LAND MANAGEMENT PLAN for the WATERSHEDS of the SUDBURY RESERVOIRS:

2005-2014

Sudbury Reservoir Gate House, October 2004 Photo by J.Kowalski

Prepared by:
The Massachusetts Department of Conservation and Recreation,
Division of Water Supply Protection,
Office of Watershed Management

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Executive Summary

The 3,113 acres of undeveloped land controlled by the Department of Conservation and Recreation (DCR), Division of Water Supply Protection (DWSP), Office of Watershed Management (OWM) surrounding the Sudbury, Foss, Stearns, and Brackett reservoirs and their tributaries are the system's most valuable asset. The Watershed Protection Plan for the Sudbury Reservoir watershed system describes the lands surrounding these four reservoirs as the most significant existing protection measure for the Sudbury water supply (MWRA, 1997). This 10-year Land Management Plan for the Watersheds of the Sudbury Reservoirs sets out policies, goals, and methods for managing these lands within the primary purpose of protecting this emergency use public water supply. In addition, the plan describes active forest management, a program for tree planting on private land along key tributaries, and plans to protect wildlife, biological diversity, and cultural resources through specific management practices.

In planning the management of OWM land in the Sudbury watersheds in the context of the overall DWSP/OWM - MWRA System (Figure 1), the two basins (North and South Basins - Figure 2) are treated differently. The 2,323 acres of OWM land in the North Basin serve to protect the Sudbury and Foss Reservoirs, which have emergency standby status, while the 790 acres of OWM land in the South Basin serve to protect the Brackett and Stearns Reservoirs as well as Cedar Swamp and the Sudbury River, none of which have any status as water supply for the OWM/MWRA system (and have not been used since the early part of the last century). The bulk of active land management will be focused on the North Basin.

The primary goal of OWM's land management plans is to provide the best possible vegetative cover throughout the watersheds for protecting tributary and reservoir water quality. The most important objective for this plan is to maintain the functioning of this watershed protection forest, in both the short and long terms, by first correcting deficiencies in pine plantations and understory development, and then working steadily to produce a vigorous, diverse, stable, multi-layered forest cover. In the process of reaching the above objectives, OWM managers will simultaneously address the protection of wildlife, biological diversity, and cultural resources. In addition, staff will maintain OWM property boundaries, identify and work to quickly resolve boundary encroachments, enforce public access guidelines, protect against fires, and maintain access roads.

Section 1 of this plan presents the legislative **mandates**, **agency mission statements, and other foundations for OWM's land management program**, as well as a general overview of the plan. A recent reorganization merged the former Department of Environmental Management and the former Metropolitan District Commission into the new Department of Conservation and Recreation (DCR). DCR includes the Division of Water Supply Protection and, within that Division, the Office of Watershed Management (OWM). The legislatively mandated mission of OWM (formerly known as the MDC Division of Watershed Management), found in MGL Ch. 92, Sections 104-120 (repealed by 2003, 26, Sec. 289. Also see 2003, 26, Sec. 715) is to "*…construct, maintain and operate a system of watersheds, reservoirs, water rights and rights in sources of water supply, …supply thereby a sufficient supply of pure water to the Massachusetts Water Resources Authority, and …utilize and conserve said water and other natural resources in order to protect, preserve and enhance the environment of the commonwealth and to assure the availability of pure water for future generations …*" OWM land management on the properties surrounding the Sudbury Reservoirs recently received "green" certification by the international Forest Stewardship Council as part of a successful Commonwealth forest certification effort by the Executive Office of Environmental Affairs.

Section 2 of the plan, a **description of Sudbury Reservoir Watershed Resources**, provides an overview of the natural and cultural resources contained in the Sudbury system lands. OWM controls 3,113 acres of land and 1,830 acres of water, or approximately 10% of the 47,840 acres of land and water in the watersheds of the entire Sudbury system. In the Sudbury Reservoir and Foss Reservoir watersheds (North Basin), OWM controls approximately 22% of the total area (land and water) and an additional 7% is protected by other state, municipal, or non-profit conservation ownership or by private land under Chapter 61, the Massachusetts Forest Tax Law. In the Brackett Reservoir and Stearns Reservoir watersheds (South Basin), OWM controls approximately 4% of the total area (land and water), and an additional 16% is protected by other owners or programs. In the North Basin, OWM and MWRA control 74% of the land within 400 feet of the reservoir and the open channel. In the North Basin, OWM controls approximately 32% of the land within 400 feet of the reservoir and its tributaries. Overall, forests cover 38% of the North Basin and 51% of the South Basin.

Soils on OWM Sudbury land are grouped into five types: excessively well-drained (11%), well-drained thin (5%), well-drained thick (31%), moderately well-drained (9%), and poorly drained (44%). Elevations range from 252 feet on the Sudbury Reservoir surface (when full) to 464 feet at Pine Hill (the peak on the East shore of Sudbury Reservoir, due east from Newton Island), and 97% of the land in the system is less than 20% slope while just 0.5% exceeds 30% slope.

The South Basin is dominated by the Sudbury River. The North Basin includes two major tributaries (Crane and Marlborough Brooks) and many small streams. Average annual precipitation on the watersheds is 44 inches, and average precipitation yield to the reservoirs is 50%.

The majority of the present forest overstory on OWM-controlled Sudbury land is 60 to more than 100 years old, originating from farm abandonment and plantation establishment beginning in the late 1800s, as well as an unknown acreage that was reinitiated by the hurricane of 1938. Forest types are approximately 60% softwood and 40% hardwood in the managed forest (approximately 1,200 acres) with 45% in white pine types, 24% in red maple and mixed hardwood types and 17% in oak types. Approximately 410 acres (35% of the managed forest) have been silviculturally treated over the past 10 years.

Wildlife on the Sudbury system lands is abundant and varied, and includes at least five species on the rare and endangered and "special concern" list of the Natural Heritage and Endangered Species Program.

Cultural resources on the Sudbury system lands include both historic and prehistoric sites. The Cedar Swamp is listed on the National Register of Historic Places as an Archaeological District with thirty-two pre-historic sites documented, three of which are on OWM lands. The Sudbury watershed is one of the most historically significant components in OWM/MWRA system and dates to when construction began in 1873. Eight historic districts, comprising 77 buildings and structures on eleven individual OWM properties, are listed in the National Register of Historic Places.

Section 3 identifies **principles of watershed management** that drive management goals and objectives for the Sudbury watershed lands. These principles were distilled from an extensive literature review and principles are identified in the areas of Watershed Protection, Water Yields, Watershed Forest Management, Air Pollution Impacts, and Wildlife Impacts.

Section 4 identifies **OWM goals** for managing the Sudbury lands during the ten years from 2005 through 2014. Goals are identified for overall Watershed Management, Water Quality and Yields, Land Protection, Forest Management, Wildlife Management, and Cultural Resource Protection. Goals identified are as follows:

- Provide the best possible protection for reservoir water quality, by maintaining vigorous forest cover, diverse in species composition and tree sizes and ages, across the vast majority of OWM lands surrounding the Sudbury Reservoirs.
- Minimize or mitigate both point and non-point sources of water pollution, including export of phosphorus, nitrogen, and turbidity to the reservoirs to provide a safe supply of water, under emergency conditions, for present and future generations.
- Limit land uses on OWM lands to those that do not threaten water quality, and limit the disposition of OWM land for municipal or private use, through adherence to OWM Land Disposition Policy.
- Mitigate adverse impacts of wildlife on infrastructure and other watershed resources.
- Identify and protect rare and uncommon species and habitats on OWM lands.
- Maintain limited early successional forested and non-forested habitats on OWM lands.
- Work to identify and eliminate invasive species from OWM properties.
- Maintain unmanaged forest reserves on a portion of OWM's holdings.
- Identify significant cultural resources on watershed lands, and prevent their degradation.

Section 5 describes the **objectives and methods** proposed in the plan for meeting the stated goals for **Land Protection, Forest Management, Management of Biodiversity, Wildlife Management**, and the **Protection of Cultural Resources**.

Land Protection Objectives

OWM has not had an active land acquisition program at Sudbury watershed due to the higher priority of programs at the three active water supply watersheds and the lack of bond monies earmarked for Sudbury. Due to the emergency-only status for the Sudbury system, this is not likely to change. Some properties may be disposed of or reassigned to other state agencies, according to an established land disposition policy.

The condition of the riparian areas along the reservoirs and their tributaries has been identified as a priority concern for Sudbury land management. A pilot program to reestablish forest and shrub cover within deforested riparian zones was successfully implemented during the past decade and will be expanded, as funding allows, during the coming decade.

OWM staff works to maintain agency property boundaries within the Sudbury watersheds and to rapidly resolve any encroachments encountered. Watershed Rangers provide infrequent patrols for violations of access regulations and works with local police to enhance this surveillance and reduce the impacts of inappropriate or illegal activities on Sudbury natural resources.

Fire protection for OWM properties is primarily the responsibility of the local municipal fire departments. The plan identifies the need to maintain access roads and train and equip OWM staff in order to improve response to fires that do occur.

There are approximately 10 miles of OWM-maintained access roads within the Sudbury system, 3.7 of which have been identified for upgrading during the period covered by this plan. Best Management Practices are identified for access road work, as well as an internal review process for proposed new roads or gravel operations to maintain existing access roads. Guidelines are described for determining when beaver impact control is required, as well as methods for reducing these impacts.

Approximately 1,026 acres of OWM Sudbury lands have been classified as Areas with Special Management Restrictions. These areas include large blocks of land such as the Cedar Swamp and Crane Swamps. Overall, they include 116 acres of islands in the Sudbury Reservoir, 505 acres of wetlands, and 405 acres of riparian zones. In addition, many small areas have been included, representing sensitive resources and buffers around historic and rare wildlife habitats.

Forest Management Objectives

There are two major objectives for forest management activities on the Sudbury watersheds during the next 10 years; 1) to foster tree regeneration where it is lacking and 2) to replace plantations with a mix of native species better suited to these sites. Management activities recommended in this plan attempt to mitigate the effects of natural disturbances. While the frequency of occurrence of catastrophic winds or major insects or diseases in New England cannot be changed, the resistance and resilience of a forest to such impacts can be enhanced.

Silviculture is proposed to accomplish these objectives and to move the forest generally toward a stable, multi-layered, diverse, and vigorous condition across the watersheds. This will include, for the ten year period of the plan, 300 acres of plantation thinnings and regeneration cuts, 10 acres of intermediate thinnings in non-plantation stands, and 100 acres of preparatory and regeneration cuts in non-plantation stands. Regeneration cuts will generally produce openings ranging from ¼ to 2 acres in size, averaging about 1 acre. For unstable plantations, openings may range to 5 acres in size in order to more quickly replace these with more stable mixed natural forests. Finally, up to 3,000 seedlings will be planted on 30 acres during this coming decade, to enhance regeneration as needed.

Silviculture is described in the plan by forest type, and a carefully designed set of conservation management practices is outlined that will guide all forest management activities and limit short-term negative effects. The details of the timber harvest permit used to control harvesting and the internal review process for all proposed timber sales are reviewed. Specific policies are explained regarding the management of lands in the South Basin, where less active management is necessary due to the off-line nature of these reservoirs

Objectives for the Management of Biodiversity

OWM recognizes that its greatest contribution to regional and local biodiversity is protecting significant areas of land from development and maintaining those lands in forest or other natural cover. The Sudbury watershed system is an exceptionally difficult place to address the challenges of conserving biodiversity. The watersheds are densely populated, fragmented, subjected to invasive species, and under intense development pressure. Remaining natural areas tend to be relatively small and isolated. Nonetheless, there are opportunities within these properties to pay attention to and enhance biological diversity.

The plan reviews the sources of the mandate to protect biodiversity and then describes what is currently known about the diversity of Sudbury flora and fauna and natural communities, including Cedar Swamp. The problem of invasive plants is pronounced in the Sudbury system, due to the frequency of landscape disturbances, but with adequate staff and funding, control measures can be applied to at least protect against the loss of rare species or habitats to invasive species.

Finally, this section reviews the importance of early successional habitats, both wooded and non-wooded, in supporting biodiversity. OWM intends to maintain its 227 acres of open grasslands in the Sudbury system to support Neotropical migratory birds, raptors, and butterflies, among other species, as well as to regularly produce small areas of early-successional woody habitats.

Wildlife Management Objectives

Land management activities that alter vegetation and other habitat conditions have corresponding impacts on the wildlife community in that area. Changes in wildlife habitat conditions at Sudbury will result from the planned forest management activities. The net result will be increased structural diversity of the forest cover on much of OWM holdings. These changes will occur gradually over the next several decades, but should begin to be evident during this ten year management period. Overall wildlife diversity on the reservation will likely increase, as species that utilize lower and middle strata of forest cover will increase. Decreases in those species that prefer closed-canopy, open-understory conditions will also likely occur. The larger openings created when weakened pine plantations are removed will favor species that utilize early-successional habitats.

The forest management program described in this plan can result in substantial changes in wildlife habitat. The plan recommends specific actions to minimize the negative impacts and maximize the benefits of OWM's silvicultural operations for wildlife. These actions include: observing buffer zones around rare species habitats, using a low intensity of management whereby each site is treated on an average of every 25-30 years, conducting operations in certain areas only in winter, and observing certain guidelines in the selection of trees to be removed and left (especially leaving large snags and important cavity and mast trees). The importance of abundant levels of dead and downed material is highlighted as well as providing protection for vernal pools and wintering areas. Specific recommendations for maintaining each of these habitat features are outlined in the plan.

Some wildlife species require direct management to prevent negative impacts on water quality, forest conditions, or infrastructure. The plan outlines situations in the Sudbury system that require direct wildlife management, including flooding of access roads by beaver and disruption of dam integrity by burrowing animals. OWM will follow specific procedures outlined in the plan to address these situations on the Sudbury watersheds, resorting to lethal controls only when non-lethal controls are not effective.

Objectives for the Protection of Cultural Resources

Without appropriate controls, land management programs can be detrimental to archaeological resources. Accordingly, the foundation of OWM's cultural resource management program is a process for reviewing proposed silvicultural operations and recommending management practices to protect important cultural resources. For those silvicultural operations planned for sites that have been classified as *highly* or *moderately sensitive for prehistoric resources*, restrictions are recommended on the time of year and the types of equipment and techniques used. Recommendations are also provided for protecting historic resources. Vegetation, if left to grow unchecked in and around stone foundations, and other historic structures like dams, raceways, etc., will ultimately alter these archaeological features. Accordingly, a limited and selective management program to control vegetation growth in and around archaeological sites and historic buildings and structures is recommended. Further inventory, archaeological sampling, and public education are recommended to bolster cultural resource protection in the long term.

Section 6 identifies priorities for **research, inventory, and monitoring**. While outside research takes place regularly on OWM watershed properties, this section specifically identifies research that would address current and future agency concerns. Identified needs include monitoring of forest management effects, analysis of optimum riparian vegetation, inventory and control of invasive plant species, analysis of Sudbury road conditions, and measurements to describe the age structure of the current Sudbury forests. Wildlife topics needing further research include documentation of critical habitats and rare species occurrences, and monitoring of wildlife activities, including loon nesting, breeding success of Canada geese, and general breeding bird surveys. The principal research need for the continued protection of cultural resources within OWM properties on the Sudbury Reservoir watersheds is to inventory, accurately map, and digitize all known historic cultural sites.

Section 7 of the plan outlines the strategy for regular **public involvement** in the development and implementation of the Sudbury Land Management Plan, including objectives for better understanding the public's interest in the Sudbury watershed properties, for better informing the public about OWM intentions and obligations in managing these lands, and for involving the public in regular reviews and revisions of the plan as conditions change through time.

Section 8 provides a bibliography of **literature cited** in the plan as well as general references that are frequently used by OWM in the development of land management plans (a total of 329 references).

Section 9 provides a **glossary** of terms used in the plan.

SUMMARY

The Sudbury Land Management Plan outlined above represents a comprehensive approach to the management of the natural resources within the Sudbury watersheds. One of the main tenets of this plan is that a proactive and long-range approach is well justified, given the importance of the task at hand. This plan synthesizes a large body of research, literature, and staff expertise on a focused goal of protecting and enhancing the natural filtration capabilities of the 2,323 acres of OWM property surrounding the Sudbury and Foss Reservoirs in the North Basin of this system.

1 Introduction, Mandates and Statement of Mission

Perhaps no other issue in the management of natural resources is as critical to the well-being of our society as the provision of pure and adequate drinking water supplies. This is especially true in recent years, given the frequency with which incidents of contaminated wells, fouled lakes, and water-borne disease outbreaks have been reported. The protection and careful management of public water supply reservoirs and their watersheds will thus continue to be of utmost importance in future years.

This document outlines a plan for protecting and managing the watersheds of the Sudbury Reservoirs, the only emergency back-up to an extensive water supply system that could be utilized to serve the emergency drinking water needs of 2.2 million people (MWRA/MDC, 1997).

1.1 2003 Reorganization of State Agencies and Effects on this Plan

A major change occurred in the Executive Office of Environmental Affairs during the preparation of this document for public review. On June 30, 2003, Governor Mitt Romney signed legislation that merged the Metropolitan District Commission (MDC) and the Department of Environmental Management (DEM) into the new Department of Conservation and Recreation (DCR). There are three new Divisions within the Department of Conservation and Recreation: the Division of Urban Parks and Recreation (DUPR), the Division of State Parks and Recreation (DSPR), and the Division of Water Supply Protection (DWSP). The Office of Watershed Management (OWM) is the specific office within the current Division of Water Supply Protection whose purpose is the management of Boston's water supply watersheds. DCR/DWSP/OWM is the current equivalent of the old MDC/Division of Watershed Management.

Throughout this Sudbury Land Management Plan, attempts have been made to make appropriate changes in terminology. In some contexts, particularly in historical discussions, the term "Metropolitan District Commission/Division of Watershed Management" or simply MDC or MDC/DWM remain accurate (e.g., "MDC developed land acquisition models in 1998 for the Ware River"). In the context of this plan, "the Division" refers to the Division of Water Supply Protection or the former Division of Watershed Management, not to any other Division in the Commonwealth.

While the agency adjusts to structural changes, the agency mission remains unchanged. Like the former MDC/Division of Watershed Management, the DCR/Division of Water Supply Protection/Office of Watershed Management manages and protects the drinking water supply watersheds for 2.2 million residents of Massachusetts. The Ware River watershed, Quabbin Reservoir watershed, and Wachusett Reservoir watershed are the sources of drinking water for distribution by the Massachusetts Water Resources Authority (MWRA). The Sudbury Reservoirs are currently off-line emergency back-ups for the system.

1.2 Agency Mission and Mandates

The DCR/DWSP/OWM and the Massachusetts Water Resources Authority (MWRA) supply drinking water to 47 Massachusetts communities, most of which are in the metropolitan Boston area. OWM is responsible for collection and storage of water, protection of water quality, and management of the watersheds (Quabbin Reservoir, Ware River, Wachusett Reservoir and Sudbury Reservoir). The watershed management group was established in 1984 when the state legislature divided the former MDC Water Division into the new Division of Watershed Management (DWM), responsible for watershed operations and management, and the Massachusetts Water Resources Agency (MWRA), responsible for water distribution and treatment. As noted above, the MDC/DWM became the DCR/DWSP/OWM on June 30, 2003.

The former MDC Division of Watershed Management's mission was laid out in its enabling legislation and subsequent amendments, found in MGL Ch. 92, Sections 104-120 (repealed by 2003, 26, Sec. 289. Also see 2003, 26, Sec. 715). The statute directed the DWM to"*…construct, maintain and operate a system of watersheds, reservoirs, water rights and rights in sources of water supply, …supply thereby a sufficient supply of pure water to the Massachusetts Water Resources Authority, and…utilize and conserve said water and other natural resources in order to protect, preserve and enhance the environment of the commonwealth and to assure the availability of pure water for future generations*." In order to meet these legislative mandates, the Division has established programs in Environmental Quality, Engineering and Construction, Watershed Operations, Public Education, and Natural Resources, all tasked primarily to the protection of this drinking water supply. The long-term goals of the DWSP/OWM are to:

- Ensure availability of clean water for present and future generations.
- Effectively manage, protect, conserve and enhance the natural and structural resources under the responsibility of OWM to ensure public health and safety.
- Prevent adverse environmental impacts that could degrade watershed resources.
- Provide educational programs in order to protect watershed resources.
- Conduct research that guides and assists the effective management of watershed resources.
- Develop emergency contingency plans that address existing and potential threats to OWM resources.

Chapter 92, Section 105 of the Massachusetts General Laws also states that the Division (now Office) of Watershed Management "…shall be subject to the provisions of chapter seven-hundred and thirty-seven of the acts of 1972." Chapter 737, commonly referred to as the "Kelly-Wetmore bill," included far-reaching guidelines on the types and extent of both public and management activities permitted on watershed properties. Section 8 of Chapter 737 states that: "Lumbering or logging operations shall be permitted…to the extent and for the purpose of maintaining and conserving its forests in a healthful state of natural ecological balance consistent with reservoir and watershed purposes…" While Chapter 737 specifically addresses the treatment of the lands of the Quabbin section, which includes properties at Quabbin and Ware River, it has been interpreted to provide guidance for the management of OWM properties on the Wachusett and Sudbury reservoir watersheds as well.

1.3 "Green Certification" of MA State Forest Land Management

On April 10, 2004, all state forest lands in Massachusetts became "green" certified. Certification provides third-party review and auditing of forest management practices for the long-term sustainability of their relationship to the environment and to the regional human economy. The certification was granted by Scientific Certification Systems (www.scs1.com), an independent, third-party certification body accredited by the international Forest Stewardship Council (www.fsc.org). Certified lands are managed by different agencies of the Executive Office of Environmental Affairs (EOEA), including the Division of State Parks and Recreation (285,000 acres), the Division of Fisheries and Wildlife (110,000 acres), and the Division of Water Supply Protection (104,000 acres). With this certification Massachusetts becomes the first state in which multiple forest management agencies have joined forces to earn certification of all of the publicly managed state forestland. The 1997 certification of Quabbin Reservoir watershed forestry practices was the first certification of state lands in North America. Certification is an endorsement, but conditions for improvements in management practices must be attained within a five-year period for this endorsement to remain valid.

Final condition number 2002.9 in the MA Certification Evaluation Report requires that this plan for management of the Sudbury DWSP properties must include a determination of the percentage of OWM lands that fall under “High Conservation Value Forest” designation under category 4 (watershed values), and a description of the ways in which management of these lands is consistent with maintaining or enhancing HCVF attributes. On further discussion with the auditor, it was agreed that 100% of these properties meets the criteria for High Conservation Value Forest, and furthermore, that the management practices described herein are fully consistent with category 4 watershed values inasmuch as watershed protection is the priority for all lands under OWM management. The full MA certification report, including the details of these conditions is available online, at www.mass.gov/envir/forest/default.htm .

1.4 Plan Overview

In formulating this management plan, OWM staff has provided the necessary interpretation of the above mandates so that they could be transformed into specific management goals and direction. Although this plan addresses various natural resources, it is mainly focused on managing for OWM’s primary purpose - the long-term protection and maintenance of water quality. The land management strategies outlined in the plan are primarily designed to establish and maintain the most effective and practical watershed cover in order to maximize the natural filtering capability of the lands surrounding the Sudbury and Foss Reservoirs. The plan also makes recommendations for the protection of OWM lands within the South Basin at the Cedar Swamp, along the Sudbury River, and surrounding the Brackett and Stearns Reservoirs, which are not connected to OWM/MWRA water supply system.

As a land management plan, this document focuses on enhancing the water supply protection qualities of OWM land surrounding the Sudbury reservoirs. Additional documents focus on other watershed protection activities in the Sudbury Reservoir watershed. The Sudbury Watershed Protection Plan (MWRA/MDC, 1997) sets the program direction for reducing major threats to the water supply within the entire drainage, most of which occur on private, developed or agricultural land. For example, the key threats listed in the Watershed Protection Plan include phosphorus loading and microbiological contamination (from residential and agricultural areas). Urban runoff to the reservoir from the estimated 26% of the watershed that is impervious due to development contributes a range of additional contaminants. The 1994 Sudbury Public Access Plan and the December 2002 update of that plan focus on the threat to the water supply associated with the potential for human contamination resulting from authorized and unauthorized public access to OWM land.

This plan calls for the maintenance of a diverse, multi-layered forest cover on OWM land in the watersheds. This decision was based on the review and analysis of documents, studies, and professional opinions, and represents the culmination of hundreds of hours of reading and discussions by OWM staff. As a result, the management program described in the plan is both conservative and appropriate, given the current state of knowledge on watershed management.

OWM recognizes, however, that the science of watershed management is far from exact, and that gaps exist in the current understanding of watershed relationships. Despite these gaps, OWM is directed to act on the current state of knowledge and to manage under uncertainty. This plan should be viewed as an “adaptive watershed management plan” or a “working hypothesis,” to be applied but updated and modified as new information comes to light.

This plan primarily focuses on management over the next ten years, but it also projects the forest cover and watershed conditions 60 years into the future. This long-range view is clearly consistent with OWM mandate “to assure the availability of pure water for future generations.” The importance of this long-range view is that it plans for the future integrity of the “land/forest filter” in the face of such events as hurricanes, floods, fires, insect and disease outbreaks, environmental pollution, and other impacts unknown to managers today.

This plan relies heavily on the standard operating procedures developed in the MDC Quabbin Land Management Plan (1995) in which a large amount of useful information was researched, compiled and summarized. The Sudbury watersheds, however, are significantly different from the Quabbin watershed. The Sudbury watersheds are more developed with lower percentages of OWM ownership and different forest composition, resulting in a strong emphasis on stream/reservoir buffer forest management and urban forestry initiatives.

The plan's sections include: 1) Introduction, Mandates, and Statement of Mission; 2) Description of Sudbury Reservoir Watershed Resources; 3) Research-based Principles Guiding Watershed Management; 4) Watershed Management Goals; 5) 2005-2014 Management Plan Objectives and Methods, for Land Protection, Forest Management, Management of Biodiversity, Wildlife Management, and the Protection of Cultural Resources; 6) Research, Inventory, and Monitoring Needs; 7) Public Involvement; 8) Literature Cited and General References; and 9) Glossary of Terms. The plan is written so that the management components are based on principles outlined in sections that precede them. OWM's intent is for this plan, when implemented, to achieve drinking water protection while also allowing controlled public use of some drinking water supply lands.

SUDBURY RESERVOIR

2 Description of Sudbury Reservoir Watershed Resources

2.1 Watershed Description

The Sudbury Reservoir System watershed is 8.8% of the greater Sudbury-Assabet-Concord (SuAsCo) drainage basin in Massachusetts. OWM/MWRA drinking water supply system includes 4.3 square miles within two sub-basins that comprise the Sudbury Reservoir System watersheds. These sub-basins are divided geographically and referred to as the North and South Basins of Sudbury System. The current system consists of four supply reservoirs: the Sudbury Reservoir, and the Stearns, Brackett, and Foss Reservoirs (also known respectively as Framingham Reservoirs Nos. 1, 2, and 3). The system also contains five aqueducts: the Sudbury, Weston, Wachusett, and Hultman Aqueducts, and the new MetroWest Tunnel. Both the North and South Basins drain into Stearns Reservoir. Releases from Stearns flow into the Sudbury River at the Winter Street Dam and continue east towards the Assabet and Concord Rivers.

2.1.1 North Basin

The North Basin of the Sudbury Reservoir watershed is contained within five municipalities: Framingham, Marlborough, Southborough, Westborough, and Northborough. Water flows from Stony Brook through the North Basin in a west to east direction.

The North Basin area contains two reservoirs, the Sudbury Reservoir and Foss Reservoir (Framingham Reservoir No. 3). Four aqueducts, the Wachusett, Hultman and Weston Aqueducts and the MetroWest Tunnel, are also contained within the North Basin. The Wachusett Aqueduct delivers water to the Sudbury Reservoir directly from the Wachusett Reservoir. The Wachusett Aqueduct connects the Wachusett and Sudbury Reservoirs at Shaft C, which is located in Marlborough and is part of the north Sudbury basin. Water from the Wachusett Aqueduct flows directly into the Sudbury Reservoir through the Wachusett Open Channel. This is currently the only active supply of drinking water within the entire Sudbury system. Water from Sudbury's North Basin can be used for a DEP declared emergency if the water is boiled prior to consumption. The Sudbury System was last used as an emergency supply in 1981 during a temporary shutdown of City Tunnel for repair work.

The Wachusett Open Channel, from the terminal chamber to Deerfoot Road, is under the jurisdiction of the MWRA. The Authority prohibits public access to the Wachusett Open Channel and all aqueducts. Several easements exist that allow residents to draw water directly from the Wachusett Open Channel, but most of these were written in the early 1900s. There is an ongoing review of these easements underway to determine their current status.

Headwaters for the Sudbury's North Basin lie in Crane's Swamp, which is located in Northborough and Westborough. The Wachusett Aqueduct terminates at Shaft C, located in Crane's Swamp, and water in the aqueduct flows eastward through the Wachusett Open Channel, which is the main tributary of the Sudbury Reservoir. Water from the reservoir is released at the Sudbury Dam and flows into the Stony Brook open channel. The Stony Brook Channel fills Foss Reservoir (Framingham Reservoir No. 3) and then drains into Stearns Reservoir (Framingham Reservoir No. 1), where it is released into the Sudbury River and flows northward.

2.1.2 South Basin

The South Basin is located within six municipalities: Framingham, Ashland, Marlborough, Westborough, Southborough and Hopkinton. The South Basin area contains one aqueduct, the Sudbury Aqueduct, and two reservoirs: Stearns and Brackett Reservoirs (Framingham Reservoirs No. 1 and No. 2). OWM lands also include a portion of the Sudbury River and Cedar Swamp. Headwaters for the Sudbury River originate in brooks in the towns of Upton and Westborough and empty into Cedar Swamp. Water from Cedar Swamp flows easterly into the Sudbury River and drains into Brackett Reservoir. Water from Brackett Reservoir flows north and is released into Stearns Reservoir. The South Basin also includes the Ashland, Hopkinton and Whitehall Reservoirs. These reservoirs were built as part of the drinking water system. However, as adequate drinking water quality could not be maintained, they were transferred in 1948 to another state agency and are now managed as State Parks by the DCR Division of State Parks and Recreation.

The Sudbury South Basin has not been used for water supply since 1930. In the 1970s, mercury from the Nyanza textile plant was found to have settled in the sediments in the Stearns and Brackett Reservoirs, and led to a Superfund designation for the plant site in 1982. While the EPA-administered clean-up has resulted in significant improvements, Sudbury's South Basin remains unusable for public water supply.

2.2 Sudbury Watershed Ownership and Land Use

The Sudbury Reservoir watershed (including the Sudbury Reservoir and Foss Reservoir (Framingham No. 3) and their drainage areas), referred to in this plan as the North Basin, includes approximately 17,782 acres. 37.5% of this area is in forest cover (on both public and private holdings), 1.2% is in wetland, and 8.2% is open water. Including land and water, OWM controls approximately 22% of the North Basin. 7.2% or 1,275 acres of the remaining watershed are maintained primarily in undeveloped forest cover by the DCR Division of State Parks and Recreation or private conservation organizations (e.g., Sudbury Valley Trustees). Approximately 28% is in developed residential areas, 9% is in industrial/commercial development, and 6% is in agriculture. Future development may cause significant changes to land use as 47% and 20% of the watershed is zoned residential and commercial/industrial respectively (MWRA/MDC, 1997).

From a water supply viewpoint, the land use pattern in the North Basin is of great concern, with a significant percentage of the land currently developed or in uses that compromise water quality protection. Although OWM ownership is small, it is located around the reservoir and some of the main tributaries and represents an important buffer to the reservoir. OWM controls approximately 32% of the land within 400 feet of the reservoir and its tributaries. The management of these lands is an important part of the protection of the Sudbury Reservoir.

The upper Sudbury River watershed includes Stearns Reservoir (Framingham Reservoir No.1) and Brackett Reservoir (Framingham Reservoir No.2) and their watersheds, collectively referred to in this plan as the South Basin. The South Basin includes approximately 30,058 acres. OWM has care and control of 1,078 acres, or about 4% (288 acres is the reservoirs and 790 is OWM land). As these lands are not part of the water supply, OWM has made initial investigations into surplusing much of this land for conservation purposes to local towns and the MA Division of Fisheries and Wildlife. For this reason, this basin is not a primary focus of this plan. 16.2% or 4,872 acres of the remaining 96% of the watershed over which OWM does not have care and control are currently maintained in undeveloped open space by the MA Division of Fisheries and Wildlife or private organizations (Table 1).

TABLE 1: SUDBURY RESERVOIR WATERSHED SYSTEM FACTS AND FIGURES

Table 1A: Reservoir Information

Attribute	NORTH BASIN		SOUTH BASIN	
	Sudbury Reservoir	Foss Reservoir (Framingham No.3)	Brackett Reservoir (Framingham No.2)	Stearns Reservoir (Framingham No.1)
Year Built	1896	1878	1878	1878
Volume Capacity	7.254 billion gallons	1.074 billion gallons	562.6 million gallons	311 million gallons
Surface Area	1,292 acres	250 acres	134 acres	154 acres
Watershed Area	22.3 mi^2	27.6 mi^2	45.1 mi^2	74.66 mi^2
Length of Dam	2000′	1,640′	1,340′	758.8′
Maximum Depth	65′	24′	20′	16′

Information from OWM records

Table 1-B: Land Cover and Land Use Data

Land Cover and Land Use in the Sudbury System Watersheds (includes reservoirs)														
Watershed	Forest		Wetland		Agriculture		Residential		Commercial/ Industrial		Open Water		Other	
	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%	Acres	%
North Basin	6,669	37.5%	221	1.2%	998	5.6%	4,983	28.0%	1,568	8.8%	1,467	8.2%	1,876	10.5%
South Basin	15,220	50.6%	662	2.2%	1,330	4.4%	8,115	27.0%	1,334	4.4%	1,296	4.3%	2,101	7.0%
Total Sudbury System	21,889	45.6%	883	1.8%	2,328	4.8%	13,098	27.4%	2,902	6.1%	2,763	5.8%	3,977	8.3%

Information derived from MassGIS data

Table 1-C: Open Space Ownership

Open Space Ownership in Sudbury System Watershed (area in acres)									
Watershed	Total Acres	DCR/DWSP/OWM Protected				Other Protected		Total Protected	
		Land	Water	Total	%	Acres	%	Acres	%
North Basin	17,782	2,323	1,542	3,865	21.7%	1,275	7.2%	5,140	28.9%
South Basin	30,058	790	288	1,078	3.6%	4,872	16.2%	5,950	19.8%
Total Sudbury System	47,840	3,113	1,830	4,943	10.3%	6,147	12.8%	11,091	23.1%

Information derived from MassGIS data

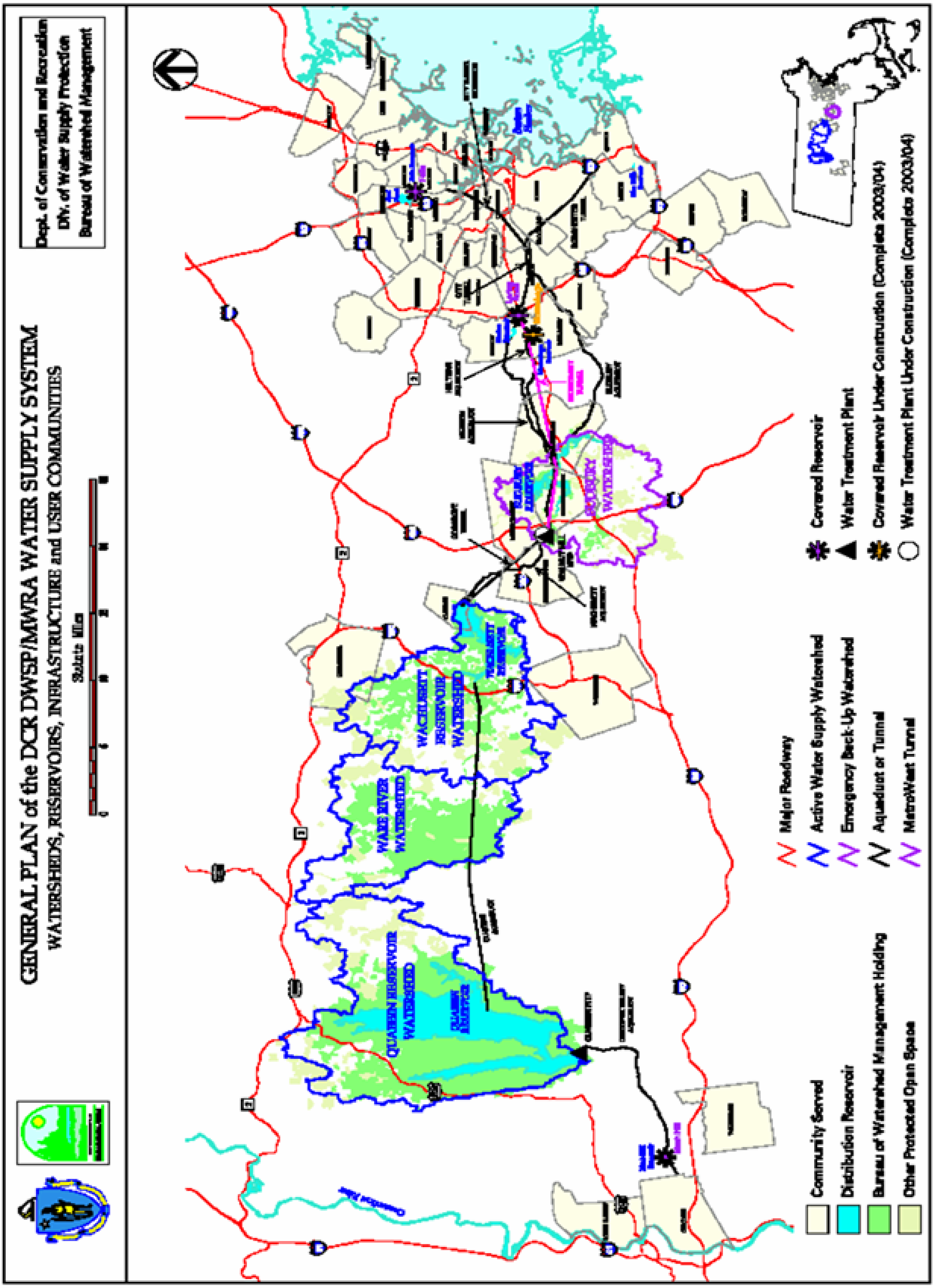

FIGURE 1: DWSP/OWM - MWRA WATER SUPPLY SYSTEM

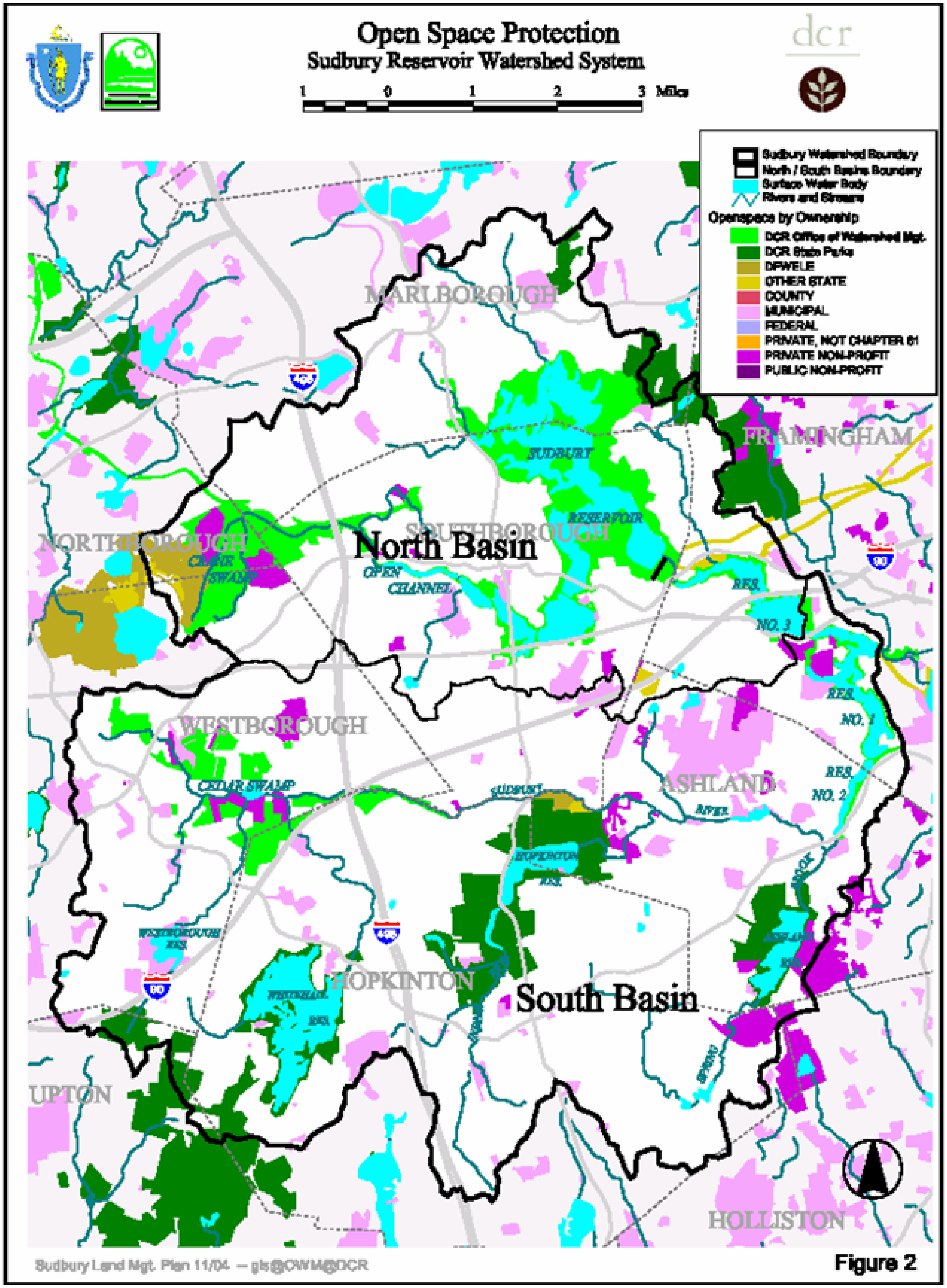

FIGURE 2: NORTH AND SOUTH SUDBURY BASINS

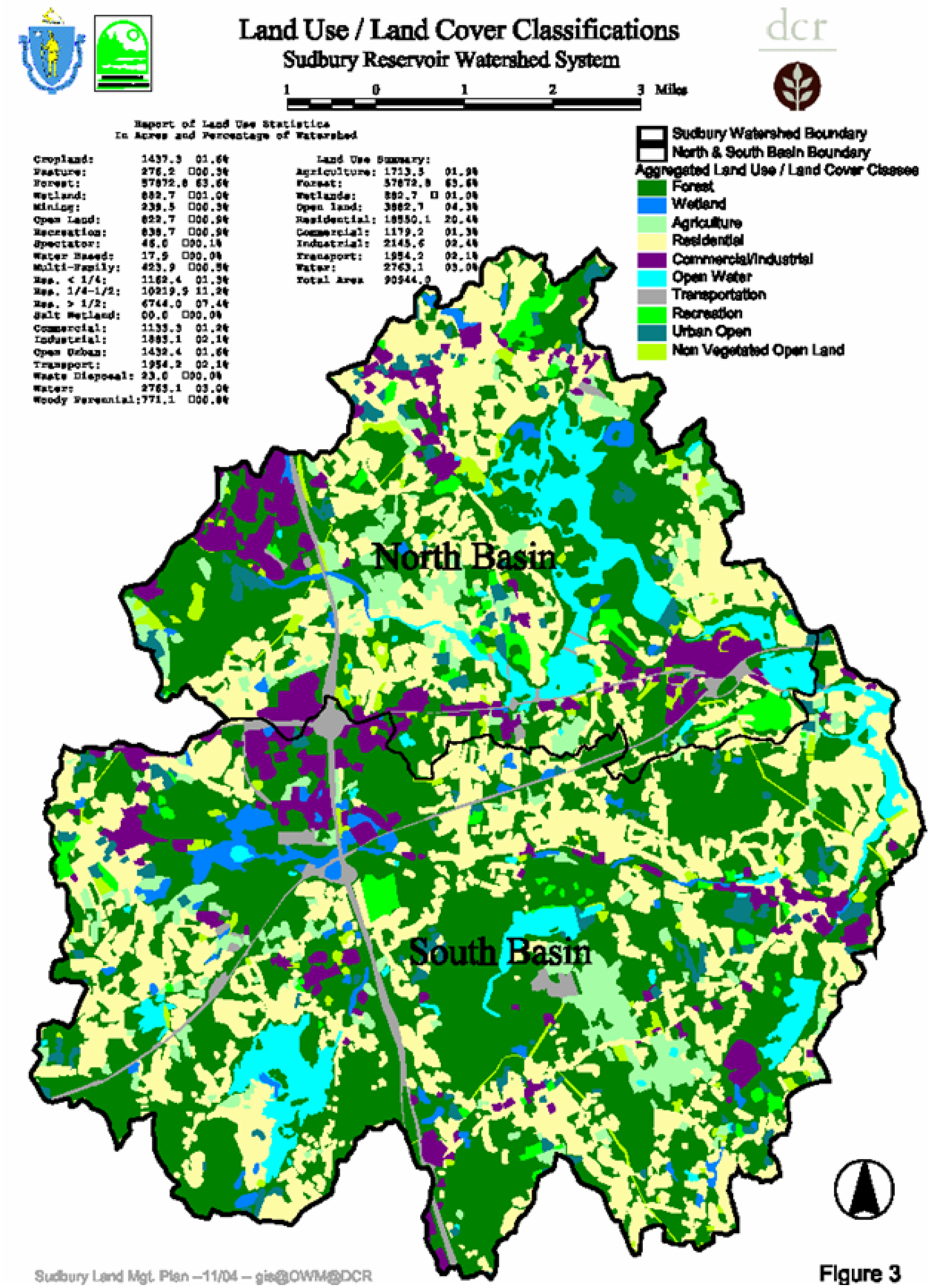

FIGURE 3: LAND USE/LAND COVER SUDBURY WATERSHED SYSTEM

2.3 Physical Characteristics of Sudbury Watershed Lands

2.3.1 Soils

For the purposes of watershed management, the Sudbury soils have been grouped and mapped into five classes, based on the most current United States Department of Agriculture Soil Conservation Service publications. These classifications are based upon soil depth and drainage characteristics.

