 94 LCAs, most of which are papers published in scientific journals. More than half of the studies were from North America and Europe. Increased numbers of South Asia, Africa, and South America can be found. About 50% of the studies limited the LCA to GHG and energy balances without considering contributions of bioenergy programs to other impact categories such as soils and water. They concluded that there are a number of issues and methodological assumptions in currently used LCA approaches that make it impossible to quantify environmental impacts from bioenergy programs. Some of the key indirect effects issues strongly depend on local operations, vegetation, soil, and climate conditions that render accurate assessment of environmental effects very problematic. Although policy makers claim that methods exist for assessing environmental impacts on soil and water, the scientific foundation for estimating indirect effects of bioenergy programs is constrained by the lack of adequate validation research, accurate assessment methods, and the relative infancy of the LCA process. Cherubini and Strømman (2011) clearly pointed out that determination of environmental outcomes of bioenergy production is complex and can lead to a wide range of results. They stated that the inclusion of indirect environmental effects in LCA represents the next research challenge and not the immediate incorporation into the methodology.

1.3 Sustainability and Productivity

In regard to the second approach, soil quality monitoring was developed as a means of evaluating the effects of forestry and agricultural management practices on soil functions that might affect site productivity (Doran and Jones 1996, Neary et al. 2010). A number of soil physical, biological. And chemical parameters, which have linkages to soil productivity have been proposed as forming a minimum monitoring set The way forward relative to assessing soils impacts and the sustainability of biomass production systems rests with proactive proper soil management and not reactive monitoring. for screening the condition, quality, and health of soils relative to sustaining productivity (Doran et al. 1998, Burger et al. 2010, Johnson 2010). Evaluation of soil condition thus would lead to a time-trend analysis that can in turn be used to assess the sustainability of land management practices and bioenergy programs. However, even though sustainability is the stewardship goal of land management, more specific definitions of its goals and attributes is often complex and open to considerable interpretation (Allen and Hoekstra 1994, Moir and Mowrer 1995). Many scientists have attempted to answer the “what”, “what level”, “for whom”, “biological or economic”, and “how long” questions of sustainability. Allen and Hoekstra (1994) clearly pointed out that there is no absolute definition of sustainability, and that it must be viewed within the context of the human conceptual framework, societal decisions on the state of ecosystem to be sustained, and the temporal and spatial scales over which sustainability is to be judged. In short, this approach is loaded with considerable uncertainty and lack of consensus.

1.4 Best Management Practices

Absent some breakthrough in validating a key set of soil parameters that will predict soil productivity and sustainability trajectories, the most sensible approach is the third, specifically the development, implementation, monitoring, and assessment of “Best Management Practices” (BMPs) (Neary 2013). Collectively, a large number of BMPs for forestry and agriculture have been developed throughout the world because of national regulatory demands and the international development of “Codes of Land Management Practice” (Neary et al. 2011). The BMPs in the Codes and regulations cover traditional forestry and agricultural activities. New BMPs have been developed for bioenergy applications such as energy production facilities, ash recycling, and short-rotation cropping. Best Management Practices were originally developed in the 1970s for water quality protection but now extend to other environmental concerns such as sustainability. An important part of BMP utilization is the cycle of application, monitoring, evaluation, refinement, and re-application. Research and development studies play a key part in the refinement and communication of improved BMPs. Existing studies of BMP effectiveness have demonstrated that most BMPs, if applied correctly, are very effective in mitigating or preventing adverse soil and water quality impacts. Some jurisdictions have mandatory BMPs but others operate completely under voluntary systems.

The key components of successful BMP-based codes of practice for bioenergy systems, whether voluntary or mandatory, revolve around the cyclical strategy of planning, implementation, monitoring, evaluation, adaptation, and renewed implementation. The minimum number of BMPs needed should come out of the planning process and is dependent on resources to be protected, site physical characteristics, regulatory requirements, and overall organization and operation goals. These will obviously vary from site to site, region to region, country to country, and organization to organization. Life cycle analysis should always be included in order to identify all water and ecological impacts. The next step is crucial. Monitoring and evaluation should be conducted routinely in order to decide if selected BMPs are effective and can be reapplied, or if they need to be modified, researched further, or discarded. Research and development studies play a key part in the refinement and communication of improved BMPs. They are also crucial in validating the effectiveness of BMPs. This is especially important where local environmental conditions or operational standards are unique. Best Management Practices ensure that bioenergy programs can be a sustainable part of land management and renewable energy production. There are a number of management practices that are accepted as means of reducing or eliminating the environmental effects of forestry operations, agriculture activities, and energy production (Minnesota Forest Resources Council 2005, USDA Forest Service 2012) These are collectively known as BMPs (Loehr et al. 1979, Lynch et al. 1985). This term is used in many domains from accounting and tourism to forestry. It implies that there is a widely acceptable combination of management actions that under most conditions ensure desirable outcomes.

In forestry and farming, the term BMP usually refers to practical and economic operational procedures and practices that eliminate or keep risks to environmental quality at an acceptably low level (D'Arcy and Frost 2001, Broadmeadow and Nisbet 2004). In most instances the key environmental parameter is water quality, and the focus of BMPs in both forest and agricultural management is the Streamside Management Zone (SMZ) (Neary et al. 2011). However, as discussed in this paper, BMPs exist and can be used for all life cycle phases of forest products and bioenergy feedstock production. For example, one BMP for forestry operations is to keep machinery out of waterways (Phillips et al. 2000). Another set minimizes road stream crossings by efficient design of main roads and skidder tracks (Foreman and Alexander 1998). Still others establish sediment control treatments such as gabions, sediment fences, straw bales, or wattles, and ditch-line diversions in order to trap sediment on-site and minimize sediment runoff into streams at road crossings (Forest Practices Board 2000, New Zealand Forest Owners Association 2012, USDA Forest Service 2012). Still other BMPs exist for wood processing facilities like sawmills and pulp and paper manufacturing plants as well as power transmission lines pipelines associated with bioenergy production facilities. Not all BMPs are necessarily accepted by all stakeholder groups or land managers as providing the desired environmental outcome for all sites.

The term BMP can be misleading if "Best" is understood to imply that better practices do not exist. There is always the possibility that new scientific knowledge and practical experience can be used to improve a currently accepted BMP or create new ones (Ice 2004). Best Management Practices are effective, practical, structural or non-structural methods which prevent or reduce environmental degradation. In the forestry and bioenergy context, they are used most commonly to protect water resources, and are usually developed to achieve a balance between environmental protection and the production of woody and herbaceous crops within natural and economic limitations (Aust et al. 1996).

Codes of Practice are collections of BMPs that are, if compulsory, prescribed in regulations and guidelines, and therefore require compliance. The BMPs embodied in Codes of Practice may be applicable to all or any combination of target groups, e.g., forestry operations on public and private land, and in small or large areas. Forest practices in many developed countries tend to be regulated in this manner. However, BMPs and Codes of Practice can also be voluntarily developed and adopted, which is more common in the agricultural sector (Logan 1993). BMPs can be general in nature or tailored to specific activities such as bioenergy production (Minnesota Forest Resources Council 2005, 2007). General BMP guidelines are designed to sustain forest or agricultural resources such as cultural resources, soil productivity, riparian areas, visual quality, water quality, wetlands, and wildlife habitat. They are applicable to activities such as road construction and maintenance, harvesting, site preparation, pesticide use, reforestation, stand tending and thinning, fire management, and recreation management. Specific BMPs are activity-specific guidelines which are unique to an activity and designed to work with general guidelines to provide an integrated framework needed to ensure forest or agricultural resource sustainability.

1.5 BMP Use Rationale

The use of BMPs in land management for bioenergy objectives requires additional effort and expense to follow guidelines and achieve objectives (Richardson et al. 2002). This fact logically raises a number of questions for land managers: "Why are we doing this?", "What is the advantage for my farm/forest?", "Who is making me incorporate these practices?", "What is the economic value?", etc. There are many answers that are obvious in the short-term and long-term. These include but are not limited to:

- State and National environmental regulations,
- Agency regulations and goals,
- Private land management objectives,
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For forest bioenergy programs, BMPs are essential to ensure long-term productivity and sustainability because management of forests for bioenergy objectives often involves intensification of forest access, harvesting, and disturbance (Dyck and Bow 1992, Dyck et al. 1994, Richardson et al. 2002). Since many forest bioenergy producers seek certification of sustainability through the Forest Stewardship Council (FSC), the Programme for the Endorsement of Forest Certification (PEFC), or other certification systems, adoption and use of BMPs is a necessity (Lewandowski and Faaji 2006, Janowiak and Webster 2010, van Dam et al. 2008, Scarlat and Dallemond 2011). This paper provides an overview of BMPs used in bioenergy feedstock production (Buford et al. 2011). It discusses development of BMPs, types of BMPs, and examples of their implementation (Neary et al. 2010). While most forestry BMPs are directly applicable to forest bioenergy programs, there are some aspects of the forest bioenergy life cycle that are different from production forestry and require unique BMPs. These include slash harvesting, woody biomass storage, power generation, powerline right-of-way maintenance, and ash recycling. Agriculture has its own set of BMPs, many of which are common to forestry ones. However, the intensity of agriculture activities necessitates a unique set of BMPs tied to the frequency and degree of land disturbance activities.

This report summarizes forestry and agriculture BMPs in the context of multi-feedstock bioenergy programs. Since BMP usage and development is an iterative process, evolution of individual BMPs to deal with site-specific and feedstock-specific issues is to be expected.

2 BIOENERGY FEEDSTOCKS

A bioenergy feedstock is the basic biological material used to produce energy. Biomass feedstocks and fuels exhibit a wide range of physical, chemical, and engineering properties (Nordin 1994). Despite their wide range of possible sources, biomass feedstocks are remarkably similar in many of their fuel properties, compared with alternative competing conventional power feedstocks such as coal or petroleum.

Plants and trees are made of inedible cellulose. Cellulose, in the form of firewood has been used as a basic form of bioenergy for millenia. Recent advances in bioenergy, ranging from the simple (biomass pellets) to the complex (cellulosic ethanol), have created a need for high-yield feedstocks. The crops under consideration as "second generation" biofuels are mostly grasses and trees, which as perennial crops may also provide a range of environmental benefits over annual crops like corn and soybeans. Crops, like miscanthus, prairie grasses, and switchgrass, which are grown purely for energy and have no use as food or fibre, can be dedicated energy crops.

Most biomass materials are easier to process thermochemically into higher-value fuels such as methanol or hydrogen. Their ash and sulphur contents are typically lower than for most fossil fuels. Unlike coal ash, which may contain toxic metals and other trace contaminants, ash produced by bioenergy facilities may be used as a soil amendment to help replenish nutrients removed by harvest. A few biomass feedstocks stand out for their peculiar properties, such as high silicon or alkali metal contents – these may require special precautions for harvesting, processing and combustion equipment. Mineral content can vary as a function of soil type and the timing of feedstock collection. In contrast to their fairly uniform physical properties, biomass fuels are rather heterogeneous with respect to their chemical elemental composition (Nordin 1994).

The biomass feedstock resource base identified by Perlack et al. (2005) for the United States is composed of a variety of forestry and agricultural resources, industrial processing residues, municipal solid wastes, and urban wood residues (Figure 1). Primary wood feedstocks originate from conventional forestry (Richardson et al. 2002) as well as short-rotation forestry (Hinchee et al. 2009). Commonly used tree species include willow (*Salix* spp.), poplar (*Populus* spp.), spruce (*Picea* spp.), fir (*Abies* spp.), pine (*Pinus* spp.), and a variety of hardwoods. The forest bioenergy resource includes slash residues left over from the harvesting of conventional stemwood, fuelwood extracted from forest lands, residues generated at primary forest product processing facilities, and thinning wood available through programs designed to reduce fire hazard and improve forest health (Table 1). They include residence yard trimmings, right-of-way maintenance, development land-clearing woody biomass, discarded wood pallets, packaging materials, residence and commercial construction and demolition debris, and other organic wastes. Some of the concentrated sources of wood feedstocks are currently being used for bioenergy (Table 2). Not all of these sources are fully utilized at the present time.

The most notable agricultural bioenergy resources include grains such as corn, soybeans, and wheat. They can be used for biofuels production, particularly ethanol, but their biofuels use impacts human food supplies. Bioenergy-suitable residues from agriculture-based sources include animal manures and residues, and crop residues derived primarily from corn (e.g. corn stover) and small grains (e.g., wheat straw). A variety of regionally significant crops, such as cotton, sugarcane, rice, and fruit and nut orchards can also be a source of bioenergy feedstocks, but they have other competing uses. Other agriculture-based bioenergy feed stocks include sugar beets, sugar cane, sugar palm, sorghum, cassava, milo, sweet potato, citrus peels, and whey.

(a) (b)

Figure 1. Forestry and agriculture bioenergy feedstocks: (a) Forest thinning material being harvested in Finland (Photo by Daniel G. Neary), and (b) Corn harvest in central Kansas (Photo courtesy of Haysville Community Library)

Plant and animal oils and fats have been used as sources of bioenergy, light and heat since the earliest periods of human civilization. Many of the plants with the highest oil-yields are also important sources of food like soybeans. As a result there are real concerns over the food vs fuel conflicts. There are also a range of waste biomass-derived oil products that can be used without effecting food supplies. Typical sources come from edible oil plants (coconut oil, mustard seed, oil palm, rapeseed, soy beans, sunflower seeds etc.) and non-edible-oil plants (camelina, castor beans, jatropha, jojoba, and karanj).

Table 1. USA wood bioenergy feedstock materials (From Perlack et al. 2005).

Feedstock Type	Wood Cellulose Source	Percent of Potential Supply	Percent of Potential Currently Utilized (2005)
Primary	Logging Residues	13	<1
	Other Removal Residues	5	<1
	Fuel Treatments	16	<1
	Conventional Fuelwood	14	69
Secondary	Processing Residues	19	66
	Pulping Liquors	20	70
Tertiary	Urban Wood Residues	13	17

Table 2. Sources, types, and relative location of woody feedstocks (From Perlack et al. 2005).

Wood-Related Activity	Material	Location
Harvesting	Tops & Branches	Dispersed
	Noncommercial Stems	Dispersed

	Understory Woody Debris	Dispersed
Thinning	Tops & Branches	Dispersed
	Noncommercial Stems	Dispersed
	Understory Woody Debris	Dispersed
Fuelwood Gathering	Stems	Dispersed
	Tops & Branches	Dispersed
	Stumps	Dispersed
Processing Facilities	Saw Kerf	Concentrated
	Slabs & Edgings	Concentrated
	Grade Rejects	Concentrated
	Pulp Wastes	Concentrated
Urban Wood	Residence Tree Trimmings	Dispersed
	Utility Corridor Maintenance	Dispersed
	Tree Removal	Dispersed
	Storm Clean Up	Dispersed
	Waste Wood	Dispersed
Commercial Sources	Construction Debris	Concentrated
	Demolition Debris	Concentrated
	Discarded Pallets	Concentrated

Table 3. USA agriculture bioenergy feedstock materials (From Perlack et al. 2005).

Crop Type	**Crop**	**Production Dry Tons^{-1} ac^{-1} yr^{-1}**	**Production Dry Mg^{-1} ha^{-1} yr^{-1}**
Human Foods	Corn Grain	3.3	7.4
	Sorghum	1.4	3.1
	Oats	1.2	2.7
	Barley	0.8	1.8
	Winter Wheat	1.1	2.5
	Spring Wheat	0.9	2.0
	Soybeans	1.1	2.5
	Rice	2.9	6.5
	Other Crops	1.0	2.2
Animal Fodder	Alfalfa	3.0	6.7
	Other Hay	1.7	3.8
	Silage Corn	6.6	14.8
	Silage Sorghum	4.4	9.9
Other	Cotton Lint	0.3	0.7
	Pasture	1.5	3.4
	Grasses	2.0	4.5

Some of the issues related to biomass feedstock production were elucidated by Perlack et al. (2005). For forest-related feedstock sources, these issues included changes in operations management, labor availability, economics, resource dispersal, supply availability, contamination of wood material, equipment adaptability, and environmental impact. The latter is the focus of this report. Similar issues were raised by Perlack et al. (2005) for agriculture-based bioenergy feedstocks. Competition for food and animal feed uses were discussed as being very important. Even more issues related to environmental impact of agriculture bioenergy feedstock production were raised because of the perennial nature of agriculture. This highlights the importance of the topic of Best Management Practices.

3 BEST MANAGEMENT PRACTICES OVERVIEW

3.1 BMP Concept

In the early 20th century, engineers designing industrial and municipal sewage pollution controls typically utilized physical systems (e.g. filters, clarifiers, biological reactors) to provide the core components of pollution control systems. They used the term "BMPs" to describe the supporting functions for engineered pollution control systems (Weightman 1996). The BMPs they used included support items such as operator training and equipment maintenance. Later in the century, storm water managers used the term BMP to describe both structural control devices systems as well as operational or procedural approaches to reduce pollutant loadings (e.g. reducing the use of fertilizers and pesticides) (D’Arcy and Frost 2001).

The use of BMPs is a “best management” approach based on known science that, if followed, should allow a manager or group of managers to comply with regulatory standards or achieve desired management objectives. The term was associated with water pollution since it was specifically mentioned in the USA Clean Water Act of 1977, as amended in 1987. Functionally, BMPs are much broader in scope and application and are now associated with a diverse suite of actions aimed at protecting the environment. They are practical control measures with technological, economic, and institutional considerations that have been demonstrated to effectively minimize environmental impacts. The use of BMPs is widely accepted as the most appropriate method of controlling nonpoint sources of pollution because BMPs prevent or minimize pollution rather than retrospectively respond to it (Aust and Blinn 2004, Ice 2004). Extensive testing of BMPs and nonpoint source control programs has demonstrated that these approaches are not a lesser companion to engineered effluent treatment and point source control efforts. Assessments have demonstrated that BMPs are able to effectively address extremely complex and variable watershed conditions. Best Management Practices continue to evolve as research identifies new challenges and practices. As the primary tool for controlling nonpoint source pollution, BMPs have the most important role in addressing water quality problems for threatened water resources (Ice 2004).

Best Management Practices usage for complex problems is context specific and often occurs in a context of imperfect, but constantly improving knowledge. Thus, it is more appropriate to think of BMP application to land management activities as an adaptive learning process rather than a rigid set of rules or guidelines. This approach to best practice focuses on fostering continuous improvements in quality and promoting continuous learning (Gitau et al. 2005). Codes of Practice that do not incorporate the adaptive learning concept embodied in BMPs revert to a regulatory approach that is reactive rather than proactive.

Best Management Practices development is an iterative process that begins with selection of a land management objective or activity that requires a BMP. A BMP can be selected from known, existing BMPs, or specifically designed (Figure 2). Once the BMP is applied for the management activity of concern, it is then evaluated through monitoring to determine if it is effective (Briggs et al. 1998). If the BMP is effective it then becomes part of the management activity process and is applied again. If the decision is that the BMP was not effective then it is adjusted or refined for another application and evaluation or it is abandoned. At the point the development cycle goes back to the beginning for design or selection of a new BMP. Monitoring and evaluation are constant factors in the BMP application and use cycle since environmental or operations conditions are subject to change and improvement is a constant factor in BMP use.

Bioenergy feedstocks can be viewed as presenting opportunities and risks to the environment throughout the production life cycle (Lattimore et al. 2009). Forest bioenergy has a number of components where BMPs can be employed due to the nature of disturbances associated with production components (Fazio and Monti 2011, González-García et al. 2012). A key part of any bioenergy system is the periodic assessment of life cycle components to determine the net environmental benefits and costs (Cherubini and Strømman 2011). These evaluations also measure the benefits and costs of BMPs, and identify areas needing refinement, BMP improvements, or replacement BMPs (Heller et al. 2003, Pennington et al. 2004).

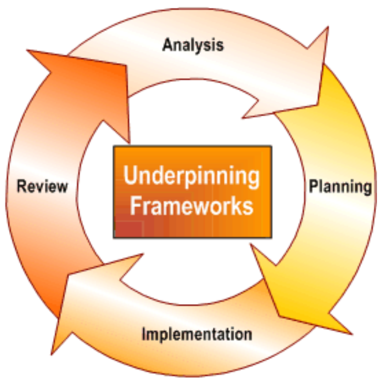

Figure 2. BMP development, implementation, review, and analysis framework.

3.2 Life Cycle Assessment

The forest bioenergy life cycle starts with stand establishment (Figure 3). In some instances, there are few impacts of this phase since naturally regenerated forests can be placed under forest bioenergy objectives and management. Operations during the forest or bioenergy plantation re-establishment phase can include site preparation, tree planting, weed control, and fertilization. The next step involves intermediate stand treatments that may or may not include harvesting of thinned stems and slash depending on the particular silvicultural prescription, economics of the management plan, and demands for feedstocks. Weed control and fertilization might be included if warranted. The final harvest usually causes the greatest site disturbances. Temporary roads used to haul felled trees or slash to landings, and permanent, but unpaved, roads are often the main sources of sediment that enters water bodies as nonpoint source pollution. Wood processing facilities and power generation stations have a minimal environmental footprint and their pollution generation activities can be more readily controlled and mitigated. Power lines used to distribute energy generated at bioenergy power plants normally require BMPS only during construction and routine weed control. However, permanent powerline access roads require on-going BMPs for the life of the powerline. The handling of ash wastes is the final step in the cycle where BMPs can be employed.

Life Cycle Assessment (LCA) is a tool used to assess the environmental impacts of a product, a process or an action (Cherubini and Strømman 2011, Heller et al. 2003). The LCA methodology consists of four stages: (1) goal and scope definition, (2) inventory analysis (LCI - Life Cycle Inventory), (3) impact assessment and (4) interpretation and improvement evaluation (Figure 4) (Pennington et al. 2004, Rebitzer et al.2004). An integrated LCA must include all of the above four stages according to ISO 14040 (ISO 14040 1997). The last stage of an LCA is to interpret and check the results of the study and not to assess improvements. This last stage can then lead to continued use of current methods, product or operation improvement, strategic planning, public policy making, marketing, technology transfer actions, media contact planning etc. The LCA process can be used at large scales or focused down on specific activities as is done with a nonpoint source pollution control strategy and BMP implementation for a specific feedstock harvesting activities (Figure 4) (USDA Forest Service 2012). The BMPs selected by the LCA are then implemented and evaluated in a similar process to the initial LCA process.

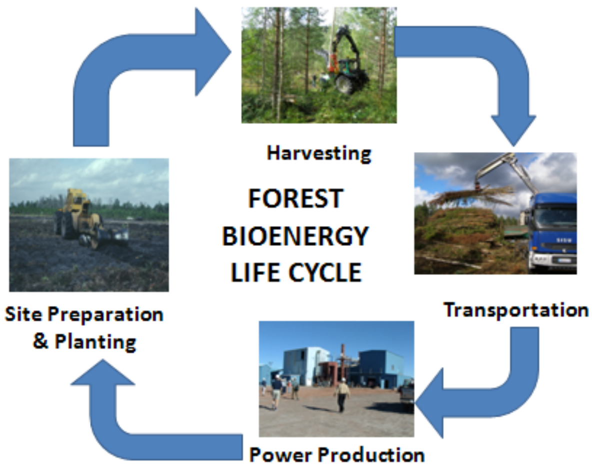

Figure 3. Schematic of a lifecycle for forest bioenergy (Neary 2013, Photos by Daniel G. Neary). Reproduced with permission of Wiley Interdisciplinary Reviews in Energy and the Environment.

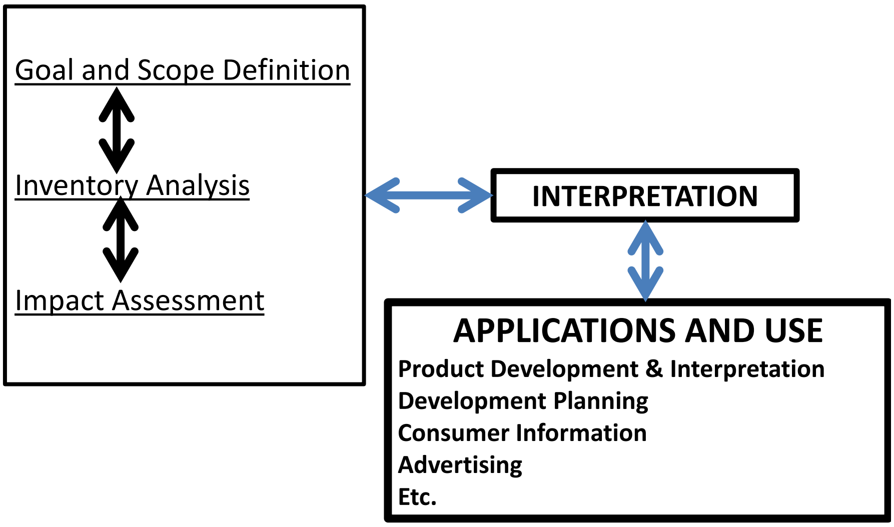

Figure 4. Life cycle assessment phases according to ISO 14040 (1997) and adapted by Neary (2013). Reproduced with permission of Wiley Interdisciplinary Reviews in Energy and the Environment.