1. **Excessively drained soils:** Excessively drained soils are usually very coarse textured, rocky or shallow. Water is removed from the soil very rapidly. These soils are thick loamy sands occurring primarily on glacial outwash. The principle soils occurring most frequently in these areas are the Hinckley, Merrimac and Windsor series. These are relatively deep soils (>65") and occupy 66% of the area. Inclusions of the Deerfield and Sudbury series occupy the remaining 44% of the area and are located usually in the lower landscape positions. They are moderately well-drained fine sandy loams, usually very deep and very stony.

2. **Well drained thin soils:** These soils are commonly of medium texture. Water is removed from the soil reasonably fast and is available to plants during most of the growing season. The principle soils occurring in these areas are the Chatfield-Hollis-Bedrock complex. This complex consists of 45% deep Chatfield soils, 25% shallow Hollis soils, 5% rock outcrops, and 25% other soils. These other soils, listed as inclusions, are the well drained Canton soils on the lower slopes and very poorly drained Swansea, Freetown and Whitman soils in depressions.

3. **Well drained thick soils:** These thick soils (24"-65") are formed in loamy and sandy glacial till on uplands. The Paxton and Canton series are generally found on the lower sides of hills and ridges. Inclusions are dominated by poorly drained Ridgbury soils and very poorly drained Whitman and Swansea in swales and low lying areas.

4. **Moderately well drained soils:** Moderately well drained soils are wet for only a short period during the growing season but the removal of water is somewhat slow during these times. These soils consist of very deep (to 65" and greater), fine sandy loams. The Sudbury and Deerfield series are formed on outwash plains and terraces and occupy nearly level positions on the landscape. Other soil inclusions found within these types have been identified as the Merrimac, Walpole, Scarboro, Hinckley, and Windsor series. The Woodbridge series are formed on glacial till on uplands and are generally found on the tops of upper parts of hills and ridges. Inclusions of Charlton, Paxton, Canton, Montauk, and Ridgebury may occur within the Woodbridge series. The Scituate soil series, formed in glacial till on the uplands, is commonly found on the lower slopes of hills and ridges. Inclusions within this type are the Montauk, Canton, Woodbridge, Paxton, Ridgebury, and Walpole.

5. **Poorly to very poorly drained soils:** Poor drainage usually results from a high water table where water is removed so slowly that the soil is saturated or remains wet for long periods during the growing season. These soils are very deep, extending to a depth of 50" or more, and consist of fine sandy loams and mucks. The Ridgebury and Whitman series are found in depressions and in low areas on uplands. Inclusions of Woodbridge, Paxton, Scituate, and Swansea series comprise about 20% of these soils. Freetown and Swansea mucks are organic soils formed in depressions and on plain areas. These types can also contain 20% included soils such as the Whitman, Scarboro, Ridgebury, and Walpole series. The Scarboro-Rippowam complex and the Walpole series occur in depressions and along drainage ways. The complex includes 40% Scarboro, 30%

Rippowam, and 30% other soils, while the Walpole has 20% included soils from the Sudbury, Deerfield, and Swansea series.

Note: Because of the scale used in mapping, small areas generally less then 5 acres cannot be shown separately on the soil maps. These small areas are known as inclusions. Urban land and Udorthents (areas altered by excavation and/or filling) are mapped separately and include power transmission lines, administrative areas and filter beds.

TABLE 2: ACRES OF COMPOSITE SOIL TYPE ON OWM SUDBURY PROPERTIES

Composite Soil Type	1 Excessively drained soils	2 Well-drained thin soils	3 Well-drained thick soils	4 Moderately well-drained soils	5 Poorly to very poorly drained soils
ACREAGE	245	121	685	203	991
PERCENT	11%	5%	31%	9%	44%

Generally, the soil within the Sudbury watersheds supports a wide variety of native tree species, most notably eastern white pine, northern red oak, red maple, black oak, white oak, and white ash. The dominant forest cover is white pine established in plantations during the early part of the 20th century. There are significant red pine plantations as well. Oaks are common on the drier hillsides and red maple dominates the wetter sites. Sugar maple and white ash are generally limited to "sweet" soils (less acidic) with moderately high moisture content. OWM's efforts to create a low-maintenance watershed forest require consideration of site/species compatibility. The 44% of OWM land which has poorly drained soils represent a significant constraint on forestry activity, due to the potential for damage to fragile, organic soils.

2.3.2 Hydrology

A land area of 12,457 acres drains into the Sudbury Reservoir and Framingham Reservoir No.3. In order of the estimated volume of inflow to the reservoirs, the most important sub-watershed drainages are Sudbury Reservoir direct inflow (12.6% of total inflow to the reservoirs), Crane Brook (11.2%), Marlborough Brook (North and South) (7.7%), Capen/Hessell/Willow Brooks (7.2%), Angelica Brook (6.4%), Mowry Brook (5.4%), Brewer Brook (5.4%), Hyde/Howe Brooks (5.3%), and Broad Meadow Brook (4.3%) (MWRA/MDC, 1997). Within the portion of the watershed owned by OWM, there are approximately 3.8 miles of streams, excluding intermittent streams, and 899 acres of wetlands (403 acres in the South Basin and 496 in the North Basin), excluding areas of open water (MDC GIS from 1994 aerial photo interpretation, which may miss some wetland areas, especially under conifer cover).

RESERVOIR TRIBUTARY

Annual precipitation since 1898 has averaged 44 inches per year, with a range from 30.1 inches in 1965 to 59.5 inches in 1954. Historically (1898-1995), November has been the wettest month, with an average of 4.11 and a maximum of 8.9 inches of precipitation, while May has been the driest month, with an average of 3.11 inches. The highest precipitation in a single month occurred in August of 1955 when 19.39 inches fell. The average precipitation yield to the Reservoir from the entire watershed is approximately 50%. The storage capacities of the Sudbury Reservoir and Framingham Reservoir No.3 are 7.25 and .5 billion gallons respectively.

The hydrology of the few remaining heavily forested stream drainages within the watershed is strongly affected by the forest cover. Forest cover has both positive and negative effects on water yield, with net yield the result of precipitation, evapotranspiration, interception, soil moisture, and ground water storage. Evapotranspiration losses from forests are significant, with watershed studies showing significant, but highly variable, water yield increases occurring when part or all of a forest cover is removed or replaced by herbaceous vegetation. The most significant yield differences among forest covers are between conifers and deciduous trees. (Note that the current forest cover on OWM Sudbury land is approximately 41% deciduous and 59% conifer, primarily pine.) In general, interception (due to evaporation) and evapotranspirational losses are greater for conifers than for deciduous species, although this varies with stocking and with storm size (deciduous forests average 13% overall interception losses, while coniferous forests average 28% (Dunne and Leopold, 1978)). The creation and maintenance of open land generally reduces this interception loss and can result in a significant increase in yield, although this conversion can also compromise water quality.

The manipulation of forest cover also affects infiltration, storage, and overland flow. While the actual operating model in any given forest is complex, two factors related to forest manipulations have significant effects - organic matter content and pore space. New England forest soils generally absorb water readily, as the accumulation of organic matter plus the burrowing activities of soil organisms create a forest floor with rapid infiltration rates and a large potential water storage capacity. The actual depth of the organic layer is influenced directly by species composition and stocking, with the greatest accumulations occurring beneath dense stands of conifers, where cool, acid conditions delay the decay of organics. While there are differences between species in root depths, tree roots generally function to penetrate deeply into soils, ultimately creating macropores and increasing water storage capacities within and beneath the organic layers of the soil. The maintenance of a forest cover prevents the sharp rises in soil temperature which can cause the rapid depletion of organic matter and thus reduce the water storage and filtering capacity of the forest. Therefore, the replacement of trees with herbaceous cover may reduce water storage.

2.3.3 Topography

The topography of OWM land in the Sudbury watersheds varies from level to moderately sloped. Steep slopes are few and limited in extent. For the entire Sudbury Watershed (North and South Basins), 97% of the land is 20% slope or less; 74% is 10% or less; only 0.5% is greater than 30% slope. Elevation ranges from 252 feet (elevation of full reservoir) to 464 feet at Pine Hill. The watershed contains numerous drumlins. Walnut Hill is a prime example. Upland slopes are generally covered with glacial till material while lowlands are typically filled with the stratified silt, sand and gravel that constitute glacial outwash. Extensive forested wetlands exist at the north end of the reservoir and in the watershed headwaters at Crane Swamp.

OWM land in the South Sudbury basin consists mainly of a narrow buffer around the Brackett and Stearns Reservoirs as well as extensive wetlands in the Cedar Swamp. Limited areas of steep slopes occur along portions of the banks of the two reservoirs.

2.3.4 Developed Areas

There are numerous structures and facilities within OWM land that include: MWRA lab and maintenance facilities at the Sudbury Dam and an OWM residence on Salem End Road. Additional facilities include pump stations, the Marlborough filter beds, aqueduct terminal chambers and headhouses, causeways, gatehouses, dams, and spillways. There are 10 miles of unpaved access roads that are maintained by OWM that occupy approximately 12 acres. Cleared utility rights of way cover roughly 22 acres.

2.3.5 Other Open Lands

Other open lands consist of non-wooded wetlands (212 acres) and mowed lawn areas associated with dams and buildings and other open areas (approximately 339 acres) (OWM GIS from 1992 aerial photography). Areas where forest cover is recovering after storm damage or forestry operations are considered part of the forest cover.

HARDWOOD FOREST

2.4 Sudbury Forest and Wildlife Conditions

2.4.1 Forest

2.4.1.1 Forest Types and Ages

The current Sudbury forest consists of numerous stands, each defined as "a contiguous group of trees sufficiently uniform in species composition, arrangement of age-classes, and condition to be a distinguishable unit" (Smith, 1986). The simplest Sudbury stands are even-aged conifer plantations of a single species. Complex stands are multi-aged, with a stratified mixture of both shade-tolerant and shade-intolerant species. With the passage of time, stand boundaries which were created and maintained by past land-use practices will fade and stand definition will become less important. However, boundaries between forest types will remain evident where there are significant differences in site characteristics, and these type changes will dictate some differences in management (for instance opening sizes and choices of species where underplanting is required).

Acres of forest types currently under management (Table 3) were obtained from MDC/DWM forest type maps that were created from 1989 to 1994. The most recent version of these type maps has been updated and digitized for use in GIS analysis and mapping. OWM plans to continually update typing to account for changes. Note that this typing only includes actively managed forest in the North Basin.

TABLE 3: ACREAGE OF MANAGED OWM FOREST ON NORTH BASIN WATERSHED BY TYPE

Type	Acres	Percent
White pine	327	24
Red maple/Mixed hardwoods	313	23
White pine-oak/hardwoods	299	22
Oak	249	19
Mixed pine/Mixed pine-oak/Hemlock	59	5
Red pine	55	4
Spruce	31	2
Others	13	1
TOTAL	1,347	100

TABLE 4: ACREAGE OF MANAGED OWM FOREST ON NORTH BASIN WATERSHED BY SIZE CLASS

Size Class	Acres	Percent
Less than 20 feet tall	100	7
20 to 40 feet	112	8
40 to 60 feet	77	6
60 to 80 feet	768	57
More than 80 feet	290	22
TOTAL	1,347	100

The current Sudbury forest originates primarily from plantation establishment from 1907 to 1947. Of the approximately 1.75 million seedlings planted during this period, the majority were planted from 1913 to 1921. The balance of the Sudbury forest is the result of farm abandonment following the takings of the land prior to reservoir construction. The majority of the managed Sudbury forest is therefore 75+ years old.

There have been 30 silvicultural operations completed on OWM property in the watershed from 1984 through 2003. Salvage operations account for 8 of these operations and occurred on 49 acres. These operations were performed to cleanup damaged trees following Hurricanes Gloria and Bob and dead and dying trees resulting from gypsy moth defoliation and subsequent diseases. The remaining 22 silvicultural operations occurred on 556 acres and included thinnings, removal of diseased and declining plantation overstory trees, and regeneration cuts of varying size to encourage tree regeneration and forest diversity.

2.4.1.2 Forest Inventory

In 1986 and 1989, trees were measured and information was gathered on 305 variable radius plots throughout Division lands on the Sudbury watersheds, accomplishing the first forest inventory of these lands. All trees from 4" in diameter at breast height and up were tallied. For each tree, the species, diameter, crown classification, product rating (e.g., sawlog, fuelwood, or pulpwood) and desirability rating (an estimate of vigor and form) were collected.

Species Distribution

A random plot inventory clearly showed the predominance of white pine in the managed forest in terms of total basal area (a measure of stocking density based upon tree diameter) (Table 5). The softwood species combined account for 68% of the total basal area.

TABLE 5: DISTRIBUTION OF BASAL AREA BY SPECIES

Species	Percent
White pine	53
Maples	12
Oaks	12
Red Pine	12
Ash	5
Spruce	2
Hickory	1
Others	3

Size Distribution

The distribution of size classes across the Sudbury forest is a useful indicator of structural diversity even though it may be a fairly poor indicator of age structure. The three conventional size classes chosen are: sapling/pole (5.6" to 9.5" dbh), small sawlog (9.6' to 15.5" dbh) and large sawlog (15.6" dbh and up). The total number of trees and the percent of the total number of trees and total basal area are shown in Table 6.

TABLE 6: SIZE DISTRIBUTION OF TREES

Size Class	# of Trees	% of Total #	% of Total BA
< 9.6" dbh	95,113	42	16
9.6 - 15.5" dbh	103,591	46	52
> 15.5"dbh	28,566	13	33

Approximately 85% of the total stocking occurs in diameter classes greater than 9.6" dbh. Silvicultural activities have focused on softwood removals. White pine accounts for 71% of the stocking removed from 1987 to 1996. All softwood species combined account for 91% of the stocking removed (Table 7).

TABLE 7: SILVICULTURAL REMOVALS BY SPECIES AND BASAL AREA

Species	1990 BA (sqft)	Cut (1987 – 1996)	% Cut
White pine	85,863	21,263	24.6
Red pine	19,161	5,091	26.6
Spruce	4,081	1,008	24.7
Oaks	19,824	1,805	9.1
Red maple	19,110	286	1.5
Aspens	321	151	47.2
Others	12,067	359	3.0
TOTALS	160,421	29,864	18.6

Growth

Average annual diameter growth by species was measured using increment cores collected during the summer and fall of 1994 and is summarized in the table below.

TABLE 8: AVERAGE ANNUAL DIAMETER GROWTH BY SPECIES

Species	Growth
White pine (planted)	0.13"/year
White pine (natural)	0.20
Red pine (planted)	0.08
Scotch pine (planted)	0.09
Pitch pine	0.09
Spruce	0.12
Hemlock	0.15
Red oak	0.13
Black oak	0.10
White oak	0.09
Black cherry	0.15
Red maple	0.15
Sugar maple	0.19
Hickory	0.09
White ash	0.16
Aspen	0.18
Black birch	0.11
Paper birch	0.07
American elm	0.20

The difference in growth between plantation white pine and non-plantation white pine is directly attributable to the greater density of trees in the plantations. This high density of stems results in more intense competition between trees, less differentiation among individuals and therefore below optimum growth rates. Had these stands been thinned at some stage in their development, their growth rates would be comparable to the non-plantation rate. Indeed, many of the non-plantation stands originated as white pine plantations but were infiltrated by opportunistic hardwood species.

2.4.1.3 Regeneration Conditions

Regeneration serves to anchor soils following disturbances, resist damage from many disturbances (due to size and density), assimilate nutrients more rapidly than older vegetation, and shorten recovery times for reestablishing forests following disturbances. For these reasons, the ability of the watershed forest to regenerate continuously in the face of a wide variety of disturbances is considered critical to its ability to protect water quality.

Regeneration is most noticeably lacking under untreated plantations on the Sudbury watersheds. The limiting factor under these stands is the low light levels reaching the forest floor due to the dense canopy. Closed plantations that have significant regeneration present are often adjacent to large roadside sugar maple trees. Sugar maple is highly tolerant of low light situations and is able to build up a reservoir of regeneration over a period of years. Openings that are created in the overstory by storm events or silviculture also trigger a regeneration response. The increased light both in the opening itself and in the adjacent plantation allows a wider range of species to become established.

Many of the oak stands are limited in their levels of regeneration of either oak or associated species. Oak is among the more valuable species in the watershed forest, as a long-lived, low-maintenance species with high wildlife and timber values. However, oak is problematic to regenerate on many sites, and historically thrived best following intensive harvesting and fires that reduced competition from other species. Oak regeneration is particularly lacking beneath dry-site stands. Huckleberry and bracken and hay-scented ferns are often inhibiting influences. Mortality of the oak overstory initiated by gypsy moth defoliation often has a beneficial effect on general regeneration establishment, due to increases in light and short-term increases in nutrient availability. However, large scale mortality of overstory oak also further reduces the likelihood of regenerating oak.

Overall, there is good regeneration in many areas of the Sudbury forest currently and excellent potential for establishing regeneration where it is lacking. No statistical sample of the regeneration over the entire forest has been completed to date. OWM foresters have determined the level of regeneration at Walnut Hill resulting from the silvicultural operation in 1987-88 and storm salvage in 1989 in this extensive white and red pine plantation (Buzzell, 1993).

Three distinct zones with differing light conditions were defined at Walnut Hill. Zone 1 consists of strip cuts and other openings. Here the regeneration is dominated by cherry (both black and pin) with aspen, red maple, and white pine occurring in lesser amounts. Regeneration of all sizes less than 1 inch diameter at 4.5 feet high averages 9,310 stems per acre. Zone 2 includes unmanaged plantations that are within 100 feet of a strip or other opening and managed plantations that have a residual basal area less than 100 sqft/acre (i.e., stands that have been thinned). The regeneration here averages 8,230 stems per acre and is dominated by white pine with lesser amounts of red maple, oaks, cherries, and white ash. Zone 3 is the unmanaged plantations more than 100 feet from an opening. Here, there are only 1,330 stems per acre with a composition of white ash, oaks and cherry.

Not only is the amount and species composition of regeneration different in these three zones but the height development is distinct as well. Regeneration was grouped into three size classes: seedling (less than 1 foot tall), small sapling (1 foot to 4.5 feet tall), and large sapling (>4.5 feet tall to 1 inch diameter at 4.5 feet) (Table 9).

TABLE 9: WALNUT HILL REGENERATION

Zone	Description	Stems per acre	Seedling	Small sapling	Large sapling
1	Within strip cuts and other openings	9,310	12% (1,117)	52% (4,841)	36% (3,351)
2	Unmanaged plantation < 100 ft from opening or managed < 100 sq ft BA	8,230	53% (4,362)	42% (3,457)	5% (411)
3	Unmanaged plantations >100 feet from strips or other openings	1,330	42% (559)	50% (665)	8% (106)

2.4.2 Wildlife

All species of wildlife depend on the existence and quality of various habitat types. Some species require a very specific habitat to survive (i.e., wood frogs and vernal pools), while other species can exist in a variety of habitats (i.e., coyote). The Sudbury watershed is located in a highly developed area of eastern Massachusetts. Natural lands within the watershed are highly fragmented and separated by residential and industrial development. OWM owned land within the watershed is primarily forested. Although the landscape as a whole is fragmented, OWM owned land within the watershed represents a relatively large area of undisturbed habitat. The undeveloped and unbroken nature of these lands is a tremendous benefit to wildlife species that require large tracts of land.

The Sudbury watershed supports a variety of wildlife. OWM lands provide habitat for a diversity of birds and mammals including white-tailed deer, turkey, raccoons, and foxes. In addition, Neotropical migrant birds, including black and white warblers, rose-breasted grosbeaks, and scarlet tanagers utilize OWM forests for breeding and migratory rest stops. The largest and potentially most important habitats within the Sudbury watersheds are the open waters from the various reservoirs. These reservoirs provide aquatic habitat for migrating and resident waterfowl and other water dependent species. The two large wetlands located within the Sudbury watersheds (Crane Swamp and Cedar Swamp) support additional wetland species. Finally, several vernal pools occur on OWM land and support a unique and dependent host of animals.

One of the most important aspects of OWM land on the Sudbury watersheds is its protection from development. Some towns within the watershed are experiencing tremendous growth, and as a result open space is being converted to residential areas. The protection that OWM lands provide to wildlife species is critical to their long-term survival.

Only a few formal wildlife surveys are conducted on OWM land in the Sudbury watersheds. Common loons are surveyed each summer to document reproduction, and vernal pools are documented and sampled each spring.

While a great deal of information exists about common wildlife taxa (i.e., birds, mammals) through information collected from surveys and observations, very little is known about other Sudbury wildlife. A complete species list does not exist, and there is a paucity of information about reptiles, amphibians, insects, butterflies, dragonflies, and other more secretive species. It is quite possible that OWM lands within the Sudbury watersheds harbor state listed species that have yet to be documented.

2.5 Cultural Resources

2.5.1 State of Knowledge

Archaeological records document the presence of Native American sites throughout the Sudbury drainage. Significantly, these sites span the entire course of human settlement in New England, and reflect prehistoric settlement patterns that developed along the Sudbury, Assabet, and Concord rivers. The confluence of these rivers reveals evidence of particularly extensive human activity. Within the Sudbury Reservoir watershed itself, the Massachusetts Historical Commission (MHC) records fifty prehistoric sites, with thirty-two of these located in and around Cedar Swamp in Westborough. Cedar Swamp is listed on the National Register of Historic Places as an Archaeological District. There are five prehistoric sites within OWM holdings in the Sudbury Reservoir watershed, three of which are in the Cedar Swamp Archaeological District.

Based on thousands of known sites in Massachusetts, archaeologists have developed a model for making predictions about archaeologically sensitive areas, and to a degree the expected type and range of sites that may be found in any given area. The application of ***Site Location Criteria*** has become a valuable tool for identifying and thus protecting potentially sensitive locations. When utilized in the Sudbury watersheds it can become basis for managing archaeological resources on OWM lands.

As noted, 50 prehistoric sites are currently recorded within the Sudbury watersheds in general, and only five on OWM's lands. While informative, this figure is artificially low. Although the MHC's records are the single most complete archaeological data bank in the state, they represent but a small fraction of the actual number of sites that are known to collectors. Importantly, because of the protected nature of the watershed lands, many sites have survived the destruction that has occurred elsewhere, and it is these as yet unidentified sites that are a major concern to OWM management team.

2.5.2 Prehistoric Overview

Existing archaeological evidence suggests that *Paleo Indian* hunters and gatherers entered the tundra-like New England landscape 9,500 to 12,000 years ago, and these first colonists reached the Sudbury River drainage at that time. By about 9,500 years ago the warming climate had created an environment in southern New England that supported a mixed pine-hardwood forest. Archaeological sites indicate that human occupation of the drainage continued during the *Early Archaic period* (ca. 9,500 to 8,000 years ago).

During the *Middle Archaic period* (ca. 8,000 - 6,000 years ago) climatic and biotic changes continued and the mixed deciduous forests of southern New England were becoming established. Significantly, the present migratory patterns of many fish and birds are believed to have become established at this time (Dincauze, 1974). During the spring those rivers, streams and ponds utilized by anadromous fish for spawning would have been particularly important for fishing. Groups are likely to have traveled considerable distances to camp adjacent to falls and rapids where they could easily trap and spear the salmon, herring, shad and alewives. This subsistence strategy persisted throughout prehistory. Evidence of Native American occupation of the Sudbury region is well documented during *Middle Archaic* times.

There is a marked increase in site frequencies and densities within the Sudbury drainage during the *Late Archaic period* (ca. 6,000 to 3,000 years ago). This pattern is consistent with findings throughout most of southern New England, and may document a population increase during this period. Each of the three traditions - the Laurentian, Susquehanna and Small Stemmed Traditions - is well represented in the archaeological record of local sites. Terminal Archaic activity (ca. 3,000 - 2,500 years ago) includes a steatite quarry.

During the *Early, Middle* and *Late Woodland* periods (3,000 - 450 years ago) Native Americans continued to occupy the Sudbury River drainage. Site frequencies are comparable or slightly higher than other drainages in eastern Massachusetts. Regionally, horticulture was introduced during the Early Woodland and small gardens may have been planted in clearings located on the fertile alluvial terraces next to the Sudbury River and its larger tributaries.

Analysis of artifacts from local sites reveals a pattern of multiple, recurrent occupation of well situated sites. Few sites have yielded artifacts from a single cultural/temporal period. Instead, artifacts from several periods have typically been recovered from sites. This suggests that some particularly well-sited locations were occupied, or otherwise utilized, more than once. Recurrent, though intermittent, occupation of a single site, sometimes over a period of several thousand years, appears to have been the prevalent pattern of prehistoric site development in this region.

Small groups, probably based on kinship, would have found the uplands most attractive for short term occupation. Settlement is likely to have occurred on virtually any elevated, level and well-drained surface that was located immediately adjacent to sources of fresh water, including the headwaters of ephemeral streams, springs, and small wetlands and ponds. Rock shelters and other natural overhangs, and locations with southerly exposures would also have been utilized.

2.5.3 Historic Sites

An historic survey of the Metropolitan Water Supply System was conducted in 1983 by the MDC to document historic buildings and structures that were related to the development of the Metropolitan Water System. This was followed by a comprehensive inventory of historic watershed buildings and structures by Berger Associates in 1985, and resulted in a multiple resource nomination to the National Register of Historic Places. The nomination was accepted in January of 1990 as the ***Water Supply System of Metropolitan Boston Thematic Resource Area.***

Included in this listing are eight historic districts, which comprise 73 buildings and structures, and sixteen individual properties. Within the Sudbury watersheds are located the Sudbury Dam Historic District and a number of individual buildings, structures, and sites which are part of other National Register Historic Districts located within the Sudbury system. The National Register status of these properties provides them with an important level of protection, as any modifications to them, and/or their grounds, must follow the ***Secretary of the Interior's Standards for Historic Preservation Projects****,* and be reviewed and approved by the MHC.

To date OWM Sudbury lands have yet to be surveyed for the existence of historic archaeological sites. It is expected that watershed lands contain the remains of an occasional farmstead, with its various buildings, and possibly former mills, and other industrial and commercial sites that were located here before the lands were acquired by the Commonwealth.

While the location of a few sites is known, a comprehensive survey will be required to systematically identify others, and to determine their condition, integrity, and significance. These data will provide that basis for formulating a management strategy for the preservation of historic archaeological resources within the Sudbury watersheds.

3 Research-based Principles Guiding Watershed Management

The purpose of this section is to identify various principles of watershed management that form the basis for the specific goals and implementation objectives for management of the Sudbury watershed lands during the period covered by the plan. These principles are distilled from a literature review of nearly 400 different sources, many of which are included in the Literature Cited listing at the back of this plan.

3.1 Principles of Watershed Protection

- Forested watersheds generally yield higher quality water than non-forested cover types. Urban, suburban and agricultural land uses all contribute in some way to lowered water quality.
- Uncontrolled human activities on water supply watersheds represent a major source of potential contamination. Efficient and effective water quality protection on both filtered and unfiltered water supplies requires control over human activities.
- Watershed cover conditions differ in their regulation of certain nutrients (especially phosphorus and nitrogen); the best regulation of nutrients is provided by vigorously growing forest that is fully occupying all watershed sites.
- Fire protection, police surveillance, water sampling, and other watershed management activities, including forest management, all depend upon an adequate, well-maintained road system.
- The proper management and protection of wetland and riparian zones is a critical component of watershed protection.

3.2 Principles of Watershed Forest Management: General

- Watershed forests can be managed in a way that provides significant benefits to long-term water quality protection, while minimizing adverse impacts during management operations.
- Potential negative tributary water quality effects (including turbidity, nutrients, and streamwater temperature) resulting from forest management can be minimized or eliminated with proper road location and maintenance and proper planning and supervision of silvicultural activities.
- Stands developed through uneven-aged methods will continually include some younger, shorter trees. Older trees in these stands develop stronger, more tapered stems than those grown in dense, even-aged stands. Strongly tapered trees sustain less damage from wind, and the younger component in uneven-aged stands enable them to recover from disturbance more quickly than maturing even-aged stands, thus improving their relative long-term water quality protection.
- Tree species growing on sites and within climatic ranges to which they are best adapted generally will grow vigorously and persist longer, resulting in a watershed forest that requires less tending. For example, white pine will grow vigorously but is more prone to root disease and wind throw on wet sites, while red maple tolerates soil saturation and remains wind firm on the same sites.

3.3 Principles of Watershed Forest Management Systems: Literature Review

3.3.1 Naturally-managed Forests

3.3.1.1 Water Yield

Tree growth and naturally occurring forest disturbances (fires, wind, disease, and insects) heavily influence the water yields from naturally-managed forests. Eschner and Satterlund (1965) studied a 491 square-mile watershed in the Adirondack Mountains of New York from 1912-1962. This study is particularly relevant to an examination of the impact of naturally-managed forests upon water yields. The land use on the watershed up to 1910 included land clearings, extensive fires, and heavy forest cuttings (chiefly logging of softwoods) that involved almost the entire watershed. In the late 1800s, the state of New York began purchasing lands in the watershed for the Adirondack Forest Preserve. From 1890 to 1910 the percentage of state-owned Forest Preserve in the watershed increased from 16% to 73%. The management policies of the Forest Preserve included laws against any cutting of trees and an active program of forest fire suppression.

The average forest density (in basal area) of the watershed increased from 65 square feet per acre in 1912 to 107 square feet per acre in 1952, due to forest growth and restrictions on cutting. Average basal area decreased to 97 square feet per acre in 1963 due in part to mortality from a windstorm in 1950. Another impact upon the watershed was a large increase in the beaver population during the study period. Throughout the Adirondacks, the number of beaver increased from an estimated 10 individuals in 1895 to an estimated 20,000 individuals by 1914, due to a prohibition on trapping introduced in 1895 and the introduction of 25 Canadian beaver and 14 Yellowstone Park beaver between 1901 and 1907. In 1965, most perennial drainages in the watershed had resident beaver.

The combined effects of unregulated forest growth and the increased number of beaver dams reduced the annual water yield of the watershed by 7.72 area-inches or 23% from 1912 to 1950. The authors postulated that forest growth reduced water yields through changes in evapotranspiration and snowmelt and beaver reduced yields through losses due to evaporation from beaver ponds. Although the net effect from beaver was a reduction in water yield, they tended to increase dormant season flow due to reduced interception and evapotranspiration following the killing of trees in flooded areas. Conversely, increased forest growth delays peak discharge and reduces yield. The effect of unregulated forest growth in lowering water yields was offset by increased in water yields resulting from the paving, straightening, and widening of 75 miles of roads within the watershed during the study period.

The trend of decreased water yields from 1912-1950 was reversed due to the large number of trees that were killed by the 1950 windstorm and the continued increase in mortality during the 13 years after the storm. The authors summarized the impact of the 1950 windstorm:

> The storm of November 1950, disrupted the associated patterns of forest stand development and streamflow change, returning both to a point nearer their 1912 levels.

In another study, Eschner (1978) analyzed four small watersheds in the Adirondack Mountains of New York. Logging, farming, and fires up to the early 1900s heavily impacted the East Branch of the Ausable River. Of the four watersheds, only the East Branch of the Ausable River was unaffected by the windstorm of 1950. Thus, this watershed offers a good example of a 42 year, stream-gauged period of uninterrupted forest re-growth. During this period, streamflow decreased by 4.2 area inches. Eschner concluded that this decrease was probably due to the natural regrowth of vegetation.

3.3.1.2 Water Quality

There have been few long-term studies of the impact of naturally-managed forests upon water quality. Several studies were cited above with regard to the impacts of old forests upon nutrient releases and the processes that are apparently involved. Other areas where naturally-managed forests may differ from actively-managed forests include response to natural disturbances, and nutrient/sediment interactions in stream channels.

The impact of disturbance is perhaps the key difference between a naturally-managed and actively-managed forest. In the actively-managed forest, silvicultural management is in effect a deliberate and regulated form of disturbance. In the naturally-managed forest, most disturbances are the result of unregulated natural events (e.g., wind, fire, disease, insects, or ice). While both actively-managed and naturally-managed forests will be exposed to certain recurring natural disturbances (e.g., hurricanes), the two systems may respond to these disturbances very differently.

In recent years, even forests isolated from developed areas are being increasingly impacted by human factors (air pollution, introduced insect/disease complexes, wildlife browsing). Eschner and Mader (1975) note:

> When extensive areas of relatively stable vegetation are set aside for wilderness, man's activities are sharply restricted. However, changes in the vegetation continue, and in some cases the possibility of catastrophic change increases...Treatment of large areas of watershed as wilderness, currently advocated by several interest groups, may not be consonant with management for maximum yields or protection of areas. On land long undisturbed, use of water by vegetation may be maximized and water yield reduced, while hazards of windthrow, insect, disease, or fire damage may increase.

Hewlett and Nutter (1969), in defining pollution, mention the potential impact of natural disturbances upon water quality:

> Because natural waters already carry materials that can degrade water for certain uses, we have some difficulty specifying just what "pollution" is. Natural water quality over the centuries has evolved the stream ecosystem under conditions that we might, rather pointlessly, refer to as "natural pollution." For our purposes, however, we shall regard pollution as man-caused and think of polluted waters as those degraded below the natural level by some activity of man. In this sense, therefore, unabused forests and wildlands do not produce polluted waters, although they may at times produce water of impaired quality.

Parsons et al. (1994), in a study of the impact of gap size on extractable soil nitrate stated:

> Large-scale mortality events leading to macroscale gap formation, which involves the simultaneous death of many adjacent trees over thousands or tens of thousands of square meters, are known to increase mineralization and nitrification rates in temperate forest ecosystems.

Tamm (1991), in reviewing the role of nitrogen in terrestrial ecosystems, noted:

> Natural agents such as storms, insect defoliations, and, above all, fire may destroy the

existing vegetation and stimulate both nitrogen mineralization and nitrification, leading to temporary losses of nitrate.

Corbett and Spencer (1975) report that Hurricane Agnes and the 14 inches of rain that accompanied it caused significant erosional impacts to the Baltimore Municipal Watershed, chiefly due to streambank cutting and channel slumping. The authors note that these types of impacts are more related to channel depth than condition of forest cover. Hurricane Hugo caused extensive damage to coastal South Carolina. The U.S.D.A. Southeast Forest Experiment Station monitored stream waters within the Frances Marion National Forest before and after the hurricane, with a gap in monitoring for several months after the hurricane, due to access problems (McKee, 1993, pers. comm.). The forest before the storm was mature pine-hardwoods and much of it was windthrown or snapped by the storm. Preliminary results show increased nitrogen in streams compared with levels found in regular monitoring done before the storm (Swank, Harms, Neary, Benston, McKee, and Hanson, 1990, 1991, pers. comm.).

Researchers in South Carolina are also concerned about the threat of a large forest fire due to the amount of downed material that has increased from 8 tons/acre before the storm to 100 tons/acre after the storm. After a 1.6 acre simulated hurricane "pulldown" at the Harvard Forest, Carlson (1994) reported that downed woody debris increased from 4.1 tons/hectare in a control area to 33.5 tons/hectare. He suggests that the potential threat of fire will increase in the next several years as pulled-over trees die.

Numerous studies show that impacts from forest blowdown or a combination of blowdown and forest fire can increase tributary nitrate and phosphorus exports by several times background levels (Verry, 1986 and Packer, 1967 as cited in Ottenheimer, 1992; McColl and Grigal, 1975: Wright, 1976; Schindler et al., 1979). Soil disturbance from blowdown of large numbers of trees may also result in significant erosion (Patric, 1984, White et al., 1980, and Swanson, 1982, all cited in Ottenheimer, 1992). Water quality changes associated with extensive windthrow and fire confirm that dissolved nutrients and in some cases, sediment, acidity, and total organic carbon can be elevated for several years (Patric, 1984 and Swanson, 1982 as cited in Ottenheimer, 1992; Verry, 1986; Schindler et al., 1980; Wright, 1976; Corbett and Spencer, 1975; McColl and Grigal, 1975; Dobson et al., 1990; Dyrness, 1965 and McKee 1993, pers. comm.). For example, nitrates increased by up to nine times and phosphorus by more than three times after extensive windthrow followed the next year by a wildfire in a monitored watershed in Ontario (Schindler et al., 1980).

Dobson et al. (1990), in reviewing data from hundreds of lakes in New York, New Hampshire and Sweden, found strong spatial and temporal associations between percentage of watersheds affected by large blowdown events and long-term lowered pH in basin lakes. They concluded that extensive blowdown alters hydrologic pathways by channeling flow through large macropores created by rotting roots so that water is less buffered by subsurface soils and bedrock. One lake adjacent to heavy blowdown that was extensively salvaged did not acidify, leading the authors to speculate that salvage may partially counter the impacts of blowdown on acidification.

The value of advance regeneration (regeneration established before overstory removal) in reducing the impacts of natural disturbances may be the critical factor distinguishing actively managed and naturally managed watersheds. After disturbance, areas that are quickly occupied with dense, fast-growing seedling/sapling growth will minimize transitional losses of nutrients, and particulate and erosional losses. OWM foresters Buzzell (1991) and Kyker-Snowman (1989a) compared actively managed and naturally managed forests with regard to the presence and abundance of advance regeneration. Their findings definitively show that areas that have been actively managed have a much greater amount and density of regeneration and young forest growth. Arbogast (1957) also notes that a key consideration when implementing uneven-aged silviculture on previously unmanaged and undisturbed stands is to enhance age-class balance by encouraging development of sapling and pole-sized trees.

The impact of actively managed and naturally managed forests adjacent to stream channels is discussed thoroughly in Maser et al. (1988). Although this study is focused on forests of the Pacific Northwest, some principles are applicable to the northeast. The authors documented that streams flowing through young forests and those recently harvested contain only 5-20% of the large woody material found in streams flowing through naturally managed forests. The stability and length of wood pieces is also increased in naturally managed forests. While the authors document a clear difference in the fish habitat of the two streams, they also note that the increased debris in streams bounded by naturally managed forests may impact the stability of streams.

While it may seem that large amounts of woody debris would increase the amount of decomposed material in streams, wood in direct contact with water decomposes very slowly. The authors note that only 5-10% of a stream's nitrogen supply is derived from rotting instream debris. On the positive side, debris serves to create hundreds of dams that slow the flow of particulate material down the stream. The authors speculate that stream stabilization after floods is accelerated by large woody debris, noting that "large stable tree stems lying along contours reduce erosion by forming a barrier to downhill soil movement."

While the conditions in the Pacific Northwest are very different from those in the northeast (for example Pacific NW soils are less stable, forest types are totally different, and forest management systems consist generally of even-aged management using clear-cutting), some of the above material is applicable to the northeast and to OWM watersheds. Bormann et al. (1969), in a study of a small watershed in the White Mountains of New Hampshire noted that 1.4% of the watershed was included in the actual stream channel and that debris pools occurred every 1-3 meters. They speculated that these pools served to slow the movement of suspended material from the watershed and reduce the erodibility of the system. Bormann et al. (1974) note that in mature forests the export of particulate material is derived from material stored in the stream bed. However, they note that most of this material moves very little, and approximately 90% decomposes slowly in place.

The above discussion highlights the need for careful consideration of lands adjacent to tributaries. In developing management plans for these areas, consideration should be given to the need for stability of the cover type and forest structure, given the potential occurrence of major disturbances. However, the benefits of the slow addition of natural wood-fall to these areas, and the erosion impediments and the stream pools created by this material, should also be analyzed. In assessing the management of stream buffers, Stone (1973) recommends careful thinning of buffer strips as often preferable to complete non-disturbance, as such thinning will limit the amount of debris falling directly into streams. Vellidis (1994) found that forested riparian strips next to agricultural lands took up and removed nutrients in soil and vegetation, preventing agricultural outputs from reaching streams. The author recommends that these forested strips be harvested periodically to ensure a net active uptake of nutrients, if they are to serve as an effective nutrient buffer.

3.3.2 Even-Aged Silviculture

3.3.2.1 Water Yields

Beginning at Wagon Wheel Gap in Colorado in 1911, experiments relating forest removals to water yield increases have been conducted at a number of small watershed locations throughout the U.S. Since 1940, three U.S. Forest Service Experimental Forests have supplied the bulk of the data for eastern

U.S. applications. These forests are Hubbard Brook, NH; Fernow, WV; and Coweeta, NC. Experiments have included a wide variety of approaches ranging from clearing of small watersheds to patch, partial, and riparian cuts. Most experiments are paired watershed studies, where two small, adjacent or similar watersheds are studied; one watershed is treated silviculturally while the other is left intact, as a control.

Experimental findings show several general trends. However, variation due to site conditions such as slope, aspect, soils, geology, cover type, and additional factors make exact prediction of water yield increases difficult for a given site. Douglas (1983) notes that yield increases can be predicted within 14% of actual values. Federer and Lash (1978) developed a small watershed computer model aimed specifically at predicting water yield increases from forest management of small watersheds in the northeast, using input variables of precipitation, temperature, latitude, slope, aspect, cover type, and soils. This model was applied with a reasonable degree of accuracy to the Cadwell Creek watershed at Quabbin (O'Connor, 1982b).

The following general trends emerge from the many watershed experiments that have been reviewed for the development of watershed land management plans:

- Water yields increase as the percentage of forest cover removed increases - complete removal of hardwood cover on small watersheds can result in first-year yield increases of 4-14 area-inches (total average annual streamflow in the Northeast is approximately 20-25 area-inches or about 50% of total precipitation).
- Water yields decrease with reforestation of open watersheds and growth of younger forests, with a linear relationship between the percentage of watershed reforested and water yield decrease; yield decreases are significant, in the range of 6-7 area-inches lost through significant forest regrowth and forest growth.
- Water yield increases are greatest the first year after cutting and decline thereafter, usually returning to pre-cutting levels by the 4th to 8th year; most clearing experiments returning to pre-cut levels within 10 years.
- Water yield increases are generally larger on north versus south facing slopes, with yields up to two and one half times greater for clearings on north facing slopes. One study also showed that west-facing forests used more water than those did on east-facing slopes.
- Differences between cut and uncut watershed yields increase exponentially as annual rainfall increases.
- Water yield increases from cutting in the many studies in the northeast occurred chiefly during the growing season, with areas of higher snowfall, deep soils, or conifer cover showing larger dormant season increases.
- Removal of conifer forests will yield more water than hardwood forests, as conifers use more water and snow evaporation is greater in conifers.
- Conversion of hardwoods to conifers will result in significant losses in water yields - one watershed in North Carolina had a 25% yield loss after conversion of hardwoods to white pines.
- Greatest yields are usually achieved through removal of riparian vegetation or lower elevation watershed vegetation.
- Much of the increased flow generated from cutting is seen as increases in low flow periods. Increases in peak flows do occur, but are not believed to cause increased flood risk where cutting is implemented on limited areas and moderate increases are generally yielded.

- Watersheds with deep soils generate longer lasting flow increases after cutting, and yields are more balanced between growing and dormant seasons; watersheds with shallow soils generate yield increases focused within the growing season.
- Certain early successional hardwoods use measurably more water than late successional hardwoods, and changes in water yield due to shifts in species composition may last in excess of a decade.
- Yield increases are lower in deep soils and in areas with fast regrowth of regeneration.

(Douglass and Swank, 1972, 1975; Douglass, 1983; Hibbert, 1967; Federer and Lash, 1978; Hornbeck and Federer, 1975; Hornbeck et al., 1993; Lull and Reinhart, 1967; Mader et al., 1972; More and Soper, 1990; Mrazik et al., 1980; Storey and Reigner, 1970; Trimble et al., 1974.)

Douglass (1983) and Storey and Reigner (1970) emphasize the significance of the above findings as a way to help meet present and future water supply needs in the eastern United States. Given the above summary, the types of management that will yield the most water are those consistent with even-aged management, especially involving large clear cuts.

While clear cutting of entire reservoir watersheds is not feasible for water quality reasons (see next section on water quality), judicious rotation of clear cuts may provide significant flow increases, especially during the growing season when they are most needed by water supply managers. Douglas and Swank (1972) summarize the value of forestry for water supply managers:

> We can conclude from the experimental watershed evidence in the Appalachian Highlands that cutting forest vegetation has a favorable impact on the water resource by supplementing man's supply of fresh water when consumptive demands are most critical. And, the amount of extra water produced can be predicted with a degree of accuracy that is sufficient for many purposes. Although heavy forest cuttings will usually increase some stormflow characteristics on that portion of the watershed cut over, regulated cutting on upstream forest land will not produce serious flood problems downstream.

3.3.2.2 Water Quality

In describing the impacts of even-aged and uneven-aged management upon water quality, most studies reviewed involved either clear cutting (of whole watersheds or in limited blocks or strips - all of which fall under even-aged management) or partial cutting (where part of or most of the overstory is retained). It should be noted that while partial cutting falls under uneven-aged management, variations of the shelterwood cutting system (a form of even-aged management involving removal of the forest overstory in stages) involve only partial cuttings.

The impacts of even-aged management systems upon water quality vary with intensity and location of management; intensity, layout and maintenance of road systems; and planning and supervision of logging and woods roads operations (Lull and Reinhart, 1967; Kochenderfer and Aubertin, 1975; Hornbeck and Federer, 1975). The water quality parameters principally affected by these activities are turbidity, nutrient levels, and stream temperature.

Turbidity

Turbidity is affected by soil exposed in poorly planned, located, and maintained road systems and log landings (Kochenderfer and Aubertin, 1975). For example, gravel access roads may have an infiltration capacity of .5 inches per hour, while forests have capacities of 50 inches per hour (Patric, 1977, 1978). Haphazardly built road systems may utilize 20% of a watershed, while well planned road systems may utilize 10% (Lull and Reinhart, 1967). In addition to access and skid roads, the total compacted area of a typical logging area including landings may approach 40% (Lull and Reinhart, 1972). MDC conducted a study in 1986 of pine thinning on the Wachusett Reservoir watershed completed by agency crewmembers and two private loggers under MDC supervision. For this study, the total area impacted by logging - including access roads, skid roads, and landings - ranged from 14.8% (MDC crew) to 19.6% (private loggers) (Kyker-Snowman, 1989b). Stone (1973) reported soil disturbances covering 15.5% of the logged area for selection cutting, versus 29.4% for clear cutting in eastern Washington. Sediment export was directly proportional to the percentage of a watershed in roads and reducing this percentage was seen as critical for reducing sediment in streams in the Pacific Northwest (Dyrness, 1965).

Hornbeck et al. (1986) report that increases in soil disturbance means greater erosion. Martin (1988) recommends setting predetermined travel routes for equipment and doing winter logging and using tracked vehicles rather than wheeled vehicles in sensitive areas. Hewlett (1978) recommends avoiding road locations near perennial and intermittent stream channels in order to eliminate impacts.

A study of erosion on New York City's water supply watersheds highlights the importance of protecting road and stream banks from the effects of erosion. This study of the erosion sources at the Schoharie Reservoir estimated that while road banks made up only .22% of the watershed, they were the source of 11% of all erosion. Streambanks, which made up only .44% of the watershed, were the source of 21% of all erosion (S.U.N.Y., 1981).

Construction of new access roads carries the greatest risk of erosion. Massie and Bubenzer (1974 as cited in O'Connor, 1982a) found that 36% of all road erosion in the study area was produced by roads two years old or less, although this category of roads made up significantly less than 36% of all roads. Stone (1973) notes that some turbidity is inevitable with construction and initial use of new roads, but that almost all continuing damage from roads is avoidable by using recommended woods roads maintenance techniques.

A comparison study of graveled and ungraveled forest access roads in West Virginia showed that the application of even 3 inches of gravel reduced sediment losses eight-fold, even though the gravel road carried two times the traffic of the ungraveled road (Kochenderfer and Helvey, 1974).

Lynch et al. (1975) traced increased turbidity on watersheds in Pennsylvania to scarified log landing areas. However, Kochenderfer and Aubertin (1975) report that:

> Bare soil exposed by road building, and to a much lesser extent by log landings, has long been recognized as the major source of stream sediment associated with logging operations.

Turbidity in a West Virginia watershed that was clearcut was traced to both road erosion and channel scour from heavier overland flow (Patric, 1976). Channel scour is an impact that is unique to large-scale clearcuts or disturbances where peak flows may increase.

Mechanical compaction of soil reduces soil infiltration and reduces tree seedling survival (Martin, 1988). Erosion problems result when mineral soil is exposed to rain, especially on areas with long, steep slopes. However, even compacted, exposed soils have high infiltration capacities. The most significant erosion occurs when soil is bared to the "B" horizon, beneath the organic and leached horizons (Patric, 1977).

MDC measured soil bulk density (a parameter which shows soil compaction) on transects through a pine thinning at Wachusett Reservoir with three types of conventional logging equipment. Average soil bulk densities did not change significantly when measured before and after logging done by MDC's crew with a conventional small skidder and a forwarder. Average bulk density before logging was 6.18 grams/cubic centimeter (gms/cm) and 6.21 after logging; 13 gms/cm is considered the level at which root penetration is inhibited. Stone (1973) reported that soil compaction varies enormously with soil type, moisture content, frequency of traffic, and type of "packing" impact. He concluded that the key to avoiding erosion from logging is to ensure that protection steps will handle extreme rain events on the most sensitive sites. The careful planning of skid roads is essential.

Cuttings where soils are not disturbed by roads or skidding do not discernibly increase turbidity (Kochenderfer and Aubertin, 1975; Dyrness, 1965; Bormann et al., 1974). In Connecticut, 80 logging locations were checked for compaction, erosion, and stream sedimentation. All such problems were found to be related to the transportation aspects of logging (O'Haryre, 1980, as cited in More and Soper, 1990). Other studies trace turbidity to erosion from heavily used logging roads, particularly after heavy rainstorms and from increased streamflow that caused channel erosion (Patric, 1976; Pierce et al., 1970 as cited in More and Soper, 1990).

Turbidity measurements were compared on watersheds in the Fernow Experimental Forest, West Virginia; treatments included a commercial clearcut, a silvicultural clearcut, and one watershed with no cutting. Turbidity (in Jackson Turbidity Units - JTU) during logging was 490, 6, and 2 units respectively. One year after cutting, turbidity was 38, 5, and 2 units respectively (Kochenderfer and Aubertin, 1975). Douglass and Swank (1975) concluded that well-planned, well-maintained road systems do not damage water resources. In a comparison of logging with planned and unplanned skid trails, the planned logging had turbidity of 25 JTU while the unplanned logging had 56,000 JTU (Reinhart and Eschner, 1962, as cited in Brown, 1976). A comparison of regulated and unregulated logging in 1947-8 found that unregulated logging increased turbidity 10-20 times background levels while regulated logging increased turbidity only slightly (Douglass and Swank, 1975).

In a study at Hubbard Brook, New Hampshire, a watershed was logged with a strip cut even-aged method. In the two years during and after logging, 6 of 147 streamwater samples exceeded 10 turbidity units (Hornbeck and Federer, 1975). A study of different stream crossing techniques in the Ware River watershed found that temporary bridge crossings caused less impact than ford crossings or crossing on poles. Increases in turbidity caused by temporary bridge crossings were not measurable beyond 100 feet downstream from the bridge (Thompson and Kyker-Snowman, 1989).

Clearing of riparian areas has been associated with increased turbidity (Corbett and Spencer, 1975). Lynch et al. (1975) compared middle slope clear cuts with lower slope clear cuts and found turbidities of 4 part per million (ppm) on middle slope cutting, 196 ppm on lower slopes, and 2 ppm on an uncut control watershed.

While useful predictive models exist to estimate soil loss from agricultural practices, few soil loss predictive models exist for silvicultural operations. Burns and Hewlett (1983) developed a model that evaluated clearcut, disking, and planting operations in the southeastern U.S. This model is based on the percentage of bare soil after logging practices and the location of bare soil areas with regard to perennial stream channels. The authors recommend keeping any exposed soil areas away from wet and dry stream channels in order to minimize erosion. Currier et al. (1979) developed a procedure for analyzing water quality impacts from forest management. Larson et al. (1979) began assembling existing data into a system of computer models. Li et al. (1979) developed a sediment yield model based on the Universal Soil Loss Equation and tested in Colorado.

Nutrients

Logging impacts on nutrient levels can vary by the amount of cover removed, type of cover removed, watershed slope, location within the watershed (lower areas cause faster nutrient input, but higher areas cause more nutrient loss), and the timing of the regeneration response. Soil type and depth also control impacts (e.g., deep, poorly-drained, fine-textured soils tended to bind free nutrients before they reached the streams) (Bormann et al., 1968; Brown, 1976; Carlton, 1990; Martin and Pierce, 1980; Martin et al., 1984). While turbidity increases are caused by soil disturbance, increases in nutrient levels can result solely from cover removal. For example, at Hubbard Brook, New Hampshire, all trees on a catchment were cut and left on the ground and herbicides applied to prevent regrowth. As a result, stream concentrations of several ions increased significantly (Douglass and Swank, 1972). In this study, nitrates increased more than forty times background amounts (Bormann et al., 1968). Cuttings associated with significant nutrient increases typically involve clearing of large percentages of watersheds. However, even clearing of entire watersheds at Fernow Experimental Forest, WV and Pennsylvania State Experimental Watersheds did not appreciably increase nitrates (Kochenderfer and Aubertin, 1975; Lynch et al., 1975).

Nutrient increases from cleared areas are derived both from the increases of nutrients released as the decomposition process increases in sunlight and by the reduction in uptake due to the loss of plant cover (Vitousek, 1985). Strip cutting of one third of a watershed (at Hubbard Brook, New Hampshire) caused nitrate increases of nearly two times an undisturbed watershed and one third that caused by a watershed that was completely clear-cut (Hornbeck et al., 1975). The coarse-textured soils of New England that have lower nutrient-holding ability may be more susceptible to nutrient losses, particularly in areas without plant cover (Hornbeck and Federer, 1975). Soils that are shallow to bedrock, thin unincorporated humus on infertile soil, and coarse skeletal soil on steep slopes are all also susceptible to nutrient loss (Williams and Mace, 1974). In areas where soils may be sensitive to nutrient loss, limiting cutting to light partial cuts may be necessary to prevent nutrient loss (Brown, 1976).

Aber et al. (1978) modeled changes in forest floor biomass and nitrogen cycling using various regimes of clear-cutting. A projected rotation that clear-cuts a forest each 30 years versus one on a 90 year cycle will accumulate less floor biomass and release more nitrogen to streams. Williams and Mace (1974) state that, in general, the more drastic the manipulation of the forest, the larger the corresponding release of nutrients, with minor manipulations causing little or no nutrient release. In their study of jack pine clear-cutting in Minnesota, summer logging involving whole tree removal was found to cause significantly more nutrient leaching than winter logging with only stem removal.

Temperature

Stream temperature is important in protecting aquatic life because of its impact on dissolved oxygen and nutrients (Brown, 1976). Stream temperatures vary depending on the presence of forested buffer strips adjacent to stream channels (Hornbeck et al., 1986). Douglass and Swank (1975) concluded, "stream temperatures are not increased by forest cuttings if a buffer strip is retained to shade the stream."

Kochenderfer and Aubertin (1975) found that clear-cuts on upper watershed areas did not increase stream temperature, as few stream channels occur in these areas. In lower watershed cuttings where trees were left adjacent to the stream channel, cuttings had no influence on stream temperature.

Summary

Studies indicate that erodibility of a watershed impacted by either natural disturbances or logging will remain low "as long as destruction does not involve severe and widespread disruption of the forest floor" (Bormann et al., 1974). The relevant components of logging operations are skidding, log landing, and access road construction, where mineral soil may be exposed.

While increases in streamwater nutrients vary by type of cutting and watershed characteristics, the two key aspects of cutting that influence nutrient release are the location and amount of clearing and the response of forest regeneration. Even where openings are revegetated within four years by rapidly growing early successional species, nutrient losses can still occur (Bormann et al., 1974).

Studies have demonstrated the methods that will hold water temperature and turbidity increases within tolerable limits (Swank, 1972). Patric (1978) states that there is overwhelming evidence that neither the productivity of soils nor the quality of water is substantially lessened during or after responsibly managed harvests. Stone et al. (1979) report that if proper precautions are taken, water quality impacts from logging are essentially non-existent. Regarding timber harvesting, Stone (1973) concludes that "adverse impacts can be greatly reduced or entirely avoided by skilled planning and sufficient care."

3.3.3 Uneven-Aged Silviculture

3.3.3.1 Water Yields

While most of the trends summarized in the even-aged management water yields section above also hold true for uneven-aged management, the effects upon water yield vary. For example, uneven-aged management on north-facing slopes, removing conifers and involving significant percentages of basal area, will probably result in higher water yields than less intensive cuts removing hardwoods on south-facing slopes. Either approach to uneven-aged management, however, will likely result in smaller water yields than a comparable even-aged management approach. This is due to less dramatic changes in soil moisture and evapotranspiration caused by the partial cuttings and smaller openings used in uneven-aged management. Adjacent vegetation and advance regeneration more quickly fill these smaller gaps. In addition, adjacent trees utilize part of the additional soil moisture created by cutting. Hunt and Mader (1970) found that when two white pine forest plots at Quabbin Reservoir were thinned by 30% and 80%, soil moisture increased slightly to moderately and growth increased by 70% and 230% respectively. Hornbeck et al. (1993) reported that when 24% of a basin was cut in one clearing it yielded twice the water of a similar basin where 33% of the forest was removed in scattered openings.

Douglass (1983) found that "partial cuttings were not as efficient for augmenting water yield as were complete cuttings." Storey and Reigner (1970) note:

> There are several ways we can manipulate vegetation to effect water savings. The obvious one is by heavy cutting of trees, thereby removing rainfall intercepting surfaces and removing the transpiring agent. According to considerable evidence our people have collected, single tree selection cutting saves little or no water. The cutover area need not be large; cutting in blocks or strips or even group selection of trees to be removed will save water.

While it is clear that silvicultural systems employing partial cuttings yield less water than complete cuttings, partial cutting studies do show increased yields (Mrazik et al., 1980). For example, of the 10 selection cut or thinning watershed experiments in the U.S. listed by More and Soper (1990), 8 resulted in significant yields. The average annual significant yields for each of the first five years after cutting ranged from .4 to 2.3 area-inches. When the ten experiments are averaged, selection/thinning resulted in a yield of 1 area-inch per year for the first five years after cutting. Hibbert (1967) reported results of seven selective cuttings in North Carolina and West Virginia with all watersheds except one having a southerly exposure. The average annual yield for years measured after cutting was 1.13 area-inches. The lightest cuttings necessary to produce significant yields remove approximately 20% of the forest basal area (Kochenderfer and Aubertin, 1975, as cited in More and Soper, 1990; Trimble et al., 1974). Douglass and Swank (1972) assembled a model that predicts a first year water yield increase based on reduction in forest basal area. This model predicts that a 30% reduction in basal area will increase yields approximately 2-3 annual area-inches.

In predicting the significance of water yields to be derived from uneven-aged management, specific site characteristics of watersheds must be examined. For example, cuttings on north facing watersheds with deep soils will result in relatively larger yields. Using regression lines from Hibbert (1967), a one-third reduction in forest cover on a north-facing watershed is estimated to yield three times the streamflow of a similar cut on a south-facing watershed.

Yields from uneven-aged management should also be viewed in comparison to the two above alternatives: even-aged management and natural management. When compared with these two options, uneven-aged management falls between the two. For example, partial clearing of watersheds with even-aged management may yield 5 or more area-inches per year (approximately 25% increase in yield) for the first few years after cutting (estimated from Hibbert, 1967). However, aging forests or naturally-managed watersheds with new forest growth will have reduced water yields over periods without disturbance. For example, Hibbert (1967) reports on three small watersheds (all less than 2,000 acres) in New York where an average of 47% of the watersheds was planted to conifers. After 25 years, the three watersheds averaged 5.3 area-inches less streamflow. Another medium sized watershed (over 300,000 acres) that was passively managed for 38 years and on which average basal area doubled, showed a decrease in yield of 7.7 area-inches - equivalent to a 25% reduction.

Existing data show potential water yield increases of approximately 25% for even-aged management and potential decreases on unmanaged forests of up to 25%. Uneven-aged management falls in between these two approaches, but averages small yield increases (on the order of approximately 5% for the first few years after cutting). The above approximate range would be reduced in actual magnitude depending upon the percentage of the watershed cut and the frequency of the rotation of cuttings. However, the relative comparison of the three alternatives should generally hold true.

3.3.3.2 Water Quality

Many of the principles underlying the potential for water quality impacts as a result of logging operations apply equally to even-aged and uneven-aged management. In order to avoid repetition, only the potential water quality impacts unique to uneven-aged systems will be reviewed in this section. As with even-aged management, the impacts upon water quality vary with several factors: intensity and location of management; intensity, layout, and maintenance of road systems; and planning and supervision of logging and woods roads operations (Lull and Reinhart, 1967; Kochenderfer and Aubertin, 1975; Hornbeck and Federer, 1975).

Uneven-aged systems remove single trees and small groups of trees. In a temperate-region forest study of gap-size impacts on nitrates, Parsons et al. (1994) measured extractable nitrate in soil plots. Within a lodgepole pine forest in Wyoming, gaps were created by removing 1, 5, 15, or 30 trees. The authors found that, compared with adjacent undisturbed forest, gaps created by removing 1 or 5 trees had no increase in nitrate. The 15-tree gaps had higher nitrate levels, and 30-tree gaps had nitrate levels 2-3 times higher than the 15-tree gaps. This same stand was previously thinned with no increase in nitrates, and clear-cut with soil nitrate increases of 10-40 times adjacent undisturbed forest. The authors recommend selective harvesting if nitrogen availability is of concern on a site. Stone (1973) notes:

> Any management practices that reduce vigor of the residual vegetation or delay regrowth and regeneration - such as scarification, excessive herbicide application, or maintenance of excessive deer herds - could increase loss rates [nitrate leaching] above those observed on the harvest clearcuts. On the other hand, greater surface soil shading, as by partial cutting methods, narrow stripcuts, increased cover density on clearcuts, or any means of hastening regrowth, would reduce losses [nitrate leaching] even more.

Trimble et al. (1974), in comparing management systems, state that water quality is ordinarily maximized on forest land by maintaining an unbroken tree and litter cover. The city of Baltimore's forest management utilizes the selection system because "although this [the selection system] is not the most economical system of cutting to use, it leaves sufficient cover to protect the watershed..." (Hartley, 1975).

The literature clearly reports that where stream shading is unaffected, stream temperature will not change (Douglass and Swank, 1975; Hornbeck et al., 1986; Kochenderfer and Aubertin, 1975). With little significant impact upon temperature and nutrient streamwater parameters, the chief potential impact of uneven-aged management systems is turbidity. Increased turbidity appears to be less of a concern with uneven-aged management, however, due to the lighter cutting practices and the amount of forest cover. For example, a comparison study of two watersheds at the Fernow Experimental Forest in West Virginia showed only slight elevations of particulates after three selection cuts during the 1950s and 1960s (cuts included 13%, 8%, and 6% of basal area) as compared to an adjacent undisturbed watershed. In a separate study, Corbett and Spencer (1975) reported no turbidity increases from a thinning operation.

One area of potential concern regarding traditional uneven-aged systems is that cutting cycles are often more frequent, meaning more frequent forest entry and more miles of access roads in use at any given time (Stone et al., 1979). However, the actual impacts will depend upon the uneven-aged method adopted. For example, in uneven-aged forests managed for water supply purposes, trees can be grown on longer rotations and longer cutting cycles. Rhey Solomon, water resource manager for the U.S. Forest Service notes "...the way to keep the water flowing and safeguard the forest is to rotate management throughout the watershed" (American Forest Council, 1986).

3.3.4 Air Pollution Effects on the Forested Watersheds of the Northeastern U.S.

The intent of this section is to look at the impact of air pollution on present and future forests of the southern New England region. For water supply purposes, managers must consider both the forest as an ecosystem and its function as a watershed. The focus must include both the direct impacts of air pollution upon watershed forests and the impacts of resulting ecosystem degradation upon water quality.

While the following discussion outlines specific impacts of air pollution upon forests, it is extremely difficult to isolate these impacts from the many other processes and stresses occurring in forest ecosystems (climatic stresses, insects, diseases, fire, ice, wind, etc.). It is also difficult to isolate the impact of one specific pollutant (e.g., ozone or nitric acid) from the composite of impacts affecting a forest. Klein and Perkins (1988) state:

> It is now recognized that no single causal factor is responsible, but that there are a variety of anthropogenic causal factor complexes interacting with natural events and processes that, together, induce stresses in forests that culminate in declines of individual plants and of ecosystems.

3.3.4.1 Acid Deposition

Carlton (1990) contains an excellent overview of the impact of acid deposition upon watersheds. In Massachusetts, data indicate that the average pH of precipitation is 4.2, which is six times more acidic than uncontaminated precipitation (Godfrey, 1988, as cited in Carlton, 1990). In New England, approximately 60-70% of the acid falls as sulfuric acid and 30-40% as nitric acid (Murdoch and Stoddard, 1992; Rechcigl and Sparks, 1985, as cited in Carlton, 1990). Murdoch and Stoddard (1992) note a study in Maine that showed the sulfuric acid component decreasing in recent years, while the nitric acid component is increasing, leaving the pH of precipitation fairly constant. Stoddard (1991) reported that sulfate deposition had decreased by 1.8% from 1970 to 1984 in the Catskill Mountains of New York. Acidity, however, remained the same due to equal increases in the nitric acid component. In Massachusetts, depositions amount to .3 to .7 pounds of hydrogen ion, 16.2 to 27.5 pounds of sulfate, and 8 to 22 pounds of nitrate per acre per year (Petersen and Smith, 1989).

Sulfuric and nitric acids tend to accelerate replacement of aluminum, calcium, magnesium, and other base cations in the soil with hydrogen ions (Hovland et al., 1980, as cited in Carlton, 1990). In this way, acid deposition will increase soil acidity and directly impact biological activity, soil fertility, and cation-exchange capacity (Carlton, 1990). Acid precipitation can also leach aluminum directly into streams causing potential negative water supply and aquatic and fish impacts (McAvoy, 1989). Key factors in determining the susceptibility of watersheds to acid inputs include: the supply of base cations in soils; the percentage of base-rich groundwater flow versus storm flow; the relative importance of snowmelt events; the average storm rainfall intensity, volume, and duration; and the soil depth, texture, pH, and cation exchange capacity (McAvoy, 1989; Peters and Murdoch, 1985; Veneman, 1984). Records at Hubbard Brook, New Hampshire show that while sulfate inputs have declined, base cation inputs from precipitation have also declined (145 micro eq/liter in 1963 to 104 micro eq/liter 1989) causing sensitivity to acidification to actually increase (Driscoll et al., 1989). The authors attribute the decrease in base cations to a large reduction in suspended particulates since 1970 due to reduction of coal and open burning emissions.

Some researchers have questioned the extent of the impact of acid precipitation. Krug and Frink (1983) feel that most aluminum in streamwater is due to acid soils (caused by natural humic acids) not acid rain. Krug and Frink (1983) and Veneman (1984) note that streamwater can become more acidic as the acid humus layer increases with forest age and because thick humus layers may reduce the amount of water percolating into the subsoil and increase saturated overland flow. Studies in Connecticut and the Berkshires of Massachusetts show that soil acidity increases with forest age (Art and Dethier, 1986; Krug and Frink, 1983). In Connecticut, litter pH changed from 5.5 to 3.9 from 1927 to 1980 and the mineral soil pH from 5.1 to 4.6 during this period. A study in Norway also concluded that changing land use and consequent succession were largely responsible for acidification of soils and water (Krug and Frink, 1983).

Reuss and Johnson (1986) identified the key difference between natural and anthropogenic acid inputs as the ability of the stronger nitric and sulfuric acids to leach through to stream waters, whereas the weaker natural organic acids will leach from upper to lower soil horizons, acidifying soils but not stream waters. Therefore, a key factor in identifying systems acidified by pollution is whether pH is attributed to organic acids or sulfates and nitrates.

Driscoll et al. (1988) noted that the "acid rain" and "acid soil" argument is largely due to the lack of long-term data on basin soil and water quality. To help resolve this controversy, the authors compared two similar basins, one in New Hampshire (NH) where acid deposition is significant (pH 4.1) and one in British Columbia (BC) where acid deposition is insignificant (pH 5.0). The basins have similar bedrock, glacial history, and soils but differed in vegetation type and precipitation amounts. Both headwater streams were acidic. The key difference was that the BC stream was dominated by weak organic acids, had low aluminum concentrations, and low sulfate loading, while the NH stream was dominated by strong acids (nitric and sulfuric), had high aluminum concentrations, and high sulfate loading.

Two streams in the Quabbin watershed, the West Branch of the Swift River and the East Branch of Fever Brook, received similar analysis to those in NH and BC (Rittmaster and Shanley, 1990). The concentrations of sulfate and hydrogen ions in precipitation were significantly higher at Quabbin than at the New Hampshire site. While both Quabbin streams had high aluminum concentrations during high flow periods, Fever Brook aluminum was in an organic form that is not toxic to fish. Fever Brook also had one half the net export of sulfate of the Swift River, a result of sulfate reduction in the extensive beaver flowage at Fever Brook.

Veneman (1984) rated the ability of the soils of Massachusetts to buffer acid inputs using many of the criteria outlined above. Of the 25 soil types that make up almost all of the OWM lands at Quabbin, only four (all wetland soil types) were classified as "acid precipitation will have no negative impact on water quality," whereas sixteen types are listed as "acid precipitation will have a moderate or significant impact on water quality." Baker (1984) re-measured soil parameters at eight sites at Quabbin that had been measured in 1962. He found that soils had increased in acidity and exchangeable aluminum and were now releasing sulfate, whereas they were adsorbing sulfate in 1962. These changes have reduced the neutralization capacity of the soils.

3.3.4.2 Interaction between Air Pollution and Forests

Reuss and Johnson (1986) use the term "canopy leaching" for the process where hydrogen ions replace base cations in the forest canopy. Krug and Frink (1983) report that 90% of the hydrogen ions in acid rain at Hubbard Brook, NH are neutralized in the northern hardwood canopy during the growing season (rain pH of 4.1 changed to 5.0 in throughfall). In studies in the west-central Adirondack Mountain region of New York, Peters and Murdoch (1985) noted that throughfall in deciduous forests was less acid than rain, while thoughfall in coniferous forests was more acid than rain.

As the forest flora exist in several layers above and below the ground surface, the accumulation/neutralization that occurs at these various layers tells a great deal about how the forest processes incoming acid deposition. Yoshida and Ichikuni (1989) studied the chemical changes to precipitation as it passed through the canopies of three different types of Japanese forests. They reported that from 49-74% of the total incoming acid deposition was neutralized by the forest canopies, with deciduous oak forests neutralizing the least and cedar forests neutralizing the most. Virtually all of the cations and anions studied, with the exception of the hydrogen ion, increased as precipitation fell through the canopy (the authors studied Ca^{2+}, Mg^{2+}, K^+, Na^+, NH_4^+, H^+, Cl^-, NO_3^-, SO_4^{2-}, and Al). This indicates the process of "canopy leaching" is evident in these forests. The authors note that similar occurrences have been documented in New England by other authors.

Laboratory studies indicate acid precipitation increases leaching of calcium and potassium from vegetative foliage (Smith, 1981). In order for the forest canopy to replace the cations and anions lost, similar amounts of these substances must be taken up from the soil. In some cases, acid conditions cause these nutrients to be leached below the root zone where they become unavailable to plants (Klein and Perkins, 1988). The net effect of the above processes is to acidify the soils and damage forest ecosystems (Yoshida and Ichikuni, 1989).

Increasing acidity of soil water causes leaching of aluminum, an element of increasing concern to water supply managers. Aluminum also damages fine tree roots and inhibits the uptake of calcium, a nutrient vital to plant growth. This situation leads to further imbalance in nutrients and increases susceptibility to drought stress, decline in growth, and increased mortality (Johnson and Siccama, 1983, as cited in Art and Dethier, 1986; Petersen and Smith, 1989; Smith, 1981). For example, soil acidity is a potential contributor to increased nitrate leaching from forests (Vitousek, 1977). Klein and Perkins (1988) report that temperature, moisture, light, nutrients, and soil factors all contribute to susceptibility to disease. This type of pollution may also affect recovery from winter injury.

LOCAL SOURCES OF AIR POLLUTION

According to Klein and Perkins (1988), trees undergoing nutrient stresses may be predisposed to decline when natural and pollution-caused stresses are added. Forests that are damaged by decline go through a process of "reorganization" during which time increased nutrients are leached from the system into tributaries. This increased loss of nutrients may in turn perpetuate the forest decline.

Soil acidity will vary relative to air pollution levels, as well as other factors including soil type and horizon, underlying geology, and successional stage of forest cover (Art and Dethier, 1986). In general, the soils of the New England region have a low acid neutralizing capacity or "ANC" (Godfrey, 1988, as cited in Carlton, 1990). Art and Dethier (1986) studied the relationship of land use and vegetation to the chemistry of soils in the Berkshires. Acidity of the upper-most soil layer was positively correlated to species composition and stand age, with stands less than 140 years averaging pH 4.21 and those over 140 years averaging pH 3.92. Several studies verify an increase in soil acidification with successional sequences following agricultural abandonment (Robertson and Vitousek, 1981, Thorne and Hamburg, 1985, Krug and Frink, 1983, all as cited in Art and Dethier, 1986). Acidity varied with land use history, with previously pastured lands having significantly lower pH in the upper horizons than previously cultivated lands. The conclusion is that past land use has a significant impact on species composition and overall soil acidity (Art and Dethier, 1986). These studies are useful in considering overall differences in chemical processing in various types and ages of forests and in assessing the potential susceptibility of various forests to impacts of acid deposition.

Soil water pH generally decreases deeper into the soil profile. For example, in a study of eight forest soils in central Massachusetts, mean pH in the A and C horizons were 4.39 and 3.58 respectively; an increase in acidity of eight times. Exchangeable aluminum in the A horizons was nearly four times as high as in the C horizons (Baker, 1985, as cited in Carlton, 1990).

High levels of ozone cause injury to leaf surfaces of sensitive tree species such as white pine, black cherry, and white ash, especially during summer months. Ozone also reduces photosynthetic rates and the supply of carbohydrates to the roots (Petersen and Smith, 1989; Reich and Amundson, 1985; Smith, 1981). High levels of ground level ozone occur at Quabbin Reservoir, with readings recorded at Quabbin Hill sometimes exceeding other state recording stations including those in Boston.

The combined effects of acid deposition and ozone pollution may be contributing to a measurable decline in Massachusetts forests. A statewide study of the Massachusetts forests identified 24,000 acres that show signs of decline, including yellowing leaves, dead branches, and standing dead trees. This represents a 10% increase in forest decline over twenty years ago (Parker, 1988). In addition, the growth rate on one third of the red and white pines studied has dropped 20-50% since the 1960s (Freeman, 1987). The overall impact of air pollution predisposes trees to insect and disease outbreaks. Research shows that air pollution predisposes pine trees to bark beetle infestations and makes several tree species more susceptible to root rotting fungus (Smith, 1981).

In Massachusetts, the decline of red spruce and sugar maple has been examined most closely. Studies of red spruce on Mt. Greylock found that this decline involved a combination of factors, including pathogens, insects, and ice, snow, and wind. However, the decline studied was attributable only in small part to these factors. The high acidity of rain and fog, the high soil acidity, and the low soil nutrient content (including low calcium) at these sites point towards air pollution as a chief cause of the decline of red spruce. The study of sugar maple decline also concludes that many trees are in a weakened condition, which magnifies the impact of other detrimental factors (Petersen and Smith, 1989).

In addition to acid deposition and ozone pollution, current air pollution contains metals, polychlorinated biphenyls (PCBs), alkanes, and various polycyclic hydrocarbons and organic acids (Rechcigl and Sparks, 1985, as cited in Carlton, 1990). Soil and vegetation surfaces are the major “sinks” for pollutants in terrestrial ecosystems (Smith, 1981, as cited in Carlton, 1990). For example, the leaves and twigs of an average sugar maple tree 12 inches in diameter will remove the following elements from the air in one growing season: 60 mg of cadmium, 140 mg of chromium, 5800 mg of lead, and 820 mg of nickel (Smith, 1981). Klein and Perkins (1988) report that the accumulation of metals affects nitrogen transformations in hardwood forests.

Forest soils serve as sinks for lead, manganese, zinc, cadmium, nickel, vanadium, copper, and chromium; tree trunks also serve as sinks for large amounts of trace metals including nickel, lead, chromium, cadmium, and manganese (Smith, 1981, Driscoll et al., 1988, as cited in Carlton, 1990). The U.S. Environmental Protection Agency designed a 40-acre “model forest” containing several hardwood species and white pine (Smith, 1981, as cited in Carlton, 1990). The model predicts that, within five years of planting, this hypothetical forest and its soils would annually remove the following pollutants:

96,000.00 tons/year of ozone
748.00 tons/year of sulfur dioxide
2.20 tons/year of carbon monoxide
0.38 tons/year of nitrogen oxides
0.17 tons/year of peroxyacetylnitrate

The net effect of air pollution on a forest ecosystem is a combination of decreased photosynthesis, decreased growth, increased respiration, reduced biomass, and possible reductions in reproduction. These impacts produce a range of symptoms that together are termed "forest decline." The severity of the decline depends on the amount of pollutants, and the species and site conditions involved. An additional impact of air pollution is alteration of forest ecosystem composition and structure, through selectivity of impact. More severe air pollution, and air pollution on naturally stressed sites, serves to simplify the overall make up of the ecosystem and make it less diverse and less stable (Klein and Perkins, 1988; Smith, 1981). Smith (1981) defines three classes of air pollution impacts:

- Class I: low dosage, where ecosystem serves as a sink for pollutants.
- Class II: intermediate dosage causing nutrient stress, reduced photosynthesis and reproductive rate and increased predisposition to insects and diseases.
- Class III: high dosage where mortality is widespread and gross simplification of the ecosystem alters hydrology, nutrient cycling, erosion, microclimates, and overall ecosystem stability.

Klein and Perkins (1988) reviewed more than 400 studies relating to forest decline and concluded:

> There are interactions between primary causal complexes and their direct effects and secondary causes and consequences of forest decline discussed here, so that the web of interactions becomes formidable. Nevertheless, a start must be made on these analyses, not only to understand forest decline holistically, but also because of the pressing need to develop concepts and strategies to ameliorate or reverse the imminent collapse of forested ecosystems. Recognizing that species sensitivities to causal factor complexes vary greatly, inevitable simplification of ecosystems will drastically affect their ultimate stability.

3.3.4.3 Nitrogen Saturation

The potential problem of nitrogen saturation, defined as the declining ability of an ecosystem to retain added nitrogen, was only identified in 1981 (Aber, 1992). Researchers are concerned that acid deposition may also be adding significant amounts of nitrogen, originating chiefly from nitrogen oxides in air pollution. The effects of nitrogen saturation include elevated nitrate, aluminum and hydrogen ion concentrations in stream water (Van Miegroet and Johnson, 1993). Monitoring of nitrates is required for drinking water (standard=10 ppm) because of health effects upon infants and potential formation of carcinogenic byproducts (Skeffington and Wilson, 1988). Nitrates can also cause algal blooms in lakes and reservoirs. Excess nitrogen deposition may also effect forest composition and productivity (Aber, 1992).

Bormann and Likens (1979b) report a doubling in nitrate concentration in precipitation since 1955. Schindler (1988) reports that deposition of nitrogen oxides have increased much more rapidly than sulfates in recent decades. Ollinger et al. (1994) report that there is a more than twofold increase of wet nitrate deposition from east to west between eastern Maine and western New York State. The authors mapped broad-scale wet and dry nitrogen deposition across the Northeast, with the Catskill region in the highest category (10.34-12.66 kg N/ha/yr.) and the Quabbin region in the 7.99-9.16 kg N/ha/yr. category.

Processes Involved

The processes related to nitrogen saturation are more complex than those related to precipitation inputs of sulfates, mainly because nitrogen can be both an acid and plant nutrient component and because of the complex interactions between soils and plants and the various compounds of nitrogen. In the ammonium form, nitrogen is a nutrient for the plant/soil biota complex. In the nitrate form, nitrogen can be a nutrient for biota but can also be a very mobile and dominant anion involved in base cation depletion and mobilization of aluminum through the soil and into stream water.

A key reaction in this process is nitrification, the conversion of ammonium to nitrate. Others are denitrification (in which atmospheric nitrogen is released from nitrates) and nitrogen mineralization (the process by which ammonium is formed from organic nitrogen in soils). Mineralization is an important process, as the storehouse of nitrogen in soils far exceeds that in the plant system (75-97.5% of nitrogen is in inorganic form in soils) but the nitrogen can be more mobile in the plant system. As long as the soil system delivers an amount of nitrogen less than or equal to the capacity of the plant system, nitrogen is held within the system. Thus, nitrogen saturation requires both the soil and plant systems to be saturated.

The interaction of these three processes - nitrification, denitrification, and nitrogen mineralization - is dependent upon various bacteria, pH levels, season and climate, as well as variations in plant/soil composition. An added complication is the process of nitrogen fixing, by which plants transform nitrogen gas (the most prevalent component of the atmosphere) to nitrogen in a usable form in the soil/biota system. The relative importance of nitrogen fixation is dependent on the composition of nitrogen-fixing plants in the system. Bormann and Likens (1979b) estimate that 70% of the nitrogen store at Hubbard Brook, NH is derived from fixation and the remainder from deposition. In general, predictions of the timing of the onset of nitrogen saturation are limited by the lack of understanding of soil properties and the complex processes at work there (Schofield et al., 1985; Agren and Bosatta, 1988; Nadelhoffer et al., 1984; Aber, 1992,1993).

Disturbance of the plant/soil system by natural or anthropogenic events tends to increase mineralization of nitrogen and consequent nitrification in the system. Vitousek et al. (1979) analyzed processes that keep nitrate leaching in balance. These include the accumulation of ammonium in soil solution on cation exchange sites in the soil, and lack of soil water for nitrate leaching. A delay in nitrate movement after disturbance is critical as this allows vegetation to develop and take up much of the available nitrate before it can leach into stream waters.

Van Miegroet and Johnson (1993) summarize the complexity of the nitrogen saturation process:

> This soil condition is the integrated result of vegetation type, age and vigor, past N accumulation history, climatic conditions, and current and past N input regime and soil characteristics.

Aber et al. (1989) have developed equations based on field work that can help model the nitrogen cycle using soil litter analysis.

Symptoms and Susceptibility

Aber (1992) describes the characteristics - including annual stream water nitrate trends - of nitrogen-limited, nitrogen-transition, and nitrogen-saturated systems. In general, nitrogen-limited systems have low nitrate loss during snowmelt, high carbon:nitrogen ratios in soil litter, and high soil dissolved organic carbon concentrations. Nitrogen-saturated systems exhibit the reverse conditions for these three criteria. The identification of elevated nitrates in storm events, especially during snowmelt, may be a first indication that system inputs are at least temporarily exceeding capacity. Researchers at the New York City water supply watersheds in the Catskills are concerned about peaks of nitrates in the spring (up to

128 micro eq/l) combined with elevated summer levels (Murdoch and Stoddard, 1992). Rittmaster and Shanley (1990) in studying two tributaries at the Quabbin reported that nitrate concentrations were generally low, but nitrate peaks of 20 and >35 micro eq/l were reported in the two streams during the snowmelt period. The authors attributed these peaks to short soil contact time during storms. There are no other records of nitrate peaks at Quabbin, but limited storm sampling has been done.

Brown et al. (1988) recommend consideration of vegetation type and age, site history, carbon: nitrogen ratios in soil organic matter, external inputs, and nitrogen turnover rates to thoroughly evaluate the condition of a system with regard to nitrogen saturation. The authors note that because natural plant communities change, nitrogen saturation is a "moving target." Van Miegroet and Johnson (1993) reported that forests with small soil nitrogen pools, due to either limited accumulation history or frequent disturbance such as fire, generally have low nitrification potential and insignificant nitrate leaching, irrespective of age or vigor of the forest. Sites that have high soil nitrogen content coupled with a low carbon:nitrogen ratio have a high nitrification potential, and under these conditions the annual leaching of nitrates is strongly dependent on atmospheric inputs, forest age and tree nitrogen uptake rates.

Impacts of Forest Succession and Disturbance

Stand age is an important factor in determining nitrogen uptake and annual nitrogen accumulation rates in tree biomass. A declining trend in nitrogen immobilization as a stand matures may explain why nitrate leaching losses are typically larger in mature versus vigorously growing forests. Long periods without disturbance may allow high nitrogen accumulation and low carbon:nitrogen ratios and increased nitrification potentials (Van Miegroet and Johnson, 1993). Hemond and Eshleman (1984) note that both higher plant uptake and microbial immobilization contribute to limiting nitrate losses from Temperate Zone mid-successional forests. Murdoch and Stoddard (1992) state:

> In watersheds where forests are accumulating biomass, biological demand for nitrogen is often sufficient to retain virtually all atmospherically deposited and mineralized nitrogen during the growing season and reduces net nitrate release to stream water.

In their analysis of elevated summer nitrate levels in Catskill Mountain streams, Murdoch and Stoddard (1992) hypothesize that the older forests in the Catskill Preserve may have a low demand for nitrogen and may therefore be unable to retain all of the atmospheric nitrogen entering the watersheds. The authors are currently engaged in a study of nitrogen cycling in New York City water supply lands in the Catskills, investigating nitrogen input/output in different landscape types and documenting streamwater chemistry changes over short distances (Murdoch, 1993 personal communication).