3.3 The Core of BMPs - Streamside Management Zones

3.3.1 Background

Streamside Management Zones have been used for decades to buffer the potential adverse effects of agricultural and silvicultural practices on adjacent surface water quality (Comerford et al. 1992). The concept is quite old, dating to the 1700s (Porter 1887, cited in Lee et al. 2004). Streamside Management Zones came into common use in the 1960s to improve water quality by functioning as barriers or treatment zones to protect adjoining water resources from disturbances associated with agriculture and forestry (Figure 5). They are truly one of the most effective tools for reducing nonpoint source pollution from managed landscapes (Phillips 1989b).

In agricultural and forestry landscapes, the concept of an SMZ implies active management during some or all phases the zone's life cycle. Active management includes areas that may be designated as "undisturbed" trees, shrubs, or herbaceous plants. These zones could have management plans that provide for no or infrequent disturbances such as prescribed fire and thinning that are needed to maintain them in a vegetative condition conducive to achieving the overall objectives of the SMZ. The key to the concept of an SMZ is that it is actively managed and not necessarily allowed to exist passively as a "hands off" reserve that develops towards some ecological end-point.

Figure 5. Forestry Streamside Management Zone in New Zealand (Photo courtesy of SCION New Zealand Forest Research Institute Ltd.).

The size, shape, and management of these landscape units are determined by various combinations of economic, ecological, and regulatory factors (Williams et al. 2003). It can include riparian as well as upland areas (Phillips et al. 1999). The term encompasses all potential functions and management objectives for landscape units adjacent to streams. Thus, it is not tied to the hydrologically functional area of the riparian zone since it can include parts of upland areas, and it includes functions other than buffering. For these reasons, it is a preferable term to define the managed landscape units along streams (Figure 6).

An SMZ consists of a stream channel, perennial or intermittent, and parallel bands or zones moving outward from the channel onto the adjacent uplands (Figures 5 and 6). Perennial streams have a well-defined channel and flow year-round, except during periods of extreme drought. Intermittent streams have a seasonal flow and a continuous well-defined channel.

Ephemeral streams flow during and for a few hours or days after periods of heavy rain, and the stream channel is less recognizable than either perennial or intermittent streams. In agricultural ecosystems, grassed waterways are often used as a Best Management Practice SMZ to reduce erosion off of fields and within ephemeral stream channels (Figure 7).

Streamside Management Zones can consist of forest or herbaceous vegetation (Figures 6 and 7). A “Three-Zone Concept” provides a framework for planning, establishing, and maintaining a long-term riparian forest SMZ (Welsch 1991). The first sub-zone out from the stream might be an undisturbed zone of varying width or it might be absent. An important part of the concept of an SMZ is that an informed management decision is made to include or exclude this first sub-zone as a component of the SMZ depending on site conditions, waterway conditions, or the management objectives. It is not an “automatic” component that is excluded from active management. The important structural component in Zone 1, adjacent to the water’s edge, is a mixture of fast- and slow-growing native trees, including

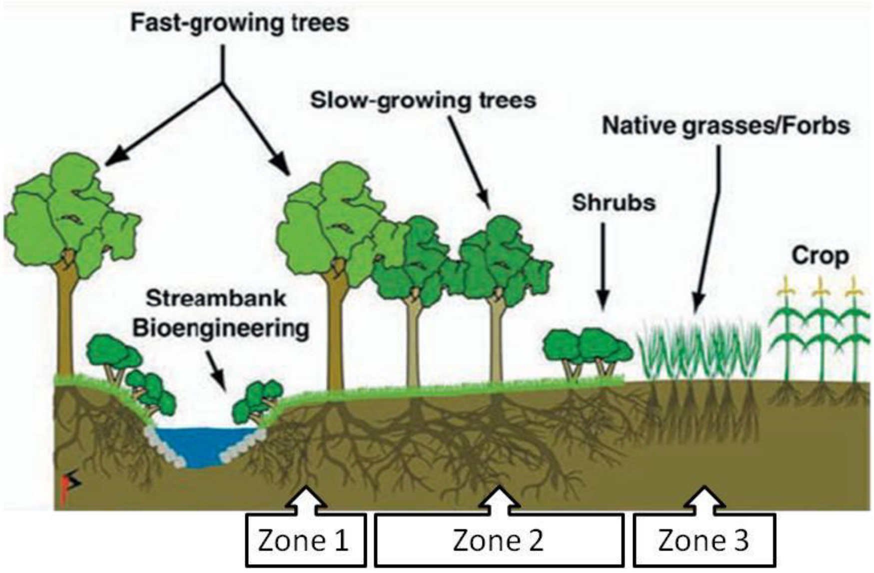

Figure 6. A planned SMZ with parallel bands of vegetation moving outward form channels to adjacent uplands. (Welsch 1991, Figure courstesy of the USDA Forest Service National Agroforestry Center, Lincoln, Nebraska, USA).

a) Marshall County, Iowa, USA

b) Polk County, Iowa, USA

c) Kent County, Maryland, USA

Figure 7. Grassed waterways in: a) Marshall County, Iowa, USA (Photo courtesy of USDA Natural Resources Conservation Service), b) Polk County, Iowa, USA (Photo courtesy of Polk Soil and Water Conservation District), and c) Kent County, Maryland, USA (Photo courtesy of the Integration and Application Network, University of Maryland, photo by Jane Thomas).

both overstory and understory species. If the stream is narrow, at maturity the tree canopy from both sides of the stream will meet or nearly meet. However, this first zone can be composed of sedges and other hydrophilic plants and still be fully functional. Trees are not an absolute necessity, because they might not be part of the natural condition, and they do not necessarily have to overhang the stream. However, this zone should be free of weed species that might colonize the site. The second sub-zone, the most important vegetation band, consists of the managed tree vegetation of variable width depending on slope or management objectives. Zone 2 can be designed for uses such as wood production (pulpwood or sawtimber), outdoor recreation, wildlife habitat, or alternative forestry products (ginseng, mushrooms, nuts, etc.). Livestock may or may not be excluded from this sub-zone depending on the SMZ objectives. Zone 2 may or may not be followed by a managed grass strip (Zone 3) which functions as a lower gradient runoff control zone. Catchment slope limits the potential size and configuration of Zone 3. Dense grasses and/or forbs (broad-leaved herbaceous plants and wildflowers) often occupy sub-zone 3. Vegetation must be managed to promote nutrient uptake and sediment filtering. Conservation reserves are often placed in Zone 3 of agricultural SMZs (Schultz et al. 2009). Managed grassland, pasture, cropland, or forest occupies the remainder of the landscape.

Variations on this design exist in many parts of the world. In Queensland, Australia, forests, the three zones beyond the “Protected Feature” concept is used for stream water quality protection (Figure 8, Neary et al. 2011). The protected feature encompasses the water area from normal levels to the usual seasonal high water line and defining bank (Figure 8). The next area is a “Buffer Zone” ranging from 2 to 10 m in width either side of the stream area depending on stream order. If the protected feature‘s defining high bank is unstable then the buffer zone is extended out three times the height of the instability. No felling of trees is allowed into streams, unstable drainage lines, within buffer zones, or into buffer zones from the next SMZ area, the “Filter Zone”. The filter zone varies from 10 to 50 m depending on stream order. Trees may be harvested within the filter zone based on a low intensity, periodic (10-40 years) system.

Variable SMZ widths are an integral part of the State of Minnesota, USA, guidelines for forest management and SMZ establishment (Figure 9, Minnesota Forest Resources Council 2005, Neary et al. 2011). Geomorphology controls the SMZ size variation as well as channel configuration. In the Minnesota system, the SMZ can be larger than or less than the area that would be classified as truly riparian.

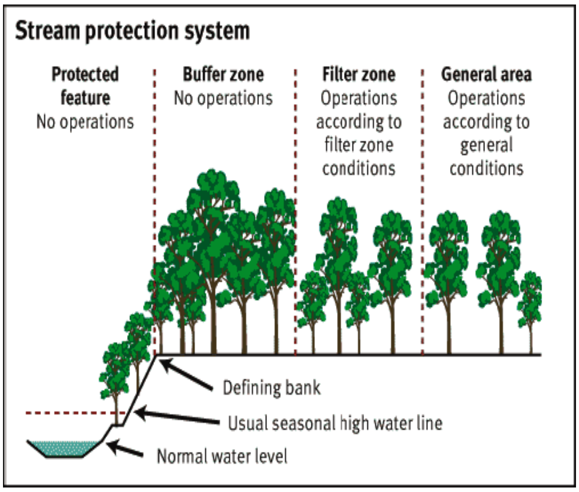

Figure 8. Queensland, Australia, SMZ system (From Department of Natural Resources and Water 2007, and Neary et al. 2011).

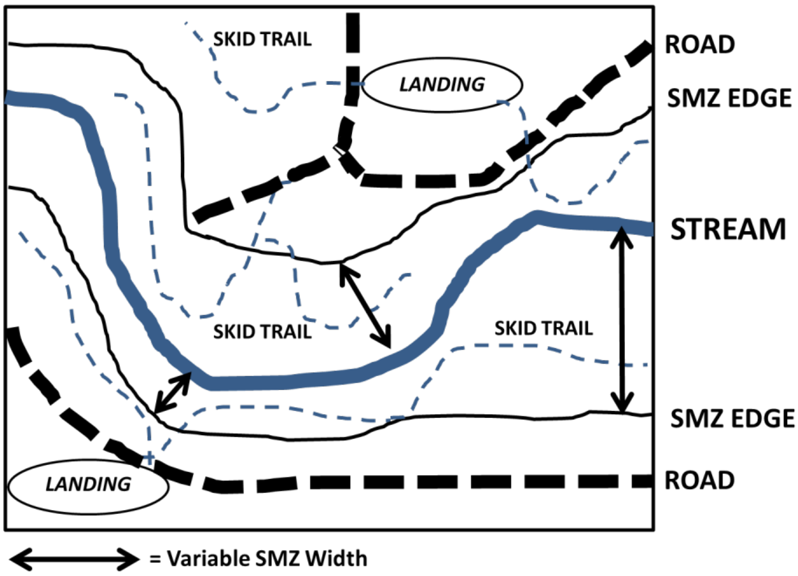

Figure 9. Adapted from Minnesota Forest Resources Council (2005) SMZ, skid trail, road, and landing design.

Streamside management zones provide a number of important functions in ecosystems (Welsch 1991, Table 1). They fall into the broad categories of water quality protection, streamflow maintenance, geomorphic stability, flora and fauna habitat, and social and economic benefits. These zones are more frequently viewed and valued in terms of their water quality benefits. While those functions are important, SMZs in an agricultural and forestry landscape provide important socio-economic functions which are important for their incorporation as a BMP.

The main water quality functions provided by SMZs are maintenance of low temperatures where vegetation is tall enough to generate shade, filtration and deposition of sediments, nutrient and chemical processing, detention of contaminants, plant uptake of nutrients, transformations of nitrogen compounds, and reduction of macrophyte growth (Table 4, Schultz et al. 2009). Sediment detention is the most commonly sought after function of SMZs. Streamside management zones are viewed as a good practice to prevent contamination of streams with pesticide residues although they are not 100% effective (Neary et al. 1993, Neary and Michael 1996, Maltby and Hills 2008).

Streamside management zones have important hydrologic and geomorphic functions. Although SMZ vegetation uses water, it is important for storing water for release later as baseflow (Schultz et al. 2009). Over-bank flows are important for reducing flood peaks.

Vegetation in SMZs reduces channel erosion by stabilizing banks. However, there are some conditions where vegetation along the edge of channels can contribute to excess bank scour and erosion (Ffolliott et al. 2003).

An important function of SMZs is providing habitat for both floral and faunal species. This function can be provided by both forested and herbaceous SMZs. It contributes greatly to landscape biodiversity, especially in semi-arid environments (Baker et al. 2003). Streamside management zones provide important landscape connections and cover for terrestrial wildlife as well as habitats for aquatic species.

The social and economic benefits of forested SMZs in agroforestry landscapes have been recognized as very important for agriculture (Correll 2005, Specht and West 2003, Reid and Burk 2002, Table 1).

Some of the key functions are:

- Improved aesthetics and property values
- Improved stock safety and management of gullies
- Provision of shelterbelts for stock protection
- Wood sales
- Carbon and other greenhouse gas credits
- Improved water quality for stock and human contact
- Soil conservation
- Increased native habitat
- Certification of farm products for environmental standards

The function of providing a future wood supply and source of income for farmers is one of several incentives for farmers to establish tree plantations along drainages, streams, lakes, and wetlands. At some point in time these plantations will need harvesting, but in an environmentally sound manner. Existing BMPs are designed to achieve that goal.

Table 4. Streamside Management Zone functions (Neary et al. 2010; adapted from U.S. Army Corps of Engineers 1991, Comerford et al. 1992, Lowrance et al. 1997, Corell 2005, Mander et al. 2005).

Category	Component	Function
Water Quality Protection	Temperature	Low temperature maintenance
	Sediment	Filtration and deposition
	Contaminants	Detention, adsorption, degradation
	Nutrients	Detention in sediments
		Plant uptake
		Transformations
	Macrophytes	Reduce growth
Streamflow Enhancement	Baseflow	Water storage
		Flow maintenance during dry periods
	Floods	Water storage
		Peakflow reduction
Geomorphic Stability	Streambanks	Bank stabilization
		Stream erosion reduction
	Streambeds	Scour reduction
	Uplands	Wind erosion reduction
Flora and Fauna Benefits	Terrestrial Habitat	Provide productive habitat
		Provide movement corridors and connectivity
		Enhance landscape biodiversity
		Create new habitats
	Aquatic Habitat	Moderate temperature
		Provide stable substrates
		Maintain streamflow
		Create new habitats
	Food Webs	Provide organic energy source
Atmosphere Improvement	Air Quality	Filter pollutants and odors
Social / Economic Benefits	Floods	Reduce damaging peakflows
	Aesthetics	Provide “greenbelt” and vegetation screens
	Real Estate	Improve farm property values
	Environment	Increase carbon sequestration
	Recreation	Provide recreational sites
	Agriculture	Provide livestock shelter
		Provide forage and water
		Provide livestock security
		Aid certification of farm products
		Provide a source of wood products and income
		Conserve soil resources
		Provide farm carbon credits

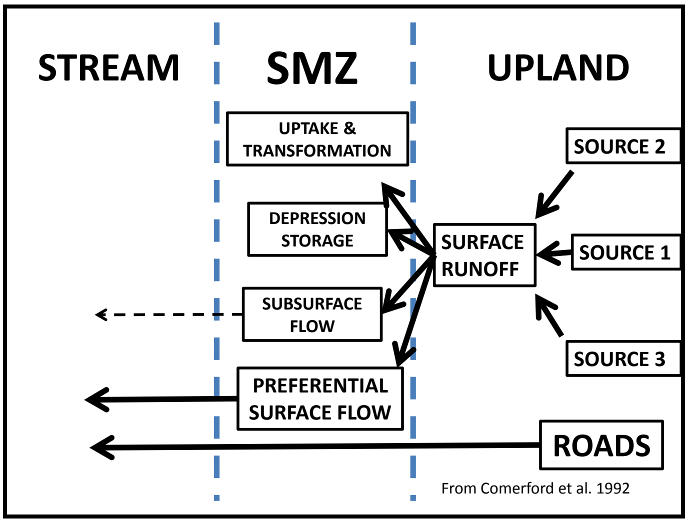

Figure 10. Water flow from upland source areas through SMZs and into streams (Adapted from Comerford et al. 1992, Neary et al. 2011).

3.3.2 Processes

There are a number of physical, chemical, and biological processes in SMZs that provide the desired functions for land managers (Table 4). Streamside Management Zones provide a mechanism for processing runoff from uplands into streams and mitigating impacts. There are flow pathways that can bypass SMZs, thereby reducing the effectiveness of functions that contribute to maintaining water quality (Figure 10). The following discussion in this section focuses on those processes that contribute to maintaining water quality and providing landscape biodiversity.

Surface Roughness: Surface roughness features include coarse-woody debris, live woody and herbaceous vegetation, emergent wetland vegetation, the soil organic horizon (litter), boulders, rock outcroppings, surface depressions and ridges, and parts of land that slope away from the stream edge. In an agroforestry landscape, SMZs usually increase surface roughness compared to adjacent tilled fields and pasture, which in turn reduces runoff velocity and thus enhances deposition of sediment and increases the opportunity for runoff to infiltrate into SMZ soils (Figures 7a and 7b). Sufficient contact time between water, vegetation and soil is important to obtain a decrease in runoff velocity. Some of the other factors that interact with surface roughness and affect trapping efficiency include the width of the SMZ, vegetation type (density, stiffness and height), and slope (Schultz et al. 2009).

Johnson and Buffler (2008) proposed a simple but useful classification system for SMZ surface roughness based on easily measurable or observable features (Table 5). The initial screening factor for their classification system is the percentage of the SMZ that contains recognizable surface roughness features. Examples of the three categories (low, moderate, and high) are shown in Figures 11a, 11b, and 11c, respectively. Johnson and Buffler (2008) recognized that SMZ roughness is not necessarily uniform, but it can be recognized and mapped. Figure 12 shows an example of an SMZ with sections characterized by variable surface roughness. This feature of SMZ roughness can be fairly uniform or highly variable.

Table 5. Streamside Management Zone surface roughness classification system of Johnson and Buffler 2008 (Adapted from Neary et al. 2011).

Degree of Surface Roughness	Description
Low	• Less than 35% of the land surface contains surface roughness features • SMZs with exposed mineral soils as a result of human use may have a low degree of surface roughness, as do managed areas that are intensively grazed, mowed, or used for agriculture).
Moderate	• Between 35 and 65 % of the SMZ surface roughness features • For an open (non-forested) system, such as shrub-steppe or wet meadow, it must not be intensively grazed, mowed, hayed, or intensively managed • Usually, there will be clumps of woody vegetation due to lack of mowing • Vegetation must be rough and dense. • There must be surface roughness features other than herbaceous vegetation, such as woody debris, boulders, or hummocky topography, over at least 5% of the land surface by aerial coverage • The surface organic horizon (duff layer) is intact throughout the SMZ unit.
High	• Greater than 65 % of the land surface contains surface roughness features. • The microtopography is complex with undulating features. The land surface does not slope smoothly and consistently toward the stream. • The SMZ unit is forested or covered with dense stands of riparian scrub, shrub-steppe vegetation, or dense rush/sedge vegetation. • The surface organic horizon (duff layer) is intact throughout the buffer unit. • In forests, dead-and-down wood and rotting logs and stumps are common. • There is a well-developed grass and forb layer. However, in shaded SMZ woodlands this will not always be the case. • Boulders and exposed bedrock are common and, where present, add microtopographical complexity. This feature is not required and may not be present in some cases.

Water Velocity and Depth: Water velocity is an important concept for SMZ functioning. Sediment transport in water is a function of water velocity and described in detail by Yalin (1977) and Haan et al. (1994). Any SMZ feature that reduces the velocity of water flowing into the buffer area will increase deposition of sediment. It will also provide additional time for infiltration of upland runoff into the soil, facilitating nutrient uptake and transformations (Schultz et al. 2009). Excessive water depths, especially in areas of concentrated flow, will reduce SMZ filtration functions since the water column will not interact with SMZ surface features and move directly into stream channels (Dosskey et al. 2002).

Sediment Size: The size of sediment transported into SMZs is a function of water velocity, which is in-turn affected by surface roughness. Sand-sized fractions of suspended sediment will usually deposit quite rapidly in SMZs as velocity drops off (Figure 13). Silt-sized sediment is able to settle out if runoff water is detained in the SMZ and velocities are dropped to near or <1 m sec^{-1} (Hjulström 1939). Figure 14 compares water samples from two adjacent catchments in Tasmania, Australia, one with an SMZ and the without, demonstrating the silt filtering capacity of SMZs. Clay-sized sediment fractions in soils do not readily settle out of a water column in even still water. The wider the SMZ buffer and the higher the surface roughness, the more likely that sediment trapping efficiencies will be high (Dosskey et al. 2002).

a) Low Surface Roughness

b) Medium Surface Roughness

c) High Surface Roughness

Figure 11. Examples of surface roughness: a) Low – Pasture on Naraglen Farm, near Burnie, Australia; b) Moderate – Pet River SMZ, on Naraglen Farm, Burnie, Australia; c) High – Pet River SMZ, Naraglen Farm, Burnie, Australia (Photos by Daniel G. Neary).

Figure 12. Adjacent areas of high (background) and low (foreground) roughness in the Pet River SMZ, Burnie, Australia (Photo by Daniel G. Neary).

Figure 13. Sand-sized streambed sediment, Cascabel Watersheds, Arizona, USA. (Photo by Daniel G. Neary).

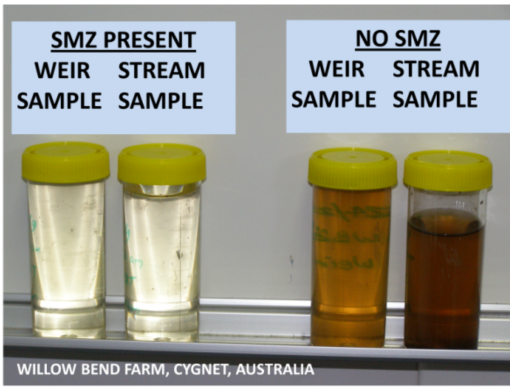

Figure 14. Silt filtering capacity of well-vegetated SMZs, Cygnet, Tasmania, Australia. (Photo by Daniel G. Neary).

SMZ Width: The widths of SMZs reported in the literature are quite varied (Neary et al. 2011). There is no one-size-fits-all although many are in the 10 to 15 m range. The important feature of SMZ width is that it is flexible enough to meet the objectives of land managers (Minnesota Forest Resources Council 2005). An SMZ width is functionally adequate if it allows sufficient time for water draining off uplands to contact vegetation, litter, and soil and decrease velocity, allowing for deposition of sediment. The SMZ width is important also for providing sufficient space for upland runoff entering as concentrated flow to convert to sheet flow (Schultz et al. 2009). When considering biodiversity, wider SMZ widths may be needed (Stauffer and Best 1980).

There are a number of variables that affect SMZ buffer functions (Comerford et al. 1992, Wenger 1999, Schultz et al. 2009). They include slope gradient, slope length, presence of converging slopes, floodplain width, soil infiltration rate, soil moisture content, sediment size distribution, catchment area, presence of impervious surfaces, vegetation, litter, coarse woody debris, inflowing water depth and rainfall. Questions have been raised if it is possible to incorporate these factors into models to predict needed SMZ widths.

A review by Wenger (1999) of several efforts provides some insights into the modelling approach to SMZ width. Phillips (1989a, 1989b) developed a Hydraulic Model and Detention Model whose key components were saturated hydraulic conductivity, slope, Manning's roughness coefficient, and soil moisture storage capacity. These models were highly dependent on existing data from a "reference" SMZ and were never verified, experimentally field tested or calibrated (Muscutt et al. 1993). However, the Phillips (1989a, 1989b) models have been used in Geographic Information Systems (GIS)-based efforts to delineate buffers (Xiang 1993, 1996). GIS applications to SMZ management are few in number and limited by the spatial resolution for small catchments and sub-basins of larger ones (Mander et al. 1997, Corell 2005). For larger rivers and forested flood plains this is less of a problem. Other simple models for designing SMZ width have been proposed by Flanagan et al. (1989), while others have incorporated the more complex CREAMS (Chemicals, Runoff, and Erosion from Agricultural Management Systems) (Williams and Nicks 1988) or WEPP (Watershed Erosion Prediction Project) (Williams and Nicks 1993) models.

Wenger (1999) reviewed two other methods to determine SMZ width. Mander et al. (1997) developed an SMZ width model more simplified than that Phillips (1989a). However it has seven components; conversion constant, mean intensity of overland flow, distance from stream to watershed boundary or the ratio of catchment area to stream segment length, slope, roughness coefficient (not Manning's), water infiltration rate, and soil adsorption capacity. Not all of these are easily obtainable or available. Nieswand et al. (1990) developed a much simpler model based on a modified Manning's equation:

$$W = k(s^{1/2})$$

Where: W = width of SMZ (buffer) in meters

k = constant size (e.g. 5, 7, 10, 15 etc. m)

s = percent slope expressed as a whole number (e.g. 5, 10, 15 etc.)

The Nieswand et al. (1990) equation is slope limited at 15%. Similar equations were among several referenced by Comerford et al. (1992):

$W = 8 - 9\ m + 0.6\ m\ (s)$ Trimble and Sartz (1957)

$W = 13\ m + 0.42\ m\ (s)$ Swift (1986)

$W = 9\ m + 0.46\ m\ (s)$ USDA Forest Service 1989b

Where: W = width of SMZ (buffer) in metres

s = percent slope expressed as a whole number (e.g. 5, 10, 15 etc.)