Aber et al. (1991) note that changes in species compositions may affect the ability of a forest to absorb nitrogen. Pine (due to longer needle retention) takes up less nitrogen than oak or maple. The authors also modeled the timing of nitrogen saturation of a hypothetical forest under different management scenarios. Forest harvesting (removal of nitrogen) slowed the onset of saturation; ozone pollution reduced net primary productivity and moved the onset of saturation up from 300 years in the future (without ozone pollution) to 50 years into the future (with ozone pollution); and alteration of forest species from low nitrogen-demanding to high nitrogen-demanding species delayed the onset of saturation. This modeling exercise did not examine the impact of forest succession.

3.4 Principles of Disturbance Impacts

- Forest overstory blowdown can temporarily increase erosion and nutrient leaching by disturbing soils, increasing decomposition rates, and causing a setback in biomass accumulation rates.
- Severe forest fire can significantly reduce soil infiltration, thereby increasing overland flow of water, sediments, and nutrients.
- A forest that is diverse in age structure and species composition limits the impacts of age- and species-specific disturbances.
- Forests with advance regeneration in the understory will recover more quickly from disturbances to the forest overstory than will forests with poor understory development.
- Younger, shorter trees will sustain less damage from severe wind storms than taller, older trees, due both to their lower tendency to "catch" the wind and stem flexibility.
- While tightly grown, "aerodynamically smooth" stands may deflect wind better than those that are "aerodynamically rough," individual trees that have been grown in more open stands will develop strongly tapered stems that resist wind better than the non-tapered stems of trees grown in tight stands.
- Runoff from infrequent, large storms with associated intense rainfall and flood waters account for much of the annual particulate, sediment, and dissolved nutrient outputs from watersheds.

Air Pollution Impacts

- Forests serve as "sinks" for various environmental pollutants, retaining them and slowing their movement into water supplies. A tall, dense, and layered forest serves this function more effectively than a short, sparse forest.
- Environmental pollution has been linked to general forest decline, which increases the susceptibility of those forests to insects, diseases and other impacts.
- Actively growing forests with a diversity of species and sizes may help buffer the impacts of acid precipitation on water supplies.
- Air pollution contributes to nitrogen saturation of forest ecosystems. Nitrogen saturation can cause elevated nitrate, aluminum, and hydrogen levels in streams and losses of cation bases from soils. These impacts can be compounded by acid precipitation and ozone pollution, and ameliorated by the accumulation of biomass and nutrients in an actively growing forest.

Wildlife Impacts

- Wildlife populations can have significant impacts on both habitat and water quality conditions.
- The composition of wildlife communities is dictated by various factors - chief among them are habitat conditions, landscape characteristics, and mortality factors.
- Land management practices that change habitat conditions will result in changes in the wildlife community.

4 Watershed Management Goals

Following are the **primary watershed management goals** of OWM for management of its Sudbury land holdings, based on the watershed management principles outlined in Section 3 and the mandates that direct OWM policy:

- **Provide the best possible land cover for protecting reservoir water quality.**
- **Minimize or mitigate both point and non-point sources of water pollution.**

The vast majority of OWM's effort to achieve these goals is focused on lands owned by OWM within the watershed. While land acquisition at Sudbury remains a low priority, an analysis in 1990 identified 350 acres near the reservoirs and the open channel that are high priorities for purchase should funding become available. In addition, OWM continues to support programs that educate and provide technical assistance to owners of non-OWM watershed lands in order to expand watershed protection practices to these lands. In recent years, these programs have included a program to establish forested riparian buffers on private land in the Sudbury drainage.

The following sections identify specific goals for the main areas addressed in this plan: Water Quality and Yields, Land Protection, Forest Management, Wildlife Management, and Cultural Resource Protection.

4.1 Water Quality Goals

- Minimize the long-term cumulative export of phosphorus, nitrogen, and turbidity to the reservoirs.
- Provide a safe supply of water, under emergency conditions, for present and future generations.

There are no drinking water quality regulations pertaining to emergency water supplies and if Sudbury Reservoir was required to be used, heavy chlorination and a 'boil water' order would likely be necessary. The long-term quality of water in the tributaries that flow into the reservoir is a function of geology, soils, topography, vegetation, weather (especially infrequent major floods, hurricanes, fires, etc.), human impacts and wildlife activity. Human and wildlife impacts can also impact water quality over the short-term. The effect of vegetation upon water quality varies with physical basin characteristics, and becomes an important factor in the long-term when the impacts of large, infrequent natural disturbances must be considered. Vegetation cover can also help to ameliorate the negative effects of stormwater runoff from developed land, on heavily developed areas such as Marlborough Brook drainage. Of these factors, OWM management can only affect vegetation and human and wildlife impacts.

It is not within the scope of this plan to include evaluations of current, short-term water quality in the Sudbury Reservoir or its tributaries, except where this is affected by land management or wildlife populations. Human impacts, especially on private lands, that directly and immediately affect the quality of Sudbury Reservoir water are addressed in the 1997 Sudbury Watershed Protection Plan. Pollution sources at the Sudbury watershed include industrial, commercial, and dense residential land uses, nurseries and golf courses, transportation activities, state and federal listed hazardous waste sites, construction activities, landfills, sand and gravel operations, waterfowl, and permitted point sources of pollution (MWRA/MDC, 1997).

The water quality parameter of primary concern in the Watershed Protection Plan is phosphorus (MWRA/MDC, 1997). Given the undeveloped nature of OWM land, the parameters of primary concern in this plan are turbidity, nitrogen and phosphorus loads, total organic carbon, and pathogens associated with wildlife populations. It is always OWM's preference to maintain tributary water quality as high as possible and in that light, any increases of monitored parameters may be of concern.

4.2 Land Protection Goals

- Limit land uses on OWM lands to those that do not threaten water quality.
- Provide control over non-forest land use on OWM lands (e.g., roads), the effects of natural events (e.g., fire), and human activities that threaten water or other natural resources.
- Limit the disposition of OWM land for municipal or private use, through adherence to the OWM Land Disposition Policy.

An effective watershed management program must address the control of both human-caused and natural impacts on watershed integrity and water quality. Much of this control on OWM watersheds is achieved through the programs and activities of the Environmental Quality section, and thus not directly addressed in this plan. However, various aspects of OWM's Land Management program do directly involve land protection functions.

Control over harmful activities on the Sudbury watershed is best achieved when the Commonwealth has actual ownership or other direct control over allowable activities on the land. While OWM has an active land acquisition program geared towards acquiring ownership of, or other rights on, key parcels on the its active water supply watersheds, such a program has not occurred at Sudbury. An analysis of the effectiveness of a limited land acquisition program is included in Section 5 of this plan.

The location, marking and maintenance of the boundaries of OWM watershed lands are also important land protection activities, since clear boundaries allow for better control over illegal activities that could threaten watershed integrity. Effective resolution of boundary encroachments is also an integral part of boundary maintenance.

The control of potentially harmful activities on watershed lands requires a human presence on those lands, both to identify and locate those activities, and to provide effective enforcement of rules and regulations. This presence is provided both by OWM Rangers and the Massachusetts State Police. This presence allows for the timely discovery and resolution of potentially harmful human activities (e.g., illegal dumping) and natural events (e.g., fires) on the watershed.

Effective monitoring and control also depends on a good road system that allows quick access to all parts of the watershed lands. However, since gravel roads also constitute a source of erosion and sedimentation into streams and water bodies, watershed road maintenance must be done in ways that minimize these potential adverse impacts.

Finally, land protection goals can sometimes be best served through the designation of "Areas of Special Management Restrictions," on which management and other human activities are restricted. Such designations are especially appropriate on sites where the topography, hydrology, vegetation or other characteristics limit the potential benefits of active management.

4.3 Forest Management Goals

- Provide a vigorous forest cover, diverse in species composition and tree sizes and ages, across the vast majority of OWM lands.
- Maintain forest cover that balances active growth and nutrient assimilation, dense filtration, temperature regulation, and active reproduction.
- Retain this forest cover by encouraging and maintaining adequate forest regeneration across OWM lands.
- Enhance and maintain the ability of the watershed forest to both resist and recover from disturbance.
- Prevent erosion of sediments and nutrients from the watershed forest, and provide for active assimilation of available nutrients.
- Limit the effects of human-caused air pollution by providing cover that filters and/or buffers pollutants.
- Develop a low-maintenance watershed forest, which provides long-term water quality protection with minimal intervention.
- Conduct any forest management activity such that the resulting benefits outweigh any potential negative impacts.
- Comply with or exceed all environmental regulations governing forest management activities in Massachusetts.
- Salvage dead and downed material in areas where this salvage will reduce the threats of fire or nutrient transport, and limit the need for salvage, through deliberate management practices aimed at reducing the likelihood of damage.

OWM has determined that a diverse, vigorous forest cover should be maintained on the vast majority of its holdings, due to the unequaled water quality protection this cover provides. The chief value of this tree cover is to act as a filter for purifying the water that passes through it. The tall crowns of the forest overstory add depth to this filter and provide temperature regulation of surface, ground, and stream waters. Those portions of the forest that are actively growing and assimilating available nutrients limit the export of these nutrients to the reservoir. The forest understory provides uninterrupted recovery from overstory losses. The forest overstory canopy, the forest understory, the vegetative ground cover, and the thick organic mat of decomposing matter on the forest floor, as well as root systems interspersed within the mineral soil below, all work in concert to produce water of high quality.

In order to retain forest cover through the variety of disturbances that affect that cover, it is a OWM goal to expediently establish and retain adequate forest regeneration across the watershed. While the specifics of “adequate regeneration” are addressed later in the plan, OWM believes it is a prudent goal to steadily maintain well-distributed reproduction, so that the forest is capable of quickly recovering from disturbance. In simple terms, the understory represents a "reserve forest," a back-up to cover the eventuality of overstory losses.

A primary goal of Sudbury forest management is to develop a diversity of age-classes, including well-distributed regeneration, in order to reduce the susceptibility of the forest to catastrophic wind damage. While hurricanes are potentially the most disruptive disturbance facing the Sudbury watershed forest, the more frequent occurrence of less dramatic disturbances is also of concern to managers. These include the effects of air pollution, insects and diseases, and changes brought about by smaller scale weather events such as localized windstorms and heavy snow or ice storms. A forest that is diverse in species composition and multi-aged will resist natural impacts and human-caused pollution because these impacts tend to be species and/or size/age specific. Thus, OWM's forest management will "condition" the forest to be able to recover quickly from both localized, endemic disturbances and widespread, catastrophic events, in part by maintaining diversity.

Producing and retaining a diverse forest cover addresses OWM goal to minimize the export of nutrients and sediments to the reservoirs in a variety of ways. First, this cover reduces the erosion potential of precipitation and minimizes damaging overland flow. It also serves to buffer chemical impacts to water quality by maximizing water contact time with vegetation and soil components. Through the process of evapotranspiration, forests act as water yield "regulators," moderating the potential water yields of watersheds and thereby regulating the loss of nutrients, minerals, and natural elements from the watersheds to the water supply below. Forests that are growing actively accumulate nutrients from the soil, reducing their export to tributaries. Finally, forests likely play an important role in reducing the effects of human-caused pollution such as acid precipitation, heavy metals, and other environmental pollutants by both buffering impacts and by acting as "sinks" for certain pollutants such as lead.

OWM has concluded that the diversity of species appropriate for watershed management purposes should reflect the basic variation in the landscape and natural site conditions (e.g., soils, topography, water, aspect, and slope) found at Sudbury. While a range of tree species may be adequately suited to a given site, the management of species that are unsuited to the site (for example, upland species on wetland sites) does not provide optimal watershed protection. Trees growing off of the sites to which they are physiologically most suited are more susceptible to disease, wind, and other environmental impacts (demonstrated by the declining vigor of many red pine plantations on wet soils). In general, species that are well suited to their sites will grow vigorously over long periods of time, reducing the frequency of mortality and salvage operations. This principle is inherent in the OWM goal to create a watershed protection forest that requires a minimum of maintenance to achieve its function.

It is an OWM goal that any forest management activities on the watershed be conducted in such a way that even if no natural disturbances affect an area, the overall benefits to the resource from the activity still outweigh the potential impacts resulting from the activity itself. All activities have both long- and short-term consequences. In assessing the net costs or benefits of forest management activities, OWM considers both immediate and future impacts. For example, activities such as the cutting and/or removal of trees to deliberately regenerate an area must be controlled such that any short term negative water quality impacts from harvesting will be less than the long term benefits derived from diversifying the forest cover.

When major losses of forest trees occur naturally, it is an OWM goal to salvage dead and downed materials when such salvage will reduce nutrient export and will decrease the risk of catastrophic fires. Further, by reducing the likelihood of damage requiring salvage, and by maintaining good access to forest areas susceptible to damage, forest management should reduce the difficulty and potential water quality threat of these salvage operations.

4.4 Wildlife Management Goals

- Mitigate adverse impacts of wildlife on infrastructure and other watershed resources.
- Protect uncommon, rare, and otherwise significant wildlife species and habitats wherever they exist on OWM lands.
- Assess and mitigate impacts of watershed management activities on wildlife through a process of notification, site visits, review of records and literature, and recommendations to appropriate staff.

The overall goal of the wildlife program on the Sudbury watersheds is to protect important wildlife and their habitats while minimizing or eliminating adverse wildlife impacts on other watershed resources. In certain circumstances, where applicable, active management to enhance wildlife habitat may occur.

Certain wildlife species within the Sudbury watersheds can negatively impact both infrastructure and other critical resources in certain areas. Mitigating these impacts is a top priority.

Although active wildlife management is not a large part of this plan, OWM recognizes that its forest management activities may impact certain wildlife species or habitats. It is an OWM goal to avoid adversely impacting significant wildlife species or their habitats. This will be accomplished primarily through inventory and survey work to locate rare species and habitats, proper coordination with MassWildlife's Natural Heritage and Endangered Species Program, and proper precautions using management guidelines and Conservation Management Practices (CMPs).

While directly protecting rare or endangered wildlife will be a priority, OWM recognizes that its management activities have the potential to impact more common wildlife. Another objective is to assess the impacts of these land management activities on the wildlife communities at the Sudbury, and thereby minimize any adverse impacts. This will be accomplished through long-term monitoring programs and an in-house review process for all planned management activities.

4.5 Biodiversity Goals

- Maintain an undeveloped, forested condition on most of OWM's land holdings.
- Work to identify all uncommon or rare species present on OWM lands, and provide habitat conditions and levels of protection recommended for perpetuating these species.
- Where feasible and applicable, and on limited acreage, maintain early successional forested and non-forested habitats on OWM lands.
- Work to identify and eliminate invasive species from OWM properties.
- Maintain forest reserves on a portion of OWM's holdings.

OWM's greatest single contribution to regional biodiversity is the maintenance and management of large areas of undeveloped, forested habitat. Forests in general can contribute to soil and water conservation, while providing habitat for a range of indigenous plants and animals, aesthetic values, and recreational opportunities (Norton, 1999). The protection from development that results from OWM ownership contributes significantly to the long-term viability of a variety of organisms and natural communities.

Rare and uncommon species contribute to the biological complexity of a landscape or region. Efforts to identify and protect rare or endangered species or habitats occur continually on OWM land. Future studies to locate and classify rare natural communities may be initiated. Actions to protect and enhance these species and habitats will provide critical protection of important components of biodiversity.

Across all of its watersheds, OWM owns several hundred acres of non-forested habitat, including abandoned agricultural fields, active and inactive hay fields, and scrub/shrub meadows. On the Sudbury watersheds, OWM owns fewer than 50 acres of non-forested habitat, including 29 acres in the Marlboro filter beds. A majority of these habitats will be maintained in an early successional stage through mowing and/or the use of fire in order to provide habitat for an array of organisms that depend on non-forested areas. As discussed previously, in order to ensure biological representation of indigenous species, a range of habitat conditions must be present. Early successional forested habitat has been clearly identified as a rare habitat type within the state (MassWildlife, pers. comm., Dettmers and Rosenberg 2000). By its nature, early successional forested habitat is dynamic both spatially and temporally. It must either be continually created or maintained at that successional stage or it will mature into older forest. When possible, even-aged management techniques will be used to create and/or maintain this habitat in selected portions of OWM holdings.

FIELD HABITAT

Invasive species are commonly recognized as a major threat to native flora and fauna and biodiversity. In extreme cases, invading exotics can out-compete and exclude native vegetation, resulting in a monoculture of the invasive plant. The result is a tremendous loss of native plant and associated animal diversity. OWM will strive to identify, control and eliminate invasive species from OWM lands, within the limits imposed by water quality protection or limitations of resources and personnel.

The primary reason for incorporating forest reserves into land management planning is to ensure that representative examples of biodiversity indigenous to an area are protected (Norton, 1999). Forest reserves are important because they contribute to the full range of biodiversity and are important to a wide spectrum of species requiring undisturbed habitat. In addition, forest reserves can act as a reference or "control" site in which to assess the impact of management activities. Further, reserves also provide a different aesthetic opportunity and have a different character than managed forests. OWM will assess the feasibility of creating reserves within the Sudbury watersheds, and is in particular looking at the Cedar Swamp area for designating a reserve.

4.6 Cultural Resource Protection Goals

- Identify significant cultural resources on watershed lands.
- Prevent degradation of cultural sites and resources.

Cultural resources are fragile and non-renewable. Once destroyed, they are gone forever. They cannot be regrown, rebuilt or repaired. Similar to endangered and threatened species of flora and fauna, the fragility of these resources places a value on them that is difficult to calculate.

Preservation legislation is designed to ensure that future generations will have the opportunity to understand, appreciate, and learn about the past. DCR's Cultural Resource Management Program is concerned with locating and assessing the condition of both historic and prehistoric cultural resources, and generating plans for protecting those resources that are considered unique or are otherwise significant.

OWM's Cultural Resource Management Program at Sudbury is adapted from a broader plan that was developed for the MDC in 1990. The original plan was articulated in draft form in an MDC document entitled *Cultural Resource Management Plan: Volume One Management Policies, Operating Procedures & Organization*, by then Chief MDC Archaeologist Thomas F. Mahlstedt. The agency plan has been modified to address the specific requirements and nature of the resources contained on watersheds lands under OWM jurisdiction.


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5 2005-2014 Management Objectives and Methods

The sections below detail the conversion of the goals specified for each of the Sudbury watershed land management programs into objectives for the ten year management period and methods for achieving these objectives.

5.1 Land Protection

5.1.1 Land Acquisition

Land acquisition has been an important part of protection efforts in the three active water supply watersheds (Quabbin Reservoir, Ware River, and Wachusett Reservoir), with more than 14,000 acres purchased in the past 15 years. Land acquisition has not occurred at Sudbury, however, because of its status as an emergency supply. The Division did not have a legislative vehicle for land acquisition at Sudbury until 1996. The 1996 open space bond provided an allotment of $10 million for the four OWM watersheds, including Sudbury. While the 1997 Watershed Protection Plan for Sudbury does not include a recommendation for land acquisition, purchases may be considered in extreme cases where imminent development may have significant negative impacts to a main tributary or the reservoir.

In 1990, staff from MDC, DEM, and DFW looked at management issues in the upper Sudbury watershed. As part of this effort, MDC staff set priorities for land acquisitions in the Sudbury Reservoir watershed, in case funding became available. At that time, 350 acres were listed in various parcels near the reservoir and the open channel. This review would need to be updated, including an analysis of land sensitivity utilizing new stream, wetland, and land use data, before land could be recommended for acquisition. At this time, however, there is no immediate intent to acquire further property at Sudbury.

5.1.2 Restrictions on Land Disposition

OWM regularly comes under pressure from both private and municipal parties for disposition of parcels of its lands for purposes that may be inconsistent with drinking water supply protection. While there are certain areas of land ownership throughout the water supply system that may not be of critical importance to water supply protection, these areas require careful scrutiny prior to disposition. OWM will consider land disposition only under exceptional circumstances for private or municipal uses. Discussions of the transfer of certain lands within the South Basin to other state agencies are ongoing and based on the assumption that these agencies will retain land use practices that are consistent with drinking water supply protection.

The Watershed Land Disposition Policy, approved in April, 1998, provides a framework for the agency to properly discharge its obligations to protect the water supply and to protect the Commonwealth's broader interests in open space protection under Article 97 of the Constitution of the Commonwealth. The intent of the policy is to provide additional watershed-specific instructions to the Executive Office of Environmental Affairs on disposition of Article 97 lands.

5.1.3 Establishment of Forested Riparian Buffers on Private Land

The current Watershed Protection Plan for the Sudbury Reservoir and Framingham Reservoir No.3 watersheds recommends that OWM encourage the establishment of vegetative buffers on private lands along tributaries to the two back-up reservoirs. The vegetative buffers will help reduce pollution (especially sediment and nutrients) flowing from land under commercial, industrial, and residential development. Using 1994 aerial photography, OWM staff estimated there are at least 4,800 acres of riparian areas in these developed land cover/land uses on the Sudbury North Basin watersheds.

From 1996-1997, MDC worked with the Department of Environmental Management, the City of Marlborough, and American Forests, a non-profit environmental organization, to complete an inventory of the forest, grass, and impervious cover on the 1,200 acre Marlborough Brook basin. Using the CityGreen software developed by American Forests, it was estimated that the residential and commercial areas (which made up 66% of the area) averaged 14% tree canopy cover, 24% impervious area, and 61% grass cover.

The program estimated that the tree cover on these developed areas reduced stormwater runoff from a 3 inch rain storm by 711 cubic feet per acre or 600,000 cubic feet for the developed area in the basin. If stormwater detention infrastructure needed to be built to accommodate this added flow, it would cost $2,488 per acre or 2.1 million dollars for the basin. If the above figures were representative of the 4,800 acres of residential/commercial land in the Sudbury Reservoir and Reservoir No.3 watershed, the urban forest on this land would reduce the stormwater from a 3 inch storm by 3.4 million cubic feet, a volume that would cost approximately twelve million dollars in added stormwater infrastructure.

Furthermore, if the sample areas within Marlborough Brook are representative of the 4,800 acres of residential/commercial riparian area in the North Basin, it is estimated that there are over 2,900 acres of grass cover within these areas. As reduction of phosphorus is the highest water quality goal in the Sudbury Watershed Protection Plan (MWRA/MDC, 1997), public education to reduce lawn fertilizer inputs, as proposed in the Protection Plan, could have significant impacts on water quality.

With the goals of improving tributary water quality and reducing urban storm flow, OWM initiated a pilot program at the Sudbury and Foss Reservoir watersheds to encourage the development of vegetative buffers, especially riparian forests, on OWM and private lands near tributaries. This program included technical assistance and funding for tree and shrub planting for private landowners with appropriate streamside locations. The initial pilot program funded $25,000 of tree and shrub planting on approximately 40 parcels of land within the Angelica Brook basin. Planting occurred during the spring of 1998. Based on the success of this pilot, OWM is considering expanding the program to other appropriate sites.

In selecting the 40 parcels of land on Angelica Brook, OWM picked areas that have adequate unused land for a buffer, a relatively small drainage area up gradient, gentle topography, moist soils with shallow groundwater, an absence of vigorous vegetative cover, and little up gradient impervious area. Many of the sites currently have manicured lawn adjacent to the brook. The Angelica Brook area was also selected because it is not sewered, so dense streamside vegetation may help remove excess nutrients from shallow groundwater (Gold, 1994 and Lowrance, 1994). Landowners involved in the program have agreed to water and care for the plantings.

5.1.4 Boundaries

OWM property boundaries are the “front line” of watershed protection, in that they are immediately adjacent to private land on which OWM’s watershed protection principles may or may not be followed. Many of OWM’s holdings in the Sudbury watersheds are in narrow, scattered strips of land adjacent to development. The protection provided by boundaries is therefore enhanced by regular maintenance to keep them visible, and by immediate identification and resolution of encroachments. Tree and shrub plantings in buffers on OWM land will serve a dual role of water supply protection and protection of OWM boundaries from encroachment from adjacent development.

5.1.4.1 Maintenance

Maintenance of OWM boundaries is a straightforward but daunting task. Before maintaining boundaries, OWM engineering and forestry staff must ascertain their exact location. Establishing boundaries in heavily developed areas for properties that were acquired approximately 100 years ago can be difficult. These boundaries are kept visible by the forestry staff on a regular 10 year cycle, primarily by clearing brush along the line and repainting blazes. This regular perambulation of the boundaries also serves to identify encroachments, discussed in greater detail below.

5.1.4.2 Encroachments

Encroachment by abutters onto the Commonwealth’s properties has become a significant problem in the Sudbury watersheds. This is due in part to limited ownership, unclear boundaries and a lack of monitoring and enforcement. Some of these encroachments are minor (e.g., mowing onto Commonwealth property), while others are quite significant (e.g., re-grading, landscaping, or placing structures directly adjacent to, and in some cases in, the Reservoirs). The most significant encroachments are around Reservoirs Nos. 1, 2 and 3.

As resources allow, OWM will begin an inventory of all DWSP lands in the Sudbury system. Staff will identify the types and severity of encroachments, and then work with the property owners to eliminate these encroachments. Most encroachments are discovered by field staff (civil engineers and foresters) while performing routine boundary marking or survey of areas where boundary lines are unclear. Once an encroachment is identified, a series of letters and field inspections are required in order to ensure compliance with the actions recommended by OWM. The best method of preventing new encroachments is by swift, effective, and fair resolution of those that are discovered. A small number of encroachments need to be resolved through court actions that require a great deal of additional police and OWM staff time. OWM strives whenever possible to resolve encroachments outside of the court.

5.1.5 Policing

This plan focuses on the management and protection of OWM watershed lands. Policing of public access and recreational activities is described in 2002 Sudbury Reservoir Watershed System Public Access Plan Update. Policing is necessary in the following categories to support this plan:

- Patrol and enforcement of public access regulations to prevent violations that may degrade water, forest, wildlife, and cultural resources (for example, all-terrain vehicle use on the area where tree planting occurred at the Marlborough Brook filter beds).
- Patrol and enforcement of regulations regarding illegal activities such as dumping and boundary encroachment that may degrade water, forest, and wildlife resources.

In order to assure that adequate policing of the above activities occurs, OWM staff collaborate with the Massachusetts State Police. The Watershed Ranger program also assists police by locating and reporting violations of OWM rules and regulations and by educating the public regarding these rules. No Rangers are presently assigned full time to the Sudbury watersheds. OWM may investigate the development of Memoranda of Understanding between OWM and local police departments, so that they may enforce certain OWM rules and regulations on OWM Sudbury land.

5.1.6 Fire Protection

OWM is committed to protecting the watershed forest, as well as visitors and neighbors, from the impacts of forest fires. While light burns in forest areas without forest regeneration cause little harm, hotter fires, especially in areas with younger forests, can cause serious impacts including death of both understory and overstory trees and exposure of mineral soil over large areas, causing an increased potential for overland flow, erosion, and nutrient loading.

Nearly all recent wildfires at Sudbury have been caused by the visiting public and were associated with illegal campfires or improper disposal of smoking materials. No comprehensive records are kept of past fires. The local town fire departments have responsibility for initial suppression and only infrequently notify OWM when assistance is needed.

The following recommendations are necessary to improve the protection of OWM Sudbury lands from wildfires:

- Improve cooperation with local fire departments.
- Improve forest road conditions in areas of poor access and high fire hazard and risk.
- Improve training of OWM staff in fire suppression.
- Draft and implement a fire policy and procedures manual.

In the past ten years, OWM upgraded its fire equipment with the purchase of two 100 gallon slip-on tanks. These are mounted on appropriate existing vehicles during fire season making rapid delivery of water possible down the often narrow and sometimes rough internal Sudbury roads.

5.1.7 Forest Roads

5.1.7.1 General Description

The Sudbury woods road system is essential in order to gain access for key watershed management activities including fire protection, forest management and police patrols. The proper maintenance of woods roads can greatly reduce the deposition of sediment and organic matter into nearby tributaries.

OWM Sudbury watershed lands have a woods road system of nearly 10 miles that provide vehicle access throughout most of the watershed area. Many of these roads date to the pre-reservoir communities that were settled in this area. Some of these were well-constructed, well-drained roads and have been only partially maintained by OWM. At an average width of ten feet, the 10 miles of Sudbury woods roads cover approximately 12 acres of OWM lands on the Sudbury watersheds.

The amount of maintenance needed on each type of roadway is difficult to predict. The work needed to keep all major roads open throughout the year is largely dependent on the weather. Major storm events affect roadways as trees or limbs fall into the roadway making them impassable. Crews are dispatched after major storm events to clear roads of fallen debris. Washouts due to culvert failure or clogged drainage ditches occasionally occur after major storms.

OWM has identified approximately 3.7 miles of road that will need grading and the addition of bank run and processed gravel, or other work, in the next ten years. Other general road maintenance occurring on a regular basis includes grading, removal of hazardous roadside trees, roadside mowing (which facilitates drainage and keeps roads open), and the processing and spreading of gravel as needed to maintain access or for specific land management activities.

5.1.7.2 Best Management Practices for Road Maintenance Activities

The objectives of forest road maintenance on the watershed are to provide for vehicle access to support key watershed management activities, and to minimize adverse water quality impacts associated with this road system. Activities that are dependent upon a good access road system include fire protection, forest management, and police patrols. These activities require stable, properly shaped and ditched road surfaces with adequate structures to manage storm event runoff. The vast majority of road maintenance on OWM properties is accomplished by OWM staff and equipment.

To accomplish these objectives OWM crews use various mitigating procedures to protect stream water quality during routine maintenance activities. These procedures are outlined below. It should be noted that specific sites may require special systems not described here, such as the use of geotextile, erosion control blankets, subsurface drainage, and rip-rap materials.

- **Shaping Road Surface:** The most basic component of a stable road is proper crowning and ditching, which allow storm runoff to leave the travel surface and be collected in the roadside ditch.

- **Relief Ditches, Relief Culverts, and Waterbars:** The frequent removal of storm water runoff from the roadside ditch is important to limit the amount of soil and gravel that is washed from an area during an event. The spacing of the relief structures is determined by combining site data such as slope of the road, slope of adjacent woodland, soil type and depth, and physical structure of the road. The general rule of thumb is to place relief structures as often as the landscape allows on most slopes. Relief structures, wherever possible, will discharge the storm runoff not less than 50 feet from streams or wetlands.

- **Detention and Retention Basins:** These basins will be installed where needed during road reconstruction activities to reduce the velocity of stormwater and increase infiltration.

- **Dry Season Work:** All road work, except for emergency repair work, some major bridge work (which may extend beyond dry periods), and emergency culvert replacement, will be accomplished during dry periods (primarily summer), when low water flow and stable soil conditions will help mitigate impacts from soil disruption.

- **Use of Silt Fence/Hay Bales:** Wetlands will be protected by properly installed hay bales or industry standard silt fence whenever road maintenance work requires disturbance near these resources.

- **Seeding of Disturbed Areas:** Areas of disturbed soil will be graded and seeded with quick-growing grass species upon completion of road maintenance projects. OWM has purchased a "hydro-seeder" for this purpose.

- **Special Road Surfaces:** Alternative road surface materials may be appropriate in limiting loss of material through erosion because of the huge variation of historical forest road construction and use. Forest roads that are rarely used may be shaped and seeded with grass. These roads would then be maintained by yearly mowing and culvert cleaning. Depending on location and use, these roads may also be blocked by use of barways to keep out all but essential traffic.

It is OWM's intention to limit washouts by replacing under-sized culverts with structures that will meet standards for a 50-year flood. Both culverts and ditches will be kept open and clear of all restrictions in order to prevent the back up of storm runoff and the resulting washout. In addition, OWM will continue installation of overflow spill areas (reinforced, low areas on a road adjacent to major streams) capable of spilling the flow from a 100 year flood on major tributaries.

5.1.7.3 Internal Review of Proposed Roadwork or Gravel Operations

Much of the roadwork conducted on the watershed is routine and of a maintenance nature. Occasionally however, new access roads must be constructed, or new sources of gravel developed. In these cases, since the operations may result in habitat changes and possible impacts on water quality, wildlife, or cultural resources, the following procedure will be followed:

- Development of a plan showing the location to be affected, time sequence of removals and procedures to be employed,
- Consultation with OWM Section Regional Directors, Natural Resources, Environmental Quality, and the DCR Archaeologist to determine that no significant impacts will occur to water quality, wildlife, or cultural resources,
- Consultation with and completion of all necessary approvals from the Department of Environmental Protection, the Department of Fish and Game, Division of Fisheries and Wildlife (for information on both fisheries and rare species impacts), the local town Conservation Commission, and any other governmental entity with jurisdiction over the chosen site.

5.1.7.4 Considering Beaver Populations in Long-term Planning for Access

Beaver populations in the state (and throughout the Northeast) continue to increase as the number of trappers and amount of human-caused mortality remain low. OWM constantly deals with plugging of road culverts by beaver. In some situations, OWM has successfully installed fences and water level control devices. These solutions, however, require continual maintenance and do not offer permanent relief. Further, fencing and/or water-level control devices may not be useful in all problem situations on the watersheds. Based on research in New York State, only 3% of sites are suitable for water-level control devices (Jensen et al., 1999). In situations where water level control devices are not an option, OWM removes beaver either by trapping or shooting individual animals. Although this solution may offer immediate relief, the habitat and conditions that attracted beaver initially have not been altered and these sites are often re-colonized within a short period of time. OWM recognizes the limitations of these various techniques and is working to develop a long-term plan for beaver management along roads.

Recent research suggests several management techniques to protect against beaver plugging of culverts. In 81% of sites examined in New York State, culvert size (area of inlet opening) was the major determinant of whether beaver plugged the pipe. The probability of a culvert being plugged increased with decreased culvert inlet opening area. Culverts with just 8 ft^2 of area were plugged 73% of the time, while culverts with 113 ft^2 of area were only plugged 7% of the time. The design of the culvert was also an important determinant of whether beaver altered the site. Pipe-arch culverts were less prone to being plugged by beaver than round culverts. Round culverts are more likely to channel the water and reduce the stream width, alter flow rates, and generate noise that attracts beaver. Unplugged pipe-arch culverts tended to retain the natural stream width. The width of the stream at plugged culverts was twice that of the culvert inlet opening (Jensen et al., 1999).

Both research and general observations suggest that beaver are more likely to occupy sites with lower gradient and smaller width streams (e.g., first or second order), as well as abundant woody vegetation. In areas with flat topography, the total amount of woody vegetation was the primary predictor of beaver presence in New York State (Jensen et al., 1999). Because each site can be evaluated for potential beaver habitat and the probability of culvert plugging, OWM will incorporate beaver considerations in choosing stream crossing methods. In addition to evaluating watershed area, road classification, and stream size and gradient, OWM personnel will also consider potential beaver habitat during replacement or installations of culverts. Culverts that may already be experiencing chronic beaver plugging will be prioritized for upgrading or replacement.

5.1.7.5 Management Guidelines for Beaver at Road Stream Crossings

OWM will incorporate beaver management considerations into road and culvert planning when possible to reduce the probability of culverts being plugged by beavers. Recommended practices include the following:

- Where feasible and applicable, replace existing smaller culvert pipes with larger, oversized pipes.
- When possible, box or pipe-arch culverts should be used with a minimum inlet opening area of 18 ft^2. Smaller sizes are easily plugged.
- When sizing the culvert, it is important that the width of the culvert inlet is at least equal to or greater than the width of the stream. This will decrease noise and minimize the potential for altering flow.
- When installing culverts, avoid creating a depression or pond at the inlet as these are attractive to beaver.
- Installing multiple smaller pipes at a site instead of a larger pipe is not a workable alternative. Smaller pipes are much more likely to be plugged.
- In situations where beaver have a history of plugging even large culverts, other management options may be needed (see section 5.4.3).

5.1.8 Areas with Special Management Restrictions

The recognition of a category of land on which management is restricted was first proposed in the 1972 Quabbin Reservoir Watershed Management Plan. That plan recognized those areas as "Protection Areas" where management would not be allowed due to potentially negative water quality or other impacts. Sites falling into this category included islands, rock quarries, mill sites and exceptional forests among others. This idea was further refined in subsequent Quabbin plans and that tradition and concept is carried forward into this land management plan for the Sudbury reservoirs.

Areas under special management restrictions fall into two general categories:

- Areas where regular forest management is impractical or may result in unacceptable impacts.
- Areas with uncommon, rare or potentially rare resources.

The first category includes areas that are commonly occurring but are also fragile, sensitive or impractical such as forested wetlands, marshes, bogs, vernal pools or steep slopes greater than 30%. The second category includes areas such as uncommon forest types, locations of rare, endangered or threatened species of plant or animal, and historic or prehistoric sites.

A new addition to the second category is areas known as "Primitive Woodlands." Henry David Thoreau discussed the concept of primitive woodlands as part of an overall forest classification system. He adapted this system from a land classification system put forth by the English landscape architect William Gilpin. Thoreau defined primitive woodlands as those that have always been forested, even thought they may have been cut one or more times in the past. The critical characteristic is that these woodlots were never used for agricultural purposes and that they therefore have always had a forest floor (Foster, 1999). Many questions need to be answered before specific management recommendations can be made. What ecological value do primitive woodlands have? Does the presence of these areas add to the biological diversity of the area? How many acres and where are the primitive woodlands on OWM lands? Initial investigations looking at 1830 survey plans of each town indicate that there is the potential for a significant acreage of primitive woodlands. These plans show the areas within each town that were still forested at the peak of agricultural clearing. However, how many of these areas that were forested in 1830 were subsequently cleared? OWM hopes to further investigate this intriguing concept.

To date, OWM has identified 1,026 acres of land in the Sudbury watersheds that will be classified as "Areas with Special Management Restrictions" (Table 9). These areas include the 386 acres of Big Crane and Little Crane swamps plus 119 acres of other wetlands, 116 acres of islands, and 405 acres of riparian zones. In addition, there are many small areas not yet tallied, representing sensitive resources and buffers around historic and rare wildlife habitat areas such as vernal ponds, as well as potential areas of "primitive woodlands." OWM also limits management on areas considered to be sheltered from the exposures that historically have been damaged by catastrophic hurricanes.

TABLE 10: AREAS WITH SPECIAL MANAGEMENT RESTRICTIONS

Type of Area	Size	Restrictions
Islands	116 acres	No management
Wetlands	505 acres	No management except limited beaver control (see beaver policy)
Riparian zones adjacent to tributaries and the Reservoir shore	405 acres	All areas subject to filter strip restrictions of FCPA (Ch. 132); some also limited to non-harvest silviculture
Disturbance-sheltered areas	Undetermined	Relatively low intensity management
Areas of historic, cultural or natural significance	Undetermined	Varies from no management to selective restoration and management
Primitive woodlands	Undetermined	Restrictions yet to be determined (see text 5.1.8 above)

LARGE VERNAL POOL: BREEDING HABITAT FOR AMPHIBIANS

5.2 Forest Management

5.2.1 Description of Forest Management Approach for Ten Years (2005-2014)

5.2.1.1 Objectives for Sudbury Forest Management

OWM has determined that the watershed protection function will be served best by a forest in which the majority of acreage is diverse in age, species, and vertical structure, is actively accumulating biomass, and is continuously reproducing. Establishing and maintaining this "watershed protection" forest can provide benefits throughout the watershed, but to the extent that reservoir shoreline and streamside areas provide the critical final buffer for capturing nutrients and sediments originating on developed lands in the Sudbury watersheds, a dense, vigorous *riparian* forest is of particular importance.

The Sudbury watershed forest is chronically subjected to natural disturbances, including wind, fire, insects, diseases, animals, and floods. In addition, the majority of the current Sudbury forest consists of 75 to 90 year old even-aged stands often without well-established regeneration and usually without graduated vertical structure. Without a graduated vertical structure, the ability of this forest to continuously maintain its protective function following large and/or a series of small natural disturbances may be impaired.

As the principal value of the OWM lands within the Sudbury watershed forests is as a buffer along reservoir shorelines and tributary banks, the most important objective of this management period is to maintain this forest buffer and its function in protecting water quality. On areas away from water courses, the objective of management over the next ten years is to foster regeneration where it is missing and to encourage existing regeneration that is appropriate to the site. On all sites, the objective over the long term is to enhance age and species diversity on each site, while keeping the majority of the forest cover in a state of active growth (to assist in water and nutrient regulation), through a range of silvicultural practices.

A silvicultural system is defined as, "…a planned program of silvicultural treatments during the whole life of the stand" (Smith, 1986). The name of the system is commonly derived from the name of the reproduction method that is used to regenerate the stand. The silvicultural system that will be employed throughout the vast majority of the Sudbury forest in order to create three distinct age classes is a variation of an uneven-aged system. The silvicultural method that perhaps best describes the regeneration plan for the Sudbury forest is group-selection or uneven-aged with patch cutting as suggested by Marquis (1991). However, the tendency to pigeonhole a complicated and highly variable process into a pre-defined term can unnecessarily restrict the wide variety of techniques available to forest managers. "Formulation of a silvicultural system should start with analysis of the natural and socioeconomic factors of the situation. A solution is then devised…When the important act of inventing the solution has proceeded far enough, the less important step of attaching a name to it can be taken." (Smith, 1996)

Over the next 30 years, 30%, or about 400 acres of the managed forest at Sudbury will be converted to a new age-class. For this age class to be evenly distributed throughout DCR land and evenly spaced through time, 13 acres must be regenerated each year. Therefore, approximately 40 acres will be treated annually (one third of which is regenerated).

5.2.1.2 The Role of Natural Disturbance

Natural disturbances occur at virtually all scales of time and area. The infestation of individual trees by the *Nectria* fungus, the perpetual browsing of regeneration by deer, and a 500 acre, lightening-caused forest fire are all natural disturbances. These disturbances, though "natural," can compromise the ability of the forest to protect water quality. It is the goal of OWM to insure the supply of high quality drinking water for both the short and long term. The management of the Sudbury forest must be planned to mitigate negative impacts resulting from natural disturbances on many scales.

WACHUSETT MICROBURST 1989

The most significant disturbance that affects the forests of Massachusetts is hurricanes. From meteorological records and forest reconstruction it has been estimated that hurricanes strike southern and central New England every 20-40 years, while catastrophic storms like those of 1635, 1788, 1815 and 1938 occur approximately every 100-150 years (Foster, 1988). Catastrophic hurricanes have the ability to disturb a significant portion of the forest, changing species composition and age distributions suddenly. However, there are variables that affect the extent to which a forest is impacted by various windstorms and some of these are under the forester's control. A study of the Hurricane of 1938 at Harvard Forest in Petersham, MA (Foster and Boose, 1992) showed that conifers are more susceptible to windthrow than hardwoods and tall trees are more susceptible than short trees. These two factors in combination with the slope and aspect of any given site are significant determinants of wind damage. In the Harvard study, conifers greater than 34 feet tall and hardwoods greater than 74 feet tall on nearly level sites (<5 degrees) or windward oriented slopes (S, SE, E) were severely damaged (>75% of all trees were damaged); there was intermediate damage (50-75% of all trees were damaged) on mild leeward slopes (5-10 degrees, N, NW, W) or intermediate orientation (NE, SW; >5 degrees). Hardwoods greater than 64 feet tall on these same exposures were damaged 51-75% and 25-50% respectively.

The structure of an uneven-aged forest, with three age classes well distributed across the landscape, is well designed to both resist and recover from the impacts of windstorms. Resistance should be improved when much of the forest is shorter than the critical height categories according to the Harvard model and resilience is improved when there are enough young trees in place to reoccupy the site should the overstory be destroyed. This structure should translate to less risk to water quality from nutrient or sediment flux in the event of a major windstorm. Fewer trees blown over means fewer trees needing to be salvaged and reduced fire hazard, and therefore a lower risk of subsequent nutrient losses to tributaries and the reservoir.

One of the most significant impacts to the riparian zone through history has been catastrophic flooding. Several studies show that the scouring that occurs in large infrequent storms contributes significant amounts of annual outputs of sediments and nutrients (Patric, 1980). One of the effects of urbanization on a watershed is to greatly increase the size and frequency of flood flows. As OWM forest lands are located downstream of many urbanized areas, they can help protect the reservoirs from the effects of floods by settling and absorbing sediment before it reaches the reservoir. By maintaining a diverse and actively growing forest within the riparian zone, these values can be enhanced (Welsch, 1991).

5.2.1.3 Forest Insects and Diseases

Damaging insects and disease-causing organisms are as normal and natural a part of the forest ecosystem as the trees themselves. To view these organisms as nothing more than destructive agents whose absence would only benefit forest health is to misunderstand their ecological role. They are vital components of biological diversity and play key roles in nutrient cycling, decomposition and predator-prey relationships. The impact of an infestation or disease outbreak becomes a concern when it conflicts with management objectives. A homeowner, whose specimen birch tree is infested by the bronze birch borer, is justified in viewing the situation as serious and worthy of immediate action. The death of this tree would conflict with the objective of an attractive yard. A single infested tree in the middle of the forest is not a concern where the objective is to have a vigorous, functioning forest ecosystem.

In the Sudbury forest, insects and disease are a major problem only when their impacts conflict with the OWM's objective of creating and maintaining a watershed protection forest. For the most part, this means that only large-scale outbreaks that threaten to alter tree species diversity or forest structure fall into this category. Chestnut blight was such a disease. It was first discovered in the Sudbury forest in 1911 and had already spread to chestnut trees in all towns of the watershed. Salvage of the dead and dying trees began immediately in the hope of protecting the yet uninfected chestnuts. Before the blight, chestnut was one of the dominant trees in the forest. Today, it is essentially a minor shrub, seldom reaching the size of a small tree before again being infected, dying back to the ground and perhaps putting out new sprouts.

The gypsy moth is another example of a serious pest. It was first found in the Sudbury forest in 1909. A great deal of effort was spent in trying to control the inexorable spread of this insect. Every winter, all egg masses that could be found were painted with creosote. The Sudbury Reservoir Annual Report for 1916 states, "Some time was spent scouting for gypsy moth egg clusters and painting them with creosote, and 120,200 clusters were painted at Sudbury Reservoir, 67,400 at the Framingham reservoirs…at a cost of $864.07." This work continued at least until 1947 when the last annual report was written. Epidemics of this insect can result in significant mortality of a wide range of tree species both in the overstory and understory resulting in alterations to forest structure, composition and health.

Both the fungus that causes chestnut blight (*Cryphonectria parasitica*) and the gypsy moth (*Lymantria dispar*) are introduced organisms that came to the Sudbury forest without their co-evolved complement of predators and parasites; a recipe for the development of an unhealthy ecological condition. Other examples that have in the past or currently affected the Sudbury forest include Dutch elm disease, beech bark disease, and white pine blister rust. Native species generally remain in balance with their predators except when cultural effects (past land use or deliberate forest management) create unusual conditions. Some examples are establishing species that are unsuited to the site, deliberately creating single species stands (i.e., plantations), and growing forests on soils that are nutrient depleted from a long history of farming practices.

The next significant threat to the Sudbury forest is the hemlock woolly adelgid (*Aldeges tsugae*), a small aphid like insect native to Asia, which was first seen in the eastern U.S. in Virginia in 1955 and has been moving up the east coast since then. It feeds on hemlock at the base of the needles, removing nutrients and secreting a toxic substance in its saliva. The most recent research and observations indicate that the amount of hemlock in the forests of Massachusetts may be significantly reduced by this insect over the next decade or more. Hemlock comprises less than 1% of the stocking of the Sudbury forest and no extraordinary measures will be taken to salvage infested hemlock on upland sites. However, sites deemed more critical to water quality will be considered for salvage operations or non-harvest treatments within the constraints of the current OWM Hemlock Woolly Adelgid Management Policy (OWM 2004).

5.2.1.4 Species/Site Suitability

Although some Sudbury forest stands are established on sites suited to their long-term growth and development, many are not. The current Sudbury forest originates primarily from plantation establishment from 1907 to 1947, with the majority of the approximately 1.75 million seedlings planted from 1913 to 1921. As many of the pines were planted on rich soils more suited to native hardwood species, some plantations are unstable and lack vigor. The most pronounced examples are red and white pine plantations on poorly-drained soils, which are prone to various diseases. These sites would support a diversity of long-lived, low-maintenance hardwoods if the pine canopy were opened to allow light to the forest floor. Therefore, it is one of the objectives of forest management at Sudbury to identify stable soil/species combinations and to encourage their development through silvicultural operations.

5.2.1.5 Analysis of Sudbury Forest Regeneration

Regeneration is the key to the creation of a diverse and stable forest. Procuring an adequate level of regeneration beneath the Sudbury forest overstory depends upon seed sources, appropriate seedbed conditions for germination and initial establishment, and proper conditions for development of the established seedlings. Each species of trees has a specific range of conditions that must be met for the reproduction of that species to occur. Evolution through natural selection has insured that all possible site conditions are suitable for some species of plant from lichens growing on bare rock to red maples living in swamps. It is the job of the OWM forester through silvicultural operations to encourage, through management, the necessary conditions for the regeneration of the species best suited to the site.

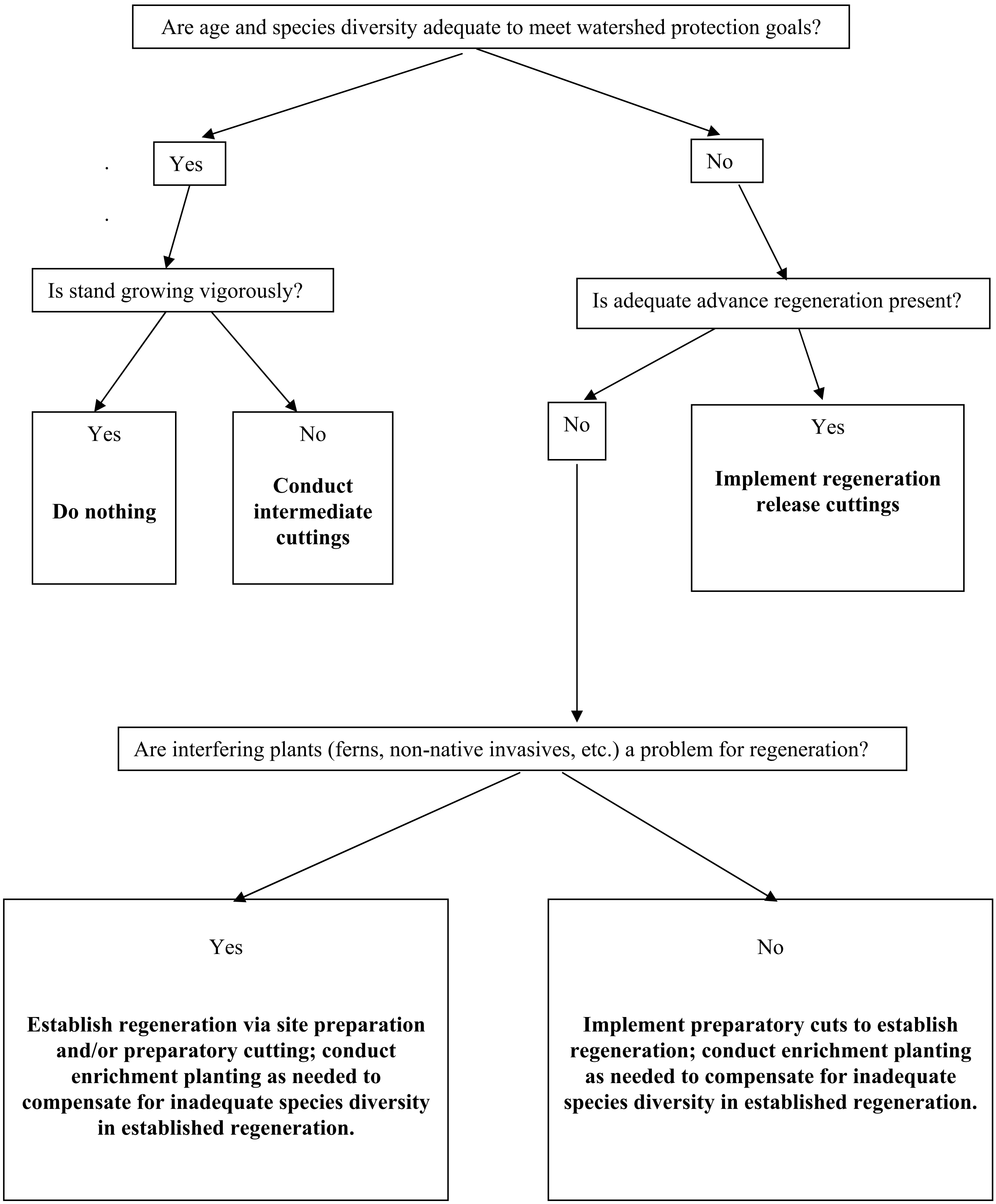
The current condition of regeneration on the Sudbury watersheds was described in Section 2.4.1.3. The Division defined “adequate regeneration in its 1991 Quabbin Deer Impact Management Plan (MDC, 1991), in order to specify what was meant by "success" in efforts to recover a Quabbin understory. Adequate regeneration was defined as the establishment of at least 2,000 stems per acre of seedlings/saplings greater than 4.5 feet in height with a diverse species composition well-suited to prosper on the range of sites present across the forest. While natural disturbances can positively affect local regeneration conditions, the effects are unpredictable. Carefully planned silviculture will encourage persistent regeneration throughout the managed forest and provide better control over species composition. This controlled regeneration response will increase the resistance of the watershed forest to major disturbances such as catastrophic hurricanes and the resilience of this protection forest in recovering from these disturbances.

5.2.1.6 Silvicultural Practices

Figure 4 outlines the general decision-making process OWM Foresters follow to determine the appropriate silviculture for any area. At its most basic, the process can be simplified to the following:

- Where regeneration is lacking, establish it.
- Where regeneration is adequate, released it.
- Encourage species appropriate to the site.
- Cut the poorest quality trees first and leave the best.

FIGURE 4: SILVICULTURAL DECISION-MAKING PROCESS



Establishment of Regeneration: Preparatory Cutting and Planting

There are at least three factors to consider when determining the adequacy of existing regeneration at a site: the species composition/site suitability, the number of seedlings/saplings, and the spatial arrangement. A high number of seedlings well distributed but of a species poorly suited to the site is considered inadequate. Conversely, a patchy distribution of a variety of species well suited to the site may be adequate if it occupies enough of the area to warrant release as a new age class. In the 1991 Quabbin Reservation Deer Impact Management Plan (MDC, 1991), an exhaustive literature review and a survey of regeneration in "off-Reservation" lands at the Quabbin were performed in order to determine what "success" meant regarding the level of regeneration following deer population control efforts. Adequate regeneration was defined as the establishment of at least 2,000 stems per acre of seedlings/saplings greater than 4.5 feet in height of a diverse species distribution. Spatial arrangement, the distribution of regeneration across the forest, is an additional objective of regeneration adequacy.

On sites where the level of regeneration is considered inadequate, preparatory cuttings will be prescribed. These are designed to open the canopy sufficiently to allow increased light and heat levels at the forest floor thereby stimulating seed germination and seedling development. At the same time, the species composition of the overstory, and therefore the makeup of the seed sources, can be adjusted, disturbing the leaf litter can enhance the seedbed, and competing vegetation can be reduced.

In situations where a desired species is absent from the overstory and therefore a seed source is unavailable, planting will be considered. The most common examples of this situation are dry site mixed oak stands with no white pine component in the overstory. The only practical method to establish white pine in these stands is through planting.

Release of Regeneration

Once adequate regeneration is in place, it will be released systematically to give it light and space to grow. This is accomplished by harvesting a portion of the overstory from designated stands. The cutting cycle (the period between harvests) for any given area will average 20 to as long as 30 years, depending on the site. Most areas will be treated using a variation of the selection method as previously described. Trees will be removed either singly or more often in groups and patches ranging from ¼ acre to 2 acres in size, with an average of about 1 acre. This range in opening size allows for the successful regeneration of a wide diversity of species due to varying tolerances of shade. It is anticipated that openings larger than one acre will become increasingly rare as the forest is brought into a more balanced distribution of ages, sizes, and species than currently exists.

Occasionally, there is the need to take a more wholesale approach to the conversion of stands comprised of species poorly suited to the site or unstable stands of damaged, low-vigor trees. Overstory removals larger than 2 acres are considered an option for the treatment of some plantations on the Sudbury watersheds, generally including those comprised of red or white pine and Norway or white spruce. Some of these plantations were never thinned and consequently the trees are tightly spaced with short, narrow crowns. These stands are poor candidates for small openings or partial overstory removal due to poor form and inadequate wind-firmness of the residual trees. The most practical method for regenerating these stands is the removal of larger blocks of overstory trees following the establishment of regeneration. Regeneration may be established in these stands either through the very careful application of a preparatory operation (the creation of strips within the plantation or overstory removal immediately adjacent to the plantation) or through planting.

In order that an adequate accounting be kept and to insure that each regeneration cut leads to the desired result, the acreage of the area that is released to a new age class for each silvicultural operation will be recorded, usually through precise mapping of openings using GIS mapping software. In this way, the long-term impacts of management will be assessed as well as the immediate impact on the distribution of age classes within the stand, sub-basin and forest. OWM intends to contract a photographic fly-over of OWM property mid-way through each ten-year management plan period. This will greatly enhance the ability to document and monitor the progress of this gradual conversion of the forest. Figure 4 depicts the generalized, long-term silvicultural strategy for converting the current even-aged forest to one composed of balanced distributions of three age classes.

Intermediate Cuttings

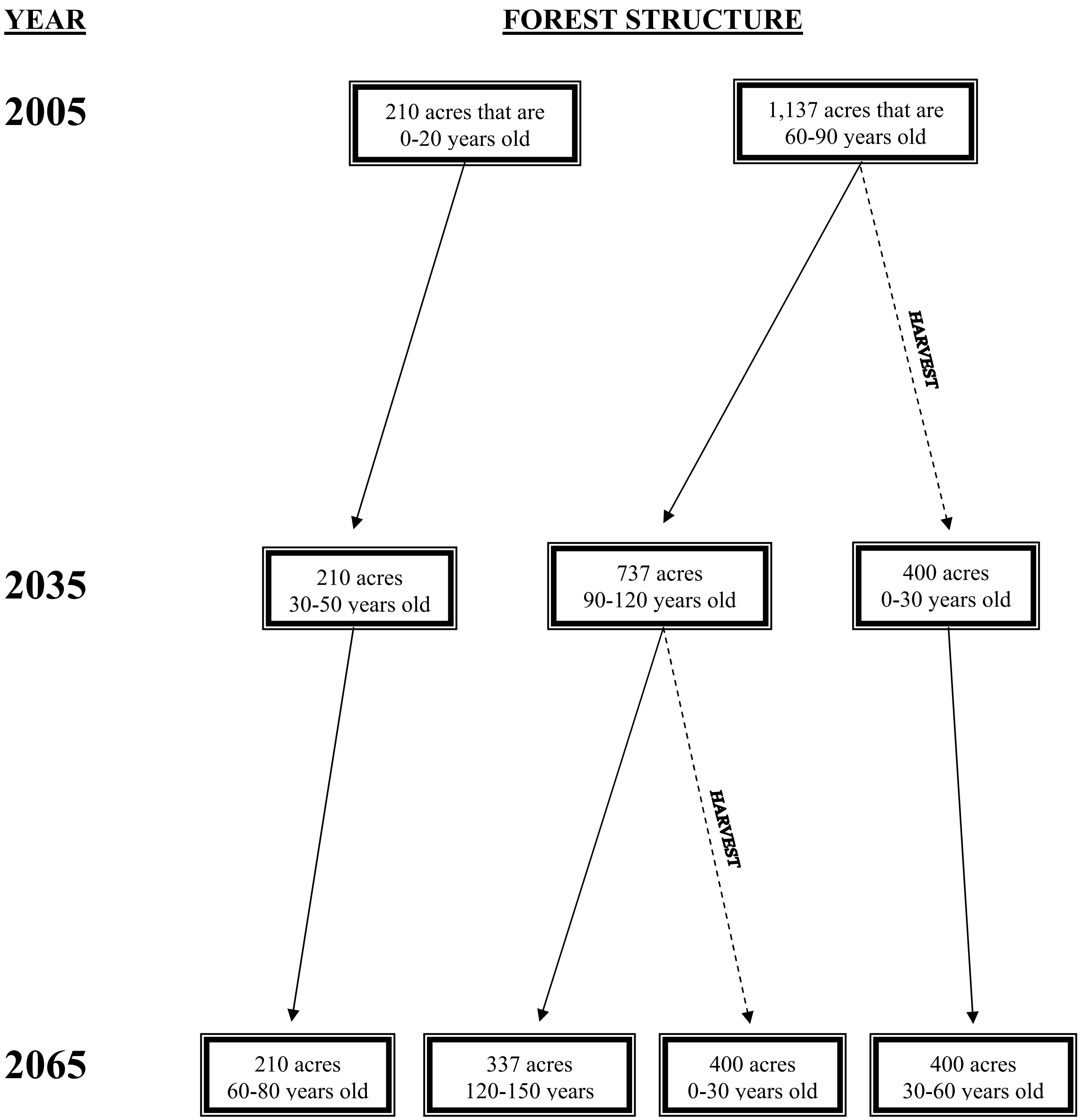
Intermediate cuttings are performed on stands prior to maturity. They are designated as "thinnings" when the objective is to remove trees of low vigor thereby decreasing competition within the stand and increasing the vigor and growth rate of the remaining trees. "Improvement" operations are designed to adjust the species and quality composition of stand. In fact, virtually all intermediate cuttings are a combination of both thinning and improvement. The defining characteristic of all intermediate operations is that there is no intention regarding the establishment or encouragement of regeneration.

In the Sudbury forest, intermediate cuttings are rarely performed independent of other treatments, as there are very few purely pole-sized stands on OWM property needing only thinnings. Most intermediate operations are performed simultaneously with preparatory and regeneration cuts, particularly when stands are being treated for the first time without the benefit of prior management.

Riparian Zone Management

The most common riparian zone management strategy applied by land managers is simply to leave these areas alone. In fact, this strategy has the force of law in many states, as a component of wetland protection or timber harvesting regulations. MGL Ch. 131 (Wetlands Protection Act) and Ch. 132 (Forest Cutting Practices Act) both contain language that restricts activities within riparian zones. The assumption behind these regulations is that manipulations of these zones will degrade the critical buffering capacity of these areas and may result in soil disturbances that are more likely to result in sediment transport into streams. Studies show however, that it is not the cutting of trees but the soil impacts associated with harvesting equipment that is associated with these effects. OWM recognizes these zones as the final, and most critical, opportunity to slow or capture nutrients and sediments released by a variety of natural and man-caused events on the watersheds. OWM therefore works to bring positive changes without negative impacts. For example, trees may be felled to bring light to the understory but not removed, or trees may be winched from the site without driving equipment into the riparian zone.

FIGURE 5: CHANGES IN SUDBURY FOREST AGE STRUCTURE VIA SILVICULTURE, 2005-2065



While urbanization increases flood flows and the concentration of a number of pollutants in stormwater, forested buffers help to filter these pollutants before they reach streams. Depending upon the size of the forested area, these buffers may also reduce the magnitude of flood flows (Anacostia Restoration Team 1992, Neville pers comm., 1996, Lowrance, 1994, Schueler, 1987, USDA Forest Service, 1991, and U.S. EPA, 1993). Forested buffers also have the benefit of discouraging geese from grazing and loafing on the reservoir shoreline. While most OWM riparian lands are already forested, additional protection can be gained by enhancing the structure and composition of riparian forests and by reducing shoreline and streamside mowing practices.

The preferred vegetative structure of riparian zones is an actively growing, diverse, self-perpetuating, and disturbance-resistant forest cover. Maintaining this forest structure throughout the variety of disturbances that impact all New England forests may be best accomplished through carefully planned and implemented management. To some degree, being located within the bottom of stream and river valleys shelters riparian forests from wind damage. However, as these forests mature, and especially where they are in the path of prevailing storms, they become vulnerable to sudden and dramatic damage. When this damage occurs, it is of great concern to watershed managers because it can result in substantial amounts of soil and nutrient transport. Additional concerns include sudden changes in stream temperatures due to the loss of forest cover and heavy additions of organic matter to the stream when groups of trees fall directly into the stream course.

As is true for maintaining the watershed forest in general, the most important resistance to build into these forests is the establishment of regeneration. This regeneration serves to anchor soils following disturbances, resists damage from many disturbances (due to size and density), and shortens recovery times for reestablishing riparian forests following disturbances.

Riparian forests that are simply left alone will establish regeneration as the overstory begins to age and decline in vigor. However, where full crown closure is maintained for long periods of time, understory development will be limited by low understory light and thus there will be delays in recovery following major disturbances. Through carefully implemented manipulations of the overstory and understory, OWM intends to systematically "condition" certain vulnerable riparian forests to be better able to fulfill their critical buffering functions throughout significant disturbances. Specific management strategies, and the types of riparian zones to which they will be applied:

- Standard silvicultural removals will occur within the managed forest where soils and cutting practices allow.
- Directional felling of small groups and individual trees, without removal, will be done to bring light to the understory where soils prevent equipment of any size. Trees will be felled perpendicular to prevailing slopes and cut into sections so that the trunk comes in contact with the ground to enhance the sediment trapping capabilities of the riparian zone. Felling will not be done into streams. It is felt that natural fall due to individual tree death (as opposed to catastrophic events) will add sufficient material in streams to create beneficial debris dams.
- Planting will occur in areas where seed source is limited, where herbaceous competition is significant, where protective ground cover is currently lacking (e.g., under dense plantations), and where aesthetics is a concern (e.g., near residences or high use areas). This practice may include planting with "tree tubes" sufficiently tall to bring seedlings above herbaceous cover and reduce deer damage. Non-harvest fellings may also be included in order to maintain light levels sufficient to support understory growth.

This technique will initially consist chiefly of directional fellings and tree plantings. The areas chosen to apply this approach include:

- Areas where an important buffer or riparian area is involved.
- An area that is exposed to significant disturbance, such as from future hurricanes.
- An area that would benefit from planting and tubing to help establish regeneration.

Salvage Policy

Salvage cutting has increased in recent decades on OWM properties due to the advancing average age of the watershed forests, the steady arrival of new insect pests, and storm events such as the microburst of 1989. In addition to (or shortly following) insect and disease damage, this older forest is more susceptible to windthrow (especially of trees with weakened root structures), and ice and snow damage. Salvage activities are not planned, but are important components of watershed maintenance when the disturbance damages large areas of forest, or greatly increases the threat of additional damage. Removals of dead or dying trees from damaged forests can lower fire hazard (e.g., in hemlock defoliated by hemlock looper or woolly adelgid), allow the salvaging of timber value, and strengthen the resistance of surviving trees (e.g., by removing trees weakened by gypsy moth to shift site resources to adjacent, healthier trees). OWM staff is aware of the importance of the steady addition of large woody debris to the forest ecosystem. However, the volume of dead and dying wood that is eventually salvaged is a small fraction of the total mortality in any given period of time. Therefore, ecosystem functions will continue to be met while other short-term concerns are addressed.

Where large areas are involved, salvage activities may preempt planned activities described in this plan. Following the microburst tornado that struck the Wachusett and Sudbury watersheds in 1989 (and damaged 300 acres of OWM forest in less than 20 minutes), there was strong public pressure to "clean up the mess." The close proximity of these watershed forests to residential developments may increase the priority for salvage following disturbances, to improve aesthetics and reduce both perceived and actual fire danger. In addition to public pressure for a rapid response, there are often other time pressures driving salvage operations. For example, when white pine is damaged during the warm months of the year, its wood loses value rapidly due to fungal invasions that cause discoloration (e.g., "blue-stain"). Wood-boring insects also invade damaged timber rapidly during warmer months and can greatly reduce value. Where roads are blocked by disturbances in adjacent forests, there is also an obvious need to conduct salvage rapidly in order to restore access, which is critical for fire control and emergency response. In situations that involve these time pressures, review and timber harvest permit procedures may be streamlined when an operation is deemed to be salvage and conditions warrant rapid action.

5.2.1.7 Summary of Planned Silvicultural Activities

Table 11 presents OWM plans for silvicultural activities from 2005-2014.

TABLE 11: PLANNED SILVICULTURAL ACTIVITY, 2005-2014

Operation	Estimated Amount
Pine Plantation Intermediate and Regeneration Cuttings	300 acres
Non-Plantation Intermediate Cuttings	10 acres
Non-Plantation Preparatory and Regeneration Cuttings	100 acres
Tree Planting	3,000 seedlings on 30 acres

5.2.1.8 Reducing Shoreline and Streamside Mowing Practices

The impact of the shoreline areas upon reservoir water quality is significant at Sudbury Reservoir. The Sudbury Reservoir has a relatively small drainage basin compared to the surface area of the reservoir. The drainage area/surface area ratio for Sudbury Reservoir is 9.8 compared to 18.7 for the Wachusett Reservoir (CDM, 1995). Therefore the land draining directly to the reservoir and not into a stream channel first is relatively large (more than 15% of the watershed as measured in a recent study (Comprehensive Environmental, 1997). The Sudbury Reservoir also has a very dendritic shoreline, which magnifies the impact of these lands. This feature means that a relatively large percentage of the watershed is in proximity to the reservoir (4,974 acres or 28% of the watershed is within 400 feet of the reservoir).

The management of the shoreline buffer zone is, therefore, a very important part of the overall protection of the water quality of the reservoir. In the past, OWM has actively cut vegetation along many sections of the reservoir shoreline and some tributaries. The MWRA, which has jurisdiction over the "open channel" that flows from the terminus of the Sudbury Aqueduct in Northborough to the Sudbury Reservoir, has also regularly cut woody vegetation along this waterway. The reason for past vegetation cutting was to reduce the amount of leaf litter in the reservoir. Leaf litter adds organic material and color to the reservoir. This is the same reason why pine plantations and arborvitae hedges were often planted along reservoir shorelines in the region. However, for larger reservoirs, such as the Sudbury, which do not have an arborvitae hedge (unlike the Wachusett Reservoir), it is felt that the following benefits of a stable and actively growing forest outweigh the potential problems caused by leaf litter:

- Stabilization of shoreline soils with differential rooting patterns and depths.
- Reduced shoreline usage by Canada geese.
- Increased infiltration capacity of soils.
- Protection of erodible mineral soil by thick layer of organic material.
- Absorption of excess nutrients.
- Detention of sediment and associated pollutants.
- Reduction in raindrop erosion potential via interception by forest canopy.
- Reduction of amount of precipitation reaching the ground through interception by vegetation.
- Reduction of flood peaks.
- Near elimination of overland flow.

(Dyrness, 1965, Hewlett and Nutter, 1969, Lull and Reinhart, 1972, Patric, 1978, Robinson et al., 1979, Schueler, 1987, Welsch, 1991, and U.S. EPA, 1993).

For these reasons, the Division implemented a program of reduced shoreline mowing and cutting in the mid-1990s. The only areas where regular cutting will continue will be on and adjacent to dams and other water supply facilities and buildings and access roads. OWM will coordinate with MWRA staff for a similar program for buffer areas along the Open Channel with the same exceptions.

5.2.1.9 Silviculture by Forest Type

The principal forest types found in the Sudbury watershed forests are described below, with a brief description of silvicultural approaches applicable to the type within the context of watershed management. Due to the relatively small acreage of OWM-controlled land in the Sudbury watersheds, it has been possible to map the forest types in extremely fine detail. For the purposes of this section, some of the types have been grouped together. For example, there is a total of five acres of the northern hardwood type. This represents less than one half of a percent of the total forested land. Rather than describe this type separately, it has been grouped with the mixed hardwoods type to which it is most similar. The composition of the managed forest on OWM land at Sudbury is summarized in the table below:

TABLE 12: COMPOSITION OF MANAGED FOREST IN OWM PROPERTIES AT SUDBURY

Forest Type	Acres
White Pine	327
Mixed Hardwood/Red Maple	313
White Pine/Oak/Hardwoods	299
Oak	249
Mixed Pine	59
Red Pine	55
Spruce	31
TOTAL	1,333

White Pine Type

White pine covers 327 acres or about 24% of the management zone. The vast majority of this type was established by the planting of nearly 900,000 seedlings from 1907 to 1947. The bulk of the planting took place from 1913 to 1921 around the Sudbury Reservoir and Reservoir #3 which makes these plantations 80 to 90 years old. The Walnut Hill and Crane Swamp plantations are 60 to 80 years old having been established from 1924 to 1943. These stands are nearly pure white pine with occasional small inclusions of various hardwoods.

Most of the white pine is growing on sites that are far better suited to growing hardwood species or at least a mixture of hardwoods and pine. In fact, many of these plantations currently possess an understory of excellent hardwood regeneration. The soils in these situations are generally deep and well to moderately well-drained tills. The problem with pines growing on hardwood sites is that they are more susceptible to wind and ice damage and disease. In addition, a stand comprised of a single species is inconsistent with OWM's goal of a diverse, multi-layer watershed protection forest. The long range goal is to convert these pure stands to either a mixture of white pine and hardwoods or to all hardwoods. This will be accomplished through a combination of preparatory and regeneration cuts utilizing group selection and shelterwood, depending upon specific site conditions.

Thinnings, along with an occasional sanitation cut to remove diseased plantations, will continue into the foreseeable future when feasible. However, the majority of pine plantations are not in a suitable condition for thinning. These trees were planted at a 6 by 6 foot spacing which necessitates a series of thinnings as the stand grows. These thinnings did not occur. As a result, these pine plantations are greatly over-crowded with very small live crowns perched atop spindly 70 to 100 foot tall stems. Such trees are unable to utilize the increase in light, moisture and nutrients that the removal of their competitors provides. These stands are presently highly susceptible to wind and ice damage and thinning would only serve to increase the likelihood of such damage.

Most silvicultural activities during the next 10 years will therefore be overstory removals with the objective of releasing regeneration and other younger age classes when adequately present or to encourage the establishment of regeneration when such levels are not adequate. The intensiveness of the removal will be directly related to the level and nature of the regeneration. Where the regeneration is of an adequate amount and of suitable species, white pine overstory removal will be more aggressive and intensive. Where the regeneration is not adequate, either due to insufficient amounts or an unsuitable mix of species, the removal of the overstory will occur more gradually over time. The history of Sudbury pine plantation management is summarized below:

TABLE 13: SUDBURY PLANTATION HISTORY

Practice/Condition	Acres
Original plantings	640
Plantings that survived to 1988	520
Harvesting/thinning 1980s	215
Harvesting/thinning 1990s	122
Harvesting/thinnings since 2000	99
Total harvests	436
Salvage cutting	36
Current plantations	454

Mixed Hardwood and Red Maple Types

Mixed hardwood and red maple types cover 313 acres or about 23% of the management zone. About 45 acres of this type is the sapling sized regeneration growing in the openings made by OWM in the extensive pine plantation on Walnut Hill in 1988. Pin and black cherry, red maple, aspen and white pine are the dominant species. Enrichment planting took place in 1995 when 1,500 red oak and sugar maple were planted on a portion of Walnut Hill that blew down and was then salvaged in 1989. Some areas now have a significant component of oaks due in small part to the planting but primarily to natural regeneration.

The balance of this type is pole to sawlog sized and is dominated by red maple and white ash. Black cherry, red and white oak, sugar maple, hickory, elm, aspen, and white pine are also found in this type. Moderately to poorly drained soils tend to support this mix of species. The 1911 cover type map describes these sites as generally “grass,” “pasture growing to brush,” or a mixture of early successional species such as “birch, poplar, willow.” The ash and maple therefore are no more than about 85 years old.

Regeneration is often lacking beneath these stands due to a thick and aggressive shrub understory. Honeysuckle is the most prevalent problem. False spirea (Sorbaria sorbifolia) has created a similar situation in a few locations. Silviculture in these areas will seek to establish a new age class of suitable species. This interfering shrub layer will be physically controlled by logging equipment during partial overstory removal operations. A mix of primarily long-lived hardwood species will be sought.

White Pine/Oak/Hardwoods Type

The white pine/oak/hardwood type covers 299 acres or about 22% of the management zone. Most of this type originated as white pine plantations that gradually gave way to hardwood intrusions. Insects, disease, fire, and storms all contributed to breaking up the initially pure pine overstory. The mix of hardwood species that now share these stands with the pine is largely determined by the site. Red maple, ash, and elm moved into the wetter, more poorly drained lowland sites. Oaks and hickories now grow with pine on drier, better drained soils. Regeneration is generally very good with a wide range of species represented.

The goal of silviculture is to release this young age class by partial removals of the overstory. The size of these openings will primarily be determined by the regeneration present. Openings ranging in size from 1/4 to 2 acres will generally be used. Larger removals will be considered where adequate regeneration is present beneath a poor quality overstory that is unsuited to the site. An example is a predominantly pine overstory on a poorly drained site with adequate red maple and ash regeneration.

Oak Type

The oak type occupies 249 acres or about 19% of the management zone. The majority of this type is found in the Pine Hill Compartment. A vegetation type map created in 1911 describes the areas that are currently oak forest as "chestnut, oak and maple," "large chestnut and oak," or "sproutland, scrub oak and other wood." The chestnut blight, first detected at the Sudbury Reservoir in 1911, effectively eliminated the American chestnut from the forest. Today, chestnut exists as a minor understory shrub. Red, black, scarlet, and white oak are the dominant species. Red maple, hickory, white ash, black birch, and white pine are minor components.

The more upland, well drained sites are dominated by black, scarlet, and white oak. Gypsy moth infestations have been the most severe in these stands. It will be the goal of silviculture to encourage the establishment of other species into these generally low vigor stands. White pine is the best candidate as it competes and grows well on these dry upland sites. Natural regeneration will be sought where there are suitable white pine seed sources. Otherwise, planting of pine seedlings will occur. Regardless of the source of the regeneration, openings will be created in the oak overstory to provide suitable conditions for white pine development.

Red oak is the dominant species where soil moisture is less limiting. Chestnut blight and the superior ability of red oak to sprout following fire or grazing are why there are nearly pure stands of red oak today. The long lived and high vigor red oak will be the favored species on these sites. However, a transition to a wider variety of species is inevitable and will be encouraged to diversify the species composition.

Mixed Pine Type

The mixed pine type covers 59 acres or about 5% of the management zone. This type includes mixtures of species that are unusual. Scotch pine was planted in 1917 in Compartment 3, the Route 85 and Acre Bridge Road area. Much of this Scotch pine was removed in an operation in 2000 that released the excellent sugar maple dominated understory. Since then, white pine and a mix of hardwood species have infiltrated the formerly pure plantations. At Walnut Hill and Crane Swamp, red pine and white pine were planted together in 1928. These stands have maintained a nearly pure pine overstory. This type occupies soils ranging from excessively drained outwash to moderately well-drained till.

Many of these stands have abundant and diverse regeneration. Silvicultural operations will begin the process of removing the overstory in stages. The resulting forest will consist of a diversity of species and size classes. Scotch pine will not be encouraged. This introduced species is typically of poor vigor and is not appropriate for a watershed forest.

Red Pine Type

The red pine type occupies 55 acres or about 4% of the management zone. It was established in plantations from 1917 to 1947 making these stands approximately 60 to 90 years old. The red pine on Walnut Hill was planted from 1937 to 1943 and is therefore about 60 to 70 years old.

Plantations were established on a wide range of soil types. Red pine on the moister, more fertile soils tends to be more susceptible to root rot diseases and windthrow. Many of these stands are currently infected by such diseases. For this reason, these stands will be converted to a cover of mixed hardwoods. Overstory removal will precede gradually where adequate regeneration is lacking and more aggressively where it is present. Red pine is best suited to the better drained soils. Plantations on such sites will be converted to a mix of hardwood and white pine or maintained where the plantations are growing vigorously. Red pine will remain a component where natural regeneration exists.

Spruce Type

The spruce type occupies 31 acres or about 2% of the management zone. The vast majority of the spruce that was planted is white spruce. Norway and red spruce were also planted. The most extensive stand occurs in the Stony Brook compartment. Approximately 36 acres were planted in 1917 of which 18 acres still exists. The balance of the spruce was planted from 1928 to 1942 in small patches at a variety of locations.

The general condition of the Stony Brook plantation is poor although the site is well-suited to growing spruce. As is the case with all Sudbury plantations, the tightly spaced trees were never thinned resulting in an over-stocked, small crowned stand. As individual or small groups of trees die or are blown over, the remaining nearly 100 foot tall spruce were ill-equipped to stand on their own. The result was the acceleration of the disintegration of the plantation. A silvicultural operation in 1998 was designed to secure and release a new age class of primarily hardwood species.

5.2.1.10 **Management of OWM Lands in the South Basin**

The South Basin, which includes the main brand of Sudbury River in Westborough, Hopkinton, Ashland, and Framingham, is hydrologically separated from the Sudbury Reservoir and has not been used for water supply since 1912. MWRA policy states that these water sources (Sudbury River and Framingham Reservoirs No.1 and No.2) should not be considered for future use within the OWM/MWRA system (Yeo, 1991). Management of the approximately 875 acres of OWM lands in the South Basin is thus based on a different set of premises than the North Basin, including the following:

- OWM will manage lands utilized as local water supply sources to protect these sources (e.g., Cedar Swamp and Westborough town wells and future wells).
- Lands that do not have direct bearing on drinking water supplies will be managed primarily for uses such as wildlife management or education. OWM will consider proposals to transfer these lands to a more appropriate authority, such as a local municipality or the Massachusetts Department of Fish and Game, Division of Fisheries and Wildlife.

5.2.2 Conservation Management Practices for Water Supply Forestry

Forest management on OWM properties on the watersheds of the Sudbury reservoirs is conducted to improve the protection of the drinking water supply. Short-term impacts from forest management practices must be exceeded by the long-term benefits to water quality protection. Accomplishing this objective requires strict compliance with management practices designed to protect against losses of sediments and nutrients to adjacent water resources. Described below are specific Conservation Management Practices (CMPs) designed to protect water supplies, which are the standard for OWM's forest management. It should be noted that OWM meets or exceeds the requirements of both the Forest Cutting Practices Act and the Wetlands Protection Act (MGL Chapters 132 and 131). Whenever these regulations are revised, OWM management practices will meet or exceed the revised standards.

Strict adherence to OWM CMPs ensures that forest management is conducted in a manner that does not impair water resources or other natural/cultural resources on the watersheds. Silvicultural practices, as described in the management plan, are employed to bring about specific forest conditions that protect the water supply. These practices require the cutting and removal of overstory trees to diversify structural and species compositions and to maintain the vigor of the residual overstory. A given forest stand is treated, on an average, every 25-30 years, and at that time 1/3 or more of the overstory may be removed to establish and release forest regeneration. The process of removing trees can impact the forest and soils essential to water quality if not carefully designed, implemented, and monitored.

Among the areas of greatest concern is the placement of forwarder and skid roads and log landings, where logging work is concentrated. Proper location of these in relation to streams, rivers, reservoirs, ponds, vernal pools, and bordering vegetated wetlands is important so that soils do not move from these areas into water or wetland resources. Beyond this principal concern, CMPs are designed to diminish the negative impact of silvicultural operations on the residual vegetation, to minimize soil compaction during these operations, and to keep potential pollutants out of the water resource.

5.2.2.1 Planning Variables

There are many variables to consider when planning and conducting a logging operation, including equipment limitations, weather, soil depth, soil moisture, topography, silvicultural practices, vegetation, and operator workmanship. Variables such as weather, soil moisture, soil depth, topography, and existing vegetation are constraints placed on logging that must be factored into planning and logging schedules. Variables such as equipment, silvicultural planning, and operator workmanship can be modified, for instance by matching allowable logging equipment with the constraints of a given site.

Logging Equipment

Logging equipment has changed dramatically in the 30-40 years that forest management has been active on OWM watersheds. The primary logging machine was once the 50-70 horsepower (hp) crawler tractor-sled combination. These tracked machines were 5-6' wide and weighed 5-7 tons. Today, most logging is done with 4-wheel drive articulated skidders or forwarders with 70-100 hp, widths of 7-8 feet, and weights of 6-8 tons. Skidders drag logs attached to a rear-mounted cable and winch, while forwarders carry logs on an integrated trailer.

Other types of logging equipment include grapple skidders, wheeled and tracked feller-bunchers, and feller-processors. A grapple is an add-on feature that replaces the winch and cable with hydraulically operated grapple arms. Feller-bunchers cut trees and put them in piles, usually for removal by a grapple skidder. There are 3 or 4 wheel feller-bunchers that must drive up to each tree for felling, whereas tracked models can fell a tree 10-20 feet from the machine. A feller-processor (usually on tracks) fells, de-limbs, and cuts trees, leaving piles of logs or cordwood, which are retrieved by forwarders.

Small skidders are desirable for most intermediate thinnings on OWM watersheds, while larger models may be acceptable for regeneration cuttings limited to frozen or dry conditions. Combinations of small, maneuverable feller-bunchers and forwarders, small skidders and forwarders, and tracked feller-processors and forwarders have all worked successfully on OWM watersheds. There are combinations of equipment that typically work on various types of harvesting operations on OWM properties (Table 14).

TABLE 14: HARVESTING METHODS/EQUIPMENT USED ON OWM WATERSHED LANDS

Method/Equipment	4-8' Cordwood or pulpwood	8-20' Sawlogs, fuelwood, pulpwood	Whole-tree
1. Chainsaw felling with 4WD pickup truck	✓		
2. Chainsaw felling with cable skidding	✓	✓	
3. Chainsaw felling with forwarding	✓	✓	
4. Rubber-tired, four-wheeled feller/buncher with grapple skidding		✓	✓
5. Rubber-tired, four-wheeled feller/buncher with chainsaw limbing and forwarding		✓	✓
6. Rubber-tired, three-wheeled feller/buncher with grapple skidding			✓
7. Tracked feller/buncher with grapple skidding		✓	✓
8. Tracked feller/processor with forwarding	✓	✓	


TRACKED FELLER/PROCESSOR

In an effort to specify equipment that is appropriate on specific soils and within specific forest types, OWM has determined ground pressure and width measurements for most of the equipment common to the area, and specifies restrictions, where needed, in timber harvesting permits. Widths are either from direct measurement or from manufacturer's specifications; ground pressures are based upon a formula that combines machine weight and weight of an average load of logs with an estimated footprint for the tire size specified, at an average tire inflation pressure. Examples from this rating system are listed in Table 15.

TABLE 15: SAMPLE EQUIPMENT SIZE/GROUND PRESSURE RATINGS

Machine Model	Tires	Width	Ground Pressure
TimberJack 208	23.1 x 26	102"	4.9 lbs/sq in
JohnDeere 440C	23.1 x 26	102"	5.0 lbs/sq in
Franklin 105XL	23.1 x 26	110"	5.3 lbs/sq in
TreeFarmer C4	18.4 x 26	93"	6.5 lbs/sq in
JohnDeere 540	23.1 x 26	105"	6.6 lbs/sq in
CAT 508GR	23.1 x 26	106"	7.1 lbs/sq in
Clark 665	23.1 x 26	114"	7.9 lbs/sq in
Clark 665	18.4 x 24	104"	9.5 lbs/sq in
TreeFarmer C6	18.4 x 34	97"	10.1 lbs/sq in
CAT 518	18.4 x 34	99"	11.2 lbs/sq in

Some of the logging equipment available is too large or heavy to meet OWM requirements in certain vegetation or soil conditions, and some is limited by terrain. Matching the equipment with the site conditions so that minimal damage occurs is critical to the success of watershed silvicultural activities. OWM specifies equipment requirements for each site in its timber harvest permits. This includes machine width and ground pressure limits, as well as specific equipment requirements (e.g., forwarders). While each site has unique conditions that require the experienced judgment of the forester to predict impacts, ground pressures are generally limited to 8 pounds per square inch or less on soils that are less well-drained. Machine widths are limited in intermediate cuttings of dense, unthinned stands with moderate topography, most typically to not more than 9 feet (108"). Larger machinery may be permitted in regeneration cuts.