Dosskey et al. (2008) reported on computer model simulations using the process-based VFSMOD model to illustrate the effectiveness of SMZ filter strips from site to site and between individual nonpoint source pollutants. They noted that slope and soil texture are the most influential site factors that determine the necessary SMZ width needed to achieve adequate retention of pollutants. A graphical design tool developed with the VFSMOD model enables resource planners to designate appropriate design widths. The graphics tool is simple to use, accounts for several major variables that determine SMZ filter performance, and is based on a validated, process-based, model (Tomer et al. 2008). This SMZ design tool fills a large gap between existing complex assessment-type models and simple design guides. It can be applied quickly in a broad range of agroforestry settings with greater accuracy than existing design guides (Tomer et al. 2005). Furthermore, the model design logic is clear and sufficiently flexible that landscape planners can incorporate changes based on their expertise and local familiarity. While modeling simplifications inherent in this model limit its accuracy, the SMZ width tool provides a better and more quantitative method for selecting the appropriate SMZ width than other methods currently in use.

Using 73 published studies, only two of which were the same as those used by Mayer et al. (2007) for nitrate nitrogen (NO_3-N), Zhang et al (2010) found that SMZ width explained 44% of the variation in N removal efficiency that included three forms of N (total N, ammonium and NO_3-N), and that treed systems were more effective than those containing grass only or grass and trees. A buffer width of 15 m was predicted to remove 80% of N entering the up-slope side of the buffer.

Key Nutrient Transformations: Streamside management zone soils are critical for transforming N and detaining phosphorus on organic matter and mineral exchange sites (Lowrance et al. 1984, 1985; Hubbard and Lowrance 1994, 1996; Schultz et al. 2009). The ability of SMZs to reduce waterborne pollutants is a function of the physico-chemical conditions of the water, chemical and soil in the SMZ, and the types of plants, animals, and microbiological communities present (Comerford et al. 1992).

Nitrogen, in the form of a solute, can be removed from water flowing through an SMZ by at least two abiotic processes or by several biotic processes. The abiotic processes are volatilization as ammonia and sorption on the soil solid phase. The key N transformations are mineralization of organic N, nitrification, and then denitrification via the pathway NO_3-N to NO_2-N to N_2O-N to N_2 gas (Hubbard and Lowrance 1994, Smethurst et al. 2011). Denitrification occurs under anaerobic conditions in the presence of facultative anaerobic bacteria (e.g. *Thiobacillus denitrificans, Micrococcus denitrificans, Paraoccus denitrificans and Pseudomonas spp.)*. Denitrification rates are affected by soil pH, temperature, degree of water saturation, soil texture, and soil organic matter content.

4 FEEDSTOCK-SPECIFIC BEST MANAGEMENT PRACTICES

4.1 Sources of Information

There is a considerable body of knowledge in the refereed and other literature regarding BMPs. A number of forestry and agricultural organizations have developed Best Management Practices guides for their specific operations, ecosystems, and climates. These sources were utilized in this publication and are listed here.

4.1.1 United Nations Food and Agriculture Organization

The Food and Agriculture Organization of the United Nations (FAO) has developed a number of “Good Practices” for a number of agricultural and forestry land management activities. They can be found at:

http://www.fao.org/knowledge/goodpractices/gphome/jp/?lang=en

These practices include crop production systems management, crop production systems management, livestock production systems management, diseases and pests of animals and plants management, forest management and conservation, fisheries and aquaculture management and conservation, and sustainable natural resources management.

4.1.2 U.S. Environmental Protection Agency

The U.S. Environmental Protection Agency (U.S. EPA) has promulgated a number of Best Management Practices on individual web sites by practice. The suggested agricultural BMPs are listed on the web site: http://www.epa.gov/agriculture//tpol.html

Best Management Practices recommended for pasture, rangeland, and grazing operations are posted at: http://www.epa.gov/oecaagct/anprgbmp.html

Forestry BMPs recommended by the U.S. EPA can be found at:

http://water.epa.gov/polwaste/nps/forestry/forestrymgmt_index.cfm

Stormwater management BMPs are posted at:
http://www.epa.gov/oaintrnt/stormwater/best_practices.htm

4.1.3 USDA Forest Service

The USDA Forest Service recently published a volume on “National Best Management Practices for Water Quality Management on National Forest Lands - Volume 1: National Core BMP Technical Guide” (USDA Forest Service 2012). It was developed by National Forest System personnel and is available at:

http://www.fs.fed.us/biology/resources/pubs/watershed/FS_National_Core_BMPs_April2012.pdf

4.1.4 USDA-Natural Resources Conservation Service

Field Office Technical Guides (FOTGs) are the primary BMP scientific references for the Natural Resources Conservation Service (NRCS). They contain technical information about the conservation of soil, water, air, and related plant and animal resources. The FOTGs used in each field office are developed so that they are applicable to the geographic area for which they are prepared. The FOTGs contain sections titled: 1. General References, 2. Soil and Site Information, 3. Conservation Management Systems, 4. Practice Standards and Specifications, and 5. Conservation Effects. Individual State and County FOTGs can be found at the NRCS web site: http://efotg.sc.egov.usda.gov/efotg_locator.aspx

4.1.5 New Zealand

Best Management Practices for forestry in New Zealand are contained in the "New Zealand Environmental Code of Practice for Plantation Forestry" established and published by the New Zealand Forest Owners Association (NZFOA 2012). The Code was developed by FITEC (Forest Industry Training and Educational Council) and is available at: http://www.fitec.org.nz/COP/Preface.htm#nzcode.

The FITEC was established in 1992 under the Industry Training Act and merged with Competenz Forestry and Wood Manufacturing program in 2013.

4.1.6 State and Country Sources

Individual States within the USA and Australia, and countries in general, have their own specific BMPs for agriculture and forestry that focus on the unique and common biophysical and management characteristics of crop production systems. Detailed information on these BMPs can be obtained through on-line searches using search engines such as *Google* and *Bing*.

4.1.7 Scientific Journals

While there is no specific journal on BMPs, a good source for the scope and titles of journals can be found at the Thomson Reuters Master Journal List – Journal Search:

http://ip-science.thomsonreuters.com/cgi-bin/jrnlst/jlsearch.cgi?PC=MASTER&Error=1

Some of the more recent articles on BMPs have come from journals such as Environment International, Journal of Water Resources Planning and Management, Wiley Interdisciplinary Reviews in Environmental Science, Farming Systems Journal, Journal of the American Water Resources Association, Journal of the Soil Science Society of America, Journal of Environmental Quality, Water Environment Research, Water Resources Management, Rangeland Ecology and Management, and Forest Ecology and Management

4.2 Feedstock BMPs Discussed in This Report

The bioenergy feedstock BMPs are coded and listed as follows in Tables 6a, and 6c. The primary BMP codes are: FL – long rotation forests, AC - agriculture crops, WW – wood wastes, and BP – bioenergy production. The activity codes are: PL – planning, AQ – aquatic ecosystem activities, CU – chemical use, RxF – prescribed fire, RD – roads, VM – vegetation management, GH – biomass harvesting practices, MP – management practices, VT – vegetation and tillage management, SP – structural practices, EQ – equipment handling and maintenance, TL – treated lumber, WP _ wood pallets, CD – construction and debris facilities, CS – construction sites, CI – commercial and industrial, and OP – operations.

4.3 Long Rotation Wood Feedstock Production BMPs

The conventional forestry BMPs that were developed in the USA and other countries since the 1970s have been generally accepted as applicable to forest bioenergy systems (Shepard 2006, Neary 2013). However, some special considerations specific to the use of harvested woody material for bioenergy feedstocks need to be considered in order to achieve the goal of sustainable biofuels from forests (Buford and Neary 2010). Some of these considerations are accelerated removal of site biomass and nutrients, more common and frequent use of fertilizers, more frequent entry into stands with associated road improvements and better harvesting equipment, better stream crossing design and construction, greater site preparation, and intensified soil disturbance.

The range of BMPs for conventional woody biomass production is extensive. A summary of bioenergy feedstock BMPs and research needs can be found in Buford et al. 2011. They list 77 references for forestry BMPs.

Table 6a. Bioenergy feedstock production BMP types and codes, long rotation forests.

Code	Feedstock Type	Activity Code	BMP Activity Description	Numbers
FL	Long Rotation Forests	PL	Planning	
			Forest Planning	1
			Specific Project Planning	2
			SMZ Planning	3
FL	Long Rotation Forests	AQ	Aquatic Ecosystem Activities	
			Aquatic Area Planning	1
			Operations for SMZs	2
			Stream Channel Hydrology	3
			Stream Channel Structures	4
			Shorelines	5
FL	Long Rotation Forests	CU	Chemical use	
			Chemical Use Planning	1
			Label Directions Adherence	2
			Application Near Water	3
			Chemical Handling and Disposal	4
			Chemical Application Monitoring	5
FL	Long Rotation Forests	RxF	Prescribed Fire	
			Prescribed Fire Planning	1
			Pre-Fire Operations	2
			Fire Treatments	3
			Post-Fire Activities	4
FL	Long Rotation Forests	RD	Roads	
			Road Planning	1
			Road Location	2
			Road Pre-design	3
			Road Design	4
			Road Construction	5
FL	Long Rotation Forests	VM	Vegetation Management	
			Planning	1
			Erosion Prevention and Control	2
			Aquatic Zone Management	3
			Ground Skidding and Yarding	4
			Cable and Aerial Yarding	5

			Landings Operations	6
			Mechanical Site Preparation	7
FL	Long Rotation Forests	GH	Biomass Harvesting Practices	1

Table 6b. Bioenergy feedstock production BMP types and codes, agriculture.

Code	Feedstock Type	Activity Code	BMP Activity Description	Numbers
AC	Agriculture Crops	MP	Management Practices	
			Irrigation	1
			Nutrients	2
			Pests	3
			Riparian and Runoff	4
			Soil Salinity	5
			Manure	6
			Pasture	7
AC	Agriculture Crops	VT	Vegetation & Tillage Management	
			Conservation Tillage	1
			Contour Farming	2
			Crop Rotation	3
			Field Border Cover	4
			Field Strip & Ally Cropping	5
			Field Windbreaks	6
			Filter Strips	7
			Grasses & Legumes	8
			Green Manure Cropping	9
AC	Agriculture Crops	SP	Structural Practices	
			Diversions	1
			Grade Control	2
			Grass Waterways	3
			Sediment Basins	4
			Stream Stabilization	5
			Terraces	6
			Wetland Restoration	7
AC	Agriculture Crops	EQ	Equipment Handling & Maintenance	
			Pesticides and Fertilizers	1
			Fuels, Solvents, Paints, Oils, etc.	2

Table 6c. Bioenergy feedstock production BMP types and codes, wood wastes and bioenergy production.

Code	Feedstock Type	Activity Code	BMP Activity Description	Numbers
WW	Wood Wastes	TL	Treated Lumber	1
		WP	Wood Pallets	1
		CD	C&D Facilities	1
		CS	Construction Sites	1
		CI	Commercial and Industrial	1
BP	Bioenergy Production	PL	Planning	
			Feedstocks	1
			Location	2
			Design	3
			Energy	4
		OP	Operations	
			Water Management	1
			Waters and Emissions	2
			Plant Operations	3

The USDA Forest Service recently published its national BMP guide (USDA Forest Service 2012). The guide's objectives are to provide uniform direction to field units, improve water quality to restore impaired water resources, improve relationships with National and State regulatory agencies and the general public, improve the Forest Service's ability to clearly demonstrate progress in watershed management, improve the use of adaptive land management in forest plan implementation, establish a consistent process to monitor and evaluate the effectiveness of the BMPs, and improve compliance with Federal environmental laws. There are 11 National Core BMP categories, but only six directly relate to forest bioenergy operations. These are planning, aquatic ecosystems, chemical use, wildland fire, roads, and mechanical vegetation management. Each BMP is organized by title, reference, objective, explanation, and recommended practices. Not all the listed BMPs need to be utilized in every forest bioenergy program. They should be used as needed by forest managers and bioenergy engineers.

4.3.1 Bioenergy Planning

Planning is an important BMP in itself since the process identifies potential impacts to water quality and other resources such as soils, biodiversity (flora and fauna), and riparian areas (USDA Forest Service 2012). A critical part of planning BMPs is to include trained and qualified watershed specialists (hydrologists, soil scientists, geologists, fish biologists, and aquatic ecologists) to make up an interdisciplinary team for general and project planning. Planning is a critical part of forest bioenergy programs so these BMPs are very relevant. There are three National Core BMPs in the general planning category: Forests and Grasslands Planning, Project Planning and Analysis, and Aquatic Management Zone Planning. Examples of specific BMPs within the Project Planning and Analysis core BMP are listed in Table 7.

BMP-FL-PL-1 General Forest Planning: Establish desired conditions, goals, and objectives for soil, water quality, and riparian resources that contribute to the overall sustainability of social, economic, and ecological systems in the plan area consistent with established local or national water quality goals. The important components of this BMP are:

- Consider the water quantity, quality, location, and timing of flows needed to provide water supplies for municipal, agricultural, commercial, and industrial uses; hydropower generation; water recreation, transportation, and spiritual uses; aesthetic appreciation; and tourism to contribute to social and economic sustainability.

- Assess the water quantity, quality, location, and timing of flows needed to provide the ecological conditions to support diversity of native and desired nonnative plants and animal species in the plan area to contribute to ecological sustainability. Include plan objectives to maintain or, where appropriate, improve or restore watershed conditions to achieve desired conditions of soil, water quality, and riparian resources.

- Consider watershed characteristics, current and expected environmental conditions (including climate change), and potential effects of land uses when determining suitability of lands within the planning area for various uses. Include standards and guidelines to maintain and, where appropriate, improve over time the quality of soil, water resources, and riparian areas when implementing site-specific projects and activities.

- Include monitoring questions and associated performance measures to address watershed condition and water quality goals and objectives.

Table 7. Selected USDA Forest Service planning BMPs (USDA Forest Service 2012).

General Considerations	Specific BMPs
Water Quality (WQ) Management	Identify WQ management desired conditions and objectives
	Identify and evaluate the current condition of water resources
	Identify designated beneficial uses and critical WQ parameters
	Identify dams, water supplies, diversions, & other special uses
	Identify impaired water resources
	Identify aquatic threatened, endangered, & sensitive species
Potential Impacts to WQ	Assume hydrological connections exist surface to groundwater
	Consider impacts of current use
	Consider impacts of expected in climate
	Evaluate sources of water impairment - WQ, yield, floods, etc)
	Identify unstable areas and sensitive soils
	Identify soil limitations and productivity impacts
	Develop site-specific BMP prescriptions
	Consider enhanced BMPs
	Verify preliminary findings with field inspections
	Identify Federal, State, and local permit requirements
	Plan to limit surface disturbances
	Design specific Streamside Management Zones
	Plan minimal management impacts on unstable/sensitive soils

Use suitable tools to analyse cumulative watershed effects
Integrate restoration and rehabilitation needs into project plans
Identify monitoring needs
Clearly delineate protected or excluded areas on project maps

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BMP-FI-PL-2 Specific Project Planning: Include watershed specialists (hydrologist, soil scientist, geologist, and fish biologist) and other trained and qualified individuals on the interdisciplinary team for project planning, environmental analysis, and decision making to evaluate onsite watershed characteristics and the potential environmental consequences of the proposed activity(s). The important components of this BMP are:

- Determine water quality management objectives for the project area including identifying and evaluate the condition of water features in the project area (e.g., streams, lakes, ponds, reservoirs, wetlands, riparian areas, springs, groundwater-dependent ecosystems, recharge areas, and floodplains).
- Identify locations of dams and diversions for municipal or irrigation water supplies, fish hatcheries, stock water sources, fire protection, or other water uses within the project area.
- Identify threatened, endangered, or sensitive species in or near water, wetlands, and riparian areas in the project area and their habitat needs related to water quality.
- Determine potential or likely direct and indirect impacts to chemical, physical, and biological water quality, and watershed condition from the proposed activity.
- Use suitable tools to analyze the potential for cumulative effects to occur from the additive impacts of the proposed project and past, present, and reasonably foreseeable future activities on all lands within the project catchments. Integrate restoration and rehabilitation needs into the project plan.
- Identify project-specific monitoring needs.
- Document site-specific BMP prescriptions, design criteria, mitigation measures, and restoration, rehabilitation, and monitoring needs in the applicable documents, design plans, contracts, permits, authorizations, and operation and maintenance plans.

BMP-FL-PL-3 SMZ Planning: Develop site-specific SMZ BMP prescriptions for harvesting, transportation, reforestation, and other activities, as appropriate or when required, using local, regional, and national guidance, and property land management plan direction. Use of BMP monitoring information, and professional judgment is important. Proactively manage SMZs to maintain or improve long-term health and sustainability of riparian ecosystems and adjacent water resources body consistent with desired conditions, goals, and objectives in land management plan. The specific components of this BMP are:

- Determine the physical dimensions and layout of SMZs for water bodies in the project area that may be affected by the proposed activities. Use stream class and type, channel condition, aspect, side slope steepness, precipitation and climate characteristics, soil erodibility, slope stability, groundwater features, and aquatic and riparian conditions and functions to determine appropriate SMZ widths to achieve desired conditions (See Figure 9).

- Design and implement project activities to avoid or minimize unacceptable impacts to riparian vegetation, groundwater recharge areas, steep slopes, highly erodible soils, or unstable areas.

- Establish plans to maintain or provide sufficient ground cover to encourage infiltration, avoid or minimize erosion, and to filter pollutants.

- Develop plans to avoid, minimize, or restore detrimental soil compactions, and retain trees necessary for shading, bank stabilization, and as a future source of large woody debris. Project plans should include actions to retain floodplain function, and restore existing disturbed areas that are eroding and contributing sediment to water courses. Include plans to mark all SMZ boundaries and sensitive areas like riparian areas, wetlands, and unstable areas on the ground before land disturbing activities begin (See Figure 9).

4.3.2 Aquatic Ecosystems Activities

The purpose of this set of Best Management Practices (BMPs) is to avoid, minimize, or mitigate adverse effects to soil, water quality, and riparian resources that may result from road or skid trail construction and maintenance activities in flowing and ephemeral aquatic ecosystems (USDA Forest Service 2012). Properly functioning streams, lakes, riparian areas, and wetlands are critical in maintaining water quality, water quantity, riparian habitat, aquatic fauna populations and diversity, and downstream beneficial uses.

BMP-FL-AQ-1 Aquatic Area Planning: This BMP tiers off of the Planning BMPs (BMP-FL-PL-1 through BMP-FL-PL-3). A rigorous approach that uses a combination of best available science and professional experience to inform planning is necessary to enhance the potential for long-term success. When planning aquatic ecosystem projects, it is important to understand all the factors that may affect the watershed currently and in the future.

BMP-FL-AQ-2 Operations for SMZs: Develop site-specific BMP prescriptions for SMZ areas following planning BMP guidelines:

- Identify aquatic and aquatic-dependent species that live in potentially affected water bodies, SMZs, or on floodplains to determine protection strategies, such as timing of construction, sediment management, species relocation, and monitoring during construction.

- Coordinate stream channel, shoreline, lake, pond, and wetland activities with appropriate water management agencies. Use suitable measures to protect the water resources when preparing sites for construction, operations, or maintenance activities.

- Clearly delineate work areas and locate equipment access and staging areas near the project site but outside of work area boundaries, SMZs, wetlands, and sensitive soil areas. Refuel and service equipment only in designated staging areas.

- Develop an erosion and sediment control plan to avoid or minimize downstream impacts using measures appropriate to the site and the proposed activity.
- Prepare for unexpected failures of erosion control measures.

- Consider needs for solid waste disposal and worksite sanitation.

- Use small, low ground pressure equipment, and hand labor where practicable.

- Ensure that all equipment operated in or adjacent to aquatic areas is clean of aquatic invasive species, as well as oil and grease, and is well maintained.

- Schedule construction or maintenance operations to occur in the least critical periods for sensitive aquatic and aquatic-dependent species and avoid known high flow periods.

Specific measures include:

- Protect water courses with silt fencing, straw bales, straw wattles, or soil berms during clearing (Figures 15a, b, and c).

- Clearly delineate the geographic limits of the area to be cleared.

- Avoid or minimize unacceptable damage to existing streambank vegetation,

- Use suitable drainage measures to improve the workability and trafficability of wet sites including culverts, drainage channels, and metal mats.

- Use vegetable oil or other biodegradable hydraulic oil for heavy equipment hydraulics wherever practicable when operating in or near water.

- Minimize heavy equipment entry into or crossing water as is practicable.

- Conduct operations during dry periods.

- Stage construction operations as needed to limit the extent of disturbed areas without installed stabilization measures.

- Promptly install and appropriately maintain erosion control measures such as straw wattles (Figure 15a), silt fences (Figure 15b), storm runoff detention basins (Figure 16), road turnouts (Figure 17), broad-based dips, etc.

- Promptly rehabilitate or stabilize disturbed areas as needed following construction or maintenance activities.

- Stockpile and protect topsoil for reuse in site re-vegetation.

- Minimize bank and riparian area excavation during construction to the extent practicable.

- Keep excavated materials out of wet areas.

- Use only clean, suitable fill materials

- Properly compact fills to avoid or minimize erosion.

- Balance cuts and fills to minimize disposal needs.

- Identify suitable areas offsite or away from water areas for disposal sites before beginning operations.

- Remove all project debris from the waterbody in a manner that will cause the least disturbance.

- Contour sites to disperse runoff, minimize erosion, stabilize slopes, and provide a favorable environment for plant growth. Use suitable species and establishment techniques to revegetate the site in compliance with local direction and plan requirements.

- Use suitable measures to divert or partition channelized flow around construction sites or dewater sites as needed to the extent practicable.

a) Straw Wattles

b) Silt Fence

c) Silt Fence

Figure 15. Water course protection measures: a) Straw wattles, b) Silt fence close-up. C) silt fence installation along a disturbed forest area. Photos courtesy of the USDA Natural Resources Conservation Service).

Figure 16. Storm runoff detention basin utilizing a constructed road fill, Cibola National Forest, New Mexico. (Photo by Roy Jemison).

Figure 17. Constructing a road turnout, Apalachicola National Forest, Florida. (Photo by Daniel G. Neary).

Figure 18. Broad-based dip in a forest road near South River, Virginia. (Photo by Matthew Yancey).

BMP-FL-AQ-3 Stream Channel Hydrology: Develop site-specific prescriptions for these areas following planning BMPs and BMP-FL-AQ-2 guidelines (USDA Forest Service 2012). Determine stream specific hydrologic and geomorphic characteristics including:

- Type and classification of stream channels using suitable accepted protocols (Rosgen 1996, Montgomery and Buffington 1998, or others; Figure 19).
- Channel grade to avoid or minimize erosion of channel bed and banks before selecting measures for bank stabilization or protection. Incorporate grade control measures into project design as needed.
- Design flows based on the value or safety of area to be protected, repair cost, and the sensitivity and value of the ecological system involved.
- Peak flow, low flow, channel forming flow, and flow duration estimates. Use these estimates to determine the best time to implement the project, as well as to select design flows.

The BMP analysis should determine design velocities appropriate to the site, and limit maximum velocity to the velocity that is non-scouring on the least resistant streambed and bank material. Consideration should be given to flow needs to transport bedload through the reach. Efforts should be made to maintain the depth-area-velocity relationship of the upstream channel through the project reach. The effects of design velocities on desired aquatic organism habitat and passage should be evaluated.

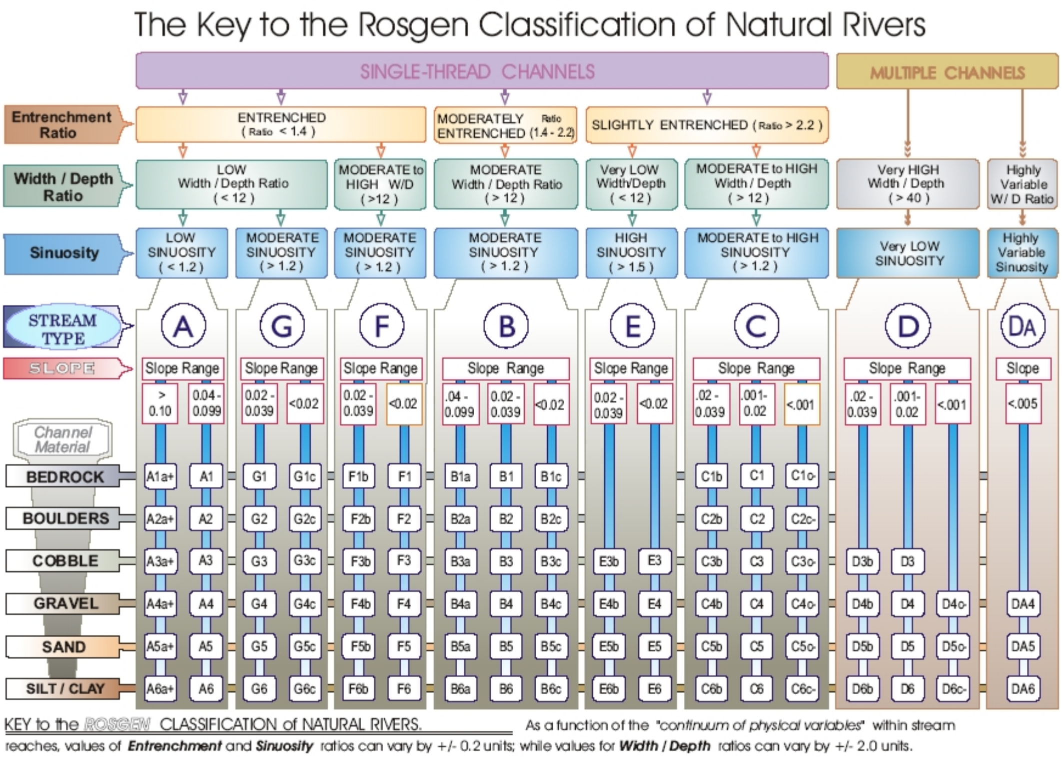


Figure 19. Classification system for natural rivers according to Rosgen (1996) (From Endrenny 2003).