An example of a “preferred logging system,” that accomplishes OWM goals under difficult conditions is a small feller-processor and forwarder combination, used for thinning dense pine plantations on a variety of soil conditions. Both machines are able to work in these conditions with minimal damage to roots, stems, crowns, or soils. In addition, these machines can successfully work around walls and foundations and do not require a landing, as logs are stacked on the roadside. This combination can also work in previously thinned stands that have an understory of young pines, with minimal damage to the young growth.

Most feller-processors are limited to stable ground conditions (few rocks and gentle slopes) and trees less than 16" DBH. In older multi-aged stands where the trees are much larger, hand felling is necessary. Multi-aged stands will always have many more stems/acre than the present even-aged stands and consequently are more difficult to work in without damaging residual trees. A combination of a winching machine and forwarder works well in multi-aged stands. This logging system addresses the problem of damage to the residual trees associated with long skid roads.

Matching logging systems to soil, topography, and silvicultural conditions is implemented by fine tuning general categories (Table 16) to the specific situation.

TABLE 16: HARVESTING METHODS/EQUIPMENT USED IN VARIOUS SOIL/TERRAIN COMBINATIONS
(Note: The methods listed in Table 16 are taken from Table 14.)

	Excessively Drained Soils	**Well-Drained Thin Soils**	**Well-Drained Thick Soils**	**Moderately Well-Drained Soils**	**Poorly to Very Poorly Drained Soils**
Level to 10% Grade	Harvesting Methods 1-8	Harvesting Methods 1-8	Harvesting Methods 1-8	Methods 1-8 with frozen or dry soils only; ground pressure < 8 lbs/sq. in	Generally not worked with machines
11-20% Grades	Harvesting Methods 2-6	Harvesting Methods 2-6	Harvesting Methods 2-6	Methods 2-6 with frozen or dry soils only; ground pressure < 8 lbs/sq. in	NA
Slopes Greater than 20%	Harvesting Method 2	Harvesting Method 2	Harvesting Method 2	NA	NA

Silvicultural Planning

OWM land management plans have to address present and future cutting practices, landscape aesthetics, cultural resources, wildlife resources, wetlands, and rare or endangered species. The most difficult aspect of planning concerns the maintenance of multi-age stands of trees. These stands have great numbers of trees, especially seedlings, saplings, and poles that are more easily damaged than larger trees. The positioning of logging roads, landings, and small and large group cuts is crucial to the long-term success of silvicultural treatments. In turn, logging operation success is dependent upon careful advance planning (see Figure 6 for an example of silvicultural planning).

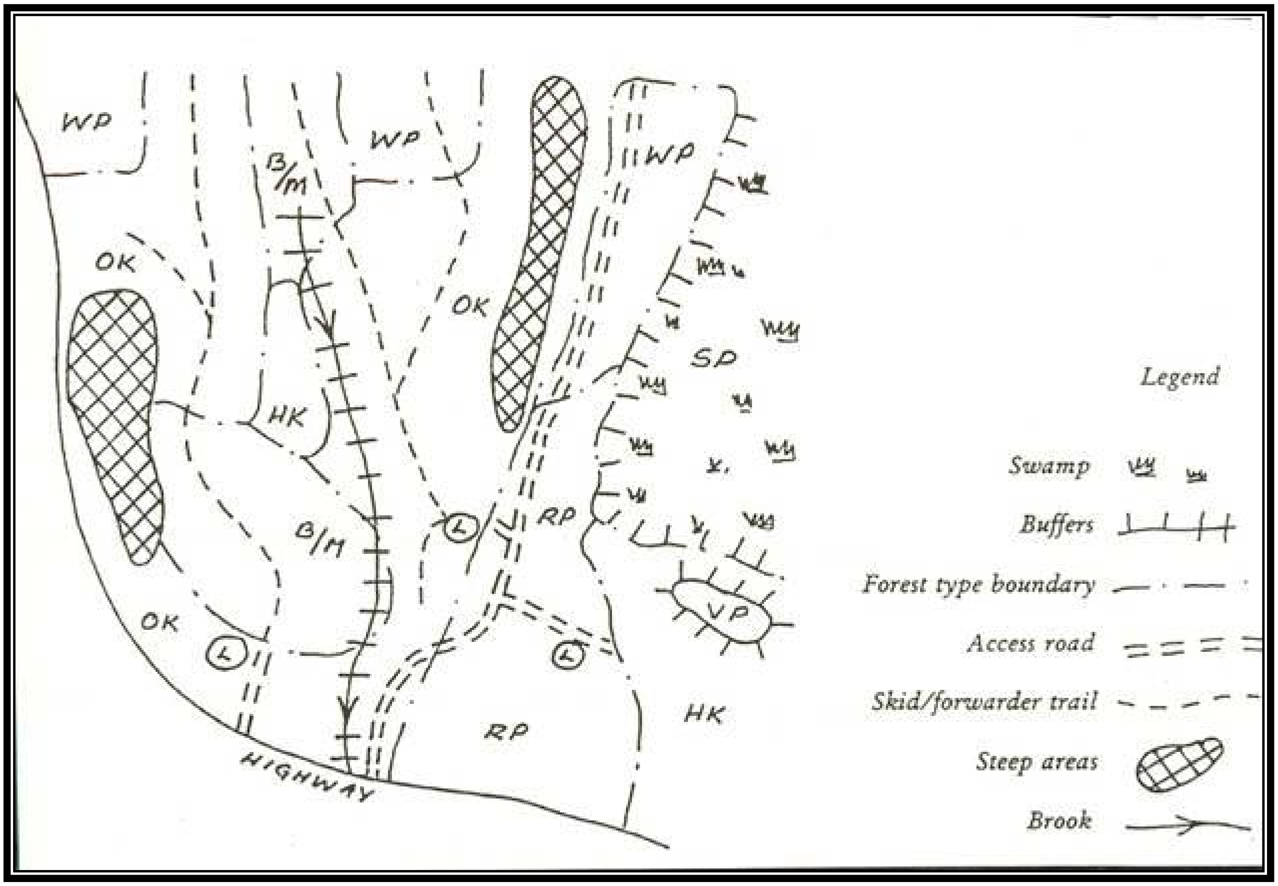


FIGURE 6: HYPOTHETICAL EXAMPLE OF SILVICULTURAL PLANNING

This approximately 200-acre area of OWM forest contains separate stands of white pine (WP), hemlock (HK), birch/maple (B/M), oak (OK), spruce (SP), and planted red pine (RP). A fire in 1957 severely burned the lower 1/3 of the area, and the red pine was planted shortly after this fire. The topography and hydrography of the area include large areas of well-drained sandy soils, but also several small steep areas, a year-round brook, a swamp, and a vernal pool (VP). These areas are delineated with buffers where required. Work within these areas is restricted; steep areas and muck soils are not worked, and buffers are only worked on frozen or dry ground. Fairy shrimp and mole salamander eggs have been found in the vernal pool, verifying its importance to wildlife. No work is proposed adjacent to this pool.

Except for the steep and wet areas, all the stands have received preparatory cuttings within the past 25 years, and the understory has developed in response. Additional work in this area will release advance regeneration by removing patches of overstory trees averaging 1 acre in size. Where understory species diversity is limited, further preparatory cuttings will occur, as well as enrichment plantings of appropriate species. Primary access is across the permanent road shown by a double dashed line. Single dashed lines are skidder and forwarder roads that have been used in the past and seeded and drained to prevent erosion. Landings are designated by a circled L, and represent areas used in the past and maintained as wildlife openings between operations. These roads and landings will be used again in current operations, and then returned to grass. There is evidence that the landings have been used between operations by wild turkey.

Operator Workmanship

Operator workmanship is one of the most crucial and variable factors in forestry operations. Good planning and preparation can be negated if operators perform poorly. Most loggers are paid on a piecework basis. Their paycheck does not always relate to how hard or how carefully they worked, but on the amount of wood that gets to the mill. OWM maintains tight control over loggers working on the watersheds through close monitoring, the timber harvest access permit and associated performance bond, and it's right to remove operators who fail to adhere to permit standards. It is important that foresters and loggers develop mutual respect that is based upon a shared commitment to the sustainable stewardship of the land for the protection of the drinking water supply.

5.2.2.2 Filter Strips

Filter strips are vegetated borders along streams, rivers, or water bodies (including vernal pools) and represent the final opportunity to prevent transport of sediment or nutrients into streams or reservoirs from nearby roads or landings. When roads and landings are near water resources, filter strips are given special attention. Chapter 132 (Forest Cutting Practices regulations) requires a minimum 50 foot filter strip, in which cutting is limited to 50% of the basal area and machinery is generally not allowed (exceptions include stream crossings).

Chapter 132 regulations require increasing the filter strip based upon slope conditions and along Outstanding Resource Waters (protected public water supplies) and their tributaries, streams that are 25 feet or more from bank to bank, ponds of 10 acres or more, and designated scenic rivers. OWM meets these requirements and also increases the filter strip, based on both slopes and soils, for other areas not included in the definitions above. For example, on moderately and poorly drained soils the filter strip is increased 40 feet for each 10% increment of slope angle above 10%. On well-drained outwash and till soils the filter strip is increased 40 feet for each 10% increase in slope angle above 20%. Equipment may enter the filter strip in limited cases where streams must be crossed.

5.2.2.3 Buffer Strip

Buffer strips are retained and managed for aesthetic purposes along the edges of highways and public roads. Chapter 132 requires that within this strip, no more than 50% of the basal area can be cut at any one time and that no additional trees can be cut for five years. Buffer strips will be 50 feet except along designated scenic roads, where Chapter 132 requires them to be 100 feet in width. Exceptions are allowed for public safety considerations. In certain cases, the entire overstory may be removed to prevent hazardous conditions from developing.

5.2.2.4 Wetlands

OWM's forest management operations will comply with all the requirements of the Wetlands Protection Act, MGL Ch. 131 section 40, and the Forest Cutting Practices Act MGL Ch. 132 section 40-50 for cutting in wetlands (including bordering vegetated wetlands and freshwater wetlands as defined in the most current revision of Ch. 131 and 310 CMR 10.00, and as these are revised). Generally, activities that are not conducted under a Ch. 132 Forest Cutting Plan but will alter wetland resource areas (which include a 100 foot "buffer zone" beyond the water or the bordering vegetated wetland), are subject to approval through the filing of a Notice of Intent with the local conservation commission.

All of OWM's silvicultural activities that involve wetland resources are conducted under a Chapter 132 cutting plan, supervised by both OWM foresters and DCR service foresters, and therefore are exempt from Chapter 131 procedures. Exceptions include limited work that does not include harvesting, such as planting, pruning, and pre-commercial thinning, and maintenance of boundaries and fire breaks. All of these latter activities are defined as "normal maintenance of land in agricultural use" by Chapter 131, and are therefore exempt from its filing procedures.

Chapter 132 requires a 50 foot filter strip along all water bodies and Certified Vernal Pools, but allows harvesting in wetland areas provided that no more than 50% of the basal area is cut and the ground is only traveled by machinery when it will support that machinery (when it is frozen or dry). In addition, OWM does not allow machinery within low, flat wetland forest with muck soils that are seasonally flooded, even though statewide regulations allow work in some of these areas during frozen or dry conditions. Most of the muck soils on OWM lands at Sudbury are included within the designated wetlands on the watershed. OWM has identified and mapped most wetlands within the Sudbury watershed properties, which are avoided when lot boundaries are drawn for proposed annual silvicultural operations. OWM also adheres to, or exceeds the statewide recommended practices for protection of vernal pools, providing a 15 foot no-cut buffer, a 50 foot no-machinery zone, a 100 foot shade zone, and a 200 foot low-ground disturbance zone (see Figure 7). This vernal pool protection is provided to all vernal pools, whether or not they have been certified.

5.2.2.5 Logging Practices

A primary purpose of CMPs is to prevent or minimize the movement of soil to the water resource. During a logging operation, this is most likely to occur on a landing or skid/forwarder road. In these areas, the humus layer is sometimes lost and the soils may be temporarily compacted and channelized so that water will flow over the surface instead of passing through the soil. If the road is unwisely placed on a continuous slope, rainwater will gather volume and velocity as it travels down-slope, scouring the path, removing soil, and creating a gully. If the road connects with a stream, the suspended soil may be carried much further. The result of careless logging practices can be erosion, increased stream turbidity levels, and deposition of the eroded materials downstream.

Logging practices and the human behavior necessary to avoid environmental degradation during logging are discussed in the following sections. A cutting plan still relies upon the judgment and common sense of the logger and forester to make the right decisions in order to protect the land and associated resources in a custom tailored, case-by-case manner.

FIGURE 7: TIMBER HARVESTING GUIDELINES NEAR VERNAL POOLS

Adapted from guidelines that were cooperatively developed by foresters and wildlife biologists in Massachusetts.

Vernal pools provide critical habitat for a number of amphibians and invertebrates, some of which breed only in these unique ecosystems, and/or may be rare, threatened or endangered species. Although vernal pools may only hold water for a period in the spring, the most important protective measure is learning to recognize these pool locations, even in the dry season. Foresters can then incorporate the guidelines below in their plans to ensure that these habitats thrive.

Vernal Pool and Depression and No-cut Area — 15 foot buffer around pool

Objective 1: Maintain the physical integrity of the pool depression and its ability to hold seasonal water.

1. Keep heavy equipment out of the pool depression at all times of the year. Rutting here could cause the water to drain too early, stranding amphibian eggs before they hatch. Compaction could alter water flow and harm eggs and/or larvae buried in leaf litter at the bottom of the depression.
2. Prevent sedimentation from nearby areas of disturbed soil, so as not to disrupt the pool's breeding environment.
3. Keep tops and slash out of the pool depression. Although amphibians often use twigs up to an inch in diameter to attach their eggs, branches should not be added, nor existing branches removed. If an occasional top lands in the pool depression leave it only if it falls in during the breeding season and its removal would disturb newly laid eggs or hatched salamanders.
4. Cut no vegetation within 15 feet of the high-water mark of the pool depression. Silvicultural manipulations are limited to girdling (for instance, to enhance vigor of uncommon swamp white oak trees).

Shade Zone — 100 foot buffer around pool edge

Objective 2: Keep a shaded condition in this 100-ft.-wide buffer around the pool depression. Amphibians require that the temperature and relativity humidity at the soil surface be cool and moist.

1. No equipment is allowed to operate within 50 feet of the pool edge.
2. Light, partial cuts that can maintain this microclimate are acceptable; clear cuts are not.
3. Understory vegetation such as mountain laurel, hemlock, advance regeneration or vigorous hardwood sprouts after a harvest will help to maintain this condition. Avoid leaving only trees with small or damaged tops, or dead and dying trees.

Objective 3: Minimize disturbance of the forest floor.

1. Operate in this area when the ground is frozen and covered with snow, whenever possible. Keep equipment 50 feet away from the pool depression and winch out logs or wood cut in this first 50 feet.
2. Avoid operating during muddy conditions that would create ruts deeper than 6 inches. Ruts can be an impediment to migrating salamanders, some of which are known to use the same vernal pools and migratory routes for 15 to 20 years.
3. Minimize disturbance of the leaf litter and mineral soil that insulate the ground and create proper moisture and temperature conditions for amphibian migrations.

Low Ground Disturbance Zone — 100-200 feet from pool edge

Objective 4: As above, minimize disturbance of the forest floor in this area.

1. Operate equipment in this area when the ground is frozen or covered with snow, whenever possible.
2. Follow 2 and 3 from objective 3 above.
3. Locate landings and heavily used skid roads outside of this area. Be sure any water diversion structures associated with skid trails and roads do not connect to or cause sedimentation in the shaded zone or the vernal pool itself.

Landings

When determining placement and layout of landings, their size and number are minimized and they are located on soils that will support the logging equipment. Landings are permanent sites and are placed on level and well-drained ground whenever possible. Frozen soils are desirable because they support heavy trucks, but these conditions cannot be assumed to occur for more than a month or two each year. When located on moderately drained soils, landings are constructed with natural and/or man-made materials that prevent rutting and maintain a workable surface. This generally includes the use of crushed gravel, which allows water infiltration and supports heavy equipment, and may also include the use of "geo-textiles," woven road construction fabrics that prevent mixing of gravel with the soils below. Landings will not be accessed by skidder or forwarder roads that direct water into the landing. An effective barrier is maintained between the landing and access road (e.g., road ditch, hay bales) and landings are required to be smoothed and seeded after use. Also, to prevent inappropriate uses of landings, for instance as access points for illegal off-road or all-terrain vehicle use, the access to landings from adjacent roadways will be blocked with logs, stones, or a locked gate if necessary.

Skid Roads

Skid roads are designed to be reused and are therefore located on soils that can support the skidder, such as well-drained gravel or well-to-moderately-drained stony till soils. Some soils, regardless of their drainage capacity, are wet in the spring, early summer, and late fall and harvesting must be scheduled for dry or frozen conditions. Skid roads are cut out before use and limbs left in the road to protect the soil. Skid roads are relatively straight to avoid damaging roadside tree stems and roots, but they are not allowed to carry water for more than 100 feet. Continuous grades are deliberately interrupted to divert rainwater off the road. Most skid road grades are less than 10%, but in some cases, climbing grades may reach a maximum of 20%. These steeper climbing grades are limited to 200 continuous feet. Downhill skidding grades are allowed up to 30% but for no more than 200 feet on grades greater than 20%. On skidding grades greater than 20%, which are not protected by frozen ground or snow cover, tree branches will be put on the road and other erosion-control measures taken as necessary.

Skidding distances are minimized to prevent excessive wear to roads unless frozen ground, snow, or rocks protect them. Skidder width and weight requirements are tailored to site conditions. OWM has rated many commercially available skidders by taking into account their horsepower, weight, load capacity, tire size, and width to determine their suitability for logging on water supply watersheds (see Table 15 for examples). Skidder width ranges from 85-114 inches and loaded ground pressures range from 5-11 lbs/sq. inch. Typically, machines with loaded ground pressures of less than 8.5 lbs/square inch and widths of less than 110 inches are allowed on OWM watersheds. Skidding is stopped when rains or thaws make the soils unable to support skidders.

At the end of the logging operation or when work is suspended, efforts will be made to prevent access by unauthorized vehicles (such as ATV or other off-road vehicles) by blocking access with boulders, logs, or, if appropriate, locked gates. Skid roads are also stabilized to prevent erosion following the completion of the operation. The construction of water bars accomplishes this task. On slopes greater than 10%, water bars are spaced every 50 feet and on slopes less than 10%, they are spaced every 100 feet. It is sometimes difficult to regularly space water bars due to rocky conditions and lack of places to discharge water, so spacing may vary. Water bars are designed to meet two criteria:

- They must angle across and down the road to create a 3-5% pitch.
- They must discharge water to an area that drains away from the road.

A skidder can usually be used to construct water bars unless the soils are very rocky or ledgy. In rocky soils, they may have to be dug by hand. They do not have to be more than 6-8 inches deep, including the berm, unless they have to deflect more than the overland flow off skid roads (in which case depths are doubled). After completion of logging, water bars on skid roads are seeded during the growing season.

Forwarder Roads

Forwarder roads are located on soils that can support these machines. The layout of forwarder roads is more flexible than for skid roads because forwarders do not require straight roads. Forwarder roads can pass through the forest avoiding soft soils, trees, and sloping ground. Forwarder roads usually have less than a 5% slope with an occasional grade up to 10% for a maximum of 100 feet. Forwarder roads sometimes require rough preliminary grading to remove stumps and rocks.

Forwarders were originally designed to stay on the road and pick up logs brought to the road by a skidder, but they also replace skidders when soil and/or vegetation conditions and cultural features cannot accommodate skid roads and skidder landings. In operations that combine skidders and forwarders, skidders operate the sloping and rough ground for distances of less than 1,000 feet, while forwarders operate on the more level terrain and handle long hauling distances. Water bar requirements for forwarder roads are the same as for skid roads, and unauthorized access to these roads will be blocked following the completion of the operation.

Stream Crossings

OWM forestry operations cross streams on a limited basis. For example, from 1978 to 1990, the Division conducted 130 logging operations on the Quabbin and Ware River watersheds that involved twelve stream crossings. Seven of these twelve were across existing culverts, two were mitigated with approved methods, and three were crossings of intermittent streams in dry or frozen conditions. Stream crossings are frequently avoidable on OWM watershed properties because the size of the property holdings often makes it possible to access a given stand from several directions. Frozen conditions are favored whenever streams must be crossed. These conditions not only protect the actual crossing but also protect the approach and limit the amount of soil carried in machine tires or on skidded logs.

Portable bridging is used to cross all streams with a continuous flow. This bridging consists of either pre-fabricated sections transported to the site (OWM has constructed portable bridge sections for use by private timber harvesters) or site-constructed bridging. Past studies (Thompson and Kyker-Snowman, 1989) have shown that machine placement and removal of crossing mitigation can move substantial sediments into the stream, especially where banks are steep or unstable. It may be preferable in some conditions to construct mitigation on-site and without machinery. In either case, the bridging will be designed and constructed so as to prevent degradation of stream water downstream of the logging activity before, during, and after that activity.

Correct siting of crossing locations is important in order to avoid soft soils that the machine may carry onto the bridge and into the water. Chapter 132 requires that all crossings be marked with paint or flagging and carefully mapped prior to filing of a cutting plan. All crossings are made at right angles to the streamflow. If frozen conditions are not available, then banks and adjacent soils are protected with tops of trees, poles, or other suitable material. In all crossings, any mitigation that involves structures that obstruct streamflow is designed and installed to accommodate the 25-year stormflow for the upgrade drainage. All temporary crossing construction is removed at the completion of the operation, and the site stabilized. OWM foresters supervise the design, construction, placement, and removal of bridging or other mitigation and the proper protection of approaches, prior to the commencement of logging on the site.

Crossings of small, intermittent streams subject to MGL Chapter 131/132 protection (those portions downstream from the highest bog, swamp, wet meadow, or marsh in the drainage) are mitigated to prevent measurable downstream water quality degradation when these streams are flowing. These streams are only crossed without mitigation during frozen or dry conditions (when they are not flowing). No intermittent stream crossing will be allowed that would result in rutting or disruption of stream bank integrity. Chapter 132 further requires that all streams within 1,000 feet of the reservoir high water mark, including intermittent streams downstream of the highest wetland, must be crossed with portable bridging. OWM foresters will monitor all unbridged crossings frequently and discontinue or mitigate them if conditions deteriorate and downstream water quality is threatened.

Table 17 outlines the various stream-crossing situations encountered on OWM watersheds and level of protection these crossings are given.

TABLE 17: PROTECTION MEASURES APPLIED TO VARIOUS STREAM CROSSING SITUATIONS

	Level of Protection		
Type of Crossing Situation	CMPs Only	Mitigate	Bridge
Intermittent stream, above the highest wetland in the drainage.	✓		
Intermittent stream, downstream of highest wetland, when not flowing; crossing further than 1,000 feet from reservoir high water mark.	✓		
Intermittent stream, downstream of highest wetland; crossing further than 1,000 feet from reservoir high water mark; when flowing.		✓	
Any intermittent stream with unstable banks/approach; regardless of flow conditions.		✓	
Intermittent stream, downstream of highest wetland, crossing within 1,000 feet of reservoir high water mark; regardless of flow conditions.			✓
Continuously flowing stream.			✓

Key: "Wetland" refers to bogs, swamps, wet meadows, and marshes. "Mitigate" includes use of poles, brush, or slabs placed in or beside a small stream to minimize equipment impacts on bank or streambed integrity. "Bridge" includes installed or site-built structures that are above the stream profile and capable of keeping all equipment and harvested products out of the profile.

5.2.2.6 Pollution Control

This section describes methods for control of petroleum product spills, human waste, and the disposal of rubbish generated by loggers and logging machinery maintenance.

Petroleum products: All machines are inspected by OWM foresters for leaks prior to arrival and for the duration of their stay on the watershed. Checks are made of all hydraulic components, fuel tanks and lines, engine, transmission and axles. Trucks, forwarders, skidders and other equipment that carry petroleum products must have a minimum of 6 petroleum-absorbent pads (3'x 3') on the machine. Immediate action to contain and stop any petroleum spills followed by prompt notification of the forester is required. The forester in turn contacts OWM Environmental Quality personnel.

All petroleum products that are not in machine storage are stored in safe durable containers and removed from the watershed at the completion of each day. Petroleum storage is only allowed in tanks designed, manufactured, inspected, and certified for commercial use. No re-fueling or servicing is allowed within the 50 foot filter strip along water bodies or within 25 feet of any wetland.

Human waste: Deposition of human solid waste is not allowed on the watershed. Permit specifications require the use of a portable bathroom facility (a minimum of a “Coleman” chemical toilet). The only exception to this policy will be the use of existing sanitary facilities on the watershed, which include those installed for recreational access.

Rubbish: All waste material, including parts, packaging, lubricants, garbage, sandwich wrappers, and other litter must be stored in appropriate containers and removed daily from the watershed.

5.2.2.7 Fire Prevention

Fire prevention concerns both the forest and machinery. MGL Ch. 48, s. 16, a.k.a. the “Slash Law,” adequately deals with the disposal of slash along boundaries, water bodies, wetlands, highways, roads and utility right-of-ways. Slash is not allowed within 25' of any stream, river, pond or reservoir. This law is also the OWM standard.

Machine fires can spread to forest fires and cause water and soil pollution. Keeping a leak-free, well-maintained machine and having the proper fire extinguishers on the machine can prevent damaging machine fires. All machines are inspected for proper fire extinguisher and spark arresters by a OWM forester before entering the site.

5.2.2.8 Protection of Residual Vegetation

Avoiding damage to roots, stems, and crowns of understory and overstory vegetation is essential in maintaining a protection forest. Damage can occur from unskilled tree felling, skidding, forwarding and the development of skid/forwarder roads. Skilled loggers and foresters can prevent most damage if the proper logging system is used. OWM permits include the right to suspend operations due to operator inexperience or negligence.

5.2.2.9 Cultural Resource Protection

The protection of cultural resources fits well with watershed protection forestry because they both require low-impact logging systems. For example, small versatile equipment can reduce soil compaction and work around walls and foundations without damage. In many locations, there are no places for a landing due to cultural sites or poor soil conditions. Forwarders mitigate this problem by stacking logs on the roadside. The preferred logging system in these situations is a combination of cutting, lifting, or winching trees out, and forwarding them to an appropriate landing to meet cultural resource protection objectives (see Section 5.5 for a more detailed discussion on this subject).

5.2.2.10 Aesthetics

Aesthetics can be affected by all of the practices described in the above sections, and are the demonstration of quality workmanship. The maintenance of aesthetics reflects how the logger feels about the work and the land on which it is taking place. This perspective cannot be forced, but it can be encouraged and learned. When work is done correctly it is less conspicuous, but when it is done carelessly, it is obvious to all. These are public lands and the public regularly passes through them either along public roads or on roads within the watersheds. Attention to aesthetics is important everywhere, but most important along traveled ways. All slash and debris from fallen trees is kept 20' back from the road's edge or on the backside of a bordering stone wall. Landings are cleaned of unmerchantable tree debris. Care is taken to maintain large roadside trees and to promote replacement trees.

5.2.3 Control of Harvest Operations through Timber Sale Permit

In conducting silvicultural operations that require the removal of forest products from the forest, OWM policy is to protect water quality as well as watershed resources such as soils, residual trees, and cultural resources. The Chapter 132 Forest Cutting Plan, the OWM timber sale permit (discussed below), and the Conservation Management Practices presented in the preceding section address these concerns. In general, the timber sale permit specifies the performance standards, whereas the CMPs explain how these permit specifications are met.

The Permit consists of written specifications, details of the forest products offered for sale, maps delineating the sale area, and a proposal page where a bid for the timber is entered and signed. The written specifications deal most directly with protecting watershed resources. Specifications consist of four parts: a.) General Conditions, b.) Water Quality Specifications, c.) Harvesting Specifications (including utilization, silviculture, and equipment requirements), and d.) Bidding and Bond Specifications. Parts b. and c. pertain to protecting watershed resources.

5.2.3.1 Water Quality Specifications

Water quality specifications are primarily concerned with petroleum leaks and spills and control of human waste. Petroleum products are required to be kept in suitable containers and removed from the work site each day, unless stored in tanks designed for fuel, such as those on the logging equipment. Oil absorbent pads and blankets are required on site and with all equipment, in order to intercept and immediately control a petroleum spill, should one occur. All associated refuse from maintenance and repair is required to be stored in appropriate containers and removed from OWM lands as soon as possible. Human waste is required to be deposited in OWM toilets or toilets supplied by the operator.

5.2.3.2 Harvesting Specifications

Harvesting specifications are concerned primarily with the process of cutting trees and removing forest products from the forest. OWM timber harvesting permits specify conditions for lopping slash to enhance decomposition and reduce fire hazards. Specifications are described for keeping slash out of streams and back from access roads. The penalty for cutting unmarked trees is set at three times the value of the tree. Utilization standards are specified in each permit in order to limit slash (by indicating the maximum diameter of slash that may be left in the woods). There are also specifications to limit damage to residual trees and soils, especially in the felling and removal of forest products. Locations for logging roads and landings are determined by the OWM forester and delineated in the field and on the approved cutting plan; the permit specifies the condition in which these areas must be left at the completion of the operation. The permit makes it clear that the logging operation may be suspended due to wet or extremely dry conditions, at the forester's discretion.

Equipment specifications limit the size of skidders and other equipment to minimize soil compaction and rutting and to minimize physical damage to residual trees and cultural resources. These specifications may require specific equipment due to the conditions of the lot. For instance, where it is difficult to place straight skid trails, or where dense regeneration is present, the forester may specify that a forwarder must be used and that skidders are not allowed. Where hauling distances to a truck landing are long, but the lot itself requires skidding, the forester may require that both pieces of equipment must be used. OWM also may require a tracked feller-buncher-processor on lots that have sensitive cultural resources requiring specialized tree removal, on soils that cannot support heavy equipment, or in stands with heavy forest stocking that cannot be thinned properly with standard equipment.

5.2.4 Internal Review and Monitoring of Forest Management Operations

The key to the proper protection and management of the resources under the care and control of OWM is its staff, and the care and expertise they bring to their work. Because the foresters walk each acre of land on which forest management occurs, the management controls enforced by this staff are of paramount importance. As the on-the ground implementers of OWM's land management plans and policies, the foresters' knowledge of, and sensitivity to the various aspects of the watershed management plan have a direct bearing on the ultimate success of the program. However, it is impossible for any one individual to assimilate all aspects of the diversity of knowledge in the evolving fields of natural and cultural resource management. Therefore, the second key to implementing sensitive management is in-house review by specialists in the various key disciplines of study in natural and cultural resources, and effective communication between these specialists and the forest managers.

Within OWM, these supporting disciplines include wildlife biology, forest planning, water quality and environmental engineering, civil engineering, and cultural resource protection. Experts available outside OWM include rare species botanists and zoologists (Massachusetts Natural Heritage and Endangered Species Program) and cultural resources specialists (Massachusetts Historic Commission). OWM also has available a wide variety of experts conducting academic research on the watersheds at any given time, in part because of the research value of the resources under OWM's care and control. These professionals and interested non-professionals who spend time studying and exploring the watersheds, contribute invaluable observations that complement OWM's understanding of its watershed resources.

To efficiently and effectively coordinate and focus this collective knowledge towards the improved protection of the drinking water supply and other natural and cultural resources, OWM has developed the following procedure for the annual review of all proposed OWM forest management activities on the Sudbury watersheds. These reviews are in addition to the general guidelines for cultural and wildlife resource protection.

- Each December, OWM's foresters compile a plan of all proposed forest management that could occur during the next fiscal year (July-June). The only operations not included are emergency salvage after natural events. Each January, the foresters carefully map and describe the boundaries of each planned operation so that they are readily distinguishable on the ground (where boundaries are not easy to describe, they are marked with flagging). These outer boundaries may include internal areas where logging is restricted (vernal pools, stream filter strips, etc).
- Wachusett/Sudbury foresters digitize the maps of the planned operations, which include proximal wetlands and previously identified critical cultural and wildlife sites. The foresters then submit these maps and completed forms describing the proposed silviculture in detail to the OWM Natural Resource Section. Natural Resources staff prepare area summaries of these operations, and check the overall consistency of the operations with management plan silvicultural and resource protection objectives. After reviewing the proposed operations, Natural Resources then forwards copies to the watershed Regional Director, the DCR archaeologist, and the OWM wildlife biologist.
- In 1986, 1990, and 1994 consultants compiled cultural resource maps for Division watershed properties. These maps denote known and likely historic sites. This identification process has not yet occurred for the Sudbury Reservoir watershed. Once these resources are identified, and where forest management is planned for areas containing or likely to contain cultural resources, the DCR archaeologist will identify types of activity that could damage these resources, such as soil compaction or disruption of existing structures such as walls or foundations. The archaeologist may also make recommendations for removing trees that threaten existing historic structures, and identifies areas of high, moderate, or low probability of containing prehistoric occupation sites. With these concerns in hand, the foresters modify timber-harvesting approaches as needed to protect these resources.
- Each spring, OWM's wildlife biologist reviews the planned forest management operations. Where necessary, the wildlife specialist conducts site examinations. Landscape level wildlife changes over long time spans will also be tracked using an evolving set of techniques. Local knowledge of state rare, endangered, and threatened species is referenced, as well as the location of any critical or important habitat features in the wildlife biologist's files. After completion of fieldwork by the wildlife specialist, the foresters are alerted to any potential conflicts between the proposed work and important habitat features, keyed to flagging on the ground where necessary. Specific wildlife Conservation Management Practices are outlined in Section 5.4.2 of this plan.
- Each spring, OWM's Environmental Quality staff reviews the planned forest management and, where necessary, conducts site examinations. The Environmental Quality staff may give site-specific guidelines regarding special precautions designed to increase the protection of site water quality.
- In 1995 and 1996, the MDC contracted with a professional botanist to review all proposed DWM lots for the presence of rare or endangered plant species. The bulk of this plant inventory occurred during May and June, although the botanist made preliminary recommendations pending an additional survey for late flowering species, conducted in August, for a limited number of these operations. In the final reports, the botanist made specific conservation management recommendations to protect these plant populations.

- Where the review process identifies undesirable potential impacts, the foresters consult with the reviewers to design a practical solution. If there are any changes in the area to be harvested and/or in the proposed practices, the forester is responsible for notifying the Natural Resources Section in order to determine if further review is required by the changes. Once the review process is complete, the foresters lay out and mark the harvesting lots. At this time a Forest Cutting Practices Act (MGL Ch. 132) Cutting Plan is prepared (outlining skid roads and specific site impacts), which the logger is required to follow. The Forest Cutting Plan is submitted to the DCR Bureau of Forestry and copied to the local Conservation Commission.
- After the lot has been advertised and awarded to a private timber harvester, Chapter 132 requires DCR Bureau of Forestry staff to conduct a site visit prior to the start of the operation if wetland resources are involved. These regulations also require that DCR Service Foresters check all cutting plans against the Natural Heritage maps of rare and endangered species habitats and, if they overlap, submit these plans to Natural Heritage for review and comment. Training sessions were held in 2004 to enhance the relationship between DCR foresters and the Natural Heritage staff (which remains overburdened with review responsibilities), and an Interagency Service Agreement is being completed to enable improvements in this critical collaboration.

Throughout the active operation, it is the responsibility of the forester in charge to continuously monitor compliance with water quality protection measures. In particular, these include stream crossings and work near wetlands, conditions of skidder and forwarder roads as well as main access roads, equipment maintenance, and the treatment and placement of slash. The OWM "Permit to Harvest Forest Products" includes detailed specifications for each harvesting operation. During the operation, OWM reserves the right to suspend the harvesting activity if warranted by weather, soil, or wildlife conditions. Upon completion of silvicultural operations, it is the responsibility of the foresters to check for full compliance with all timber harvest permit specifications prior to the release of the performance bond and filing of final reports.

Note: a separate review process is required for proposed access road development or the opening of new gravel operations. For details of this process, see Section 5.1.7.

5.3 Management of Biodiversity

Biodiversity can be defined as the diversity of life in all its forms and at all levels of organization (Hunter, 1999). This definition looks beyond simple species diversity to include genetic and ecosystem diversity as well. Setting management goals for maintaining biodiversity is inherently difficult for a variety of reasons. In most cases natural resource managers are responsible for managing biodiversity without a complete understanding of all the elements of biodiversity that may exist. For example, approximately 1.7 million species have been described globally, although estimates of the total number of species range from 10-100 million (Hunter, 1999).

The critical component to any attempts to incorporate biodiversity into management activities is the need for a large-scale perspective. Management decisions must be made with a landscape, watershed or even a larger regional perspective. Current OWM management activities incorporate a multitude of specific activities that maintain or enhance biodiversity at the micro or stand level (i.e., saving wildlife trees, buffering vernal pools, etc.) However, current OWM management activities often lack the large-scale perspective that is so important to maintaining biodiversity. Hunter (1999) describes only 2 real goals when planning for biodiversity: 1) Maintain the biodiversity of ecosystems that are in a reasonably natural condition and 2) Restore the biodiversity of ecosystems that have been degraded.

OWM's goals for biodiversity focus on either maintaining or enhancing natural ecosystems across the watershed. OWM recognizes that its greatest contribution to regional and local biodiversity is protecting significant areas of land from development and maintaining those lands in forest or other natural cover. OWM's primary management activity on these lands is creating small openings in the forest to stimulate regeneration and diversify species. These activities maintain forest cover while mimicking small-scale disturbances that occur naturally.

The Sudbury watershed is an exceptionally difficult place to address the challenges of conserving biodiversity. The watershed is densely populated, fragmented, subject to invasive species, and under intense development pressure. Remaining natural areas tend to be relatively small and isolated. These negative characteristics combine to create a landscape where conserving biodiversity is particularly problematic. However, it is also the existence of these negative characteristics that highlight the qualities of OWM land within the watershed. OWM lands are comparatively large, undeveloped, protected, relatively contiguous, and managed for native species. OWM lands within the Sudbury watersheds represent an opportunity for some native wildlife to exist and thrive.

5.3.1 Biodiversity Mandate

In 1973, Congress passed the Endangered Species Act to provide federal protection for 292 declining species, and began to legally define the national commitment to maintaining biodiversity in the process. The ESA specifically protected 27 plant and animal species in Massachusetts, and provided both the impetus and funding to restore popular species such as the Peregrine Falcon and the Bald Eagle in the state. Subsequent to the passage of the ESA, Massachusetts has added additional statewide legal protection for biodiversity. Both Chapter 131 (the Wetlands Protection Act) and Chapter 132 (the Forest Cutting Practices Act) require regulatory bodies to consider impacts on habitat and species during proposed development or management activities. In 1990, Massachusetts passed its own Endangered Species Act, providing protection currently for 424 plant and animal species. This act provides regulatory protection for significant habitats of the listed species, as well as direct protection for the species.

In recent years, the protection of biodiversity has become a high priority for state agencies in Massachusetts. Massachusetts is a diverse environment that currently supports at least 15,000 visible (i.e., macroscopic) native species of plants and animals (including about 12,000 insects). MassWildlife (previously the Division of Fisheries and Wildlife) currently maintains the Natural Heritage and Endangered Species Program, the goal of which is to protect the state's native biological diversity. MassWildlife also recently launched the "Biodiversity Initiative," in order to coordinate two new programs that were created by the 1996 Open Space Bond Bill (Chapter 15, Acts of 1996). These programs include the Ecological Restoration Program and the Upland Habitat Management Program. The Ecological Restoration Program's major goal is to "focus future restoration action on the fundamental problems threatening biodiversity, including the restoration of natural processes and native community composition." To achieve this goal, the Ecological Restoration Program intends to follow the following strategies:

- Conserve species before they become rare by protecting their habitat.
- Restore natural processes that sustain biodiversity at key sites.
- Limit invasion by exotic or invasive species.
- Replicate natural processes, where they cannot be maintained or restored, at appropriate times, places, and in justifiable quantities.

- Consider species reintroduction only when species' requirements and causes of extirpation are sufficiently understood, and carefully consider the costs and benefits.

The Natural Heritage Program, in conjunction with the Massachusetts Chapter of The Nature Conservancy published "Our Irreplaceable Heritage: Protecting Biodiversity in Massachusetts" in 1998. This document outlines a Biodiversity Protection Strategy that includes the following:

- Encourage all conservation agencies, land trusts, municipalities, and not-for-profit conservation organizations to increase the importance given to and financial support for the conservation of uncommon and under protected components of biodiversity.
- Educate landowners about maintaining and restoring certain natural processes and minimizing disturbance.
- Aid land managers in implementing land management techniques that mimic natural processes where they cannot be maintained or restored.
- Strive to achieve an equitable distribution of biologically viable conservation lands at all topographic elevations and across all ecoregions.
- Take action to conserve natural communities and species that have experienced tremendous loss or are under considerable threat.
- Focus attention on natural communities and species, common or rare that are under protected.

The April 2000 "The State of Our Environment" from the Executive Office of Environmental Affairs (EOEA), acknowledges the link between human needs and healthy, thriving natural communities. EOEA identifies loss of habitat through development and invasive species as the two most distinct threats to maintaining natural diversity in Massachusetts, and further commits to preserving biodiversity through the identification and protection of critical habitats and the creation of bioreserves that include central cores of public land.

As stated in Section 4.5, OWM's principal goals for maintaining biodiversity on its Sudbury holdings are to retain most of these lands in a forested condition, to identify and provide habitat for the protection of uncommon and rare flora and fauna, to eliminate and prevent the spread of non-native invasive species. OWM also seeks to provide the range of seral stages from early successional habitat through unmanaged mature forest across its total holdings.

5.3.2 Rare and Endangered Species

5.3.2.1 Flora

LARGE-WHORLED POGONIA

While no deliberate, comprehensive study of rare plants has been conducted on the Sudbury watershed lands under OWM care and control, studies have been conducted on nearby Wachusett properties. *Isotria verticillata*, the large-whorled pogonia (MA watch list) was the only rare plant species discovered during the 1996 survey of proposed timber-harvesting lots at Wachusett and Sudbury for rare species (conducted by the staff of the University of Massachusetts herbarium). OWM Foresters have also located the following state-listed species during independent surveys of Wachusett properties:

Lupinus perennis	Wild lupine	WL
Arceuthobium pusillum	Eastern dwarf mistletoe	SC
Juglans cinerea	Butternut	WL
Orontium aquaticum	Golden club	T

Although there is no current record of their presence, the species below may occur on OWM watershed properties at Wachusett/Sudbury, based on past records and suitable habitats/range:

TABLE 18: RARE FLORA PREDICTED TO OCCUR ON WACHUSETT/SUDBURY WATERSHEDS

Note: Status, E=endangered, T=threatened, SC=special concern, WL=watch list

Family	Species	Common Name	Status	Flowering
Apiaceae	*Conioselium chinense*	Hemlock parsley	SC	Jul/Sep
Apiaceae	*Sanicula trifoliata*	Trefoil sanicle	WL	Jun/Oct
Asclepiadaceae	*Asclepias verticillata*	Linear-leaved milkweed	T	May/Jul
Asteraceae	*Aster radula*	Rough aster	WL	Jun/Aug
Brassicaceae	*Arabis drummondii*	Drummond's rock-cress	WL	May/Aug
Brassicaceae	*Arabis missouriensis*	Green rock-cress	T	Jul/Oct
Brassicaceae	*Cardamine bulbosa*	Spring cress	WL	Jun/Aug
Caryophyllaceae	*Stellaria borealis*	Northern stitchwort	WL	May/Aug
Cyperaceae	*Eleocharis intermedia*	Intermediate spikerush	T	Aug/Oct
Cyperaceae	*Scirpus ancistrochaetus*	Barbed-bristle bulrush	E	Jun/Jul
Gentianaceae	*Gentiana andrewsii*	Andrew's bottle gentian	T	Apr/Jun
Gentianaceae	*Gentiana linearis*	Narrow-leaved gentian	WL	Jun/Aug
Haloragaceae	*Myriophyllum alterniflorum*	Alternate leaved milfoil	T	Jun/Aug
Juncaceae	*Juncus filiformis*	Thread rush	T	Aug
Lentibulariaceae	*Utricularia minor*	Lesser bladderwort	WL	May/Nov
Liliaceae	*Smilacina trifolia*	Three-leaved Solomon	WL	Apr/Jun
Orchidaceae	*Coeloglossum viride v. bracteata*	Frog orchid	WL	May/Sep
Orchidaceae	*Corallorhiza odontorhiza*	Autumn coralroot	SC	Apr/Jul
Orchidaceae	*Cypripedium calceolus v. parviflorum*	Small yellow lady slipper	E	May/Aug
Orchidaceae	*Cypripedium calceolus v. pubescens*	Large yellow lady slipper	WL	Jun/Sep
Orchidaceae	*Isotria medeoloides*	Small-whorled pogonia	E	May/Jul
Orchidaceae	*Platanthera hookeri*	Hooker's orchid	WL	Mar/Jun

Orchidaceae	*Platanthera macrophylla*	Large leaved orchis	WL	Apr/Jul
Orchidaceae	*Platanthera. Flava var. herbiola*	Pale green orchis	T	Jun/Sep
Orchidaceae	*Triphora trianthophora*	Nodding pogonia	E	Jul/Sep
Poaceae	*Panicum philadelphicum*	Philadelphia panic grass	SC	Jul
Poaceae	*Trisetum pensylvanica*	Swamp oats	T	Aug/Oct
Poaceae	*Trisetum spicatum*	Spiked false oats	E	Jul/Sep
Ranunculaceae	*Ranunculus alleghaniensis*	Allegheny buttercup	WL	Jun/Sep
Sparganiaceae	*Sparganium angustifolium*	Narrow-leaved bur weed	WL	May/Nov
Urticaceae	*Parietaria pensylvanica*	Pellitory	WL	Aug/Sep

Primary responsibility in Massachusetts for the protection of endangered, threatened, or special concern plant species rests with the Natural Heritage and Endangered Species Program of the Division of Fisheries and Wildlife. NHESP has identified 257 species of plants in these categories across the state, and is working continually to design protection strategies. Regulatory support for these efforts exists at both the federal and the state level. The Federal Endangered Species Act of 1973 protects the small-whorled pogonia (*Isotria medeoloides*), which is found in Massachusetts though not yet on the Sudbury watersheds.

Plants are considered rare for a variety of reasons. In some cases, it is simply that Massachusetts is at the northern limit (e.g., Black maple, *Acer nigrum* or River birch, *Betula nigra*) or the southern limit (e.g., Dwarf rattlesnake plantain, *Goodyera repens* or One-flowered pyrola, *Moneses uniflora*) of their range. For species that are generally associated with the eastern deciduous forest, which dominates central and western Massachusetts, plants may be rare simply because they are poor colonizers and thus populations remain widely scattered and sparse. Loss of habitat is also a common cause of plant species loss. Bruce Sorrie, former Massachusetts state botanist, estimated that a surprising 72% of the species extirpated from the state had been lost due simply to the loss of early successional or recently disturbed habitat (Sorrie, 1989). Karen Searcy, current curator of the University of Massachusetts herbarium, reported in 1995 that 13% of the rare species likely to occur on OWM properties rely on early successional habitat or disturbance such as fire to persist (Searcy, 1995). Animal populations are responsible for some losses, either through heavy browsing or through dramatic habitat alterations such as those caused by beaver. While beaver wetlands may provide habitat for some rare plants, they also flood bogs and other uncommon habitats that may have contained rare plant populations. Some species (e.g., Ginseng, *Pallax quinquefolius L.*) have declined directly because of over-collecting. Invasive, non-native plants have also been implicated in the decline of some uncommon native species (see section 5.4.5 below).

Management recommendations for protecting rare plant populations begin with efforts to identify current populations. OWM is committed to working to locate these populations and adding them to GIS databases so that they will appear on maps even at times when they are difficult to locate in the field. Several organizations, including the NHESP in Massachusetts and the Southern New England Forest Consortium, are working to develop specific management recommendations for the perpetuation of uncommon plant species. Much remains to be learned about the specific light, moisture, and regeneration requirements for the species of concern. Some species will persist best if given a wide berth, while others rely on periodic disturbance.

OWM will rely on recommendations being developed to guide management practices around known and discovered rare plant populations. For instance, the Southern New England Forest Consortium has recently published "Rare and Endangered Species: Field Guide for Southern New England," which includes management recommendations. This guide recommends that managers looking to support one-flowered pyrola should "maintain a residual overstory or high basal area in forests where populations have been found" and "thin out understory vegetation." Roundleaf shadbush requires managers to "prevent woody vegetation from overtaking the site" because "this species does not like a closed forest canopy." OWM will continue to work to identify rare plant populations and to research and apply management recommendations for their protection.

5.3.2.2 Fauna

OWM property within the Sudbury watersheds is within the range of a number of state-listed vertebrate species, only a few of which have been documented to occur there. However, past rare animal surveys may have bypassed OWM land and it is likely that there are undiscovered populations of rare and endangered species on OWM property. Although land protection is one of the most critical factors for survival, protection would be enhanced by knowing where these species are located. OWM actively manages its landholdings, and there is the potential for these activities to impact listed species. While some species may benefit from lack of disturbance, others may require additional management in order to enhance or modify existing habitat.

In order to ensure that land management activities do not disrupt or destroy listed species or their habitats, an accurate and current species occurrence database must be available and expanded. The OWM biologist keeps records of listed species on OWM land that were discovered by in-house personnel or passed along by the public. The state's Natural Heritage and Endangered Species program (NHESP) has a much more complete and detailed databases of listed species. Land management activities carried out by OWM under a Chapter 132 forest cutting plan are reviewed by NHESP. However, routine maintenance (mowing, brush cutting) or watershed maintenance activities (road building/repair) are conducted without a requirement to inform NHESP. In these situations, it is possible to unknowingly impact rare or endangered species. This possibility will be reduced as further surveys and greater sharing of records takes place.


EASTERN BOX TURTLE

In many cases, rare and endangered species become rare because of loss of habitat. One of the greatest benefits of OWM land to wildlife is that it will remain in a natural state and not be developed. However, as mentioned, most of this land will remain covered by maturing forest. This condition will benefit rare or endangered species requiring forested habitat (e.g., sharp-shinned hawk) but will not help other species that require different habitat such as fields (upland sandpiper) or early successional forest (golden-winged warbler). Approximately half the species listed in Table 19 are either dependent on wetlands or utilize them during some portion of their lives. Protecting and maintaining functioning wetland systems is a priority for OWM and should benefit wetland species. In addition, vernal pools on OWM land receive particular attention and protection (see section 5.2.2.4 and Figure 6). State BMPs for vernal pools are being studied to determine their effectiveness in protecting vernal pool dependent species.

Non-forested upland habitat is uncommon on OWM property within the Sudbury watersheds and is limited to maintained open spaces. There are several species in Table 19 that require open fields or meadows. Although OWM will not create field habitat on the Sudbury watersheds, it does recognize the importance of this habitat in the landscape. Therefore, where feasible, OWM will maintain and enhance this habitat on select portions of its land.

Some species listed in Table 19 may be assisted by adequate habitat protection, but still need additional assistance to successfully breed. In these cases, when personnel and resources allow, OWM may provide the added breeding structures or conditions. For example, OWM may construct, deploy, and maintain floating cedar rafts in the reservoirs if common loons are attempting to nest. Although loons will nest on natural islands, the rafts provide protection from rising and falling water levels. When possible, OWM may also provide nesting structures for bald eagles.

TABLE 19: STATE-LISTED VERTEBRATE SPECIES WITH RANGES WITHIN THE SUDBURY WATERSHEDS.

SPECIES	STATUS[1]	OCCURRENCE[2]
AMPHIBIANS		
Blue-Spotted Salamander	SC	Documented
Marbled Salamander	T	Probable
Spring Salamander	SC	Probable
Four-Toed Salamander	SC	Probable
REPTILES		
Spotted Turtle	SC	Documented
Wood Turtle	SC	Documented
Blanding's Turtle	T	Probable
Eastern Box Turtle	SC	Documented
BIRDS[3]		
Common Loon	SC	Potential
American Bittern	E	Potential
Least Bittern	E	Documented
Bald Eagle	E	Potential
Northern Harrier	T	Potential
Sharp-Shinned Hawk	SC	Probable
Common Barn Owl	SC	Potential
Long-Eared Owl	SC	Probable
Golden-Winged Warbler	E	Potential
Vesper Sparrow	T	Probable
Grasshopper Sparrow	T	Probable
MAMMALS		
Water Shrew	SC	Probable
Southern Bog Lemming	SC	Probable

[1] Species status in Massachusetts: SC = species documented to have suffered a decline that could threaten the species if allowed to continue unchecked; T = species likely to become endangered within the foreseeable future throughout all or a significant portion of its range; E = species in danger of extinction throughout all or a significant portion of its range.
[2] Occurrence of species on OWM land within the watershed: Documented = species actually observed; Probable = species not documented, but given available habitat, species' range, and/or observations within the watershed, they are likely to occur; Potential = species not documented, and current habitat conditions may not be suitable, but with habitat enhancement they may occur.
[3] Occurrence of birds is limited to breeding pairs, not migratory or seasonal residents.

5.3.3 Rare Natural Communities

A natural community is a combination of physical and biotic conditions that form a functionally distinct area of the landscape (Garrett et al., 2000). An area's physical conditions (e.g., topography, hydrology, geology, etc.) will determine the vegetative composition, which in turn will dictate the type of animal community that lives there. Ideally, to adequately protect and enhance these communities, all features of the system must be properly protected and enhanced, not just individual parts.

Natural communities may be rare or uncommon globally, statewide, or at a local level. To ensure all rare communities receive adequate protection it is necessary to know where the communities are located on the landscape. Unfortunately, OWM has little information regarding rare or exemplary communities within the Sudbury watersheds. Some communities (e.g., vernal pools, Cedar Swamp) are known and documented. However, most communities considered rare or exemplary on a local or regional level have not been mapped. OWM's first step in managing rare natural communities should be to properly classify rare, unique, and exemplary communities that may occur within the watershed. When the classification system has been established, mapping can begin to locate communities. Field inspections of mapped communities will verify mapped areas. Adequate management and protection will maintain the integrity of the critical habitat and surrounding area.

A project to map rare, unique, and exemplary natural communities was completed in 2000 on the Quabbin watershed (Garrett et al., 2000). A classification system tailored to Quabbin communities was developed and preliminary field verifications were conducted. Community mapping and management recommendations were completed in September 2000. Some information from the Quabbin study can be utilized for Sudbury watersheds. Although the community classification system was tailored to Quabbin, many of the communities are rare or unique on a statewide or regional level. For example, talus slopes, pitch pine-scrub oak, hemlock ravines, tupelo swamps, vernal pools, and peat wetlands were identified as rare communities at Quabbin but also occur on other watersheds. Because OWM is constantly acquiring new land, some parcels may contain rare or exemplary communities that have not yet been identified. A complete census of OWM land needs to be done to accurately inventory community types. In addition, a project similar to the Quabbin study should be conducted on the other OWM watersheds to classify rare and exemplary communities.

5.3.4 Cedar Swamp

Cedar Swamp is a state listed Area of Critical Environmental Concern (ACEC) located in Westborough and Hopkinton, Massachusetts. It was the first ACEC in the state when it was listed in 1975. The swamp encompasses approximately 1,650 acres, and OWM owns roughly 27 percent (448 acres). The Sudbury Valley Trustees are the second largest land protectors in the swamp, owning 130 acres (8%). Conrail and Bay State Abrasives are the two largest private owners of land within the swamp's boundaries. Although Cedar Swamp remains a large wetland, is has been affected by past development. A rail line cuts through the center of the swamp from east to west, Interstate 90 crosses the southern portion of the swamp and Interstate 495 runs north to south along its eastern edge.

Cedar Swamp is the second largest remaining wetland area in central Massachusetts. Great Meadows National Wildlife Refuge is the largest (Zilligen and O'Connor, 1994). The swamp is classified as a southern northeast acidic seepage swamp. Seepage swamps are typically located at the base of slopes near the margins of wetland groundwater discharge areas (Zilligen and O'Connor, 1994). These types of swamps tend to be richer in both wildlife species and nutrients than the more common basin swamps. In addition, Cedar Swamp contains an Atlantic white cedar community which harbors many focal species associated with that habitat type (Clark, 2000).

Although Cedar Swamp has been degraded by development and fragmentation, it is still a unique habitat that provides refuge for a variety of species. There is a diversity of vegetation within the swamp, as well as vernal pools, small streams, islands, and pockets of upland. Several rare species, including the least bittern, pied-billed grebe, wood turtle, and spotted turtle have been documented within the swamp (Starkey, 1990). The swamp also provides habitat for a variety of other species including waterfowl, migratory songbirds, and a diversity of reptiles and amphibians.

A protection plan was developed for Cedar Swamp in 1990 (Starkey, 1990). The plan was developed in conjunction with a variety of public and private interest groups and was funded in part by the MDC. The 1990 plan identified a variety of threats to the swamp including abandoned dumps and landfills, highway runoff, pesticides, and salt-laden snow (Starkey, 1990). The report also included a list of recommendations for the continued protection of Cedar Swamp. These recommendations included conducting further research and monitoring (water quality testing, vernal pool monitoring, wildlife surveys), coordinating with federal and state agencies (salt reduction program, improving highway drainage), implementing local actions (low salt zones, extend wetland buffer zones), and increasing protection and education (purchasing high priority parcels, interpretive signs). It is unclear how many, if any, of these recommendations were implemented and their results.

As a designated Area of Critical Environmental Concern (ACEC), OWM is responsible for preserving and restoring the resources of Cedar Swamp. Specifically, OWM will work to acquire useful scientific data on Cedar Swamp, and to preserve, restore, or enhance the resources of Cedar Swamp, and ensure that activities in or impacting on Cedar Swamp are carried out so they minimize adverse effects on the swamp's natural, recreational, and historic values. In order to try to address these responsibilities, OWM is working to implement the following programs:

1. Inventory wildlife resources within Cedar Swamp, particularly rare or endangered species.
2. Develop a Resource Management Plan for Cedar Swamp that would comprehensively protect, enhance, and restore its resources.
3. Participate with municipalities, nonprofit groups, and individuals in providing technical assistance, management strategies, and public education to ensure the continued stewardship of Cedar Swamp.

5.3.5 Control of Invasive Plants

5.3.5.1 Definitions

"Invasive" plants fall into at least two categories – native or non-native species. Most of the difficulties associated with invasive plants involve plants that are non-native. This is true in part because these non-native "aliens" have been transported out of the ecosystem in which they evolved, and may have escaped specific population-controlling insects and diseases in the process. It is important to point out that not all non-native plants are invasive. Most have been intentionally introduced into agricultural or horticultural environments, and many are unable to reproduce outside of these intensively managed environments. There are, unfortunately, hundreds of others that were introduced either deliberately or accidentally to natural settings and have managed to aggressively force out native plants, raising serious biodiversity issues, and potential threats to water quality protection.

It has taken awhile for these issues to become apparent. Some of the invasive plant problems on OWM properties are the result of deliberate plantings of species that effectively addressed other concerns (for instance, planting autumn olive to improve wildlife habitat), but then became invasive. Other invasive species are escapees from landscaping that predates OWM's acquisition of reservoir properties, including Japanese barberry, Japanese knotweed, the buckthorns, and purple loosestrife. In all cases, a plant's "invasiveness" is composed of several defining qualities:

- The plant grows and matures rapidly in abundantly available habitats.
- It is capable of producing vast quantities of seed that is easily dispersed by animals, and often can also reproduce vegetatively.
- There are no diseases or pests effectively controlling its reproduction and spread (which generally means there are no close relatives in the habitats it invades).
- The plant does not require intensive management to thrive.

INVASION BY JAPANESE BARBERRY ON RICH, MESIC (MOIST) SITE

5.3.5.2 Problems Associated with Invasives

The EOEA report "The State of Our Environment" (April, 2000) states that "the two biggest threats to biodiversity in Massachusetts are the destruction and fragmentation of wildlife habitats and the introduction of invasive non-native species." The Nature Conservancy has reported that 42% of the declines of threatened or endangered species in the US are partly or wholly due to the effects of invasive species. Some of these threats are subtle. For instance, when the declining West Virginia White butterfly lays its eggs on the invasive garlic mustard instead of on the usual native mustards, its eggs fail to develop. Other threats are more obvious. For instance, purple loosestrife currently covers an estimated 500,000 acres in northern US and southern Canada, displacing native food sources and threatening to prevent successful nesting in 90% of the wetlands used by breeding waterfowl along the Atlantic and Mississippi flyways. Impacts from invasives on the soil and its faunal community have also been documented. There is evidence that a Chinese tallow tree is altering nutrient cycling where it invades, causing a decline in the native soil invertebrates as a consequence.

Beyond issues of biodiversity conservation, resilient plant communities are important to watershed management for controlling the erosion of soil and nutrients throughout the range of natural disturbances (e.g., droughts, insect outbreaks, fire, wind, heavy snow and ice). Resilience is dependent upon species and size diversity in the plant community, because disturbances are frequently species and/or size specific. When plants become aggressively invasive, replacing the diverse native flora with local monocultures, they increase the susceptibility of the plant community to disturbances. The prevention of forest regeneration by certain aggressive invasives has become a problem on some areas of the watersheds. Around the Quabbin Reservoir, Japanese barberry that was planted on historic home sites has taken advantage of high deer populations (which do not feed on barberry) to colonize and monopolize the understories of significant forest areas. At the Wachusett Reservoir, autumn olive has aggressively occupied open fields, delaying or precluding their return to forest cover. Invasives are often more effective than natives in colonizing disturbed areas, and may overrun young trees that do become established. Table 20 lists the invasive plants that are present at the Sudbury Reservoir.

TABLE 20: INVASIVE PLANTS PRESENT ON SUDBURY WATERSHEDS

Common name	Latin name	Habitat
Black locust	*Robinia pseudoacacia*	Edge of forest/field
Norway maple	*Acer plantanoides*	Forest
Oriental bittersweet	*Celastrus orbiculata*	Forest
Japanese barberry	*Berberis thunbergii*	Forest
Black swallow-wort	*Cynanchum louiseae*	Open areas and edges
Shining buckthorn	*Rhamnus frangula*	Forest
Common buckthorn	*Rhamnus cathartica*	Forest
Honeysuckles	*Lonicera sp.*	Open areas
Autumn olive	*Elaeagnus umbellata*	Open areas
Russian olive	*Elaeagnus augustifolia*	Open areas
Multiflora rose	*Rosa multiflora*	Open areas and edges
Goutweed	*Aegopodium podagraria*	Floodplains, riparian areas
Japanese knotweed	*Polygonum cuspidatum*	Riverbanks, wet edges
Purple loosestrife	*Lythrum salicaria*	Wetlands
Garlic mustard	*Alliaria petiolata*	Floodplains, disturbed woodlands, roadsides
Phragmites (common reed)	*Phragmites australis*	Wetlands
Winged euonymus	*Euonymus alata*	Open woods, fields, edge

5.3.5.3 Control and Management Options

In February of 1999, President Clinton signed Executive Order 13112, to "prevent the introduction of invasive species and provide for their control and to minimize the economic, ecological, and human health impacts that invasive species cause." For further information on this Order, see: http://www.invasivespecies.gov/council/nmp.shtml . EO 13112 created a federal Invasive Species Council to "recommend plans and actions at local, tribal, State, regional, and ecosystem-based levels" to address prevention and control of invasives. The first edition of a National Invasive Species Management Plan from this Council was produced in January of 2001, serving as a blueprint for invasive species actions. This plan provides both additional mandate and an overview of the costs and agency responsibilities to begin to gain control over invasives. More recently, the Massachusetts Invasive Plants Working Group produced a methodically developed list of invasive and potentially invasive plants in the Commonwealth, through cooperation among biologists, government staff, non-profits, nurseries, and landscape organizations. This list is published on the New England Wild Flower Society website, at: http://www.newfs.org/conserve/invlist.htm . Strategic recommendations for managing invasive plants in Massachusetts have also been developed by the same group, and are posted at: http://www.newfs.org/conserve/invasive.htm#strat1 .

All of the features that make a plant invasive also frustrate efforts to control and reverse its expansion. Seed production is generally prolific, and many invasives also reproduce vegetatively. General control requires the removal or killing of mature plants, but also requires that these removals be timed in such a way that they do not result in further reproduction and spread of the plant. Controls are either mechanical or chemical. Mechanical controls include hand-pulling, girdling or mowing, mulching, tilling, and the use of heat. Chemical control is often more efficient and effective, but carries stronger risks of collateral damage to non-target species, as well as risks of water and soil contamination. Controls need to be designed around the morphology, phenology, and reproductive strategies of specific plants. For instance, while prescribed fire will reduce invasions of conifers in native grasslands, it tends to stimulate growth and reproduction of many other invaders.

The primary invasive plants found on the Sudbury watersheds are listed below with recommended controls from various sources in the literature:

TABLE 21: MAJOR INVASIVE PLANTS ON SUDBURY WATERSHEDS AND CONTROL MEASURES

Invasive Species	Control [1]
Norway maple	Cut mature trees as close to base as possible. Pull seedlings/saplings including as much of the root as possible.
Oriental bittersweet	Regular mowing of edges and open areas will exclude bittersweet. Triclopyr herbicides are effective as foliar or basal applications.
Buckthorns	Seedlings are easily pulled. Larger stems can be pulled or cut, and may be killed by repeated fire. Freshly cut stumps should be treated with a 50% solution of glyphosphate to prevent resprouting. As buckthorns enter dormancy later than most species, treatments should be applied mid to late autumn to reduce risk to non-target species.
Honeysuckles	Hand-pulling is effective for isolated shrubs less than 3 years old. Most effective control of larger populations occurs through cutting and basal application of 20% glyphosphate. Seeds are not long-lived, so returning to remove seedlings by hand every two years or so should eliminate the population in time. Repeated burning is only effective for a short time, as the shrubs continue to resprout indefinitely following fire.
Olives	Repeated cutting of mature stems and sprouts and pulling of new seedlings may be effective. Best control is achieved by cutting followed by either burial or herbicide treatment of cut stump.
Multiflora rose	Regular mowing, where feasible, will remove this plant. Larger shrubs should be pulled or dug out. Where mowing is not practical, cutting followed by stump treatment with glyphosphate to prevent resprouting, is effective.

[1] Control measures are from current literature and are NOT OWM policy at this time.

5.3.5.4 Control Efforts during This Management Period

Treatment of invasive plants to control or reverse their spread will progress as time and budget allow, from the highest to the lower priority areas, as follows:

- Areas of invasive plants that are presenting a direct threat to existing rare or endangered plant communities. Control will be focused on area of direct threat.
- Areas where tree regeneration is critical and is being prevented by one or more invasive plant species. This may include riparian zones and other critical protection areas.
- Areas where invasive plant populations are recently established and limited in extent, so that control is a reasonable expectation.

5.3.6 Maintenance of Early Successional Habitat for Landscape Diversity

5.3.6.1 Importance of Early Successional Non-Forested Habitat

Broad changes in land use have dramatically impacted the number, type, and extent of open lands within the watershed. Early successional habitat was a major component in the landscape prior to

European settlement. Evidence suggests that grasslands existed in the Northeast before Europeans arrived, and grassland birds have been a component of avian diversity for a long time (Dettmers and Rosenberg 2000). Beaver activity, wildfires, windstorms, and fires set by Native Americans generated early successional habitat. By the 1800s grasslands were even more abundant in the northeast as agricultural land dominated the landscape. Since the mid-1800s, the amount of grasslands and open fields has decreased dramatically, causing a similar decrease in many species of plants and animals that depend on open habitat. As farms were abandoned, the open fields and meadows were left undisturbed. Without frequent disturbance such as mowing, burning, or grazing, grasslands will gradually revert back to forest. Some grassland species, such as the loggerhead shrike and regal fritillary butterfly, have been extirpated from Massachusetts.

Recent population trends for grassland dependent species show disturbing declines. Bobolinks and grasshopper sparrows have declined 38 and 69 percent, respectively in the last 25 years. Partners in Flight, a national conservation organization, have identified Neotropical migratory bird species of concern in Massachusetts. These species have a high perceived vulnerability (they may or may not be state or federally listed) and are critical to maintaining avifauna diversity in the state. Priority species include Henslow's sparrows, upland sandpipers, grasshopper sparrows, and bobolinks. These species are all associated with grassland habitat. As farmland continues to be abandoned or converted to house lots, the amount of viable open land continues to shrink. The remaining grasslands, particularly large (>100 acres) or clustered fields, are increasingly vital to a variety of wildlife. Eastern meadowlarks, savanna sparrows, eastern bluebirds, and bobolinks use hayfields, meadows, or pastures to forage and raise young. During the fall and winter, fields provide food for migrating sparrows, warblers, larks, and snow buntings. Raptors such as northern harriers, short-eared owls, and American kestrels hunt in fields for small mammals (meadow voles, meadow jumping mice) and insects. White-tailed deer often graze in fields, and foxes will hunt fields for small mammals or rabbits. Finally, butterflies like the monarch, tiger swallowtail, and various fritillaries feed on nectar of grassland wildflowers.

OWM recognizes the regional importance of these open lands to the diversity of wildlife within the state. OWM-owned land within the Sudbury watersheds is 83% forested and 10% non-forested upland. The non-forested uplands are restricted to mowed lawns and other maintained openings encompassing approximately 227 acres. It is unlikely that these non-forested uplands provide quality habitat for grassland dependant species (the average size is 1.5 acres), although they may provide marginal habitat for some animals. OWM does not own any abandoned or reclaimed hay fields in the Sudbury watersheds, which provide better early successional habitat. When possible, OWM attempts to maintain and enhance its non-forested uplands by delaying mowing until late summer to protect nesting birds, limiting mowing to once every 2-3 years to encourage native vegetation, and raising the height of the mower to at least 8 inches to provide small mammal habitat.

5.3.6.2 Importance of Early Successional Woody Habitat

In general, there are 2 broad types of early successional woody habitat. There is successional habitat that is dominated by pioneer species (thickets) and forest habitat dominated by young stands of late successional species (Askins, 2001). Thickets are typically dominated by pioneering species of vines, shrubs, and trees. These habitats tend to be denser than young forest habitats and can persist for longer periods of time in that stage, particularly if actively maintained (power line rights-of-way) or associated with beaver ponds. Young forested habitats are dominated by seedlings and sprouts of mature forest trees, in addition to shrubs and herbs already in the understory. Young forest habitats are much more transitory and may only provide quality habitat for a period of years before the saplings grow and form a closed canopy. Because the two habitats differ in structure and species composition, their value to various wildlife species is also unique. Evidence suggests that since thickets have a larger component of shrubs, they provide a unique habitat that supports some breeding birds that are not found in young forests (Askins, 2001).

Early successional woody habitat was present in sufficient amounts and distributed well enough across the landscape to support long-term populations of early successional birds in the Northeast prior to either European or Native American intervention (Dettmers and Rosenberg, 2000). Fire, major weather events, or beaver activity maintained or generated these habitats across the landscape. European and Native American populations increased the amount of early successional habitat in the region. By the mid 1800s, forest cover in New England had dropped from >90% to <50% (Dettmers and Rosenberg, 2000). As farms were abandoned during the late 1800s large amounts of early successional habitat became available. Over time these large areas of early successional habitat grew beyond the early seral stages used by early successional species.

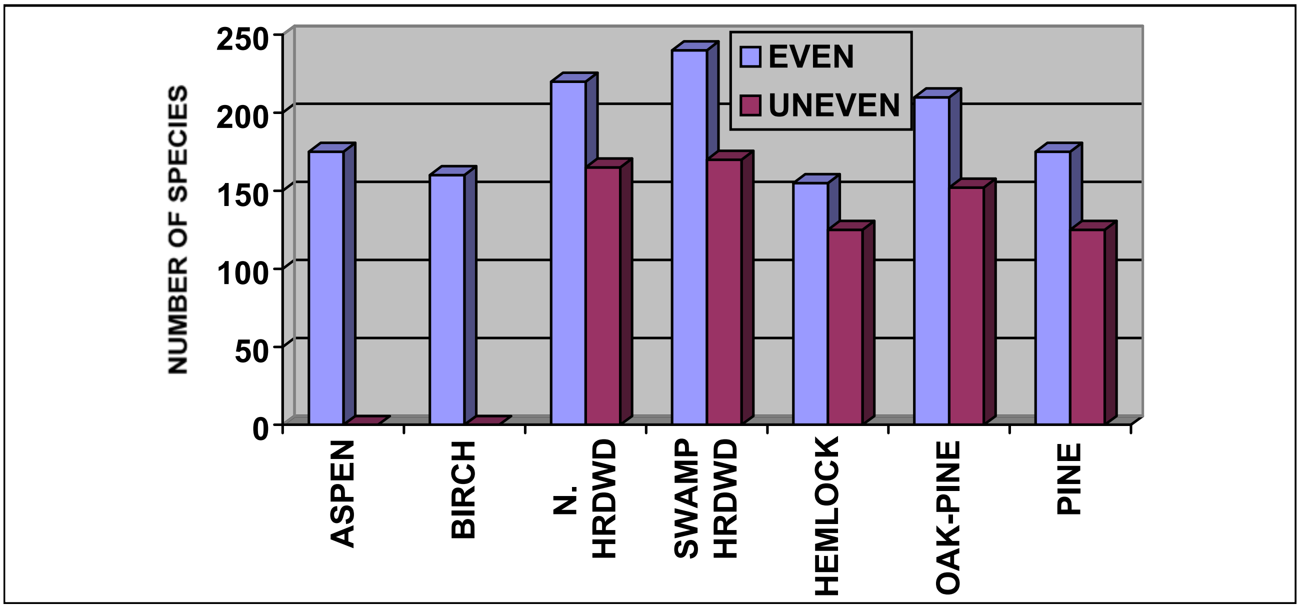
Species dependent on these early successional woody habitats have been declining since the 1950s as the amount of available habitat continues to shrink (Scanlon, 2000). The Partners in Flight list of regionally declining birds highlights species associated with early successional woody habitat (i.e., blue-winged warbler, Eastern towhee, and prairie warbler). Providing habitat for early successional species involves considerations in both space and time. Young forest habitats are temporal and only support wildlife for 8-15 years. Therefore, either young forest habitat needs to be set back on a regular basis or new areas need to be created. In addition, thicket habitats may also need to be maintained to prevent succession.

Thicket habitats can exist on power line rights-of-way, shrub swamps, active and abandoned beaver ponds, or abandoned open areas that have been recolonized by pioneer species. Some thicket habitat may persist for much longer periods of time than young forests. Beaver ponds may retain early successional habitat in various forms (ponds, wet meadows, shrubs) for more than 60 years (Litvaitis et al., 1999). Other thicket habitats (power lines, abandoned areas) may require active management to maintain them in an early successional state. Cutting, mowing, burning, and herbicides can be used to regenerate or maintain thicket habitats.

Even-aged forest management is the primary technique used to produce young forest stands. This type of silviculture provides the opportunity to regenerate shade-intolerant species such as aspen and birch. The resulting habitat provides distinct foraging and shelter opportunities for species that are not usually available when uneven-aged management is used (DeGraaf et al., 1992). Even-aged management provides habitat for up to 26% more species than uneven-aged management in similar cover types (DeGraaf et al., 1992) (Fig. 8). Failure to incorporate some even-aged management techniques within the watershed could result in fewer species. Payne and Bryant (1994) state that even-aged management tends to support more wildlife species than uneven-aged management in northern hardwood, hemlock, oak-pine, and pine forests of the northeast. As the current level of tree harvesting within the state is relatively light, widely dispersed, and generally does not provide substantial early-seral habitat, OWM will try to incorporate management techniques geared towards creating this type of habitat. In the end, utilizing a range or combination of silvicultural treatments, rather than strict adherence to one, will eventually result in increased use by a wider variety of wildlife species (DeGraaf et al., 1992).

As mentioned previously, in order to provide the widest range of habitat conditions across the watershed, a variety of management techniques and applications may be needed to either create or sustain various habitat conditions. Although uneven-aged management techniques will be primarily applied across the watershed, it is important to recognize the role even-aged management plays in maintaining biodiversity. However, it is also important to realize that early successional habitat only needs to comprise a relatively small percentage of managed land in order to meet population objectives for early successional species. Further limitations of resources and personnel preclude OWM from managing a large percentage of their land holdings in early successional stages. Therefore, for this management period, OWM's goal for early successional forested and non-forested habitat will be to try and create or maintain these habitats on appropriate areas when possible. OWM will incorporate areas already in an early successional state (rights-of-ways, maintained open areas) into its resource planning activities in order to maximize the benefit of these habitats.

FIGURE 8: POTENTIAL NUMBER OF WILDLIFE SPECIES BY SILVICULTURAL SYSTEM[A] AND COVER-TYPE GROUPS[B]



[a]Total number of amphibians, reptiles, birds and mammals using each cover type
[b] Taken from DeGraaf et al., 1992.
Even-aged: forests containing regeneration, sapling-pole, sawtimber, and large sawtimber stands in distance units of 5 acres or larger.
Uneven-aged: essentially continuous forest canopies and intermixed size and age classes produced by single-tree selection.

5.4 Wildlife Management

5.4.1 Assessment of Impacts of Planned Management Activities on Wildlife

The management activities described in this plan will have various impacts on the wildlife community at the Sudbury. Most impacts on the wildlife community will be a result of habitat changes or modifications. The forest management approach described in this plan has landscape level affects, although individual changes at any given time will be very localized and small.

The amount and types of habitat at the Sudbury has been dynamic since early colonial times. Once covered by primeval forest, a majority of the land in the Sudbury watershed was cleared for agriculture. This trend persisted for decades, until about 1840 when 75 percent of the arable land was in pasture or farm crops. The next 100 years was another period of dramatic change as most of the farmland was abandoned and new forest invaded. Dramatic changes in the wildlife community accompanied these broad landscape changes. Some species thrived and expanded their range, while other were temporarily extirpated or became extinct. When agriculture dominated the landscape, species such as black bears, wild turkeys, and white-tailed deer were gone from most of their former range. Bluebirds were abundant during the agricultural period, but are now very rare breeders. Other open habitat species (bobolinks, vesper sparrows, and golden-winged warblers) are declining as well as available habitat shrinks. Today, most of the undeveloped land in the Sudbury watersheds is forested. While OWM's management activities will alter habitat and wildlife species composition, probably the most significant impacts to the wildlife community have been these large regional changes in land use. In addition, human population expansion in the Sudbury watersheds has meant the loss of more and more open space, which is converted to residential housing. Further, large-scale disturbances to the landscape such as the flooding of the reservoir, the 1938 hurricane, and periodic fires have shaped the wildlife community that exists today. Future management will be focused on encouraging regeneration and improving the health and vigor of the forest.

While the management techniques used to reach these goals will not be as dramatic as previous events, it is important to understand how these plans will affect the habitat and wildlife communities on the watershed.

5.4.1.1 General Impacts

OWM's primary long-term forest management goal is to establish and/or maintain a forest cover of diverse native tree species of many different age classes on a majority of its land holdings. This goal will primarily be accomplished through uneven-aged forest management. A 20-30 year cutting cycle will be used in most areas, and harvest will be through selection of individual trees or small groups (1/20-1/4 up to 2 acres). Uneven-aged management is the best technique for preserving individual trees of high wildlife value (dens, nests, roost, mast producers) (Payne and Bryant, 1994). In addition, uneven-aged management increases vertical diversity. The end result is an even distribution of a low but constant population of understory plants and associated wildlife (Payne and Bryant, 1994).

Meeting the primary objective for a diverse forest cover will mean wildlife communities on OWM land will be dominated by species adapted to forested conditions. Species requiring early successional or open habitat will be less common, isolated to those areas where that type of habitat exists. Open and early successional habitat will be deliberately maintained on a small percentage of OWM land, primarily associated with developed areas (dams, dikes), and beaver impoundments. Forest wildlife communities should benefit the most from OWM's management plan.

5.4.1.2 Specific Impacts

A number of specific silvicultural practices for the modification of existing forest conditions on the Sudbury watershed were presented in Section 5.2.2. These include:

- Preparatory cutting and enrichment planting as needed to establish the next stand.
- Regeneration release cutting, which allows the established regeneration to grow and develop.
- Larger overstory removals in plantations.
- Non-harvest removals on sensitive sites to restructure the forest composition without the disruption associated with harvesting.
- Specific practices in riparian zones.

Described below are the projected possible impacts of these activities on wildlife species and habitats.

Preparatory Cutting and Planting

This type of silviculture is primarily practiced in stands that either lack adequate understory regeneration or regeneration is lacking species diversity. Prep cuts involve opening up the canopy and may also include disturbing the forest floor and planting selected species. As with most types of active management, this type of silviculture involves trade-offs. Thinning the canopy will stimulate the understory and increase vertical diversity within the stand. This should benefit species requiring a developed understory (Eastern towhee, snowshoe hare), but will negatively impact species requiring older, intact forest canopies (northern goshawk, pileated woodpecker). Overall, wildlife diversity within these stands should increase as vertical and species diversity increases, although specific wildlife species may either benefit or decline from the alteration.

Disturbing the forest floor could have a negative impact on those species living on the forest floor, or living in the leaf litter or shallow soil (ovenbird, red-backed voles, and spotted salamanders). However, this impact is temporary and the resultant increase in density of ground cover will be a benefit to these species. Planting desired species within a stand (e.g., conifers) will increase the species diversity of the area and provide a faster amount of understory cover.

Release of Regeneration

Single-tree selection: Silvicultural methods proposed during this 10-year plan focus on group selection (approx. 2 acres) removal of overstory trees to release regeneration. In addition, some single-tree selection may also be used. Group selection has a potentially larger impact on wildlife habitat and species than single-tree selection. Single-tree selection essentially maintains an intact forest canopy and is well suited to regenerating shade-tolerant tree species. Those species requiring continuous forest canopy and large tracts of unbroken forest habitat are favored by single-tree selection because the integrity of the habitat in not altered. Many Neotropical migratory forest songbirds (forest warblers, wood thrush, and ovenbird) are edge sensitive species that require unbroken tracts of forest to successfully breed. When single trees are removed from the forest, no edge or transition habitat is created and the forest interior is maintained. While this will benefit these edge sensitive species, those species that rely on edge habitat (ruffed grouse, white-tailed deer, Eastern towhee, chestnut-sided warbler) will be limited to areas where it exists.

Group selection: A good deal of attention has focused on the potential problems of forest fragmentation in the northeast. Most of this effort has centered on Neotropical migrants and the continued decline of some species. It has been shown that area-sensitive songbirds do not reproduce well along edge habitats (Sullivan and Brittingham, 1994). In most cases, when trying to conserve edge-sensitive species, it is recommended that extensive areas of contiguous forest are maintained and the amount of edge habitat minimized. Because the Sudbury watershed is a mosaic of habitat types and represents a fragmented landscape, it is hard to speculate how much impact OWM land management activities will have on edge-sensitive species. Alterations to OWM forested land is not analogous to what would occur if the same land were developed for residential housing or agriculture. However, since OWM proposes to use group selection (approx. 2 acres) to treat a majority of their stands, it is prudent to consider the impact of this practice on wildlife communities.

The most influential factor associated with this type of silviculture would be the introduction of edge effects. Many studies have documented the reduced nesting success of songbirds near forest edges when compared to the interior (see Wilcove, 1988). This reduced success is a result of nest predators (blue jays, chipmunks, raccoons, crows) and/or nest parasites (brown-headed cowbird). In addition, rates of cowbird parasitism increase near openings within large forest tracts (Wilcove, 1988). Initially it might appear that edge effects would be limited to isolated woodlots surrounded by houses or barren land. On the larger blocks of OWM land at the Sudbury, there is primarily a matrix of interconnected forest at different stages of succession. Unfortunately, edge effects are applicable to forest ecosystems because small openings within forests create edges.

Although most changes in vegetation caused by group selection extend only 30-100 feet into the forest, increases in nest predation and parasitism may extend as far as 1,000-2,000 feet into the forest. Therefore a small number of openings in the forest could impact a large area. Adding to the problem could be the nature of the Sudbury watershed. OWM land often abuts other non-forested areas or small woodlots where large numbers of nest predators potentially live and reproduce (residential areas support cats, raccoons, bluejays, etc.). Therefore, predation rates could very likely be higher in the adjacent forest openings.

Impacts of fragmentation on mammals are less well known. It is likely that species most sensitive to forest fragmentation were extirpated long before they could be studied. Mountain lions, wolves, elk, and woodland bison have been gone from the watershed for decades. As a result, those mammals left within the watershed are the ones adapted to surviving in fragmented, human-altered landscapes. It is likely that the main limiting factor on mammal populations is human disturbance and not fragmentation.

Openings within forests do benefit some wildlife species, which depend on herbaceous and early successional forest habitat. Wild turkey, ruffed grouse, Eastern towhee, red-shouldered hawk, and white-tailed deer will benefit from the proposed openings. Forest openings will allow for denser ground cover, increased light, and a more open canopy. This type of habitat favors certain species of wildlife.

Large Removals of Plantation

A full overstory removal in plantations produces the greatest immediate change in habitat. Full overstory removal is essentially even-aged management and involves both positive and negative impacts to wildlife. In general, removing the overstory will provide excellent early successional habitat that is utilized by a variety of species. Early successional species will particularly benefit from this management because the larger stand size will attract and sustain larger populations of those species. Those species requiring continuous forest canopy will be impacted by these treatments. In addition, species utilizing conifer-dominated habitat (red squirrels, some Neotropical migrants, nesting raptors) may be displaced by the removal of conifer plantations.

Non-harvest Removals on Sensitive Sites

There are areas on the Sudbury watershed where a reduction of overstory trees is desirable in order to diversify age structure, but where conventional harvesting may be impossible or risky (e.g., a shoreline plantation or a hurricane exposed island). On a limited number of these sites, OWM proposes to cut trees but not remove them. This practice would enhance forest regeneration without negatively impacting the sensitive site. Non-harvest tree cutting would add course woody debris to an area, particularly large size log classes that are important to a variety of wildlife. In addition, removing some canopy trees will increase species diversity and enhance the ground and shrub layers of the area.

Riparian Zone Management

OWM is proposing the non-harvest removal of trees along riparian wetlands within the Sudbury watersheds to increase light and stimulate regeneration. Cut trees will be left in place along the riparian area. This will add course woody debris, providing additional cover and nutrients for forest floor wildlife. In addition, the additional light will allow for a greater diversity of understory trees and ground cover. This will benefit wildlife species that benefit from a denser understory layer of vegetation.

This management practice could have potential negative impacts on the wildlife community depending on where the harvesting was to occur and how many overstory trees were removed. Removing a large number of deciduous trees along the riparian zone could have potential negative impacts to species requiring large expanses of continuous wooded streams. However, if single trees or small groups are removed, these impacts would likely be minimal.

When harvesting trees along the riparian area it is important to try and save cavity or potential cavity trees. Cavity trees along riparian wetlands are extremely valuable to a range of wildlife species.

A final consideration regarding this management technique would be to recognize that stimulating regeneration and new growth along riparian wetlands might be beneficial to beaver populations. Availability of a winter food supply is an important factor affecting beaver distribution in areas where stable water levels are possible.

5.4.2 Conservation Management Practices for Wildlife Management

OWM foresters are concerned primarily about maintaining water quality standards and improving forest health and vigor. Monetary gain from forest resources is a minor consideration when planning management activities. A direct result of this flexibility is that it allows OWM foresters to incorporate sound and beneficial wildlife management components into their forest cutting plans. High quality mast trees, active and potential den and nest trees, and critical habitats have been and continue to be conserved and encouraged on OWM property.

CMPs for wildlife management are generally complementary to water quality protection standards. The following wildlife CMPs highlight current management techniques already being practiced and elaborate on other management techniques that can be employed.