BMP-FL-AQ-4 Stream Channel Structures: Every attempt should be made to avoid changing channel alignment unless the change is to reconstruct the channel to a stable meander geometry consistent with stream type. In-stream and streambank stabilization and protection measures should be designed so they are suitable to channel alignment (straight reach versus curves). The potential effects of ice and freeze and thaw cycles on streambank erosion processes need to be evaluated. BMP design analysis should consider the effects that structures may have on downstream structures and stream morphology, including streambanks, in order to maintain natural streambeds. It is important to:

- Design channels with natural stream pattern and geometry and with stable beds and banks.
- Provide habitat complexity where reconstruction of stream channels is necessary.
- Consider sediment load (bedload and suspended load) and bed material size to determine desired sediment transport rate when designing channels.
- Design and construction of channel structures should avoid relocating natural stream channels. If channels are relocated temporarily, return flow to natural channels should be done, where practicable.
- Include suitable measures to protect against erosion around the edges of stabilization structures.
- Design revetments and similar structures to include sufficient freeboard to avoid or

- minimize overtopping at curves or other points where high-flow velocity can cause waves.

- Use suitable measures to avoid or minimize water forces undermining the toe of structures. In-stream structures should be tied into stable anchorage points, such as bridge abutments, rock outcrops, or well-vegetated stable sections, to avoid or minimize erosion around the ends.

Figure 20. Woody debris left in a stream channel to improve fish habitat. (From River Design Group Inc.)

- Add or remove rocks, wood, or other material in streams only if such action maintains or improves stream condition, provides for safety and stability at bridges and culverts, is needed to avoid or minimize excessive erosion of streambanks, or reduces flooding hazard (Figure 20). Leave rocks and portions of wood that are embedded in beds or banks to avoid or minimize channel scour and maintain natural habitat complexity.

- Choose vegetation appropriate to the site to provide streambank stabilization and protection adequate to achieve project objectives.

BMP-FL-AQ-5 Shorelines: Develop site-specific BMP prescriptions for shorelines following planning BMP, BMP-FL-AQ-2, BMP-FL-AQ-4 guidelines (USDA Foerst Service 2012). Use mean high- and low-water levels to determine the design water surface, and consider the effects of fluctuating water levels, freeze or thaw cycles, and floating ice on erosion processes at each site. Design stabilization and protection measures suitable to the site. Determine the shoreline slope configuration above and below the waterline. Consider the effects of offshore depth, dynamic wave height, and wave action on shoreline erosion processes. The nature of the bank soil material should be determined to aid in estimating erosion rates. Consider the rate, direction, supply, and seasonal changes in littoral transport when choosing the location and design of structural measures. Evaluate the effect structures may have on adjacent shoreline or other nearby structures. Use vegetation species and establishment methods suitable to the project site and objectives and consistent with local direction and plan requirements. Adequately anchor end sections to existing stabilization measures or terminate in stable areas.

4.3.3 Chemical Use

The purpose of this set of Best Management Practices (BMPs) is to avoid or minimize unacceptable impacts to water quality conditions that may result from application of chemicals used to manage biological and physical resources (USDA Forest Service 2012). Chemical treatments are applied to kill, attract, repel, defoliate, stimulate, or retard biologic growth with the intent to mitigate, control, grow, or kill the target organism. They may also be applied to ameliorate, neutralize, or stabilize certain physical resources such as soil or water chemistry. Chemical treatments include application of pesticides such as insecticides, herbicides, fungicides, nematicides, rodenticides, and piscicides. Chemical treatments also include fertilizers, fire retardants (a topic germane to wildland fire control and suppression), dyes, or other materials used in tracer studies, aggregate additives like salt, magnesium chloride, and other substances used for dust abatement, roadbed stabilization, or de-icing of roadways, and other chemical products that can be used to fulfill specific management objectives. Forest bioenergy programs are most likely to use herbicides and fertilizers but not in every location and under every forest management regime.

BMP-FL-CU-1 Chemical Use Planning: Develop site-specific BMP prescriptions for the following practices, as appropriate or when required, using land management plan direction, BMP monitoring information, and professional judgment. Use applicable practices of BMP-FL-PL-1 Forest Planning, BMP-FL-PL-2 Specific Project Planning, and BMP-FL-AQ-2 Aquatic Area Operations for SMZs when planning activities that involve use of chemicals.

- Carefully identify municipal supply watersheds; private domestic water supplies; fish hatcheries; and threatened, endangered, and sensitive aquatic dependent species and fish populations near or downstream of chemical treatment areas.

- Use Integrated Pest Management as the basis for all pesticide-use prescriptions in consultation with pesticide use professionals.

- Select chemical products suitable for use on the target species or that meet project objectives.

- Consult Materials Safety Data Sheets and product label for information on use, hazards, and safe handling procedures for chemicals products under consideration for use.

- Consider chemical solubility, absorption, breakdown rate properties, and site factors when determining which chemical products to use. Use herbicide chemicals with properties such that soil residual activity will persist only as long as needed to achieve treatment objectives.

- Always consider soil type, chemical mobility, distance to surface water, and depth to groundwater to avoid or minimize surface water and groundwater contamination.

- Use an appropriate application equipment, suitable system pressure, nozzle size, and nozzle type combination to minimize off-target drift or droplet splatter. Use selective treatment methods for target organisms to the extent practicable.

- Specify management direction and appropriate site-specific response measures in project plans and safety plans. Ensure that planned chemical use projects conform to all applicable local, regional, and national laws, regulations, and policies. Develop spill contingency plans and obtain or provide training and licensing as required by the label and government regulations.

BMP-FL-CU-2 Pesticide Label Directions Adherence: Incorporate constraints identified on the label and other legal requirements of application into project plans and contracts. Be aware that some government regulatory agencies may have more restrictive requirements than those indicated on the label instructions (Figure 21).

- Use fully trained and certified individuals equipped with appropriate personal protective equipment to apply chemical treatments.

- Notify contractor's field supervisor when violations of label or project requirements have occurred.

- Stop operations that pose a safety hazard or when violations of project requirements have not been rectified.

- Report label violations to the appropriate enforcement agency. Respond to and report spills and other accidents.

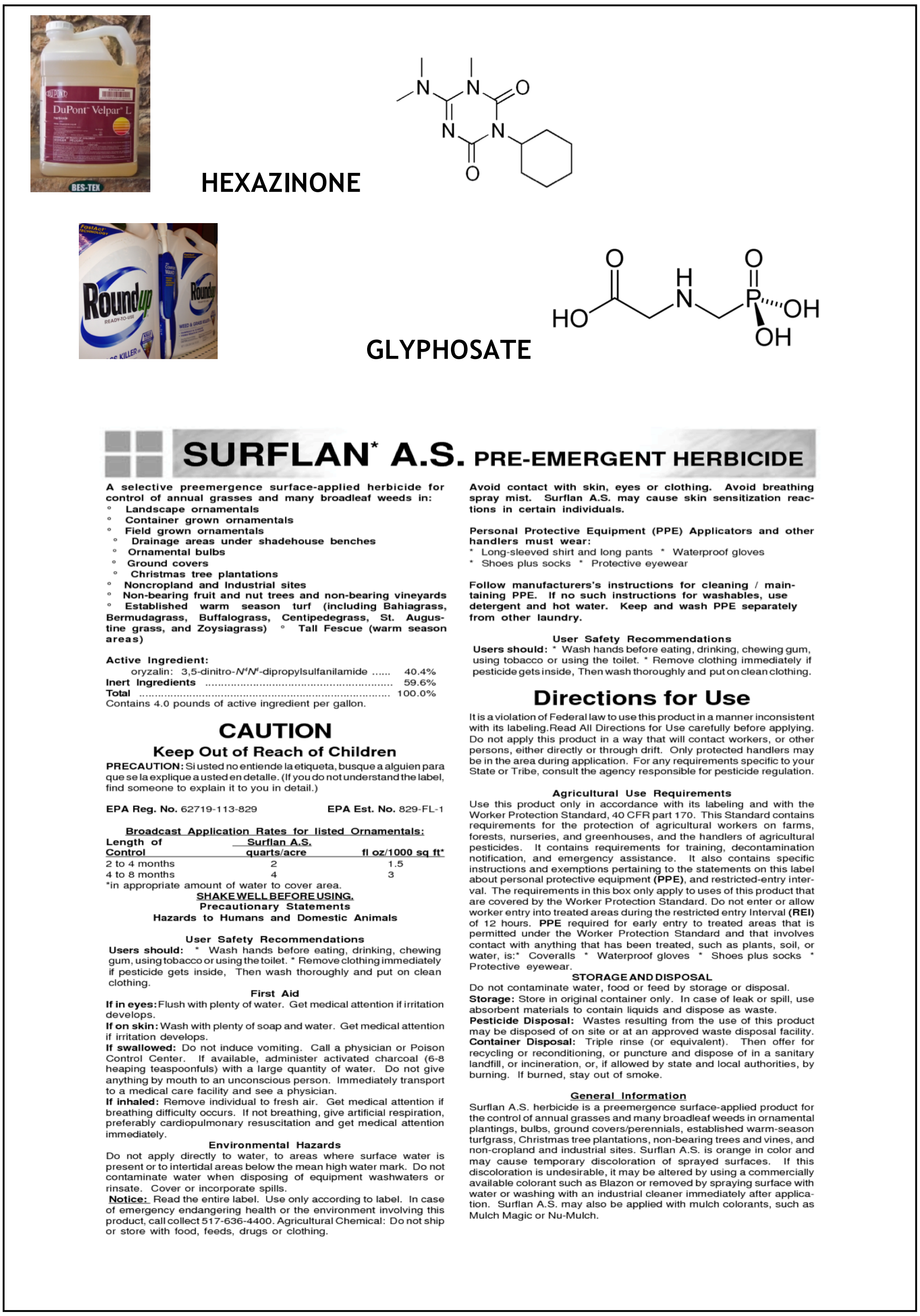


Figure 21. Pesticide labels on containers have information on active ingredients, safety, and directions for use.

BMP-FL-CU-3 Pesticide Application Near Water Resources: Develop site-specific BMP prescriptions for the following practices, as appropriate or when required, using land management plan direction, BMP monitoring information, and professional judgment. Identify during project planning those perennial and intermittent surface waters, wetlands, springs, riparian areas, and groundwater recharge areas that may be impacted by the chemical use. Use field observations to verify the extent of these areas identified from aerial observations, maps, or geographic information system data, as needed. Specific actions in this BMP include:

- Determine the width of a herbicide application buffer zone, if needed, based on a review of the project area, characteristics of the chemical to be used, and application method.

- Consider the designated uses of water, adjacent land uses, expected rainfall, wind speed and direction, terrain, slope, soils, and geology in application planning.

- Consider the persistence, mobility, toxicity profile, and bioaccumulation potential of any chemical formulation proposed for use.

- Consider the type of equipment, spray pattern, droplet size, application height, and experience in similar projects (Figure 22).

- Prescribe chemicals and application methods in the buffer zone suitable to achieve project objectives while minimizing risk to water quality.

- Mark or identify buffer zones as needed with flagging, balloons, or other easily identified material.

- Clearly communicate to those applying the chemical what areas are to be avoided or where alternative treatments are to be used.

- Locate helicopter operation bases on upland areas, outside of wetlands or areas with channel or ditch connection to surface water and SMZs. Base fixed-wing aircraft at airports as near as possible to application sites.

- Use clean equipment and personnel to collect water needed for mixing. Calibrate application equipment to apply chemicals uniformly and in the correct quantities.

- Evaluate weather conditions before beginning spray operations and monitor throughout each day to avoid or minimize chemical drift.

- Apply chemicals only under favorable weather conditions as identified in the label instructions. Avoid applying chemicals before forecasted severe storm events to limit runoff and ensure the chemical reaches intended targets. Suspend operations if project prescription or weather limitations have been exceeded.

- Apply fertilizers during high nutrient-uptake periods to avoid or minimize leaching and translocation. Base fertilizer type and application rate on soils and foliar analysis. Use slow release fertilizers that deliver fertilizer to plants during extended periods in areas with long growing seasons when appropriate to meet project objectives.

Figure 22. Forestry herbicide application equipment (Photos By James H. Miller, USDA Forest Service, Bugwood.org).

- Monitor during chemical applications to determine if chemicals are reaching surface waters.

- Implement chemical spill contingency plan elements within the project safety plan if a spill occurs

BMP-FL-CU-4 Chemical Handling and Disposal: Transport and handle chemical containers in a manner that minimizes the potential for leaks and spills. Inspect containers for leaks or loose caps or plugs before loading. Secure containers properly to avoid or minimize shifting in transport. Check containers periodically enroute. Ensure arrangements for proper storage are in place before transporting chemicals. Manage and store chemicals in accordance with all applicable governmental regulations, including label directions. Only store the amount of chemicals needed for near-term applications. Store chemicals in their original containers with labels intact. Locate chemical storage facilities at sites that minimize the possibility of impacts to surface water or groundwater in case accidents or fires occur. Dedicated pesticide storage buildings should be used or built and maintained if large amounts of chemical are stored (Figure 23). At a minimum, ensure that containment of a complete spill from the largest container being stored is possible with the spill-kit materials at the storage site.

Figure 23. Dedicated pesticide storage building (Photo courtesy of USDA Forest Service - Region 8 - Southern Archive, Bugwood.com).

BMP-FL-CU-5 Chemical Application Monitoring: Monitoring of chemical applications is used to evaluate and document chemical application accuracy, amount, and effects on soils and water quality to reduce or eliminate hazards to non-target biological or physical resources. Monitoring can occur before, during, and after chemical application depending on treatment objectives and monitoring questions. Monitoring methods may include any of the following: visual observations; vegetation surveys; use of spray cards; dye tracing (fluorometry); and sampling of water, soil, sediment, flora, or fauna to measure chemical presence in or near water (Figure 24). Monitoring needs and methods are determined in the project planning process and should consider treatment objectives; resource values at risk; chemical properties; potential for offsite movement; government regulatory requirements; monitoring costs; and available project funding.

Figure 24. Well monitoring of pesticides in groundwater in Wyoming (Photo courtesy of the U.S. Geological Survey).

Identify the following elements in all water resource monitoring plans and specify the rationale for each:

- What are the monitoring questions?
- Who will be involved and what are their roles and responsibilities?
- What parameters will be monitored and analyzed?
- When and where will monitoring take place?
- What methods will be used for sampling and analyses?
- How will Chain of Custody requirements for sample handling be met?
- What are the criteria for quality assurance and quality control?
- There are a number of important factors to consider when developing monitoring questions:
- The physical or biological resource of concern, including human health.
- Applicable local and national laws and regulations.
- Type of chemical.
- Type of application equipment used and method of application.
- Site-related difficulties that affect both application and monitoring.

- Public concerns.
- Potential benefits of the application.
- Availability of analytic methods, detection limits, tools, and laboratories.
- Costs of monitoring and resources available to implement monitoring plan.

Choose monitoring methods and sample locations suitable to address the monitoring questions.

- Consider the need to take random batch or tank samples for future testing in the event of treatment failure or an unexpected adverse effect.
- Monitor sensitive environments during and after chemical applications to detect and evaluate unanticipated events.
- Use certified laboratories for chemical sample analysis and appropriate containers, reservation, and transportation to meet Standard Methods requirements.
- Implement proper Chain of Custody procedures for sample handling.
- Evaluate and interpret the results of monitoring in terms of compliance with, and adequacy of, treatment objectives and specifications.

4.3.4 Prescribed Fire

BMP-FL-RxF-1 Prescribed Fire Planning: Use applicable practices of BMP-FL-PL-1 Forest Planning, BMP-FL-PL-2 Specific Project Planning, and BMP-FL-AQ-2 Aquatic Area Operations for SMZs when planning prescribed fire treatments (USDA Forest Service 2012). Consider prescription elements and ecosystem objectives at the appropriate catchment scale to determine the optimum and maximum burn unit size, total burn area, burn intensity, disturbance thresholds for local downstream water resources, area or length of water resources to be affected, and contingency strategies. Consider the extent, severity, and recovery of fire disturbance a catchment or stand watershed has experienced in the past to evaluate cumulative effects and re-entry intervals.

Identify environmental conditions favorable for achieving desired condition or treatment objectives of the site while minimizing detrimental mechanical and heat disturbance to soil and water considering the following factors:

- Existing and desired conditions for vegetation and fuel type, composition, structure,distribution, and density.
- Short- and long-term site objectives.
- Acceptable fire weather parameters.
- Desirable soil, duff, and fuel moisture levels.
- Existing duff and humus depths.

- Site factors such as slope and soil conditions.
- Expected fire behavior and burn severity based on past burn experience in vegetation types in the project area.
- Extent and condition of roads, fuel breaks, and other resource activities and values.

Develop burn objectives that avoid or minimize creating water-repellent soil conditions to the extent practicable considering fuel load, fuel and soil moisture levels, fire residence times, and potential burn severity. Use low-severity prescribed fire on steep slopes or highly erodible soils when prescribed fire is the only practicable means to achieve project objectives in these areas. Set target levels for desired ground cover remaining after burning based on slope, soil type, and risk of soil and hillslope movement. Plan burn areas to use natural or in-place barriers that reduce or limit fire spread, such as roads, canals, utility rights-of-way, barren or low fuel hazard areas, streams, lakes, or wetland features, where practicable, to minimize the need for fireline construction. Identify the type, width, and location of firebreaks or firelines in the prescribed fire plan. Use fire initiation techniques, control methods, and access locations for ignition and control (holding versus escape conditions) that minimize potential effects to soil, water quality, and riparian resources. Use prescribed fire in SMZs only when suitable to achieve long-term SMZ-desired conditions and management objectives.

BMP-FL-RxF-2 Prescribed Fire Use, Pre-Fire Operations: Conduct the prescribed fire in such a manner as to achieve the burn objectives outlined in the BMP-FL-RxF-1 Prescribed Fire Planning BMP. Identify safety zones and locate access routes and staging areas near the project site but outside of SMZs, wetlands, and sensitive soil areas. Keep staging areas as small as possible while allowing for safe and efficient operations. Store fuel for ignition devices in areas away from surface water bodies and wetlands. Install suitable measures to minimize and control concentrated water flow and sediment from staging areas. Collect and properly dispose of trash and other solid waste. Restore and stabilize staging areas after use. Conduct prescribed fires to minimize the residence time over the soil while meeting the burn objectives. Manage fire intensity to maintain target levels of soil temperature and duff and residual vegetative cover within the limits and at locations described in the prescribed fire plan. For fireline establishment follow these guidelines:

- Construct firelines to the minimum size and standard necessary to contain the prescribed fire and meet overall project objectives (Figure 25).
- Locate and construct firelines in a manner that minimizes erosion and runoff from directly entering water resources by considering site slope and soil conditions, and using and maintaining suitable water and erosion control measures.

Figure 25. Igniting a prescribed fire along a constructed fireline. (Photo by James H. Miller, USDA Forest Service, Bugwood.org)

- Consider alternatives to ground-disturbing fireline construction such as using wet lines, rock outcrops, or other suitable features for firelines.
- Establish permanent firelines with suitable water and erosion control measures in areas where prescribed fire treatments are used on a recurring basis.
- Maintain firebreaks in a manner that minimizes exposed soil to the extent practicable.
- Rehabilitate or otherwise stabilize firelines in areas that pose a risk to water quality.
- Avoid building firelines in or around riparian areas, wetlands, marshes, bogs, fens, or other sensitive water-dependent sites unless needed to protect life, property, or wetlands.
- Construct any essential fireline in the SMZ in a manner that minimizes the amount of area and soil disturbed.
- Alter prescribed fire prescriptions and control actions in the SMZs as needed to maintain ecosystem structure, function, and processes and onsite and downstream water quality.
- Pretreat SMZs and drainage ways to reduce excessive fuel loadings. Keep high-intensity fire out of SMZs unless suitable measures are used to avoid or minimize adverse effects to water quality.

BMP-FL-RxF-3 Prescribed Fire Use, Fire Treatments: Conduct prescribed fire treatments, including pile burning, for slash disposal in a manner that encourages efficient burning to minimize soil impacts while achieving treatment objectives.

- Pile and burn only the slash that is necessary to be disposed of to achieve treatment objectives.

- Locate slash piles in areas where the potential for soil effects is lessened (meadows, rock outcrops, etc.) and that do not interfere with natural drainage patterns.

- Remove wood products such as firewood or fence posts before piling and burning to reduce the amount of slash to be burned.

- Minimize the amount of dirt or other non-combustible material in slash piles to promote efficient burning.

- Construct piles in such a manner as to promote efficient burning. Avoid burning large stumps and sections of logs in slash piles to reduce the amount of time that the pile burns.

- Avoid burning when conditions will cause the fire to burn too hot and damage soil conditions.

- Avoid piling and burning for slash removal in SMZs to the extent practicable.

- Minimize effects on soil, water quality, and riparian resources by appropriately planning pile size, fuel piece size limits, spacing, and burn prescriptions in compliance with government laws and regulations if no practical alternatives for slash disposal in the SMZ are available.

- Avoid or minimize complete removal of the organic layer when burning in riparian areas or wetlands to maintain soil productivity, infiltration capacity, and nutrient retention.

BMP-F-RxF-4 Prescribed Fire Use, Post-Fire Activities: Rehabilitate firelines in SMZs after prescribed fire treatment is completed. Remove debris added to stream channels as a result of prescribed burning unless debris is prescribed to improve fisheries habitat. Evaluate the completed burn to identify sites that may need stabilization treatments or monitoring to minimize soil and site productivity loss and deterioration of water quality both on and off the site. Provide for rapid restoration of all denuded areas through natural processes supplemented by artificial revegetation where necessary. Use suitable measures to promote water retention and infiltration or to augment soil cover where necessary. Use suitable species and establishment techniques to stabilize the site in compliance with local requirements for vegetation ecology and prevention and control of invasive species. Clear streams and ditches of debris introduced by fire control equipment during prescribed fire operations. Consider long-term management of the site and nearby areas to promote project success. Use suitable measures to limit human, vehicle, and livestock access to site as needed to allow for recovery of vegetation.

4.3.5 Road Management

Roads are the single largest sources of sediment inputs into forest streams so planning and management of roads is very important (Forman and Alexander 1998, Neary 2002, Kellar and Sherar 2003, USDA Forest Service 2012). The term “road” encompasses paved primary highways, paved secondary roads, graveled secondary roads, permanent forest and farm roads, temporary biomass harvest roads, and temporary access trails (Figure 26). Forest road management related planning includes travel analyses as well as consideration of road management objectives and maintenance levels to address access needs and adjustments for projects.

Planning occurs at scales that range from forest-wide assessments and plans, to catchment scale or project-level analyses, to individual road activities. Effects to soil, water quality, and riparian resources are evaluated during planning and balanced with the social, economic, and land management needs of the area. Appropriate protection and mitigation measures are considered when soil, water quality, and riparian resources may be adversely impacted. Thus road BMPs are some of the most important relative to forest bioenergy.

Road Management Objectives should be developed and documented for each system and non-system road and include the intent and purpose in providing access to implement forest bioenergy objectives. The key objectives of Best Management Practices for roads were elucidated in Keller and Sherar’s (2003) publication on low volume roads engineering for Best Management Practices (Table 8). In addition to considering route needs at the site scale, these objectives also document the purpose of each road (access needs) along with operational maintenance levels and objectives. A flow chart of this process is shown in Figure 27.

BMP-FL-RD-1 Road Planning: Use applicable practices of BMP-FL-P-1 Forest Planning, BMP-FL-P-2 Specific Project Planning, and BMP-FL-A-2 Aquatic Area Operations for SMZs when planning roads. Use interdisciplinary coordination for road planning and project-level transportation analysis, including engineers, hydrologists, soil scientists, and other resource specialists as needed, to balance protection of soil, water quality, and riparian resources with transportation and access needs. Design the transportation system to meet long-term land management plan desired conditions, goals, and objectives for access rather than to just provide a means of entry into individual sites (Figure 27). Limit roads to the minimum practicable number, width, and total length consistent with the purpose of specific operations, local topography, geology, and climate to achieve land management plan desired conditions, goals, and objectives for access and water quality management.

Figure 26. Examples of forest roads.

Table 8. Ten key objectives of road Best Management Practices (From Kellar and Sherar 2003).

Objective Number	Description
1	Produce a safe, cost effective, environmentally sound, and practical road design that is supported by and meets the needs of users.
2	Protect water quality and reduce sediment loading into water bodies
3	Avoid conflicts of land use
4	Protect sensitive areas and reduce ecosystem impacts
5	Maintain natural channels and stream flow, and maintain passage for aquatic organisms.
6	Minimize ground and drainage channel disturbance
7	Control surface water on roads and stabilize driving surfaces
8	Implement slope stabilization measures to reduce mass wasting
9	Avoid problem areas
10	Extend the useful life of roads

- Use existing roads when practicable.

- Utilize forest system roads (Figure 28) where access is needed for long-term management of an area or where control is needed in the location, design, or construction of the road to avoid, minimize, or mitigate adverse effects to soil, water quality, and riparian resources.

- Use temporary roads for short-term access needs if the road can be constructed, operated, and obliterated without specific control of techniques to avoid, minimize, or mitigate adverse effects to soil, water quality, and riparian resources
- Decommission temporary roads and return to resource production when the access is no longer needed

- Evaluate placing roads "in storage" when the time between intermittent uses exceeds 1 year and the costs of annual maintenance (both economic and potential disturbance) or potential failures due to lack of maintenance exceed the benefits of keeping the road open in the interim.

- Decommission unneeded existing roads within a planning area when planning new system roads to reduce cumulative impacts to soil, water quality, and riparian resources.

- Design road networks to have the minimum number of water crossings as is practicable and necessary to achieve transportation system desired conditions, goals, and objectives.

- Develop or update plans and objectives for each system road to include design criteria, operation criteria, and maintenance criteria to avoid, minimize, or mitigate adverse effects to soil, water quality, and riparian resources.

- Identify and evaluate road segments causing, or with the potential to cause, adverse effects to soil, water quality, and riparian resources. Then identify and prioritize suitable mitigation measures to avoid, minimize, or mitigate adverse effects.

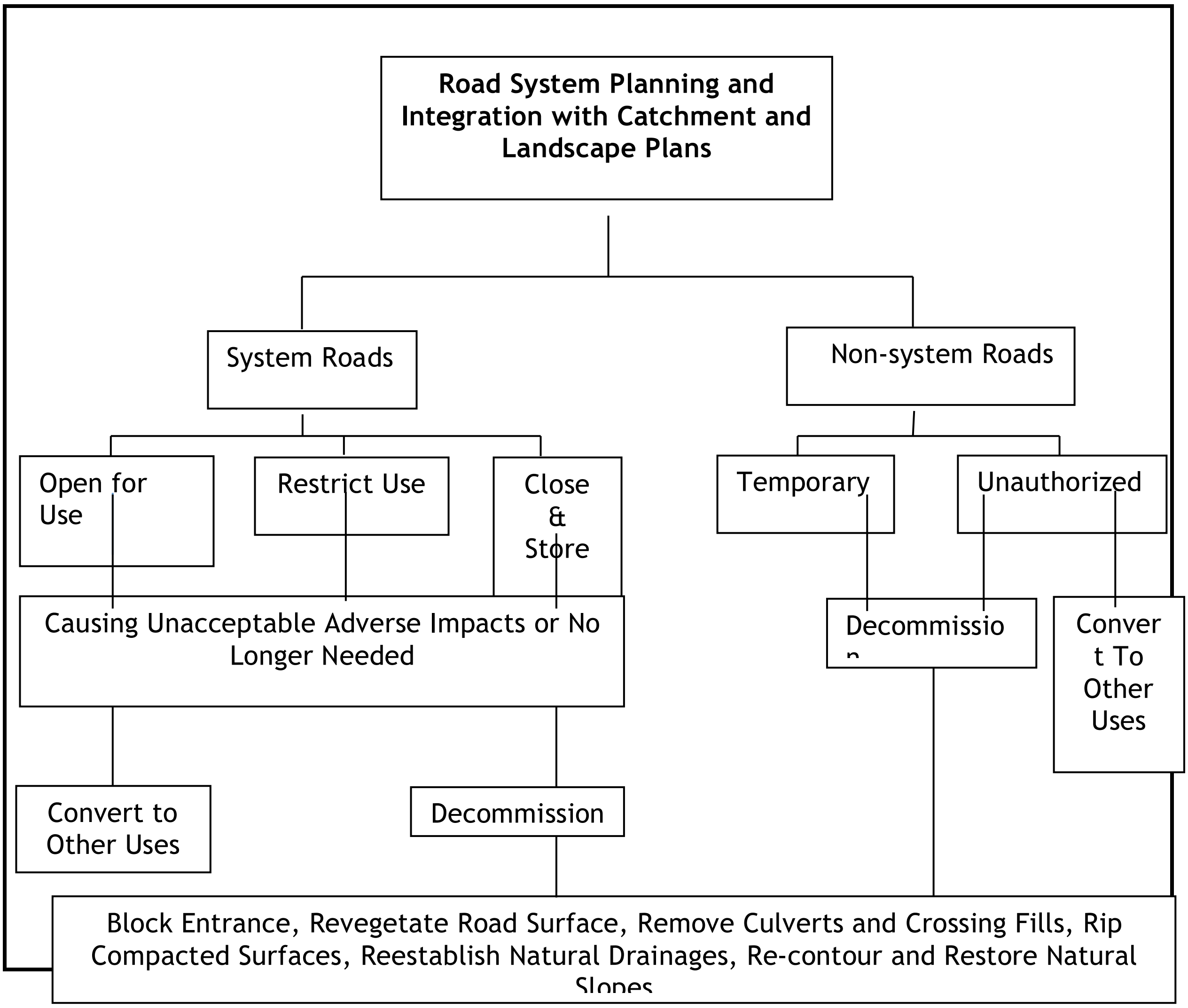


Figure 27. USDA Forest Service road planning options (USDA Forest Service 2012).

a) Primary Road

b) Secondary Road

Figure 28. Typical forest system roads: a) primary (Photo by Billy Humphries, Forest Resource Consultants, Inc., Bugwood.org), and b) secondary (Photo by Doug Page, USDI Bureau of Land Management, Bugwood.org).

BMP-FL-RD-2 Road Location: Locate roads to fit the terrain, follow natural contours, and limit the need for excavation. Avoid locations that require extended steep grades, sharp curves, or switchbacks. Locate roads on stable geology with well-drained soils and rock formations that dip into the slope. Avoid hazard areas such as hydric soils, inner gorges, overly steep slopes, and unstable landforms to the extent practicable. Position roads as far from water resources as is practicable to achieve access objectives for forest bioenergy, with a minimum number of crossings and connections between roads and the water bodies.

- Avoid sensitive areas such as riparian areas, wetlands, meadows, bogs, and fens, to the extent practicable.
- Provide a SMZ of suitable width between the road and a water resource to maintain desired conditions, goals, and objectives for structure, function, and processes of the SMZ and associated waters when a road must parallel the water ways (Figures 5, 6, 8, and 9).
- Relocate existing routes or segments that are causing, or have the potential to cause, adverse effects to soil, water quality, and riparian resources, to the extent practicable (Figure 29).

- Obliterate existing problem roads or segments after the relocated section is completed.

BMP-FL-RD-3 Road Pre-design: Consider design criteria relative to soil, water quality, and riparian resources from the decision document. Evaluate the road objectives and likely future maintenance schedule in the initial design. Implement suitable site investigations, data collection, and evaluations commensurate with the anticipated design and sensitivity of the area to soil, water quality, and riparian resource impacts. Examine subsurface conditions and conduct suitable investigations and stability analyses for road and bridge locations where slope instability can occur due to road construction. Carry out a suitable soils and geotechnical evaluation to identify susceptibility to erosion and stable angles of repose.

Figure 29. Rutting and eroded road segment causing sediment and water quality problems. (Photo by Dave Powell, USDA Forest Service, Bugwood.com).

BMP-FL-RD-4 Road Design: Many problems associated with road effects on water resources can be avoided by proper design. Some of the key design practices are:

- Design the road to fit the ground and terrain with the least practicable impacts to soil, water quality, and riparian resources considering the purpose and life of the road, safety, and cost.
    - Use road standards that minimize impacts for grade and alignment (e.g., width, turning radius, and maximum slope).
    - Use low impact development treatments that reduce long-term maintenance needs wherever practicable.
- Design the road to maintain stable road prism (Figure 30), cut, and fill slopes.
    - Design cut and fill slope ratios to reduce soil loss from mass failures.

- Use structural or nonstructural measures as necessary to stabilize slopes.

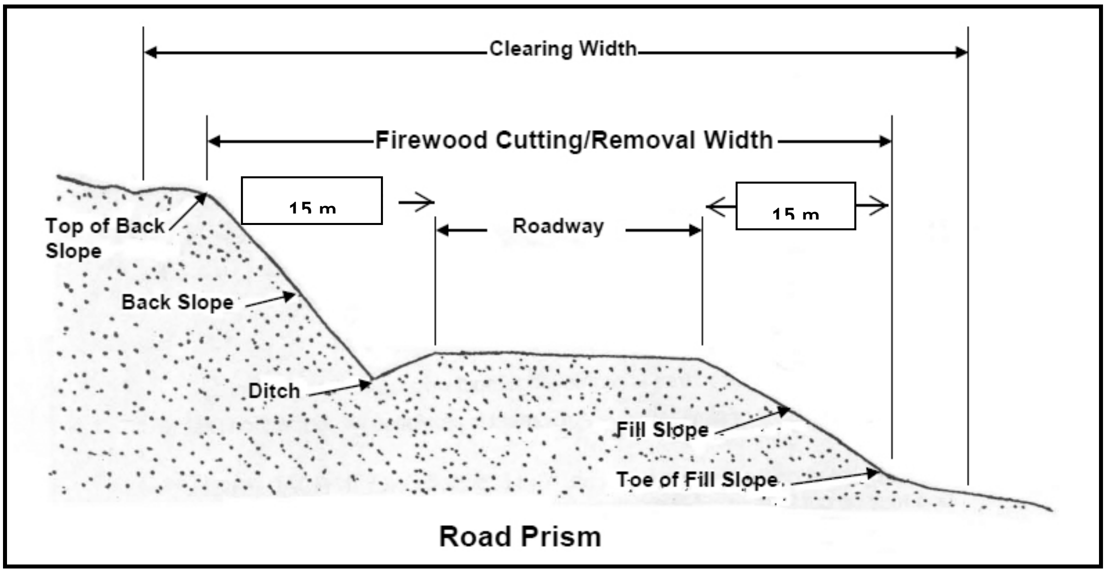


Figure 30. Constructed road prism (USDA Forest Service 2012).

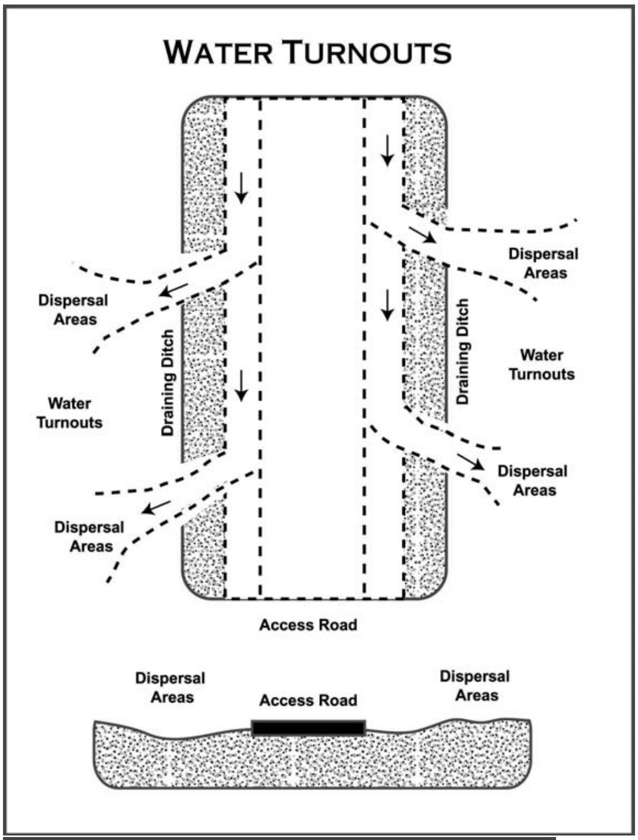
- Design the road surface drainage system to intercept, collect, and remove water from the road surface and surrounding slopes in a manner that minimizes concentrated flow.
  - Use structural or nonstructural measures such as water turnouts (Figure 31) and broad-based dips (Figure 32) suitable to the road materials, road gradient, and expected traffic levels. Turn outs should intersect roadside ditches at the same depth and be out-sloped to a maximum grade of 2% (Virginia Department of Forestry 2011). They should not feed directly into adjacent ditches, water ways, or channels. Turn outs should be constructed into solid soil and be of sufficient width to be maintained with logging equipment or road graders. On sloping roads, turnouts should leave the road ditch line at a 30° to 45° angle to the roadbed and be downsloped less than 2% of the natural contour.
  - Use an interval between drainage features that is suitable for the road gradient, surface material, and climate. (See Tables 9 and 10).
  - Use suitable measures to avoid or minimize erosion of ditches.

Table 9. Maximum Distance between wing ditches turnouts on forest roads

Topography	Slope - %	Distance – m	Distance - ft
Flat	2	76.2	250
	3	67.1	220
	4	57.9	190
	5	48.8	160
Moderate	6	43.9	144
	7	39.0	128
	8	34.1	112
	9	29.3	96
Steep	10	24.4	80
	11	18.3	60

Table 10. Recommended based dip spacing (Adapted from Forestry Best Management Practices for Water Quality, Virginia Department of Forestry, 2011, Accessed 06-15-2013, http://www.dof.virginia.gov/water/print/BMP/Manual/2011_Manual_BMP.pdf)

Road Grade - %	**Distance Between Dips - m**	**Distance Between Dips - ft**
2	91.4	300
3	71.6	235
4	61.0	200
5	54.9	180
6	50.3	165
7	47.2	155
8	45.7	150
9	44.2	145
10	43.1	140
12	41.1	135



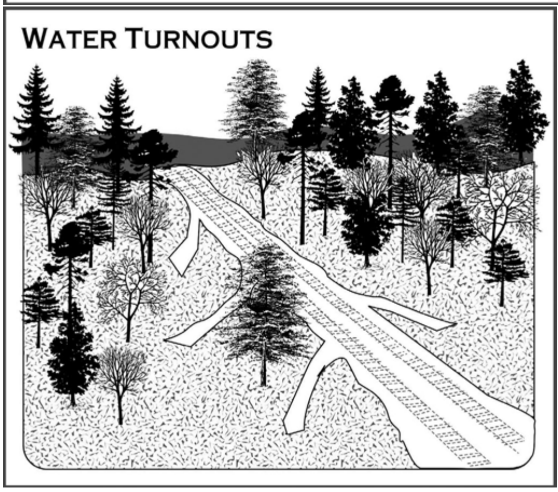
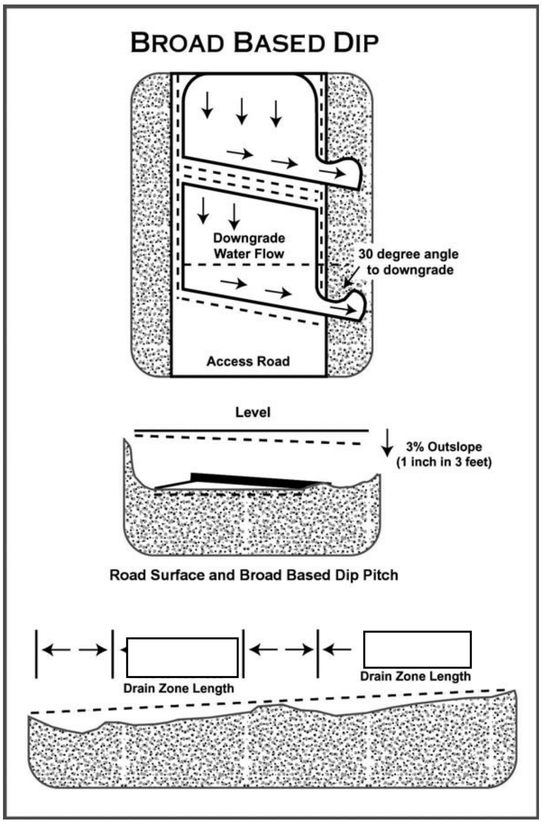


Figure 31. Diagram of a hypothetical forest road wing turnout ditch arrangement (Adapted from Virginia Department of Forestry, 2011. Forestry Best Management Practices for Water Quality http://www.dof.virginia.gov/water/print/BMP/Manual/2011_Manual_BMP.pdf ; Accessed 06-15-2013)



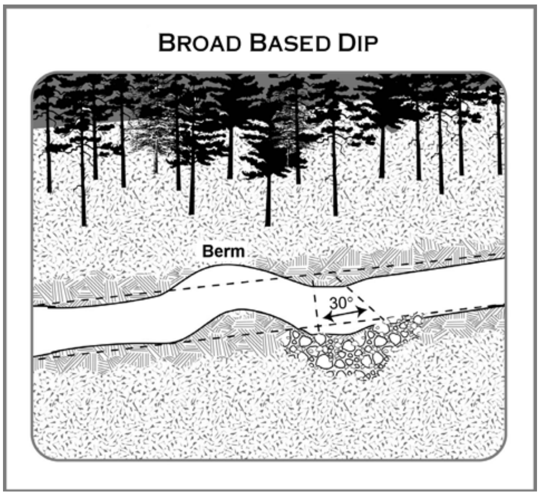


Figure 32. Broad based road dips (Adapted from Forestry Best Management Practices for Water Quality, Virginia Department of Forestry, 2011, Accessed 06-15-2013, http://www.dof.virginia.gov/water/print/BMP/Manual/2011_Manual_BMP.pdf)

- Design the road subsurface drainage system to intercept, collect, and remove groundwater that may flow into the base course and subgrade. Reduce high-water tables, and drain water pockets.

- Design the road for minimal disruption of natural drainage patterns and to minimize the hydrologic connection of the road segment or network with nearby waterbodies.

    - Use suitable structural or nonstructural measures to avoid or minimize gully formation and erosion of fill slopes at outfalls of road surface drainage structures.

    - Use suitable measures to avoid, to the extent practicable, or minimize direct discharges from road drainage structures to nearby waters.

    - Provide sufficient buffer distance at the outfalls of road surface drainage structures for water to infiltrate before reaching adjacent water courses.

    - Use applicable practices to limit the number and length of water crossing connected areas to the extent practicable.

- Design road surface treatment to support wheel loads, stabilize the roadbed, reduce dust, and control erosion consistent with anticipated traffic and use (Figure 33). Consider whether road closures or roadway surface drainage and erosion protection can adequately mitigate adverse effects to soil, water quality, and riparian resources.

- Design access roads within SMZs (when no practicable alternative exists outside of the SMZ) to achieve access objectives. The goal is to maintain desired conditions, goals, and objectives for SMZ structure, function, and processes.
- Use suitable measures to minimize or mitigate effects on water resources and other sensitive areas when adverse impacts cannot be practicably avoided.

- Design stream crossings to avoid or minimize adverse effects to soil, water quality, and riparian resources to the extent practicable consistent with road use, legal requirements, and cost considerations.

- Design a post-construction site vegetation plan, including short- and long-term objectives, using suitable species and establishment techniques to revegetate the site in compliance with local direction and requirements.

BMP-FL-RD-5 Road Construction: During road construction and reconstruction activities, vegetation and ground cover is removed exposing soil to erosion. Temporary and long-term erosion control and stormwater management measures are necessary to reduce erosion and maintain overall slope stability. These erosion control measures may include vegetative and structural practices to ensure long-term stability of the area.

- Use applicable BMPs for facility construction and storm runoff control for managing both runoff and erosion during construction of new system roads or reconstruction of existing roads.

- Employ suitable construction techniques such as full bench construction or retaining walls to create stable fills.

- Avoid incorporating woody debris in the fill portion of the road prism (Figure 28).

a) All weather gravel primary road

b) All weather bitumen-paved primary road

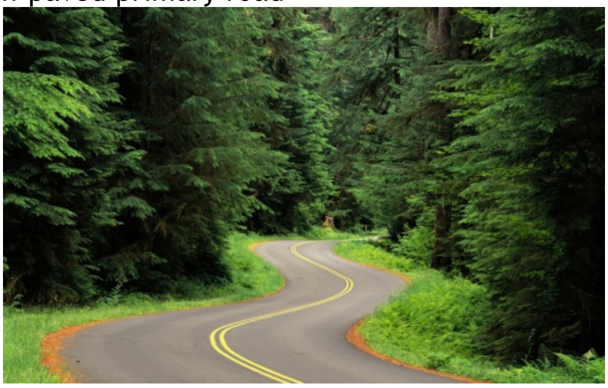


Figure 33. a) Forest access road with large to medium gravel necessary to support wheel loads in most weather conditions, b) All weather forest or county main highway. (Photos by Dave Powell, USDA Forest Service, Bugwood.com)

- Leave existing rooted trees or shrubs at the toe of the fill slope to stabilize the fill.
- Avoid use of road fills for water impoundment dams unless specifically designed for that purpose (See Figure 16).
- Identify and locate soil and rock waste areas before the start of operations. Deposit and stabilize excess and unsuitable soil and rock materials only in designated sites. Do not place such materials on slopes with a risk of excessive erosion, sediment delivery to water resources, mass failure, or within SMZs. Provide adequate surface drainage and erosion protection at disposal sites.
- Install culverts so that natural stream flow and bottom substrate are maintained through the crossing (Figure 34), and so that the structure does not constrict or fragment the stream (Southeast Aquatic Resources Partnership 2012).
    - Bridges and open bottom box culverts are the preferred methods for routing streamflow or storm runoff under roads. Alternatively, low water crossings can be used where flow is intermittent. This method is considerably less expensive but does not guarantee vehicle access during flow periods. Other types include open-bottom arch culverts, box culverts, elliptical culverts made of metal, concrete, or plastic, and circular culverts.

- Culverts should be located within a stretch of watercourse where the channel is straight, unobstructed, and well defined. Road and shoulder widths should be the minimum necessary for the crossing and side slopes should be as steep as possible without compromising stability to minimize the length of the culvert.

- A side slope grade of 2:1 is typically the steepest grade that can be vegetated. The width of the structure should be 1.25 times the normal width of the stream or dry channel bed. The overall culvert capacity should be able to accommodate expected high flows. For “closed-bottom” culverts, the channel slope must be less than 3%, and the culvert installed level with at least 20% of the vertical rise embedded at the downstream invert.

- Flared ends and/or rip rap should be used to prevent scouring around the inlet and outlet of the culvert since high flows can erode the soil surrounding the inlet and the soil underneath the culvert outlet. This can cause culvert undermining, can adversely affect the structure’s integrity, and lead to significantly increased erosion.

- Culverts require periodic maintenance. Woody and rock debris can clog culverts, leading to overtopping of the road prism and erosion of the road bed.

- Do not permit side-casting within SMZs (Figure 35). Avoid or minimize excavated materials from entering water ways or SMZs. Develop and follow blasting plans when necessary. Use restrictive blasting techniques in sensitive areas and in sites that have high landslide potential

Figure 34. Metal circular culverts (Photo courtesy of British Columbia Ministry of Transportation)

Figure 35. Sidecasting during road construction (Photo courtesy of Pacific Watershed Associates, http://www.pacificwatershed.com/projects/headwaters-forest-road-trail-conversion).

4.3.6 Mechanical Vegetation Management

Conventional forest feedstocks are harvested by a variety of methods that can impact ecosystem components that directly or indirectly affect water quality and quantity (Neary and Koestner 2012, Neary 2013). Forest lands are important sources of water as well as wood so their good management is a high priority. Actions to manage forest vegetation by mechanical methods, particularly biomass removal, produce disturbances which can affect forest ecosystem status and sustainability. The purpose of this set of BMPs is to avoid adverse soil and water effects during the removal of wood feedstocks from forest lands (USDA Forest Service 2012). The focus of vegetation management BMPs is on good harvesting and site management activities and not mitigation of bad practices (Lynch and Corbett 1990, Rashin et al. 2006).

BMP-FL-VM-1 Planning: The key to achieving targeted harvest of forest biomass for bioenergy feedstocks is planning. Planning occurs at scales that range from forest-wide assessments and plans, to catchment scale and on to project-level analyses. Effects to soil, water quality, and riparian resources are evaluated during planning and balanced with the social, economic, and land management needs of the area. Appropriate protection and mitigation measures are considered when soil, water quality, and riparian resources may be adversely impacted. Next to road BMPs, vegetation harvesting BMPs are some of the most important relative to forest bioenergy's effects on water.

Use applicable practices of BMP-FL-P-1 Forest Planning, BMP-FL-P-2 Specific Project Planning, and BMP-FL-A-2 Aquatic Area Operations for SMZs when planning mechanical operations during the harvesting phase. Specific components of this BMP include:

- Designing harvesting prescriptions and equipment to limit site disturbance and soil exposure to levels acceptable by ownership guidelines.
- Evaluate direct, indirect, and cumulative effects of harvesting disturbance on water resources at proper catchment scales.
- Use local guidance and experience regarding limiting slopes and potential erosion to determine areas suitable for skidder operations, and cable and aerial yarding systems.

- Plan for the most economical yarding system that minimizes the road network
- Establish plans for future site preparation, fuels reduction, and habitat improvement need.

- Use pre-planning to schedule entry and harvesting periods to coincide with optimal climate periods.

- Employ logging systems that work the best with harvest unit topography, soil types, and season.

- Delineate all protected or sensitive areas on planning maps.

- Plan all activities to follow guidelines in the road BMPs (FL-RD-1- through 5).

BMP-FL-VM-2 Erosion Prevention and Control: A critical part of maintaining water quality during bioenergy harvesting operations is the prevention and control of erosion. Movement of sediment can be reduced by adequate planning, harvest implementation, and monitoring to determine if water quality objectives were met by the BMPs employed in the operation. Inspection and maintenance of erosion control measures during and after harvest operations will make sure that the implemented BMPs function, are effective, and useful for future harvesting operations. Accelerated erosion or other soil damages during biomass harvesting are a function of equipment used, yarding techniques, operator proficiency, climate, soil types, slopes, and ground cover. Erosion control measures can be categorized into structural and nonstructural groupings. The latter deals with ground cover and the former pertains to methods to control runoff. The component practices in this BMP include the following:

- Develop site-specific BMP prescriptions during the planning phase (BMP-FL-VM-1).

- Establish designated areas for equipment staging.

- Develop plans to deal with the failure of erosion control methods.

- In conjunction with the plans already established , work with the contractor or operator to locate landings, skid trails, slash piles, stream crossings, SMZ avoidance zones, new road location sites, old road re-establishments, water sources, borrow sites, etc.

- Install structural sediment and storm runoff controls before harvesting activities begin (Figure 36).

- Apply slash as a soil protective cover on disturbed sites where natural vegetation and slash are insufficient to protect bare soil from future rain events.

- Do not alter drainage patterns.

- Control, collect, detain, and disperse concentrated storm runoff from harvested areas, bare soils, landings, and roads.

- Stabilize steep sections of new road or skid trail areas.

- Avoid ground equipment operations during wet periods or on easily compacted soils unless mitigated by wide-tracked, low ground pressure equipment.

- Evaluate site conditions frequently during harvest operations.

BMP-FL-VM-3 Aquatic Management Zones: Streamside Management Zones are key features in maintaining water quality during bioenergy harvesting activities. Follow guidelines for SMZ activities delineated in BMPs FL-AQ-1 through 5. Use mechanical harvest equipment and methods in SMZs when they achieve harvesting and long-term management objectives. Modify mechanical harvesting operations as needed to achieve water quality protection goals. Locate roads, landings, and skid trails outside of SMZs to the maximum extent possible within limits of harvesting goals and objectives. Minimize stream crossings and construct designated crossings using methods that minimize sediment routings in SMZs. Disperse road and skid trail runoff to prevent concentrated runoff that leads to gully formation and mass failures.

Figure 36. Silt fence installation prior to harvesting in a SMZ in Connecticut, USA (Photo courtesy of Newstimes).

BMP-FL-VM-4 Ground-Based Skidding and Yarding: This BMP addresses the use of a range of biomass extraction systems that include, rubber tired skidders, bulldozers, feller-bunchers, forwarders, and harvesters. The degree of soil disturbance of these harvesting systems depends on specific equipment configuration, operator skill, harvesting unit design, and site physical characteristics. Ground-based yarding systems can be designed and used to avoid adverse soil and water quality impacts when site physical conditions are conducive to use of the particular equipment types. Some of the key aspects of this BMP are:

- Utilize local expertise on equipment limitations and potentials for soil disturbance to guide ground-based yarding plans and operations (Figure 37).

- Use existing roads to the extent practical and follow the guideline in the road BMPs (FL-RD-1- through 5).
- Designate skid trails and limit equipment travel to limit soil disturbance

a) Tigercat 619c

b) Tigercat 845c

Figure 37. Examples of ground-based yarding types: a) Tigercat 610c rubber tired skidder (Photo courtesy of Tigercat, Branford, Ontario, Canada; b) Tigercat 845c tracked feller-buncher (Photo by Daniel G. Neary).

- Locate skid trails to avoid concentrating runoff by using a contour approach and providing breaks in any grades. Limit long slope runs by use of multiple water bars and broad-based dips.

- Limit the grade on roads and skid trails where they cross sensitive soil areas (geologically unstable, highly erodible, easily compacted, or wet).

- Avoid operations during wet periods when soils can be compacted, displaced, eroded, and damaged and suspend operations when weather deteriorates to the point where it can adversely affect erosion processes.

- Avoid skidding in SMZs in or adjacent to stream channels. Skid across streams only at designated, pre-planned locations.

- Directionally fell trees to facilitate efficient removal along planned skid trails and roads. Also directionally fell logs away from streams, shorelines and wetlands.

- Winch felled trees to skid trails to minimize vehicle traffic off of designated transportation routes.

- Use low ground pressure, wide tracked or tired vehicles whenever feasible.

- Stabilize and restore skid trails by reshaping after use, installing suitable drainage features such as water bars and dips, mitigating soil compaction with deep ripping, applying slash cover to bare areas, and seeding with fast growing grasses.

BMP-FL-VM-5 Cable and Aerial Yarding: Cable and aerial yarding systems partially or fully suspend logs off the ground when yarding logs to landings. Types of systems include skyline cable, helicopter, and balloon systems that typically are used in steep, erodible, and unstable areas where ground-based equipment could not safely operate or could cause unacceptable soil disturbance. These types of yarding systems typically operate where there is a high value wood resource to extract since they are the most expensive yarding systems in the business. Soil disturbance and erosion risks from these systems are primarily confined to cable corridors and landings.

Specific practices within this BMP include:

- Utilize local expertise to decide on areas to use cable and aerial logging where slopes, erosion potential, mass wasting potential, or unstable soils preclude ground-based yarding.

- Identify equipment capabilities and operations expertise during the planning phase.

- Locate extraction corridors making use of the terrain characteristics and road system to most efficiently extract woody biomass while minimizing soil disturbance and water quality impacts.

- Fully suspend logs when yarding over stream channels, SMZs, and sensitive soils (Figure 38).

- Postpone yarding if weather conditions might cause unacceptable increases in soil disturbance and soil erosion.

- Use logging slash to the fullest extent to minimize soil disturbance.

BMP-FL-VM-6 Landings Operations: Log landings are characterized by intense equipment activity since they function as the endpoint of both ground-based and cable and aerial yarding. Landings are the location of large equipment (e.g. skyline yarders, fuel tenders, etc.), log handlers, and large log transport trucks. Since they are the fueling and maintenance locations for heavy equipment, heavy tankers and truck maintenance equipment frequent the sites. To accommodate all this heavy equipment activity, landings tend to be large, and their soils generally become compacted, rutted, and disturbed much more than the rest of the harvest project area (Figure 39). In some instances, landings are capped with gravel to better withstand the vehicle activity. Landings have a high probability of being a relatively small but concentrated source of overland flow containing sediment and other pollutants. The numbers and sizes of landings need to be well planned when harvesting plans are prepared (see BMP-FL-VM-1). Landings need to be well-planned to insure that they will be safe, economical, efficient, and pose minimal threat to water quality.

Figure 38. Suspended logs on a skyline yarding system, Switzerland (Photo courtesy of Cleantech Switzerland http://www.cleantech-switzerland.com/en/).

- Some specific practices incorporated in the landings BMP include:
- Locating landings outside of SMZs and as far from water resources as it practical.
- Avoiding locating landings near overland flow pathways.
- Designing and locating landings to minimize the number of skid roads required.

Figure 39. Loading logs at a landing in North Carolina (Photo courtesy of Goodson's All Terrain Logging Inc., Jacksonville, NC, USA)

- Avoiding the siting of landings on steep slopes (the exception being aerial and cable landings), highly erodible soils, and where skidding across SMZs is required.

- Re-using existing or previously used landings where they do not compromise water quality objectives.

- Using applicable erosion control practices within and adjacent to landings (see BMP--FL-VM-2).

- Restoring landings after use by using good forest management practices. These include removing all logging equipment and refuse, reshaping the landing to efficiently disperse runoff, installing adequate runoff drainage structures, mitigating compaction by deep ripping and grass seeding, or mulching. Trees can be planted on mitigated landings if the use cycle is sufficiently long enough.

BMP-FL-VM-7 Mechanical Site Preparation: Mechanical treatments are used to remove or reduce the amount of remaining live vegetation and logging slash on a site to meet management objectives for the next rotation (Neary et al. 1984). These objectives include site preparation for reforestation, fuel treatments to reduce fire hazards, wildlife habitat improvement, recreation access, utility corridor maintenance, and other activities that require removing vegetation from specified areas on a periodic and repeated basis. Mechanical treatments include cutting and piling; chipping or mulching; roller chopping, masticating using heavy equipment; and pushing over vegetation. Disturbance from mechanical site preparation treatments is often considerably more than the harvesting operation (Figure 40). These treatments can expose and compact soils, resulting in accelerated runoff and erosion and deterioration in water quality (Beasley 1979).

Site specific factors should be evaluated to develop prescriptions for mechanical site preparation. Of chief importance are:

- Evaluating soil conditions, slopes, topography, competing vegetation, and climate to determine the most suitable treatment and equipment.

- Use local expertise and land management objectives to guide treatment selection as well as published reports on site preparation effectiveness.

- Use applicable Aquatic Zone and Erosion Prevention and Control BMPs to guide mechanical treatment plans and operations. (BMP-FL-VM-2 and BMP-FL-VM-3).

- Conduct operations during time periods and climate intervals when soil disturbance is minimized.

Figure 40. Site preparation discing and bedding operation, Alabama, USA (Photo courtesy of the USDA Forest Service and Auburn University).

- Use low ground-pressure and tracked equipment to minimize soil disturbance.
- Operate equipment so that furrows, soil indentations, and disturbed areas are aligned on the contour and not up-and-down hill.
- Pile slash using equipment that leaves soil in place and avoids displacing soil into windrows or piles.
- Use site-preparation that creates irregular surfaces and not aligned channels.
- Replant as soon as it is feasible.

4.4 General Biomass Harvesting and Forestry Practices

In summary, there are some general guidelines for woody biomass utilization for bioenergy feedstocks that constitute a BMP of their own.

BMP-FL-GH-1: Biomass harvesting and associated forestry practices should be conducted to maintain and build soil structure and fertility. Utilize BMPs that conserve water quantity and quality. Perennial biomass crops that enhance and protect soil quality, promote water retention, and reduce nutrient and chemical run-off should be prioritized.

- Collect and utilize residues from timber harvesting (branches, tree tops, small diameter trees, underbrush) wherever possible, while respecting state and federal forest management rules and land use policies.
- Collect and utilize primary mill residuals (sawdust, wood chips, bark and other wood by-products) wherever possible.
- Obtain third-party certification, when feasible, for forest products and management practices.

- Employ forest management practices that do not decrease biodiversity, soil health, water quality, and wildlife habitat.

- Do not use biomass from old growth or high conservation value native forests or woodlands, or natural areas of regional and cultural importance as bioenergy feedstocks.

- Do not declassify or appropriate protected areas for feedstock production and prevent conversion of native ecosystems.

- Do not convert mid- and old-growth natural forests to plantation-style management or short-rotation woody crops.

- Minimize, and eliminate whenever possible, the use of harmful agrochemicals.

- Except for sorted wood trimmings and construction debris, municipal solid waste generally should not be used as a biomass resource for biofuels production.

4.5 Short Rotation Forests Lignocellulosic Feedstock Production BMPs

Short-rotation woody crops, such as fast growing *Populus* spp., *Salix* spp, and *Eucalyptus* spp., and their respective hybrids, have shown considerable promise as wood fibre plantations on sites that enable high productivity and close proximity to bioenergy production facilities. They can be planted as specific crops, as mid-field wind buffers, or as part of SMZs. Short-rotation tree species have a variety of inherent logistical benefits and other economic advantages relative to conventional forestry and are comparable to other lignocellulosic energy crops (Table 11). Many of these advantages are driven by the fact that trees can typically be harvested year-round and continue growing over many years, thereby providing a consistent inventory of sustainable biomass (Figure 41). Due to the flexibility associated with harvest scheduling of trees, short-rotation woody crops have reduced storage and inventory holding costs, and can minimize losses typically associated with storage of annually-harvested biomass such as grains or grasses.

Since short rotation trees can be harvested after several years and at different times in the year, this feedstock source mitigates the risk of yield fluctuations due to drought, disease, insect pests, as well as other biotic or abiotic stresses. This characteristic facilitates a more consistent linkage of bioenergy feedstock supply with demand. An excess supply of annually-harvested crops is necessary to buffer years in which low yields are experienced in order to ensure full and consistent energy production. Harvest scheduling of short rotation woody crops can be distributed throughout the year, reducing intense infrastructure and equipment needs characteristic of annually-harvested crops (Sims and Venturi 2004).

Figure 41. Harvesting *Populus* sp. feedstock for bioenergy production in Italy. (Photo courtesy of the University of Pisa, Center for Interdepartmental Research on Agriculture and the Environment, http://www.avanzi.unipi.it/ricerca/quadro_gen_ric/biomass_bioenergy/Biomass&bioenergy_ENG.htm accessed 09-26-2013.)

Short-rotation tree crops minimize environmental impacts associated with herbaceous, grass, and grain biomass production since multi-year tree rotations facilitate production plans that have extended periods between harvests with no soil disturbance. The multi-year rotation of trees also offers deployment and logistical benefits by reducing the land footprint that must be planted and harvested each year. While the land area needed to feed a bioenergy plant may be similar between trees and other bioenergy crops with similar productivity, only a fraction of that total footprint would need to be planted or harvested in any given year for trees (Table 11). Trees grown for bioenergy feedstocks also provide feedstock growers greater economic flexibility relative to other energy crops. The producer is provided a choice in harvest time as well as multiple end uses: traditional forest products and energy products such as cellulosic ethanol and power generation through direct firing, co-firing, or wood pellet systems.

Table 11. Short rotation forest feedstock characteristics (Adapted from Bentrup 2008).

	Short Rotation Bioenergy Feedstock		
Bioenergy Crop Characteristics	**Poplar (*Populus* spp.)**	**Willow (*Salix* spp.)**	**Switchgrass (*Panicum virgatum*)**
Yield Range (Mg ha^{-1} yr^{-1})	7.0 - 15.7	6.7 - 12.1	9.0 – 15.0
Establishment Period	3+ yrs	3 yrs	2-3 yrs
Pesticide Requirements	Low	Low	Low
Fertilizer Requirements	Low to Medium	Low to Medium	Low
Water Usage	Medium	Medium	Low
Establishment Cost	Medium	Medium	Low
Erosion Rates (Mg ha^{-1} yr^{-1})	<2.0	<2.0	>2.0
Crop Longevity	15-30 yrs	20-30 yrs	20-30 yrs
Harvest Interval	3-10 yrs	3-4 yrs	Annual
Equipment Requirements	Cutter & Chipper	Harvester	Hay Baler
Net Energy Conversion Range	1:8 to 1:16	1:8 to 1:16	1:4 to 1:14

Short rotation woody crop systems for bioenergy production are more similar to agriculture than conventional forestry so the BMPs discussed in the following section on agriculture are more appropriate. Because of the greater frequency of entry into short rotation woody crop stands, the infrastructure needs to be of a higher standard than conventional forestry (Shepard 2006). Roads, landings, stream crossings, sediment control structures must be designed, built, and maintained for more permanence and stability. Adequate BMPs must be identified and used to deal with a greater frequency of fertilizer additions, weed control, and harvesting activities.

5 AGRICULTURAL CROP PRODUCTION BMPS

5.1 Background

National water quality assessments in major agricultural areas throughout the world have identified agriculture activities as the most wide-spread source of pollution for rivers, lakes, and groundwater (Duda 1993, Corwin and Wagenet 1996, USEPA 2002). For example, agriculture is a major industry in the United States with a base of 3.73 x 10^6 km^2. The country is a major exporter of food and agriculture-based fiber. State reports indicate that agriculture affects nearly 50% of pollution-impaired river reaches and just over 40% of the impacted lake area (USEPA 2002). Even though agriculture-derived pollution is still a serious problem, significant gains in reducing the area and severity of the nonpoint source problem have been made through the adoption of BMPs.

There are thousands of individual BMPs for agriculture based on conservation objective, land use, and individual watersheds (Rossi 2012). There is no single set of ideal BMPs for mitigating all activities affecting water quality in all situations. The BMPs selected by land managers should be based on water quality characteristics, the type of pollutant, the source of the pollutant, environmental conditions, and the socio-economic situation. Water quality characteristics include pollutant type, source of the pollutant or adverse condition, and the cause of the pollution. Environmental conditions encompass agricultural system being used, climate, soils, watershed position in the landscape, and other resources at risk of adverse impact. Socio-economic considerations include the economic situation of the land owner, pollution reduction goals, experience of the BMP system designers, and the willingness of the land manager to implement and maintain the selected BMPs.

Examples of the key BMPs used for agriculture are listed in Table 12 by objective. Some BMPs are applicable to all three objectives and several are germane to only one or two objectives. Primary bioenergy feedstock production encompasses all three conservation objective categories. The individual conservation objectives include establishing and maintaining riparian areas, improving and maintaining water quality, maintaining catchment connectivity, improving or maintaining aquatic habitat, maintaining or restoring in-stream physical conditions, maintain conditions for stream processing of sediment, and maintaining and restoring key upland habitats (Watershed Management Program, Texas Parks and Wildlife Department 2013)

Table 12. Key agriculture Best Management Practices by objective (Adapted from Best Management Practices for the conservation of Texas watersheds, Watershed Management Program, Texas Parks and Wildlife Department 2013. http://watershedbmps.com/?page_id=1036).

Water Protection	Erosion & Sediment Control	Crop Management
Integrated Pest Mgt.	*Not Applicable*	Integrated Pest Mgt.
Irrigation Management	Irrigation Management	Irrigation Management
Riparian SMZs	Riparian SMZs	Riparian SMZs
Chemical Management	Chemical Management	Chemical Management
Water & Sediment Control	Water & Sediment Control	*Not Applicable*
Cover Crops	Cover Crops	Cover Crops
Strip & Ally Cropping	Strip & Ally Cropping	Strip & Ally Cropping
Contour Farming	Contour Farming	Contour Farming 2
Grazing Systems	Grazing Systems	*Not Applicable*
Terraces	Terraces	Terraces
Soil & Water Testing	*Not Applicable*	*Not Applicable*
Manure Management	*Not Applicable*	*Not Applicable*
Crop Rotation	*Not Applicable*	Crop Rotation

The effectiveness of a variety of agricultural BMP has been rated by USDA-NRCS 1977, USDA 1990, and Brown et al. 1991 (Tables 13a and 13b). Those with category "A" scores (medium to high effectiveness) and "B" scores (low to medium effectiveness) are described in more detail (i.e BMP-AC-MP-1 to BMP-AC-SP-7).

It is important to note that no single BMP is highly effective across the whole range of water quality parameters. For instance, conservation tillage, contour farming, and crop rotation are rated as medium to high in effectiveness in dealing with sediment but have no control to low effectiveness on temperature (Table 13a). This is a situation where other BMPs (SMZs, grass crops, etc.) are needed to be utilized in tandem to achieve desired water quality effects at catchment or landscape scales. Another example is effectiveness of BMPs on nutrients and pesticides. Conservation tillage, contour farming, crop rotation, sediment basins, stream stabilization, terraces, and wetlands restoration BMPs are rated as being high to medium effectiveness in controlling adsorbed nutrients and pesticides (Table 13b). However, these BMPs are less effective in dealing with soluble nutrients and pesticides. Fortunately for sediment, usually the main parameter degrading water quality, there are a lot of BMP options (Table 13a). For salinity, temperature, pathogens there are far fewer BMP options. For groundwater, the best options for maintaining water quality are nutrient and pesticide application management (Table 13b). Post-application BMP mitigations are not very effective for groundwater pollution. This is a situation where planning is a key BMP in managing agriculture nonpoint source pollution and water quality.

Table 13a. Best Management Practices effectiveness summary guide, resource concerns for surface water quality, physical and biological parameters (Adapted from USDA Agriculture Information Bulletin No. 598, USDA 1990, Brown et al. 1991)

	Surface Water Quality Parameters				
Best Management Practices	**Salinity**	**Temperature**	**Sediment**	**Pathogens**	**Biological Oxygen Demand**
Management Practices					
Irrigation	**A**	C	**A**	C	C
Nutrient	C	C	C	C	C
Pest	C	C	C	C	C
Riparian and Runoff	C	?	**A**	**A**	**A**
Soil Salinity	**A**	C	B	C	C
Manure	C	C	**A**	**A**	**A**
Pasture	C	B	B	B	B
Vegetative and Tillage Management					
Conservation Tillage	C	C	**A**	C	C
Contour Farming	C	C	**A**	B	B
Crop Rotation	B	C	**A**	C	C
Field Border Cover	C	C	B	B	B
Field Strip & Ally Cropping	C	C	B	C	C
Field Windbreaks	C	C	B	C	C
Filter Strips	C	C	B	B	B
Grasses & Legumes	C	B	B	C	C
Green Manure Cropping	C	B	B	C	C
Structural Practices					
Diversions	C	?	B	B	C
Grade Control Structures	C	C	B	C	C
Grassed Waterways	C	C	B	C	C
Sediment Basins	C	?	**A**	B	C
Stream Stabilization	C	**A**	**A**	C	B
Terraces	?	?	**A**	B	B
Wetland Restoration	C	B	**A**	B	**A**

Key
A = Medium to high effectiveness C = No control to low effectiveness
B = Low to medium effectiveness ? = Unknown

Table 13b. Best Management Practices effectiveness summary guide, resource concerns for surface water quality and groundwater chemical parameters (Adapted from USDA Agriculture Information Bulletin No. 598, USDA 1990, Brown et al. 1991)

	Surface Water Quality Parameters				**Groundwater Quality**	
Best Management Practices	**Soluble Nutrient**	**Adsorbed Nutrient**	**Soluble Pesticides**	**Adsorbed Pesticides**	**Nutrients**	**Pesticides**
Management Practices						
Irrigation	**A**	**A**	**A**	**A**	B	B
Nutrient	**A**	**A**	C	C	A	C
Pest	C	C	**A**	**A**	C	**A**
Riparian and Runoff	**A**	**A**	C	C	**A**	C
Soil Salinity	B	B	B	B	C	C
Manure	**A**	**A**	C	C	**A**	C
Pasture	C	B	C	C	C	C
Vegetative and Tillage Management						
Conservation Tillage	C	**A**	C	**A**	?	?
Contour Farming	B	**A**	B	**A**	C	C
Crop Rotation	B	**A**	B	**A**	B	B
Field Border Cover	C	B	C	B	C	C
Field Strip & Ally Cropping	B	B	B	B	C	C
Field Windbreaks	C	B	C	B	C	C
Filter Strips	C	B	C	B	?	?
Grasses & Legumes	B	B	B	B	C	C
Manure Cropping	B	B	B	B	B	C
Structural Practices						
Diversions	C	B	C	B	C	C
Grade Control	C	B	C	C	C	C
Grass Waterways	C	B	C	B	C	C
Sediment Basins	C	**A**	C	**A**	?	?
Stream Stabilization	C	**A**	C	C	C	C
Terraces	B	**A**	B	**A**	?	?
Wetland Restoration	B	**A**	B	**A**	?	C

Key

A = Medium to high effectiveness C = No control to low effectiveness

B = Low to medium effectiveness ? = Unknown

5.2 Agriculture Feedstock Production BMPs

The agriculture BMPs discussed here are listed into the three groupings presented in Table 13a and 13b. The lists are not comprehensive of all BMPs, but represent the most commonly used practices. An additional topic in agricultural feedstock production is the use of field and manufacturing residues. It will be discussed in a separate publication focusing on residues,

5.2.1 Management Practices

BMP-AC-MP-1 Irrigation Management: Where supplemental water is a necessity for agricultural crop production, irrigation management is a critical BMP for ensuring an efficient agricultural operation and sustainable crop production (Figures 42 and 43). Irrigation management can conserve substantial amounts of water, increase farm production and profit, and prevent damage to the land through erosion and nutrient and pesticide runoff control. It is medium to high in effectiveness for controlling sediments, nutrients, and pesticides in surface waters but only low to medium in regard to groundwater (Tables 13a and 13b).

Components of the Irrigation Management BMP consist of:

- Conducting irrigation planning and auditing that involve two major activities: 1) determining the most appropriate frequency, duration, and timing for irrigation of target crops and 2) determining current efficiency of irrigation equipment to schedule maintenance or replacement. Both of these actions will decrease the amount of water used and ensure more efficient use of the water.

Figure 42. Central pivot irrigation (Photo courtesy of Wisconsin Potatoes http://eatwisconsinpotatoes.com/2012/09/irrigated-vegetable-production-key-to-central-wisconsin-economy/ accessed 06-15-13).

Figure 43. Corn irrigated by a central pivot system (Photo courtesy of Southeast Farm Press, http://southeastfarmpress.com/grains/kentucky-study-paves-way-increased-irrigation-state Accessed 06-15-13).

- Scheduling implementation using electronic or manual methods to irrigate with the appropriate frequency, duration, and timing determined during the audit phase.

- Implementing water use monitoring that involves actions like soil moisture testing to determine if crops are getting the appropriate amount of water, installing meters on wells to monitor for irrigation leaks, and becoming more aware of water use.

- Upgrading to more efficient irrigation equipment and strategies (especially from flood irrigation) that will allow for better crop production, more efficient use of water, and in some regions decreasing rates of salinity buildup in soils. Evaporation losses can be reduced by replacing open ditches with pipelines.

- Where flood irrigation is used, managing ditches to decrease the amount of water lost to evaporation and infiltration, and planting vegetation in drainage ditches to reduce the amount of erosion and soil that leave the property, thereby promoting water infiltration, and reducing the amount of chemicals and nutrients that reach nearby streams.

BMP-AC-MP-2 Nutrient Management: Chemicals used in agriculture production include pesticides, herbicides, and fertilizers. This BMP addresses fertilizers and the nutrients that they provide to plants. Proper application of any fertilizer is important to meet plant growth demands, but prevent excessive losses through runoff and contamination of surface and groundwater supplies (McColl 1978). Avoiding excessive application of fertilizer chemicals will also limit exposure to wildlife and aquatic biota. Proper application of fertilizer chemicals is a multi-step action that can include planning, soil fertility checks, calculation of nutrient demand, integrated pest management, use of proper application with a focus on equipment and application rate, equipment calibration and maintenance, timing of applications to meet nutrient demand periods and avoid adverse weather, environmental monitoring and testing, and even transitioning to organic production methods and chemicals when feasible and warranted. The conservation benefits of Nutrient Management BMPs include preventing algal blooms which deplete stream oxygen; protecting upland, riparian, and aquatic vegetation; protecting surface water and groundwater quality; and protecting wildlife, fish, birds, and other terrestrial and aquatic biota.

Any BMP for the proper application of nutrient chemicals includes a number of actions in a cyclical evaluation process (USEPA 2003). This is a nutrient life cycle approached tailored for agrichemicals. It includes:

- Planning – determine the appropriate fertilizer type (inorganic, organic, nitrogen, phosphorus, micronutrients, and trace metals), amounts, timing, and application methods.

- Integrated Pest Management – consider life cycles and knowledge of the biology of pests to determine the interactions between target crop and pests.

- Proper application with equipment and handling – fertilizers must be applied with the appropriate equipment and the right timing to be most effective and not wasteful of resources nor harmful to the environment. Drift control measures must be implemented incorporating selection of method (air versus ground), equipment, use of computer driven guidance control, timing, climate factors, adjuvants, formulations, sensitive areas, etc.

- Equipment calibration and maintenance – maintenance and calibration of equipment will make sure fertilizers are being applied at the desired doses and concentrations to maximize effectiveness.

- Monitoring and testing – monitoring of soil, groundwater, and surface water is important to determine the effectiveness of current application amounts and to determine if excessive nutrients are contaminating the environment.

Sources of nutrients added to agricultural land vary considerably depending on the availability, cost, ease of handling, preference, and environmental regulations. Amounts may range from substantial to trace levels. The sources include:

- Dry or liquid commercial fertilizers

- Manure from animal production facilities

- Sludge from municipal and industrial treatment plants

- Liquid effluents from municipal and industrial treatment plants

- Legumes and crop residues

- Irrigation water enhanced with commercial fertilizers

- Atmospheric deposition.

The BMPs for nutrients are aimed at minimizing the movement of mobile forms of nitrogen, phosphorus, and essential crop nutrients into surface waters or groundwater. Nutrients can move in organic and inorganic particulate-bound particulates, soluble nutrients, and microorganisms. Nutrient management plans should be put into place to manage pre-, during-, and post-application nutrient movement.

Nutrient management plans can consist of all or some of the flowing components (USEPA 2003):

- Soil surveys to determine soil productivity and identify ecologically sensitive sites.
- Evaluation of crop yield history in order to determine realistic yield potentials with current and enhanced nutrient levels.
- Application of nitrogen, phosphorus, other macronutrients, and micronutrients at rates to achieve realistic productivity targets.
- Soil testing for pH, macronutrients, and micronutrients to validate soil survey estimations of fertility.
- Plant tissue analysis.
- Analysis of manures, sludge, compost, and effluent when these sources of nutrients are utilized.
- Consideration of nutrient inputs from non-traditional sources such as atmospheric deposition, irrigation water, u[land runoff, etc.
- Determination of the proper timing, fertilizer formulation, and application methods needed to maximize plant uptake and minimize losses to non-agriculture ecosystem components.
- Coordination of nutrient management planning and scheduling with irrigation planning and operations.
- Use of cover crops to retain nutrients on-site and minimizes losses in storm water runoff.
- Designation and use of SMZs around water resources and buffers around sensitive areas such as sinkholes, thin soils, tile drains, highly erodible soils, and cultural features.
- Implementation of soil erosion control practices (See BMPs in the section on vegetation management and tillage, and structural practices – sections 5.2 and 5.3).

BMP-AC-MP-3 Pest Management: Integrated Pest Management (IPM) involves developing a strategy utilizing planning and a combination of biological, mechanical, cultural, and chemical controls (Caroll et al. 1990). By assessing the individual needs of agricultural crops, IPM can decrease the load of agrichemicals while at the same time effectively controlling insect and plant pests. The result is a protection of surface and ground water quality and decrease in damage to non-target upland, riparian, and aquatic plants. This BMP requires an understanding of pest biology and life cycles in order to achieve for effective implementation and results (Bottrell 1979). Successful implementation of a IPM BMP requires adhering to the following steps:

- Establish firm and reasonable IPM objectives.

- Monitor pest populations and forecast trends to determine which controls might be appropriate.

- Determine the economic thresholds for an IPM strategy and tactics.

- Evaluate the feasibility and side-effects of biological controls such as natural insect predators.

- Determine whether or not mechanical activities such as plowing and cultivating can achieve the IPM objectives.
- Evaluate the potential and actual success of cultural controls like planting insect-resistant varieties, crop rotation, destroying pest alternate habitat, etc.

- Evaluating the tradeoffs of chemical pest control methods using the least toxic pesticide application that will achieve the IPM objectives.

- Lastly, develop an IPM strategy using a mix of all feasible, economical, and effective methods.

BMP-AC-MP-4 Riparian and Runoff Management: A riparian SMZ, often called a buffer zone, is a designated and protected section of vegetation and habitat along streams, creeks, lakes, and wetlands (See section 3.3 and BMP-FL-AQ-2 for more discussion, examples, and details). These SMZs are important conservation tools for agricultural areas, and many agriculture-related industrial operations to stabilize stream banks, filter storm water runoff, provide wildlife and fish habitat, and protect water infiltration zones. A complete guide on planning and designing SMZs for conservation purposes is provided in Bentrup (2008) and accessible on-line at http://www.bufferguidelines.net. Along with the actual guidelines, a list of 1400 pertinent publications is provided. Streamside Management Zones in agricultural areas consist of vegetation bands going from crop land to water ways (see Figures 6 and 44). The vegetation bands go from crops to native grasses and forbs to shrubs to slow growing trees to fast growing trees. Riparian SMZs are usually designed, implemented, or restored under the guidance of experienced soil scientist, hydrologists, or riparian ecologists. Their dimensions and composition vary depending on the climatic region, watershed, soils, and specified SMZ objectives. Designs or restoration plans should also consider erosion potential of the soil, native plants suitable for wildlife and fish, and identify permitted or prohibited activities within the buffer zone. Streamside Management Zones provide a wide range of ecosystem services (Neary et al. 2011, Neary 2013). The SMZs can also be designed with single or multiple specific objectives like sediment control, nutrient movement, pesticide spray drift and movement in runoff, insect pest control, grazing, energy conservation, energy crop production, flood attenuation, plant pathogen control, wildlife enhancement, recreation, wildfire control, etc. Regarding runoff management, the following guidelines should be followed:

- Plan and develop SMZ's and other buffers based on site specific characteristics and land management objectives.

- Manage land to reduce runoff and increase infiltration into the soil.

- Minimize cover-free periods to maintain as much vegetation cover as possible.

- Avoid or reduce aggravating activities on areas that are prone to runoff.
- Minimize activities during seasons and weather that are prone to generating runoff.
- Use vegetation management and structural practice BMPs that are known to reduce runoff in the area being managed.

Figure 44. Riparian SMZ in agricultural land with multiple crops in Iowa. (Photo courtesy of the Natural Resources Conservation Service).

BMP-AC-MP-5 Soil Salinity Management: Salinization of soils can occur if the parent material is high in salt content, the cultivated area is near the sea and subject to salt deposition, or inadequate irrigation management leads to salt buildup. Crops like barley and sugar beets are highly tolerant of salt buildup. Wheat, oats, and maize are moderately tolerant, but sugarcane is a sensitive species (Ayers and Westcot 1985). A good publication on saline soils BMPs, although focused on turfgrass production and use, was produced by Carrow and Duncan (2011).

The key BMPs for salinity management are:

- Conduct monitoring of irrigation water quality to determine the risk of salinization. Salt concentrations < 0.5 g L^{-1} have no risk and there are no restrictions on water use. Water concentrations between 0.5 and 2.0 g L^{-1} have a slight to moderate risk and appropriate water management practices should be used. Water sources with salt contents above 2.0 g L^{-1} have a high risk and should not be used for crop irrigation unless salinity experts are consulted.
- Management of irrigation timing and amounts in conjunction with normal rainfall should be sufficient to keep salts below the plant root zone.
- Assure adequate subsurface soil drainage by using deep open drains or subsurface tile, plastic, or concrete drains connected to main drains (Figure 45).
- Ensure adequate slope in main drains to remove salinized lateral drainage water.

- Manage machinery access to prevent surface drains from blocking or ensure re-establishment after machinery operations are concluded.

Figure 45. Field drain in North Carolina (Photo courtesy of the Natural Resources Conservation Service).

BMP-AC-MP-6 Manure Management: Manure management involves implementing farming practices and BMPs that limit manure buildup and movement into stream, wetland, and lake resources. Manure can provide a good source of nutrients for bioenergy feedstocks. However, this BMP requires:

- Assessing site and manure load acceptable manure application rates.
- Developing application plans and selecting equipment to ensure adequate distribution.
- Identifying storage locations and constructing containment facilities to prevent runoff transport into water resources.
- Constructing runoff detention ponds and using field structural practices to slow manure movement from storage sites.
- Developing plans to move excess manure to other application sites or more centrally located storage areas (Nowack et al. 1998).

BMP-AC-MP-7 Pasture Management: A pasture management and grazing system may be needed to be implemented where agricultural feedstock production is integrated into normal farm operations (Altieri 1995). In addition, grazing may be used to maintain the vigor of SMZ systems that utilize grasses to protect upland, riparian, and stream habitats (see Figure 6). Grazing systems differ by accounting for plant growing seasons and life history needs, duration and timing of resting pastures, and intensity of grazing. Pasture management systems include continuous, deferred rotational, rest rotational, rotational, short, and seasonal suitability. The system selected for management of agricultural feedstock production systems should depend on the crops involved, the resources needing protection, and the objectives of land unit.

5.2.2 Vegetation and Tillage Management

BMP-AC-VT-1 Conservation Tillage: Conservation tillage involves the planting, growing, and harvesting of agricultural crops with minimal disturbance of the soil surface (Belvins et al. 1983). Traditional tillage practices completely turn over the entire pasture or field exposing valuable soil to wind and rain erosion. It includes minimum tillage, mulch tillage, ridge tillage, and no-tillage practices, and is designed to replace traditional complete tillage practices (Crosson 1981, Lal 1989).

Minimum tillage equipment leaves at least 30% of the soil surface covered by crop residue following the planting operation (Figure 46). This system is often referred to as strip tillage (Figure 47). Some minimum tillage systems leave 70% of the soil covered by crop residue. Ridge tillage involves planting crops on permanent ridges 10-15 cm high. Maintenance of the ridges is necessary and use of this system requires specialized equipment. Mulch tillage refers to any tillage system that leaves at least 30% on the mineral soil surface covered by residues from previous crops. No-tillage systems (Figure 48) involve leaving the soil undisturbed after the harvest and involves minimal soil disturbance at the next harvest for nutrient application and seed planting. Conservation tillage practices will substantially reduce the amount of soil lost from wind and soil erosion which will decrease soil entering streams (Cogo et al. 1983). The major environmental benefits are reduction in soil erosion from farms and upland habitats, and siltation of streams.

BMP-AC-VT-2 Contour Farming: Contour farming is practiced on sloping land. It involves coordinating and planning crop planting and harvesting techniques based on the contour and slope of the land to reduce soil erosion (Figures 49 - 51).

a)

b)

Figure 46. Examples of conservation tillage comparing tilled area to soil covered with plant residue.
a)http://2.bp.blogspot.com/_jWDJgGZjN4s/TA61FDudEtI/AAAAAAAAAx0/qH4k24ARW4Q/s1600/Strip+Till.jpg, and b)
http://oklahomafarmreport.com/wire/news/2011/04/media/00381_StripTillFarming.jpg

Figure 47. Strip tillage (Photo courtesy of AMIA http://agrimarketia.com/agricultural-machinery/blu-jet-min-till-strip-till-tillage-equipment/ accessed 06-15-13)

Figure 48. Example of a no tillage system (Photo courtesy of the International Efficient Agriculture Solutions and Standards Association http://ieassa.org/en/no-till/ Accessed 06-15-2013

Contour farming reduces chemical and nutrient runoff and it reduces sediment erosion from uplands into streams, lakes, and wetlands. Crops planted along the land's contour are more efficient in retaining irrigation and rainwater and will more effectively retain fertilizer. This has a strong effect on the economic viability of contour farming practices (Prato and Wu 1991).

Proper contour farming involves:

- Evaluating property contours and topography.
- Developing adequate crop planning for planting and harvesting.
- Incorporating property contour information in the development of a planting and harvesting strategy.
- Considering natural drainage patterns which will reduce or eliminate the amount of gullies formed after storm events, reduce the amount of soil erosion, and reduce the amount of chemical and nutrient runoff.
- Using tillage and harvesting equipment suitable for the slopes involved.

BMP-AC-VT-3 Conservation Crop Rotation: This BMP deals with the planned rotation of main crops and conservation crops in order to achieve agricultural production goals or environmental goals (USDA NRCS 2013b) . Some of the environmental goals are reduction of water and wind erosion, conserving water, managing salinity, balancing plant nutrient demands with biological sources, and improving soil quality and function. Production goals include managing plant pests, providing domestic livestock forage, improving soil fertility, and providing annual crops for bioenergy feedstocks. This BMP is applicable to all cropland where annual crops constitute at least 30% of the crop plan.

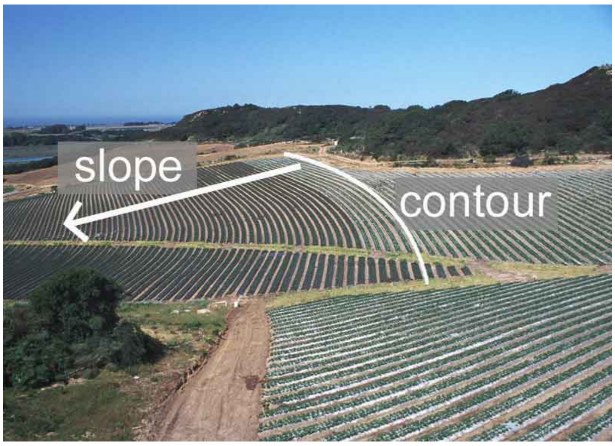


Figure 49. Contour farming layout (Photo courtesy of Plant and Soil Sciences eLibrary; University of Nebraska – Lincoln).

Figure 50. Example of contour farming in Minnesoata, USA (Photo courtesy of trhe Minnesota Department of Agriculture. http://www.mda.state.mn.us/protecting/conservation/practices/~/media/Images/protecting/practices/contourfarm.ashx?w=300&h=279&as=1)

Figure 51. Contour farming (Photo courtesy of the Encyclopedia Britannica http://media.web.britannica.com/eb-media/99/65699-004-7FCC0E1C.jpg)

Specific features of this BMP relating to water conservation are:

- Using conservation crops that produce sufficient biomass or crop residue to reduce runoff and wind erosion to meet soil loss and water quality objectives.
- Reducing excess soil nutrients such as nitrogen and phosphorus by quick germination, adequate root system development, deep rooting, and rapid uptake.
- Planting conservation crops that use water more efficiently.
- Selecting crops that use excess soil water and drop water tables below the root zones of other conventional crops.
- Rotating deep rooted with shallow rooted crops.
- Adjusting rotation crop plant densities to trap sediments and take up nutrients.
- Selecting crops that have the potential to supply larger amounts of biologically fixed nitrogen than conventional crops.

BMP-AC-VT-4 Field Border Cover: Field borders are a type of conservation buffer consisting of a grassy border along one or more edges of a field (Minnesota Department of Agriculture 2013, USDA NRCS 2013c). Cover borders can be of variable width but are usually at least 5 m wide or at least half the height of adjacent trees. As well as protecting soil and water values with perennial vegetation, field borders can be designed to provide other environmental and practical benefits. For example, field borders can straighten irregular field boundaries and provide space to turn and park tractors during field operations. Field borders can be used to connect other edge-of-field buffers such as grass filter strips, SMZs, and in-field conservation features such as contour plantings (See BMP-AC-VT-2, BMP-AC-VT-5, and BMP-AC-VT-9), and grass waterways (BMP-AC-SP-3) that protect water quality. Field borders do require grass planting and long-term pasture management (See BMP AC-MP-7).

Some of the features of this BMP documented in Natural Resources Conservation Service (USDA NRCS 2013f) practice standards are:

- Field border crops should be established with locally adapted species of permanent grass, legumes, or shrubs that meet design objectives. These plants should be able to control wind and water erosion to tolerable levels.

- Shrubs should be planted in a minimum of two rows.

- Ephemeral gullies upslope of field border crops need to be mechanically treated to change flow from concentrated to dispersed sheet flow.

- Locate borders to provide a stable area on the predominantly windward edge of the field.

- Locate borders to eliminate field areas where water flows concentrate and then enter or exit crop fields. Orient plant rows perpendicular to sheet flow direction. Field borders should be 10 m in width when used for this purpose.

- Do not burn field borders.
- Design field borders to accommodate equipment turning, loading, unloading, and grain harvest operations.

- Design field border widths and lengths based on local experience and physical criteria such as topography, slope, aspect, etc.

- Avoid vehicle traffic on field borders when soils are excessively wet.

- Conduct periodic maintenance to repair storm damage, remove accumulations of sediment, repair gully controls, mitigate vehicle-related soil compaction, and to maintain border cover plant vigor.

- Control noxious weeds.

BMP-AC-VT-5 Field Strip and Ally Cropping: Strip and alley cropping utilizes the spaces between crops that would typically not be farmed (Francis et al. 1986, USDA NRCS 2013a). Strip cropping alternates traditional row crops like cotton, corn, soybeans with rows of densely planted crops like hay, wheat, or other grains. Strip cropping: a method typically used on steep slopes to prevent erosion between crop rows (USDA NRCS 2013k). Traditional row crops like cotton, corn, soybeans are alternated with rows of densely planted crops like hay, wheat, or other grains (Figure 52). This alternating pattern holds the soil in the area and prevents erosion of soil. This type of cropping will also help prevent gully formation because it will slow runoff velocities from the field. Important components of the strip cropping BMP relative to water are:

- Strips of erosion susceptible crops should be alternated with erosion resistant ones.

- Orientation of the strip crops should be on the contour and perpendicular to water flow.

- Strip widths should be based on farm planning objectives, equal in size, and in multiples of the planting and harvesting equipment to be used.

- Two or more strips should be used within the slope conservation length.

- Sod turning strips can be used for machinery if slopes are too steep for the equipment type.

- Row grades should be of sufficient steepness (>0.2%) to allow adequate drainage where ponding is a concern.

- Maximum row grades should not exceed 50% of the hill slope percent or 10%, whichever is lowest.

- Up to a 25% deviation in maximum grade is allowed within 50 m of a stable water outlet.

- Strip cropping may need to be implemented with other conservation practices (diversions, terraces, sediment basins, grassed waterways, etc.) to achieve water quality objectives.

Alley cropping alternates large rows of permanent crops (vineyards, orchards, short rotation tree crops) with smaller rows of temporary crops like forage crops. This alternating pattern holds the soil in the area and prevents erosion of soil. This type of cropping will also help prevent gully formation because it slows runoff velocities from fields.

Some of the key points regarding alley cropping are:

- Selecting plants that are adapted to local climate and soils.

- Setting the distance between the sets of trees or shrubs based on management objectives, light requirements of the crops or forages in the alleys, erosion control needs, and machinery access requirements.

- Orienting tree and shrub rows on the contour.

- Establishing an herbaceous ground cover under the trees or shrubs.

- Orienting row trees and shrubs perpendicular to the dominant wind direction.

- Using deep rooted species to encourage infiltration and avoid windthrow.

- When using alleys for bioenergy feedstock, select plants that have adequate productivity.

- Manage the intensity and frequency of feedstock harvesting to prevent long-term damage to the alley cropping system.

- Ensure that feedstock harvesting does not compromise other management objectives.

BMP-AC-VT-6 Field Windbreaks: Windbreaks are single or multiple rows of trees or shrubs in linear configurations established for multiple purposes in regions prone to persistent or high velocity winds (Figure 53, USDA NRCS 2013n). Their main purposes are to reduce soil wind erosion, alter microenvironments to improve bioenergy plant growth, increase snow deposition and hence soil moisture status, and improve irrigation efficiency. They can also function like filter strips to detain sediments and improve water quality. Other purposes include providing shelter, acting as screens, improving air quality, reducing farm energy use, enhancing wildlife habitat, and increasing carbon fixation.

a) b)

Figure 52. Strip (a) and alley (b) cropping in USA agriculture (Photos courtesy of Green Solutions and Manfred Mieke, USDA Forest Service)

Figure 53. Windbreaks in North Dakota farmland. (Photo courtesy of North Dakota State University http://www.ag.ndsu.edu/trees/whatnew/windbreak/fw31.jpg Accessed 09-10-2013.

BMP-AC-VT-7 Filter Strips: This BMP consists of densely vegetated areas on moderate to gentle slopes that filter, temporarily detain, or infiltrate surface storm runoff. The vegetation make up of filter strips can consist of native grasses, planted exotic grasses, shrubs, fast growing woody species like *Populus* spp. or *Salix* spp., and indigenous or introduced slower growing trees (see Figure 6). Filter strips are designed to reduce suspended sediments as coarser, non-suspended sediment fractions. They can also reduce non-source pollution of hydrocarbons, nutrients, metals, microorganisms, and organic debris. They function through mechanisms of filtration, sedimentation, infiltration, plant uptake of soluble pollutants, and microbial processes. Filter strips can also assist with infiltration of storm runoff, thereby reducing shock loadings of water on streams and lakes. Filter strips are often used in conjunction with other BMPs such as conservation tillage, contour farming, strip cropping, and cover and green manure cropping. Windbreaks are a type of filter strip but their main function is to alter wind flow. Filter strips are designed primarily for non-point source pollution reduction and storm runoff management.

Some of key design elements include:

- Using filter strips for broad sheet flow.
- Designing the filter strip based on slope, vegetation cover, precipitation, and soil type.
- Designing with a minimum width of 10 m to filter runoff and allow vehicle traffic.
- Restricting filter strips to slopes <8%. Slopes <5% tend to be the most effective.
- Using grading machinery to provide uniform sheet flow at the filter strip – crop interface to prevent concentrated flow.
- Planning the filter strip width to be equal to or greater than the contributing drainage area.
- Minimizing disturbance to adjacent vegetation during filter strip establishment.
- Using vigorously growing indigenous vegetation in the filter strip.
- Avoiding use of exotic vegetation unless the species is already well-established in the vicinity.
- Conducting maintenance operations to ensure successful function of the filter strip.

BMP-AC-VT-8 Grasses and Legumes: Grasses and legumes can be planted as conservation cover crops in alleys, filter strips, and grassed waterways. They can also be utilized as bioenergy feedstocks in those areas. Grasses and legumes can be good sources of biologically available nitrogen, thereby reducing farm needs for fertilizers and ultimately improving water quality in the farming landscape.

BMP-AC-VT-9 Cover and Green Manure Cropping: Cover and green manure crop use is a management practice used to reduce soil erosion, promote nitrogen fixation between crop plantings, and infuse nutrients into the soil by using green manure to reduce the amount of fertilizer needed during and after crop planting (USDA NRCS 2013d). Cover crops are planted to provide temporary soil protection after crop harvesting and can include plants like grasses, legumes (for nitrogen fixing), or some grains (Figures 54 and 55). Green manure crops are incorporated into the soil by plowing or tilling and provide needed soil nutrients like nitrogen. Both green manure and cover crops can also suppress the amount of weeds that will grow in the field. Cover crops can be used to reduce water and wind erosion. They take up soluble nutrients and redistribute them in the soil profile through fixation and fine root turnover. Cover crops also reduce exotic plant invasions, help retain water in the soil rather than losing it to surface runoff, and improve soil structure, thereby reducing the risks of soil compaction.

Some of the key features of the cover crops BMP relative to the protection of water quality are:

- Using locally adapted species compatible with the farm cropping system.
- Avoiding burning cover crop residues.
- Timing cover crop establishment with other farm plans to ensure that the soil is adequately protected from erosion.
- Selecting cover plants with physical properties necessary to detain water and sediment.
- Determining the amount of cover needed to accomplish water protection goals.
- Establishing cover crops in a timely manner before expected periods of nutrient leaching from fertilized fields.
- Using cover crops with high rates of nutrient uptake and deep rooting characteristics.
- Maintaining cover at 90% or greater with a biomass production of at least 2.2 Mg ha^{-1}.
- Using cover crop species that can serve as bioenergy feedstock when their cover function is completed.
- Using a diverse mixture of cover plant species to achieve other ecosystem objectives.

Figure 54. Grass cover crop in the Chesapeake Bay watershed, Maryland, USA (Photo courtesy of the Chesapeake Bay Program http://www.chesapeakebay.net/images/blog/feb22_12_big.jpg accessed 06-01-2013).

Figure 55. Cover crop establishment on a harvested corn field in Iowa (Photo courtesy of 2.bp.blogspot.com http://2.bp.blogspot.com/_HBkpUzCNsGE/TEhOWgMlUnI/AAAAAAAADgU/1utLQYB8Y7E/s1600/Picture+004.jpg accessed 06-01-2013).

5.2.3 Structural Practices

Structural practices are BMPs that involve erosion and water control engineering as well as construction expertise. These methods need to follow design specifications if they are to work properly. They are more costly to install but have longer functional lifetimes. Structural BMPs are usually employed to deal with concentrated water flows. An understanding of runoff response to precipitation events of given magnitudes and frequency is required to adequately design structural BMPs.

BMP-AC-SP-1 Diversions: This BMP involves the construction of a berm across the slope to handle large amounts of sheet flow surface runoff or move concentrated flow to another structure designed for storm runoff. The purpose of diversions is to break up concentrated surface runoff on long slopes in order to reduce water velocities and erosive power. Diversions can be used to protect buildings features on farms as well as waste systems and other farm improvements. A frequent use of diversions is to protect terraces (BMP-AC-SP-6) or divert water from active gullies until these erosion features can be adequately treated.

Some of the design criteria for diversion BMPs are listed below. More details can be found in the USDA ARS (1987) and USDA NRCS (2013e) publications on the topic:

- Temporary diversions should have a lifespan of 2 years and a capacity to handle peak flows from 2-year, 24 hour, rainfall events.
- Diversions designed to protect agricultural fields should be designed to handle peak discharges from 19-year, 24 hour storm events.
- Diversions designed to protect buildings, roads, waste management systems, and other farm improvements should be able to handle 25-year, 24 hour storms.
- Cross sections of diversions can be trapezoidal, v-shaped, or parabolic but must have stable side slopes.
- Diversion channel grades may be uniform or variable. Channel outlets should be determined by site characteristics and designed to retain flow capacity and be stable.
- Diversions should not be used in high sediment transport environments. If they are installed in these areas, maintenance plans should be in place to keep the diversions functioning without causing more problems due to unintended flow diversions.
- Cover crops should be established in diversions to reduce the risk of channel bottom incision. In some instances non-vegetation linings of concrete, gravel, or geotextile materials can be used.
- Operations and maintenance plans need to be established.

BMP-AC-SP-2 Grade Control: This BMP describes structures used to control the slope of channels to prevent head cutting in natural or artificial channels (Figure 56). By stabilizing and reducing slopes, flow velocities can be reduced and concentrated water flows become less erosive. Sediment transport is a function of flow velocity so any time that water velocity can be reduce erosion will be reduced and water quality protected. Additional details on this BMP can be found in USDA ARS (1987) and USDA NRCS (2013g).

Figure 56. NRCS designed grade control structure on Sugar Creek, Franklin County, Mississippi, USA, using large rocks (Photo courtesy of USDA Agricultural Research Service).

BMP-AC-SP-3 Grass Waterways: Grassed waterways are a type of structural BMP related to filter strips, but specifically designed to reduce erosion by using a vegetated channel to conduct water at a non-erosive velocity to a stable field outlet or another structural feature specifically designed to handle larger flows at higher velocities (Figures 57 and 58). Refer to BMP-AC-VT-7 and USDA NRCS (2013h) for more details.

Figure 57. Grassed waterway in a corn field in Mercer County, Ohio, USA (Photo courtesy of the Mercer County Soil and Water Conservation District, http://www.mercercountyohio.org/SWCD/grass%20waterway.JPG accessed 06-01-2013)

BMP-AC-SP-4 Sediment Basins: Water and sediment control basins are designed and constructed in lower lying field areas to collect intermittent surface runoff (Figure 59). Sediment basins are usually not used on continuously flowing streams This BMP can also be useful in forested areas to collect runoff from roads, landings, skid trails, and fueling areas. The basins function by reducing flow velocities settling out water containing nutrients, chemicals, and sediments before the water is released into streams. These basins can also be used to promote water infiltration.

Figure 58. Grassed waterway in the Big Creek Lake Watershed near Ames, Iowa (Photo courtesy of the Boone and Polk Soil and Water Conservation Districts http://bigcreeklake.files.wordpress.com/2011/12/waterway.jpg?w=900).

The basins are usually constructed along the natural drainage pathways in order to temporarily detain runoff. Basins are also typically constructed at lower elevations of the property to facilitate collection. Size, location, and construction of basins should be determined after careful site and drainage characteristics are evaluated. Basins should not be constructed in or destroy natural upland or riparian habitats, but should be constructed to help preserve and protect these habitats. Refer to BMP-AC-VT-7 and USDA NRCS (2013i) for more details and design criteria.

Figure 59. (Photo courtesy of the St Mary's Soil Conservation District, Maryland, USA; http://www.stmarysscd.com/Photo.htm).

BMP-AC-SP-5 Stream Stabilization: The banks of streams and constructed channels should be stabilized and protected to prevent loss of land area, adverse impacts on land use, and loss of stream or channel flow capacity. Streambanks can be large sources of sediment inputs into streams if they are actively eroding. Bank erosion can easily offset sediment yield reduction on farm fields if not monitored closely and restored when necessary. Streambank stabilization should be carried out in cooperation with local and state water management and conservation authorities and organizations. Further information can be obtained from these organizations and from USDA ARS (1987) and USDA NRCS (2013j).

BMP-AC-SP-6 Terraces: Terrace farming is similar to contour farming with both strategies integrating knowledge about the property's contour and topography into planting and farming strategies (Figures 60 and 61). However, contour farming does not change the contour or gradient of the land while terrace farming creates level embankments at different elevations along the contours of the property. Terrace farming creates level embankments at different elevations along the contours of the property to minimize soil erosion and chemical runoff. The different terrace levels can also promote more efficient infiltration of irrigation water and rain water into the soil.

Terraces are earth embankments or combinations of soil mounds and channels specifically built across fields to reduce erosion by limiting slope length and retaining moisture for crops. They are usually built where slopes are steep, leading to excessive runoff and erosion. The topography and soils must be conducive to construction and farming. Specific details can be found in USDA ARS (1987) and USDA NRCS (2013l). Terrace construction should be integrated with other agricultural BMPs to achieve desired sediment runoff objectives. Management of runoff from terrace systems is necessary to prevent failures on the lower end of the terrace system. Terraces require a high degree of maintenance to ensure that they do not fail and cause excessive erosion. Breaches must be repaired in a timely fashion to guarantee successful function in subsequent storms.

Figure 60. Contour planting on terraces, Montgomery County, Iowa (Photo courtesy of USDA Natural Resources Conservation Service).

Figure 61. Terraced corn fields, Marshall County, Iowa (Photo courtesy of the Marshall County Soil and Water Conservation District)

BMP-AC-SP-7 Wetland Restoration: Water quality in a farming landscape can be improved by returning degraded wetlands to their normal functions prior to being disturbed by land management activities (USDA NRCS. 2013m). Restoration involves returning site soil conditions conducive to hydric soil maintenance, re-establishing wetland hydrology and hydroperiod, and encouraging regrowth of native hydrophytic vegetation. Although wetlands can function in treating point and nonpoint source pollution, they should not be restored solely for that purpose. The process of wetlands restoration should not be used to create wetlands where they never existed historically and it should not be used to enhance original wetland conditions. Further guidance on wetland restoration can be found in Kusler and Kentula (1990) and Wheeler et al. (1995).

6 PERENIAL HERBACEOUS BIOMASS CROP PRODUCTION BMPS

Herbaceous crop production is viewed as a fundamental element in the feedstock portfolio for a sustainable biofuel supply chain (Buford et al. 2011). Two critical components of herbaceous biomass production for use in the bioenergy industry are environmental and economic stability. Dedicated herbaceous bioenergy crops can be designed for increased yields, drought tolerance, and resource use efficiency. The typical perennial herbaceous crops grown for bioenergy feedstock purposes include both native and exotic grass and legume species (Perlack et al. 2005) . Some grass species such as *Miscanthus x giganteus* have a large potential for use in energy production (Figure 62). This grass is non-invasive since planted fields are easily reclaimed for corn and soy beans, they are high yielding (22.4 to 33.6 Mg ha^{-1}), and require low to no external inputs (Clifton-Brown et al. 2001).

Figure 62. Miscanthus grown as a bioenergy crop in Italy (Photo courtesy of the University of Pisa, Center for Interdepartmental Research on Agriculture and the Environment, http://www.avanzi.unipi.it/ricerca/quadro_gen_ric/biomass_bioenergy/Biomass&bioenergy_ENG.htm accessed 09-26-2013.)

The BMPs recommended for perennial herbaceous crops grown for bioenergy feedstock are essentially the same as most agricultural crops (Buford et al. 2011). The one additional BMP that is recommended is Integrated Pest Management. This BMP involves use of one or more cultural, biological, or chemical pest control techniques to reduce pest numbers while minimizing adverse impacts on water quality.

7 TRANSPORTATION BMPS

Many of the technical BMPs for forest roads found in Section 4.2.5 on Road Management also pertain to agricultural feedstocks. Of the five key primary BMPs for transportation and supply chain management, the most applicable for bioenergy are inbound logistics, operations and servicing (Blanchard 2010). Inbound logistics refers to activities associated with receiving, storing, and distributing inputs to energy production facilities. This includes feedstock handling (Figure 63), material storage (Figure 64), inventory control, and transportation scheduling. Operations covers activities associated with transforming feedstocks into bioenergy at production facilities and handling waste materials. Servicing covers activities acquisition, repair, training, parts supply and maintenance of transportation units. Outbound logistics, and sales and marketing BMPs are not as appropriate since energy is not a physical product.

Figure 63. Loading wood biomass feedstock for transportation to a bioenergy facility, Joensuu District, Finland. (Photo by Daniel G. Neary

a)

b)

Figure 64. Delivery of wood chips to a small bioenergy producer (a) for storage (b) prior to utilization for energy production, Joensuu District, Finland. (Photos by Daniel G. Neary).

8 MUNICIPAL SOLID WASTES

Municipal solid wastes (MSW) consist of a spectrum of materials that vary by generation source (Tchobanoglous et al. 1993). They typically consist of biodegradable wastes such as food, paper, etc., recyclable materials ranging from glass to metals to plastics, inert wastes, electronic equipment and components, hazardous wastes such as paints, chemicals, etc., toxic wastes such as pesticides, and medical wastes. Industrial wastes, medical wastes, radioactive wastes, agricultural residues, and sewage fall into a different category. Management of these materials involves recycling, composting, landfill disposal, and energy generation. The main components of MSW management are generation, collection, concentration, sorting, transfer to recycling facilities, and disposal of unusable fractions. The objective is to maximize further use of these materials, minimize disposal, reduce environmental impacts, and provide other services such as energy generation (Murphy and McKeogh 2004). The potential for additional

energy recovery from wastes is significant. However, from a global perspective, bioenergy from municipal solid wastes is a small fraction of the potential bioenergy that could be delivered from agricultural residues, forestry residues, or energy crops (Sampson et al. 1993).

9 URBAN AND INDUSTRIAL WOOD WASTE BMPS

9.1 Background

The two major sources of urban wood residues are yard and tree waste wood, which make up 13% of MSW, and construction and demolition waste wood which comprise 8.4% of MSW (Perlack et al. 2005). Yard waste includes land-clearing debris and yard waste made up of leaves, tree and shrub limbs, logs from landscape maintenance, and storm debris. Land clearing debris consists of stems, branches, leaves, roots etc. from vegetation cleared form new construction. In rapidly developing municipal areas, land clearing wastes can account for 80% of yard wastes. Other sources of combustible woody material include discarded furniture, used containers, packaging materials, pallets, scrap lumber, etc. In the case of storm debris, wood wastes produced by tropical storms, hurricanes, winter storms, and cyclones can place enormous strains on MSW systems (Figure 65). Individual hurricanes in the southern USA have been known to generate 10 to 20 years-worth of wood waste virtually overnight. The author personally observed this during Hurricane Andrew of 1990 which struck south Dade County, Florida.

Construction and demolition wood waste is generated during new building construction and repair and remodeling of existing structures (Falk and McKeever 2004). This type of wood waste is usually considered separately from MSW since these waste materials come from a variety of sources outside the normal municipal waste stream. Supply of this type of wood waste is estimated to increase future quantities of urban wood wastes are assumed to increase at 50% of the rate of population growth. Supply is affected by economic activity, population trends, building ages, the degree of waste wood recycling, firewood programs, and natural disasters.

a)

b) 

Figure 65. a) Wood storm debris from a) a 2012 winter storm in Washington, USA, and b) the 2013 Moore, Oklahoma, tornado. (Photos courtesy of Biocycle Magazine and NewsGrio).

Figure 66. Typical construction wood waste. (Photo courtesy of Recovery 1, Tacoma, WA).

The principal environmental issue associated with wood waste recycling, reuse, energy production, and disposal is the presence of preservative chemicals such as chromated copper arsenic (CCA) and other fungicides (Figure 67, Falk 1997, Kessler 2004). Other chemicals of concern are acid copper chromate, copper boron azide, and disodium octaborate, paints, glue, pentachlorophenol, creosote, tar, and asphalt. Although these chemicals extend the use of wood materials by 10 to 20 times, these all pose various levels of risk to those handling the materials, and may result in leaching into soils or water bodies. Clearly, the basic BMP for waste wood is separation of treated materials from clean, uncontaminated wood. New preservative compounds which have replaced CCA in some instances are free of arsenic. They are Copper Quat and Copper Azole. The latter contains tebuconazole, a fungicide which is used on food crops. Treated wood waste should be separated from untreated wood waste and disposed of in a special lined landfill (Kessler 2004). Special BMPs exist for the handling and disposal of treated wood waste, but these are not discussed in this report since treated wood wastes should not be part of the bioenergy feedstock supply chain.

Figure 67. Pressure treated beams used in residential and commercial construction. (Photo courtesy of Oriental Lumber, New York)

9.2 Wood Waste BMPs

The wood waste BMPs discussed here follow those developed by Kessler Consulting Inc. for Sumter County, Florida, (Kessler 2004), the Florida Department of Environmental Protection's publication "Best Management Practices for Protection of Water Resources in Florida (FDEP 2010), and principles discussed by Falk (1997).

9.2.1 Treated Wood Waste

BMP-WW-TL-1 Disposal Practices for Pressure Treated Lumber: The first step in this BMP is separation of wood waste from pressure treated lumber from untreated wood material. This begins at the point where treated wood handled or modified and waste is generated by construction and demolition activities (C&D). The basic steps are:

- Clean all sawdust and wood pieces from the work site and place in plastic bags for placement in designated trash containers.
- Use normal garbage collection procedures for disposal of treated wood.
- Do not burn pressure treated waste wood of C&D debris in open or contained combustion facilities.
- Dispose of treated wood wastes in a properly permitted landfill that has lined cells and monitoring wells to prevent leaching of chemicals into groundwater.
- Do not compost any sawdust, scraps, or demolition debris made from treated wood.

- Do not use pressure treated wood chips and sawdust for garden or landscaping mulch.

- Further information on BMPs for treated wood waste disposal can be found in Helsen and Van den Bulck (2005) Solo-gabriele and Townsend (1999), and at: http://www.dep.state.fl.us/waste/quick_topics/publications/shw/recycling/innovativegrants/igyear4/sumter_bmp_manual_final.pdf

9.2.2 Clean Wood and Construction and Demolition Woody Waste

BMP-WW-WP-1 Wood Pallets: Pallets are commonly used to safely and efficiently transport products and produce (Figure 68). Wood pallets are easy to reuse, repair, and recycle so that the waste stream from pallets is minimal. Over 80% of wood pallets in pallet recycling programs can be repaired or reused (Kessler 2004). The components of the BMP are:

- Waste pallet wood needs to be screened to eliminate treated wood for proper disposal in a landfill.

- Reuse, repair, or recycle wood pallets as much as possible.

- Untreated and unusable wood pallet wastes, which make up about 5% of damaged pallets, can be usable for bioenergy feedstocks.

Figure 68. Wood pallets used for shipping manufactured, chemical, and agricultural products. (Photo courtesy of Custom Packaging Products, Houston, Texas).

BMP-WW-LF-1 Wood Waste in Unlined Landfills: This category of wood waste includes yard trimmings and thinnings, C&D woody debris, and wood furniture. It requires good sorting since the general waste stream may include such items as tires, carpet, glass, plastic, other furniture, and paper that are not expected to generate liquids that can leach into groundwater (Kessler 2004). The important parts of this BMP are:

- Wood treated with preservatives should be screened out and sent to other appropriate landfills.

- Wood should be evaluated for recycling or reuse.

- Donate usable wood to charitable organizations, schools, training programs, etc. that have needs of wood.

- Mulch large quantities of waste wood on site for shipping to other facilities for use as mulch or bioenergy feedstock.

- Remove mineral, metal, and glass contaminates prior to bioenergy feedstock end use.

- Develop storage facilities for waste wood in case bioenergy feedstock demands are cyclical in nature.

BMP-WW-C&D-1 Construction and Demolition Facilities: Some disposal sites for waste wood are designated for C&D debris that is non-hazardous and not prone to leaching of chemical constituents (Figure 69). These facilities usually have a higher level of requirements for waster material handling. The materials that are frequently found in C&D include waste wood, lumber, glass, brick, concrete asphalt, gypsum sheeting, and steel from both new construction and older building demolition.

The principal features of this BMP are:

- Wood treated with preservatives should be screened out and sent to other appropriate landfills.

- Untreated wood waste should be screened and separated for reuse or recycling.

- Don't mix C&D wood waste with other types of waste as this will result in the C&D woody waste being downgraded.

- Donate usable wood to charitable organizations, schools, training programs, etc. that have needs of wood. Donated wood waste should be free of nails and other metal, broken glass, hazardous materials, and non-wood construction debris.

- Mulch large quantities of waste wood for storage on-site or for shipping to other facilities for use as mulch or bioenergy feedstock.

- Contact C&D facilities for instructions on handling and transporting C&D wood waste

Figure 69. Piled untreated C&D debris ready for sorting for reuse, recycling, or energy production. (Photo courtesy of M.S. in Sustainable Design, Philadelphia University).

BMP-WW-CS-1 Construction Site Operations: An excellent environmental goal in construction as well as an important economic objective for contractors is the reduction of wood waste (Kessler 2004). The reduction does not start at the on-site disposal dumpster but in the site design and planning stages. Construction costs and waste disposal costs can be significantly reduced by adequate planning and managing the waste generation stream and using BMPs. The main components of this BMP are:

- Develop a program that can adequate separate treated from non-treated wood wastes.
- Ensure that the construction client, design team, general contractors, and operations teams have the same project goals for the site environment and waste reduction.
- Develop plans that minimize material usage, incorporate C&D debris recovery, and clearly delineate waste reduction objectives and goals.
- Utilize only general contractors and subcontractors that have demonstrated wood waste reduction and proper reuse, recycling, and sorting for other uses such as mulching and bioenergy feedstock production.
- Assign an operations team member to lead reuse, recycling, and sorting efforts.
- Provide briefings to contractors and operations crew members on wood and other materials recovery and reuse objectives and techniques.

10 BIOENERGY PRODUCTION FACILITIES BMPS

10.1 Planning BMPs

Best Management Practices for bioenergy generation facilities and biorefineries relate to feedstock types, co-products, energy use, water management, waste handling, emissions, and safety. There are other BMP topics related to social impacts, economics and marketing, but they are not addressed in this discussion.

BMP-BP-PL-1 Feedstocks: The source feedstocks for bioenergy or biofuel producing facilities should originate, if possible, from third-party farms and forests that follow BMPs for production and transportation. Feedstock flexibility should be an integral part of production facility design and planning to facilitate changes in availability.

BMP-BP-PL-2 Location: Bioenergy facilities should be planned to be in close proximity to feedstock sources for economic as well as environmental impact reasons (Figure 70). Minimizing transport distance and road requirements should be a major design goal. Locations near rail and barge transportation networks should be given a high priority if possible.

BMP-BP-PL-3 Design: Bioenergy production plants should be designed to handle multiple feedstocks to provide maximum economic flexibility. Consideration should be given for the production of economically viable and environmentally benign co-products such as steam for residential and commercial heating. Integration of bioenergy facilities with other wood or food processing industries should be planned to maximize use of raw materials, wastes, and energy. Facilities should be designed to handle and store runoff waters from road surfaces, storage facilities, buildings, and industrial areas.

Figure 70. Abengoa Bioenergy second generation ethanol production plant adjacent to a feedstock source, Salamanca, Spain. (Photo courtesy of IEA Bioenergy Task 43).

10.2 Operations BMPs

BMP-BP-OP-1 Energy Usage: Primary bioenergy plants produce their own energy but should be designed and operated to be as efficient as possible. Biorefineries should use the most efficient and renewable source of energy, ideally on-site generation. Energy auditing and management should be an integral part of plant operations to improve efficiency and reduce internal energy consumption. Co-generation should always be considered and opportunities to utilize waste steam for residential and commercial heating, and other manufacturing processes should be pursued. Opportunities to utilize passive solar lighting and energy efficient lighting in production facilities should be pursued in both the design and day-to-day operations. Energy consumption per unit of output should be a standard operations activity to maximize facility efficiency, productivity, and economic return.

BMP-BP-OP-2: Water Management: The water footprint of bioenergy can be reduced by maximizing efficient use of recycled water in production facilities and processes. Adequate plans, infrastructure, and facilities should be in place to handle wastewater that can’t be used for other applications. After their end use, process water should be discharged to municipal waste treatment facilities, treated and applied to adequately designed and operated land application facilities, sent to commercial composting facilities, treated and re-used, evaporated on site, or handled in other environmentally responsible manner. Care should be taken not to discharge waters that are above ambient water temperatures. Effluent should be monitored for levels of hydrocarbons (fats, oils, petrol, grease, etc.), biological oxygen demand, total suspended solids, chemical oxygen demand, and pH levels. Runoff water from operations areas and facilities should be routed to stormwater detention areas for infiltration or treatment.

BMP-BP-OP-3 Wastes and Emissions: Eliminate or reduce liquid and solid wastes and emissions in the manufacturing or production stream by having current inventories. Frequently review plans for handling wastes and emissions, and establish measures for continued improvement. Seek opportunities for utilizing waste steam and water in municipal or other industrial uses.

BMP-BP-OP-4: Bioenergy Plant Operations: Have a current business plan and review and update it periodically. Operate as efficiently as possible and employ used but fully functional equipment when possible. Maintain an aggressive safety program to ensure safe operations on-site and for feedstock sources. Use renewable chemicals if they are available. Seek construction, operations, and routinely used materials from local sources before pursuing regional, national, and international ones.

11 SUMMARY

This publication is a synthesis of pertinent BMPs for the protection and management of water during the production and processing of woody and agricultural crops, feedstock transportation, energy production, and utilization of wood wastes. It discusses life cycle assessment, SMZs, key processes involved in water protection, and BMP information sources. There are thousands of BMPs that can be applied to forest and agriculture production. The development of BMPs is an iterative process involving constant application, assessment, and revision to improve the desired outcomes relative to water quality and other objectives.

The use of BMPs begins in the planning process and follows through during the implementation and application of biomass harvesting techniques for bioenergy production. This report examines feedstock BMPs for bioenergy production from sources such as conventional forestry, short-rotation forestry, traditional agriculture crops, non-traditional agricultural crops, wood waste production from primary and secondary forest processing industries, and wood waste generated by municipal tree and shrub thinnings and natural disasters such as wind storms, tornados, and hurricanes. It does not address the topic of BMPs for feedstocks from agricultural field and manufacturing residues, municipal and industrial sludges, manures, and pulp and paper mill wastes. These topics will be addressed in a separate analysis.

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GBEP
Global Bioenergy Partnership

IEA Bioenergy

IEA Bioenergy Task 43 – Biomass Feedstock for Energy Markets – seeks to promote sound bioenergy development that is driven by well-informed decisions in business, governments and elsewhere. This will be achieved by providing to relevant actors timely and topical analyses, syntheses and conclusions on all fields related to biomass feedstock, including biomass markets and the socioeconomic and environmental consequences of feedstock production. Task 43 currently (Jan 2011) has 14 participating countries: Australia, Canada, Croatia, Denmark, European Commission - Joint Research Centre, Finland, Germany, Ireland, Netherlands, Norway, Sweden, UK, USA.

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