5.4.2.1 Habitat Features and Management Recommendations

Vernal Pools

Vernal pools are contained basin depressions with no permanent outlet that typically hold water for at least 2-3 months in the spring and summer. Vernal pools may or may not dry completely each year, but their periodic drying, shallow water, winter freezing, and low oxygen levels keeps them free of fish populations.

Because of their unique characteristics, vernal pools play a critical role in the life cycles of many amphibians, reptiles, and invertebrates. As a result, OWM considers vernal pools to be critical wildlife habitats. In fact, many state-listed species are associated with or dependent on vernal pools. Many vernal pools dry completely during the late summer and fall and can be difficult to identify. In recent years, OWM has made efforts to locate and identify vernal pools during the spring. Accurate and detailed records of located pools, including UTM coordinates and animal use, are stored in databases. In addition, the University of Massachusetts, Amherst recently identified over 30 "potential" vernal pools on the Sudbury watershed through aerial photos. The location of these pools has been digitized and most were field checked in 2004 to ascertain their status. Locations of documented vernal pools will be transferred to a GIS data layer for inclusion in land management planning documents.

VERNAL POOL

Research is currently being conducted at Quabbin Reservation to test the effectiveness of Massachusetts Best Management Practices for vernal pools. While the state BMPs provide direct protection of the pool, there is concern that the wildlife species utilizing the pool may also rely on a larger area surrounding the pool for a majority of their life cycle. This research will test the effectiveness of the current BMPs.

<u>Vernal Pool Management Objective:</u>

Locate and identify all vernal pools on its property and maintain vernal pool depressions in an undisturbed state.

Recommended Practices - General:

- Seek additional input from NHESP when management activities are going to occur around a pool that contains state-listed species.
- Digitize all aerially interpreted vernal pools and provide data layer to GIS personnel for inclusion in land management activity plans.
- Identify and confirm status of photo-interpreted vernal pools.

Recommended Practices within Pool Depression:

- Continue to maintain physical integrity of pool depression and its ability to seasonally hold water.
- Continue to keep depression free of slash, treetops, and sediment from forestry operations. If slash does fall into pool during the breeding season do not remove it so breeding activity is not disturbed.

Recommended Practices at Edge of Pool:

- Keep shaded condition in 100-foot buffer zone around pool depression.
- Minimize disturbance of forest floor within 200 feet of pool edge.
- Avoid making ruts >6 inches deep within 200 feet of the pool.
- Conduct low-intensity harvests preferably when ground is frozen.

Seeps

Woodland seeps tend to be small (< ¼ acre) areas where ground water flows to the surface of the forest floor and saturates the soil. Seeps generally don't freeze during the winter and typically have little or no snow cover. Seeps often occur in natural depressions and may act as "seed traps" in which nuts, seeds, and fruits from surround trees and shrubs accumulate. This makes them important winter feeding sites for turkey, deer, and other wildlife.

WINTER SEEP

Seeps provide a seasonally important source of food and water for resident and migratory wildlife (Hobson et al., 1993). These areas tend to have early sources of green vegetation. This can be an important food source for black bears in the spring and early summer. Earthworms and insects at seeps attract early migrants such as robins and woodcock. Spring salamanders and hibernating frogs, which can attract skunks and raccoons, may also use seeps.

Seep Management Objectives:

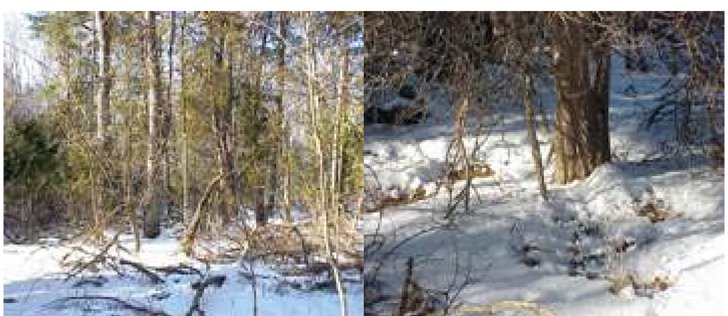
Continue to protect seeps, springs, and surrounding soils.

Recommended Practices:

- Avoid leaving slash in woodland seeps or springs.
- Maintain mast-producing trees above and around seep.
- Remove conifer trees on South side of seep; retain conifers on North and West sides.
- Where seeps are present, schedule harvests to occur on frozen ground or during the driest conditions.
- Avoid running heavy equipment within 50 feet of the edge of A SEEP.
- When feasible, use seeps as the center for uncut patches to retain cavity trees, snags, and other wildlife features.
- In stands where seeps are present, lay out skid trails and roads prior to the harvest when seeps are obvious.

Wildlife Wintering Areas

Wildlife wintering areas (WWA) provide shelter and food for animals during the winter months when cold temperatures, snow cover, and limited food resources create physiologically demanding conditions. An important wintering area is often related to white-tailed deer use of concentration areas. These deer wintering areas (DWA) typically are in hemlock or pine stands where there is >70 percent conifer crown closure (Elliot, 1998). Deer typically move to these areas when snow depths are around 12" (Flatebo et al., 1999). DWA provide reduced snow depths, higher nighttime temperatures, reduced wind, and greater relative humidity (Flatebo et al., 1999). These areas must not only provide adequate cover, but also a quality supply of deer food. Cedar, red and sugar maple, birch, and hemlock are preferred foods. Another important wintering area is dense conifer cover (i.e., spruce stands) that provides increased thermal protection and wind cover for a variety of birds and mammals. For example, grouse will seek conifer stands when snow depths are <8 inches for thermal protection.



WILDLIFE WINTERING AREAS

The general guideline for wildlife wintering areas is to maintain as much overstory as possible, while providing for the establishment and continued growth of preferred browse and conifer tree species.

Wildlife Wintering Areas Management Objectives:

Maintain functional value of wildlife wintering areas.

Recommended Practices:

- Identify and map all known or potential WWA using aerial photos, cover type maps, and field inspections.
- When feasible, schedule forest harvesting operations during December-April within WWA so tree tops are available for browse.
- Protect advanced conifer regeneration during timber harvesting.
- Cut stumps low to encourage vigorous sprouting.
- Planned activities within WWA should be conducted to ensure that at least 50% of the wintering area remains in closed canopy coniferous overstory to provide functional shelter.
- Avoid concentrating harvest in any one area of the WWA.
- Try to maintain travel corridors (unbroken, dense softwood cover 60-100m wide) that connect all areas of the WWA.

Mast

Mast is a critical component of quality wildlife habitat. Trees, shrubs, and vines produce fruits, nuts, and berries called mast. Mast can be hard (nuts, seeds) or soft (fruit, berries). It contains more fat and protein than other plant foods and is actively sought by a variety of birds and mammals. In autumn, mast is particularly important as many animals will focus on eating mast in preparation for winter. Bears, squirrels, raccoons, deer, and turkey will fatten up on acorns, beechnuts, and hickory nuts. Resident songbirds such as nuthatches, chickadees, and bluejays rely on mast during winter when other food is scarce. Migrating birds will often rely on fruits and berries during migratory stops to replenish energy.

Although all trees and shrubs are defined as mast producers, some species are more important to wildlife. The value of mast to wildlife differs with the size, palatability, accessibility, nutritional content, abundance, and production frequency (Flatebo et al., 1999). In general, oak, hickory, beech, walnut, butternut, cherry, ash, and conifers are the most important mast trees. In addition, birch, hazel, alder, and aspen are also important to some wildlife species.

a. Hard Mast

The oaks are the most important source of mast in the Sudbury watersheds. Hickories comprise a relatively small (1%) component of the overstory. Oaks are probably the most important wildlife mast trees in the northeast. Acorns are eaten by over 100 species of birds and mammals (Healy, 1997). The frequency and characteristics of oak production varies from species to species. Red oaks produce a good crop of acorns every 2-5 years, black oaks every 2-3 years, and white oaks every 4-10 years. Red and black oak acorns take 2 years to develop, while white oaks take only 1 year. Peak acorn production begins at around 25 years for red oaks, 40 years for white oaks, and 40-75 years for black oaks (Flatebo et al., 1999). White oak acorns contain less tannin and may be more palatable to wildlife.

Hickory trees comprise a much smaller component of the Sudbury watershed forest. Hickories are scattered around the watershed, usually interspersed with oaks. They have good seed crops every 1-3 years and begin producing quality crops at 40 years. Hickory nuts have one of the highest fat contents of any mast.

The seeds of maples, birches, ashes, and conifers provide food for many birds and small mammals. Red squirrels rely heavily on conifer seeds and their populations will fluctuate in response to annual crops. Birches are an important mast producer because most of the seed crop is retained on the tree above the snow. Birds, including pine siskins and grouse, count on birch seeds for their winter diet. White and red pine are the most widely distributed trees at the Sudbury. Mice, voles, grosbeaks, and finches are a few of the animals that utilize conifer mast. Chickadees and goldfinches prefer hemlock seeds.

b. Soft Mast

Black cherry trees comprise a relatively small percentage of the Sudbury watershed forest canopy. However, small mammals, and over 20 bird species eat cherries (Flatebo et al., 1999). Pin and chokecherries are short-lived, but provide valuable fruit to wildlife. A variety of understory shrubs and trees produce soft mast. Blueberries, serviceberries, dogwoods, and viburnums are abundant. In addition, herbaceous plants such as blackberry, raspberry, wild strawberry, and partridgeberry, are utilized by many species of wildlife.

Mast Management Objectives:

Continue to maintain and encourage a variety of mast-producing plants within the watershed.

Recommended Practices:

- Continue to manage stands to contain multiple species of mast-producing trees and shrubs.
- Continue to retain productive beech, oak, and hickory trees when they occur as single or scattered trees in stands dominated by other species.
- Retain beech trees with smooth or blocky bark or raised lesions to promote resistance; remove standing trees with sunken cankers or dead patches to reduce sprouting of diseased individuals. Retain some large beech trees that have potential for good mast production, regardless of disease condition.
- Lay out skid trails and roads that avoid vigorous patches of understory shrubs.
- When possible, save all hardwood mast trees that occur in conifer plantations.

Wildlife Trees

Wildlife trees are often divided into two categories: snags and den trees. Snags are standing dead or partially dead trees at least 6" dbh and 20 feet in height. Den trees are live trees possessing a cavity large enough to serve as shelter for birds and mammals or a site to give birth and raise young. In general, den trees must be 15" or greater in dbh and have a minimum cavity opening of 4" in diameter (Blodgett, 1985). Over 50 species of northeastern birds and mammals utilize snag and den trees during part of their lives (Blodgett, 1985). Some uses of snags and den trees include cavity nest sites, nesting platforms, food caches, dwellings or dens, nesting under bark, over wintering sites, hunting and hawking perches, sources of feeding substrate, and roosting.

Forestry operations most likely have the greatest potential impact on the number, type, and location of snag and den trees at the Sudbury. Thinnings, salvage, firewood cutting, and windthrow will result in wildlife tree loss. However, OWM's use of uneven-aged management is conducive to snag management. Single-tree or group selection harvest practices will have only slight to moderate adverse impacts on snag production and retention. Although it would be ideal to salvage all wildlife trees, practical field applications make that unlikely. It is possible to maintain an optimal number of snags and dens across the watershed (Table 22).

TABLE 22: OPTIMUM NUMBER OF SNAGS AND DEN TREES PER 100 ACRES BY BROAD HABITAT TYPES

	Forest Interior		Semiopen/open	Wooded Watercourse
Tree dbh (in)	Dens	Snags	Dens[1]	Dens[1]
> 19	100	0	300	200
10-19	400	400	400	1400
< 10	200	200	300	900

Source: Payne and Bryant, 1994

[1]Animals here need den trees because creating snags by deadening trees is not recommended in these land-use patterns.

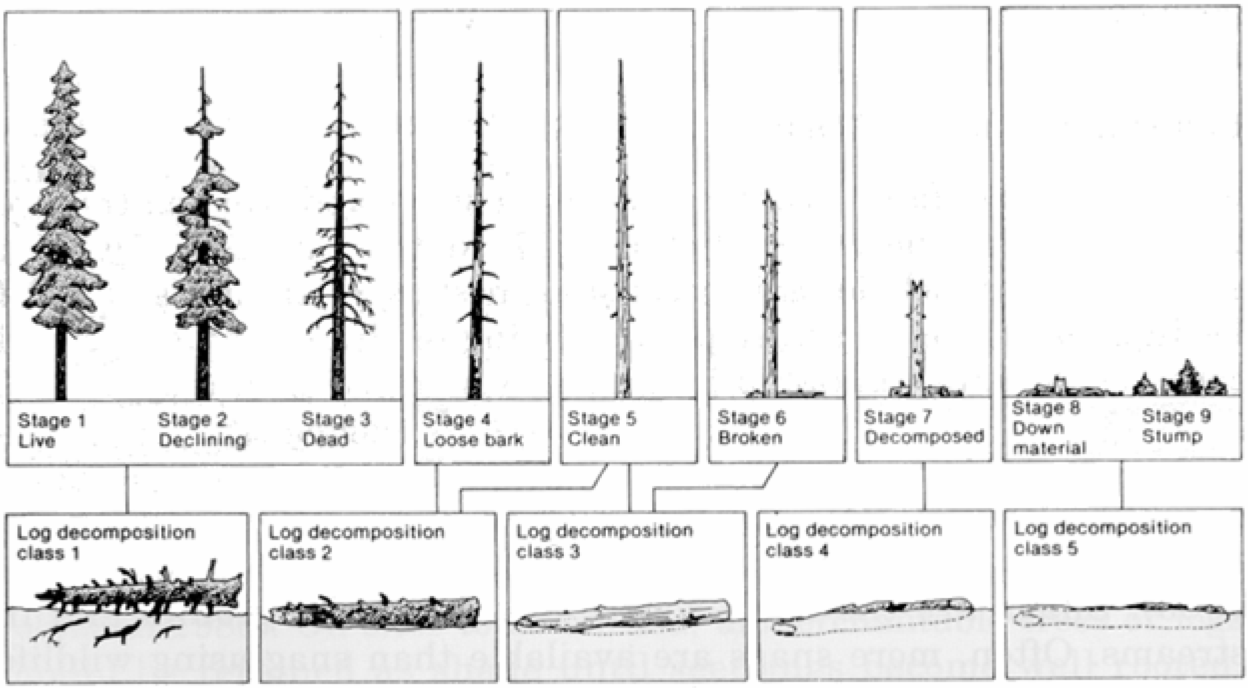


FIGURE 9: DECOMPOSITION STAGES OF SNAGS AND DOWNED LOGS

a. Snags

As a tree dies, it progresses through several stages of decay (Fig. 9) and is used by different wildlife at each stage. Newly exposed bare branches provide excellent perches for woodland hawks (Cooper's, sharp shinned), as well as flycatchers and phoebes. During the loose bark stage, brown creepers and bats may nest or roost under the bark.

As a tree deteriorates, primary excavators (woodpeckers) begin to create cavities. Almost all northeastern woodpeckers excavate nest cavities in live or dead trees. Secondary nesters then use these cavities. Once trees have decayed to a point where there are no longer branches, it is classified as a snag (< 20 feet tall is a stub). Many insectivorous birds will use the snag for foraging. Finally the snag will either topple to the ground or wear to a stump. The fallen log provides habitat for carpenter ants. In addition, amphibians and reptiles will live in and under the rotting wood. Small mammals also utilize the downed logs.

In addition to the stages of decay, other variables determine a particular snags value to specific wildlife species. Characteristics such as tree size, location, species, and how it was killed are important determinants of wildlife use (DeGraaf and Shigo, 1985). In general, when managing for cavity trees, the rule 'bigger is better' is ideal. Large birds need large diameter trees to excavate nesting cavities. Smaller birds are able to find nest sites in large trees, but it does not work the other way. In addition, large snags usually stand longer than smaller ones. Emphasis is often placed on managing for viable woodpecker populations because their success will provide enough nesting sites for secondary cavity nesters (Table 23).

TABLE 23: NUMBER OF CAVITY TREES NEEDED TO SUSTAIN NEW ENGLAND WOODPECKERS

Species	Territory Size (Acres)	Avg. nest tree[1]		(A) Cavity trees used, minimum (N)	(B) Pairs/100 acres, maximum (N)	(C) Cavity trees needed/100 acres[2] (AxB) (N)
		D.B.H (in.)	Height (ft.)			
Red-Headed Woodpecker	10	20	40	2	10	20
Red-bellied Woodpecker	15	18	40	4	6.3	25
Yellow-bellied Sapsucker	10	12	30	1	10	10
Downy Woodpecker	10	8	20	4	10	40
Hairy Woodpecker	20	12	30	4	5	20
Three-toed Woodpecker	75	14	30	4	1.3	5
Black-backed Woodpecker	75	15	30	4	1.3	5
Northern Flicker	40	15	30	2	2.5	5
Pileated Woodpecker	175	22	60	4	0.6	2.4

Source: DeGraaf and Shigo, 1985.

[1] Larger trees may be substituted for smaller trees.

[2] Number of cavity trees needed to sustain population at hypothetical maximum level.

Snag Management Objectives:

Continue to provide a supply of good to excellent quality snag trees, distributed over time and space in order to maintain self-sustaining populations of all cavity dependent wildlife. Retain poorer quality trees in areas where good den trees are lacking until better trees develop.

Recommended Practices:

- When possible, leave all snags within 100 feet of wetlands and riparian areas.
- Maintain a minimum of 6 snag trees per acre; 4 should be > 24" dbh and 2 <24" dbh.
- Avoid disturbing snags from April to July to stay away from nesting birds and denning mammals.
- If snags must be felled during management operations, then leave them in place instead of removing them.
- When possible, identify current or potential snags through exterior signs such as fungal conks, butt rot, burls, cracks, wounds/scars from lightning, fire, or mechanical damage, woodpecker holes or cavities, or dead or broken limbs or tops so they can be salvaged.

b. Den Trees

Den trees are living, hollow trees used by a variety of mammals including mice, raccoons, squirrels, and bears. In general, there are usually fewer den trees available in an area than could be used by wildlife because large (>15" dbh) rough or rotten trees are relatively rare.

DEN TREE

Unlike cavity trees, which have central columns of decay, den trees are hollow or have large hollow limbs, but are still alive and vigorous. Den trees usually have easily visible openings in the sound wood. Some heavily used den trees (i.e., by raccoons) are hardwoods with the top snapped off. Den trees usually have low commercial value, but their value to wildlife is extremely high and long lasting. It may take 100 years to develop large den trees, and once developed some trees (oaks, sugar maple) can live for several hundred years (DeGraaf and Shigo, 1985). Once den trees die and fall to the ground, the remnant hollow log may last 25 years, providing breeding habitat for redback salamanders and ringneck snakes.

Den Tree Management Objectives:

Provide a continuing supply of good to excellent quality den trees, distributed over time and space in order to maintain self-sustaining populations of all cavity dependent wildlife. Retain poorer quality trees in areas where good den trees are lacking until better trees develop.

Recommended Practices:

- Retain as many live trees with existing cavities and large unmarketable trees as possible.
- When possible, retain all trees > 29" dbh or at a minimum 2 or more trees >29" dbh per 100 acres.
- Leave at least 1 tree 15-29" dbh per acre.
- Leave at least 1 tree per acre that shows potential for developing into a den tree (broken top, large broken limbs, fire scar); oaks, sugar maples, ash, and hemlock are good trees to select because they readily form natural cavities or are long-lived.
- Leave all dens trees within 100 feet of a wetland or riparian area.

Downed Woody Material

DOWNED WOODY MATERIAL

Downed woody material refers to slash, logs, large and small limbs, stumps, and upturned tree roots that accumulate on the ground either naturally or through forestry operations. Downed woody debris provides food, cover, and nursery habitat for a range of flora, fauna, and fungi. Downed woody material provides critical wildlife habitat and is used for nesting, shelter, drumming, sunning, as a source and place to store food, and as natural bridges. The specific value of downed woody debris depends on the physical distribution, amount, size, degree of decay, and orientation of debris relative to slope and exposure (Flatebo et al., 1999). Decaying logs also serve as nurse-trees for seedlings and colonization sites for fungi. Too much or too little downed woody material can be detrimental to wildlife. In general, it is best to retain or produce downed woody material that is distributed similarly to what would occur naturally.

Logs are generally considered to be the most valuable downed woody material because of their slow decay and longer persistence. Long logs >16" dbh are especially important wildlife habitat features. As logs age and decay their role as wildlife habitat shifts. Logs supported by branches provide shelter, feeding, and display sites for a variety of birds and mammals. As the log settles to the ground and continues to decompose it may be used by small mammals, snakes, toad, and salamanders for shelter, food, and travel. Large logs with hollow portions may be used as den sites by larger mammals.

<u>Downed Woody Material Management Objectives:</u>

Continue to maintain a range of sizes and types of downed woody material and retain or provide downed woody material in sites where it is lacking.

Recommended Practices:

- If snags must be felled during management operations, leave them in place
- Avoid damaging existing downed woody material during harvesting, particularly large (>16" dbh) hollow logs and stumps.
- When possible, leave at least 4 logs of decay class 1 and 2 per acre (Fig. 9); at least 2 of these logs should be >12" dbh and >6 feet long. Hollow butt sections of felled trees can be used.
- Retain as many logs as possible of classes 3, 4, and 5 (Fig. 9).
- On slopes, orient logs along contours and place against stumps when possible.
- If clearcuts are done, leave slash on at least 10% of the site in scattered piles or rows.
- Do not add debris to streams and avoid disturbing woody material already in stream.

Woodland Raptor Nests

Hawks, owls, falcons, and vultures are known as raptors. There are 19 species of raptors that breed in New England, fourteen of which are known or potential breeders at the Sudbury (Table 24).

BALD EAGLE NEST

OSPREY NEST

TABLE 24: ACTUAL AND POTENTIAL BREEDING RAPTORS ON THE SUDBURY WATERSHEDS

Species	Breeding Status	Nest Site Selection
Turkey Vulture[1]	Potential Breeder	Rocky outcrops, ledges, cavities
Osprey	Breeder	Stick nests in trees, snags, poles
Bald Eagle[2]	Potential Breeder	Stick nests in living trees
Northern Harrier[2]	Non-Breeder	On ground, over water
Sharp-shinned Hawk[2]	Potential Breeder	Stick nest on tree limb-usually conifers
Cooper's Hawk[1]	Potential Breeder	Stick nest (may use old crow nest) on horizontal branch in hardwood or conifer
Northern Goshawk	Breeder	Stick nest (used or new) in hardwood
Red-shouldered Hawk	Breeder	Stick nest (new) in tall tree
Broad-winged Hawk	Breeder	Stick nest in tall tree
Red-tailed Hawk	Breeder	Stick nest in oak/white pine
American Kestrel	Breeder	Cavity, nest box
Barn Owl[2]	Non-Breeder	Cavities, buildings, artificial
Screech Owl	Breeder	Cavities and woodpecker holes (Pileated/Flicker)
Great-horned Owl	Breeder	Cavities, old crow, hawk, or heron nests
Barred Owl	Breeder	Large natural cavities or old bird nests
Long-eared Owl[2]	Non-Breeder	Old crow/hawk nest or natural cavity
Saw-whet Owl	Potential Breeder	Natural cavity or woodpecker hole
Short-eared Owl	Non-Breeder	Open fields, heath on Cape/Islands
Peregrine Falcon	Non-Breeder	Cliffs, tall buildings, urban areas

Source: adapted from DeGraaf and Rudis, 1986

[1]Potential breeders are raptors that have not been documented breeding within the Sudbury watersheds, but given the bird's range and habitat requirements it may be breeding or could breed there in the future.

[2]Listed with the Massachusetts Natural Heritage and Endangered Species Program as an endangered, threatened or special concern species.

Most raptors are predators and feed upon birds, mammals, fish, amphibians, insects, and snakes. While most raptors will eat a variety of animals, some species like the osprey have much narrower food requirements. Compared to other birds, raptors require relatively large home ranges (60 to more than 900 acres) in order to meet their food and nesting requirements. Raptor nests are widely dispersed across the landscape in a variety of habitats and forest conditions.

Some raptors will build a new nest each year within their territory, while other raptors will use the same nest for a number of years or claim the nest built by another species. Raptor nest trees must be large and strong enough to support nests ranging from 18" in diameter (broad-winged hawk) to over 3 feet (bald eagle, northern goshawk) (Flatebo et al., 1999). Large diameter broken stubs, closely spaced branches halfway up large white pines, and 3-pronged main forks of mature hardwoods are most frequently used by stick nest building raptors. By maintaining existing nests and identify potentially good future nest trees, an area's raptor population can be maintained over a long period.

Many raptors nest early in the year. By February-March, most great-horned owls and some red-tailed hawks and barred owls are incubating eggs. Most other raptors will be incubating by May. Nesting raptors can be vulnerable to human disturbance. There is a wide range of tolerance depending on the species. Some intolerant species (bald eagles, goshawks) may abandon the nest during the early weeks of incubation. Repeated flushing of the female from the nest may also subject the eggs to fatal chilling or the young to predation.

Identifying active nests is critical to ensuring their protection and establishing a buffer zone to minimize disturbance. The easiest, and unfortunately most infrequent, way to detect active nests is to see birds in or around the nest. However, active nests can be identified when no birds are visible by looking for the following indicators:

- Prior to laying eggs, some raptors decorate the nest with fresh branches, usually from a conifer.
- After hatching, whitewash (excrement), regurgitated pellets, and prey remains may be found on the ground near the nest tree.
- Raptor nests can be distinguished from squirrel nests by their shape (squirrel nests are saucer-shaped) and lack of leaves (squirrel nests are made mostly of leaves).
- If unsure, consult with an experienced birder or wildlife biologist.

<u>Woodland Raptor Nests Management Objectives:</u>

Maintain suitable nesting sites for woodland raptors across the landscape over time and avoid disturbing nesting pairs of raptors.

Recommended Practices:

- Contact OWM's wildlife biologist when planning forest management activities in the vicinity of a bald eagle nest.
- Inspect mature white pine and hardwood trees for large stick nests when cruising timber. When possible, do not cut trees containing large stick nests and hardwoods with 3-pronged forks.
- Maintain an uncut buffer of at least 66 feet around active raptor nest trees and retain 65-85 percent canopy closure within 165 feet of large stick nests in closed-canopy forests.
- If an active raptor nest is located before or during a scheduled harvest operation, maintain an uncut buffer of at least 66 feet around nest tree, and do not harvest within 330 feet of the nest during April-June.
- If an active raptor nest can be positively identified as belonging to a common or tolerant species (i.e., red-tailed or broad-winged hawk), then harvesting schedules and buffer zones may be relaxed.
- Retain several super canopy pines near the reservoir shoreline as potential future nest trees for bald eagles.
- Follow appropriate snag tree management guidelines.

5.4.2.2 Considerations During Marking

While careful planning and preparation can mitigate many of the potentially negative impacts on wildlife resources, some specific impacts or events cannot be discovered until operations begin in the field. Locations of active raptor nests, quality den and snag trees, and seeps may not be discovered until foresters begin marking individual trees in a lot. It is during these detailed lot inspections that some of the specific wildlife habitat management recommendations can be implemented.

In addition, broader considerations such as timing of operations, harvesting techniques, record keeping, and other miscellaneous considerations should be addressed in the field.

Timing of operations

The timing of land management activities can have a dramatic impact on wildlife species. Some species (bald eagles, great-blue heron, and coyote) are extremely sensitive to human disturbance and may abandon or forgo breeding when repeatedly disturbed. Fortunately, some sensitive species can be easily identified or have known nesting sites. Great-blue herons nest in visible colonies, usually in dead snags over water. In addition, bald eagles build large stick nests that are easily seen and may be used for many years. However, for most other species, their nest, burrow, or den is well hidden and would not be discovered until an operation had already begun. Luckily, most wildlife species tend to nest or den during the spring and early summer when land management activities are restricted. When conflicts do arise, the following procedure will be followed:

- OWM personnel will notify the wildlife biologist when land management activities have clearly disrupted a rare or uncommon species' breeding efforts.
- OWM wildlife biologist will assess the nature of the nesting/denning activities and determine what species is involved, what stage of breeding is occurring (courtship, incubation, brooding) and how they responded to the initial disturbance.
- OWM will determine what options will be used to mitigate and avoid further disturbance during the remainder of the breeding season.

Land management activities conducted at other times of the year may unknowingly impact wildlife species, and efforts should be made to reduce these conflicts. Maintenance (mowing) of fields and open areas should only be done after August 1 to avoid destroying nesting birds and mammals (Vernegaard et al., 1998, Jones and Vickery, 1998). No activity should occur in or near seeps during winter. If possible, winter activity should be avoided in and around identified wildlife wintering areas.

In some cases, activity during certain times of the year is preferred. Working around vernal pools is often best during winter when frozen/dry conditions minimize rutting and disrupting the forest floor. Further, logging during the fall and winter usually has minimal impact on most wildlife species and may actually benefit some animals by providing additional browse and cover.

Land management activities conducted at any time of the year have the potential to disrupt some wildlife species. However, this disruption is usually small in scale and scattered over the watershed. The benefits derived from actively managing the land outweigh the localized disruption. Because impacts cannot be avoided everywhere, OWM will:

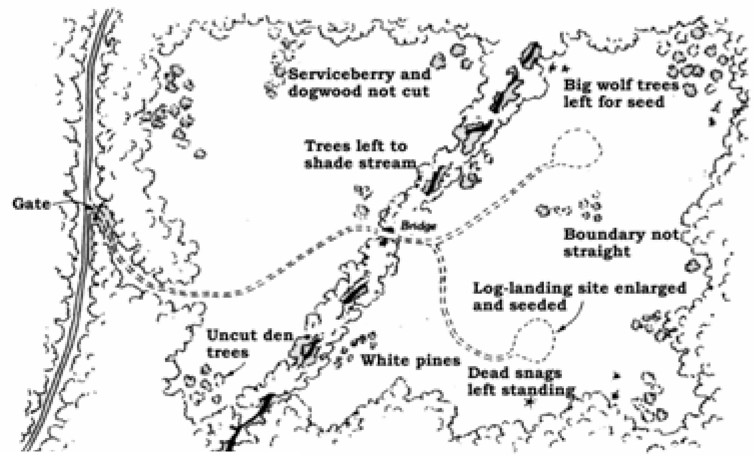
- Continue to gather data on critical and sensitive wildlife and their habitats on the watershed.
- Assess the potential impacts of when operations are conducted on a case-by-case basis to try and avoid major impacts and impacting special concern species.
- When feasible, shift the timing or location of an operation to avoid these impacts.

Harvesting Techniques

a. Group Selection Considerations

When forestry operations use group selection to remove trees in openings 1 acre or greater in size, certain techniques and considerations can be used to enhance the area for wildlife. With proper planning, harvesting operations can be conducted while still maintaining snags, den trees, and mast producing trees within the opening (Fig. 10). In addition, creating an irregular, feathered border will help reduce nest predation and parasitism.

FIGURE 10: FOREST OPENING PLANNED WITH WILDLIFE CONSIDERATIONS



Payne and Bryant, 1994

b. Logging and Skid Roads

Access roads are used by OWM to remove wood, control fires, maintain watershed structures, and aid in navigation. Most OWM roads within the watershed are narrow, grassy woods trails often referred to as logging roads. OWM's use of uneven-aged forest management requires harvest operations to extend over a relatively large area and use comparatively short rotation times (20-30 years). As a result, a network of roads are created and maintained.

The effect of forest roads on wildlife and biodiversity depends on the size, type and location of the road. The frequency with which a road is used also determines its impact, as do its proximity to wildlife habitats and travel routes. Roads effectively create an edge habitat that benefits some species, but has negative effects on species sensitive to disturbance or predators. Roads are often used by some wildlife species as travel lanes, but they may impede the movements of other species that require continuous vegetative cover. Roads may also fragment the forest and isolate individuals or populations.

Constructing and maintaining forest roads on OWM property constitutes a relatively permanent change in the habitat structure of the area. Because traffic on OWM roads, particularly at night, is minimal, there is little concern about direct mortality on wildlife populations. The more general concern is that a strip of dirt or gravel under an open canopy can serve as a physical or psychological barrier to animal movements. Studies have documented this barrier affect for small mammals, amphibians and invertebrates (deMaynadier and Hunter 2000).

When logging roads, skid trails, and landings are being planned, certain design features can be incorporated to minimize wildlife impacts.

- Logging roads/skid trails should avoid vigorous patches of shrubs.
- New logging roads should be minimized, and if possible, existing roads should instead be upgraded.
- Roads should be as narrow as possible, ideally one-lane with occasional turnouts.
- Circular routes should be avoided; a cul-de-sac design is better.

- When possible, abandoned logging roads, skid trails, and landing sites should be seeded with a grass-legume mixture.
- Road intersections should be angled to limit line of sight.
- Large-crowned hardwood trees should be left at the road's edge to provide shade and leaf litter.

c. Record Keeping

OWM foresters and other natural resource managers spend a significant amount of time walking, observing, and assessing lands within the Sudbury watersheds. It is likely that they may observe significant wildlife or important wildlife habitats. Because of the size of the watershed, these anecdotal observations are a critical source of biological information, and may be key to avoiding or mitigating potential wildlife impacts of future land management activities. These observations must be reported to OWM wildlife biologist so that records may be routinely maintained and updated.

d. Miscellaneous Considerations

In general, OWM's silvicultural practices include cutting trees with weak crown forms that are more susceptible to damage. Some of these trees have wildlife value, and OWM foresters should continue to leave some of these trees uncut. For example, trees growing on an angle ("hurricane-tipped") serve as travel routes for arboreal mammals from the ground to the forest canopy. In addition, older trees with large stocky limbs often have protected crotches that are used by nesting birds and mammals. These trees also typically have a high potential for cavity formation. While it is not necessary to maintain all examples of these trees, it is important to retain some during harvesting operations.

Particular combinations of trees species are also valuable to wildlife. Mature oak trees within hemlock or other conifer stands provide food resources within wildlife wintering areas. Small pockets of hemlock within hardwood stands can serve as significant wildlife cover. Both of these habitat conditions should receive special treatment when feasible.

5.4.3 Population or Impact Control Plans

As a water supply reservoir, OWM's primary responsibility is to the long-term adequate protection of the drinking water. In recent years, OWM has identified certain wildlife species as posing a real and persistent threat to the integrity of the water or watershed structures. As a result, OWM has spent a good deal of time addressing these wildlife concerns. In general, it is OWM's policy not to interfere with natural wildlife events. However, when wildlife activities impact either the water quality of the reservoir or the integrity of watershed structures or resources, then OWM takes an active role in mitigating these damages. The species of concern and their associated risks are discussed below.

5.4.3.1 Beaver Management Policy

Beaver management issues within the Sudbury watersheds can be broken down into two categories: water quality protection and damage to structures or resources.

Water Quality Protection

There is consensus in the scientific community that beaver can play an important role in the transmission of harmful pathogens to humans through water supplies. OWM recently completed a report that summarizes these concerns and addresses management recommendations for beaver at both the Wachusett and Quabbin watershed reservoirs. For more detailed information regarding this see the report titled Quabbin and Wachusett Reservoirs Watersheds Aquatic Wildlife Pathogen Control Zones (Clark, 1999). This report clearly defines a protection zone around each reservoir where beaver will be eliminated and excluded on a continual basis for water quality protection. The report does not address beaver management for water quality protection within the Sudbury watersheds. As discussed before, the Sudbury Reservoir is reserved for emergency use only. Because it is not an active water supply reservoir, no defined control zone exists. If a situation arises where water quality is being threatened, then these situations will be handled on a case-by-case basis.

Damage to Structures or Resource

Watershed-wide beaver population control is not conducted by OWM. However, the following are examples of situations in which beaver activity may be discouraged, mitigated, or otherwise controlled:

- Beaver activity that threatens rare or uncommon plant or animal communities.
- Beaver activity that precludes the use of necessary access roads needed for watershed maintenance, management, or protection.
- Beaver activity that threatens the proper functioning or structure of dams, culverts, and other parts of the water supply infrastructure.
- Beaver dams on unstable or flashy streams with a history of, or potential for, regular washouts.

When there is a conflict with a beaver colony, the guidelines outlined in the following section will be followed to determine the appropriate response.

5.4.3.2 Guidelines for Determining Proper Mitigation for Problem Beaver

OWM personnel who encounter problem beaver sites should fill out the Beaver Damage Observation Form and return to OWM wildlife biologist and Wachusett/Sudbury Regional Director. Upon review, the wildlife biologist and Regional Director will decide on the most appropriate control activity for each site. Options available include: water level control devices, dam stabilization, culvert protection, or lethal removal. Site-specific control options will be chosen based on site conditions, history of the site, and type of damage occurring. The goal is to try to provide the most effective control possible that mitigates the problem. Lethal removal is an option, but will only be used if all of the following criteria for the site are met:

- Beaver are causing documentable (observation, photographs, etc.) damage to OWM infrastructure (roads, culverts, bridges).
- Other, non-lethal means (water level control devices, fencing, etc.) would not be able to mitigate the problem because of limitations in access, maintenance, or effectiveness.
- OWM property being damaged is essential and cannot be temporarily abandoned.

- Lethal measures can be implemented within appropriate laws and guidelines and without threat to the safety of the public, domestic animals or other wildlife.

When lethal measures are to be used, the following procedure will be followed:

- The above criteria must be documented (using Beaver Damage Observation Form) prior to any action.
- Beaver will be removed through shooting (12 gauge shotgun), or live-trapping using Hancock, Bailey or cage traps and then shooting.
- Two staff will be present at all time and will include one supervisor. All staff participating will have a Firearms ID card. Any persons using live-traps must be properly trained beforehand by a designated trainer.
- Every attempt will be made to retrieve beaver carcasses, and upon retrieval they will be buried at a suitable location.
- Personnel taking part in beaver control activities will take adequate precautions (washing hands/wearing rubber gloves) to prevent possible transmission of *Giardia*, *Cryptosporidium*, or other pathogens.
- The supervisor in charge will document all actions and complete the proper form (Beaver Removal Documentation Form), copies of which will be sent to the Wildlife Biologist and the Regional Director.

5.4.3.3 **Burrowing Animals**

The burrowing activity of certain wildlife species such as woodchucks, moles, and voles can cause damage to the integrity of earthen dams, dikes, and other watershed structures. The Sudbury Reservoir has had reoccurring problems with this type of damage. Typically, woodchuck burrows were located on the face of earthen dams and dikes. Lethal control methods were used to remove specific individuals and halt burrowing activity. Burrowing activity will continue to be monitored.

5.5 Protection of Cultural Resources

The Sudbury watershed is rich both in its historical and pre-historical resources. Accordingly, safeguards have been built into OWM's land management program to protect cultural sites and artifacts, both through the identification and mitigation of possible impacts, and through a program of proactive vegetative management around significant historical sites.

5.5.1 Review of Proposed Silvicultural Projects

Without appropriate controls, forest management programs can be detrimental to archaeological resources. Modern harvesting methods employ a wide range of heavy machinery, some of which, because of weight distribution and/or tire characteristics, can do irreparable damage to prehistoric sites. Skidding logs can further disturb the soil. Operations also entail clearing areas for landings, turn-arounds, and access roads. Those archaeological sites that lie closest to the surface can be obliterated by such activities. It is these same type of sites - those that are the youngest in time (i.e., the Early, Middle and Late Woodland) - that were most susceptible to destruction by the plow of the local farmer, and thus represent a relatively scarce piece of the archaeological record.

Accordingly, the foundation of OWM's Cultural Resource Management Program at Sudbury is a process for reviewing proposed silvicultural operations. The review involves evaluating and assessing the impacts that harvesting could have on archaeological resources should they exist at any given operation. This process has been developed over the past three years, and is formalized in this section.

5.5.1.1 Internal Review of Cultural Sites on Proposed Harvesting Lots

After marking the boundaries of a planned silviculture operation, OWM foresters submit a *Proposed Harvesting Lot Form* for in-house review (see Section 5.2.4 for detailed description of this process). The form provides a detailed narrative of the proposed operation including: location and size, description of topography, forest cover and soils, goals of silvicultural operations, equipment limitations, notable historic features, plant and wildlife communities, and hydrology. The form is sent to a number of in-house reviewers for comment, including the DCR Archaeologist. The primary analytical tool employed in the review of impacts to prehistoric archaeological sites is the evaluation of *site location criteria,* which are discussed below.

5.5.1.2 Site Location Criteria

Prehistoric Sites

At no time in prehistory did human populations roam haphazardly and endlessly across the landscape. Even Paleo Indians, who were the first human occupants of New England approximately 12,000 years ago, are believed to have maintained an economic subsystem that involved a seasonal pattern of restricted wandering within loosely defined territories (Snow, 1980:152). Over the next 10,000 years, sea levels rose and the forests and vegetative communities became more constant. During this time, Native Americans adapted their tool kit and strategies in order to take advantage of the new resource mixes and opportunities the new environmental conditions afforded. Thus, the pattern of habitat use, and consequently the locations of prehistoric sites and artifacts are largely predictable.

The key criteria for determining the archaeological sensitivity of a given site include:

- Degree of slope (i.e., slope < 5 - 7 degrees).
- Presence of well-drained soils.
- Proximity to fresh water (i.e., within 1,000 feet).

Other variables such as aspect, availability of stone suitable for tool-making, and elevation above sea level may also be important. When one or more of these criteria are met, the site of the proposed silvicultural operation is considered to have been an attractive location for Native American habitation or subsistence activities, and is thus classified as *highly sensitive* or *moderately sensitive* for prehistoric resources.

Historic Sites

WELL-BUILT STONE WALL

In the past, OWM foresters have used original land taking plans as well as direct observation to identify the location of historic building foundations. In 1994, the MDC contracted with Boston University to inventory historic sites on the Prescott Peninsula at Quabbin. This inventory identified sites that were not on taking plans but were on 19th century town atlases. This project also improved the availability of information on the sites identified, by producing a data sheet and a map for each site. The MDC completed the historic inventory of the DWM lands at Quabbin in the fall of 1997. The inventory of the Sudbury OWM lands will be scheduled after completion of the Ware and Wachusett lands. Once completed, this information will be used by the DCR Chief Archaeologist when reviewing proposed silvicultural operations.

5.5.1.3 Harvesting Restrictions and Limitations

For those silvicultural operations planned for sites that have been classified as *highly* or *moderately sensitive for prehistoric resources*, restrictions are recommended on the time of year and the types of equipment and techniques used. By employing restrictions on harvesting operations that minimize ground disturbance, a compromise is achieved that allows the harvest to occur, while affording some protection to whatever archaeological resources may lie buried below the ground.

The following are types of restrictions/limitations that may be recommended for *highly sensitive* areas:

- The harvest should occur during the winter with frozen soil conditions.
- Skidding should not be permitted.
- Three wheeled feller-bunchers should not be employed.
- Feller-buncher-processors, with long reach and weight-distributing tracks, should be used.

For those proposed operations in areas classified as *moderately sensitive,* one or more of the above restrictions may be recommended. As this is a relatively new review process, the details of appropriate restrictions are still being fine-tuned through close interactions between OWM foresters and the DCR Chief Archaeologist, including analysis of past management sites for potential impacts.

In some cases, particularly with large acreage sales, portions of a lot may satisfy some, or all of the site location criteria, while other portions satisfy none. In this case, some of the above harvesting restrictions may be recommended for the sensitive portion of the operation, but not apply in other portions. On rugged upland sites or in previously-disturbed areas that fail to meet the key criteria, no additional restrictions are placed on the operations.

5.5.2 Vegetation Management at Historic Sites

Recognizing the realities of existing and likely future fiscal constraints, OWM has developed a strategy for preserving its historic resource base. The strategy is extremely modest in staff time and cost, but it can have a lasting effect on the survival of historic archaeological sites in the Sudbury watersheds.

Vegetation, if left to grow unchecked in and around stone foundations, and other historic structures like dams, raceways, etc., will ultimately alter these archaeological features. The dislocation of foundation stones and the spalling of cement caused by root activity are among the most immediate threats to some of these cultural resources. Should uncontrolled growth continue, in several cases the existing archaeological remains will be of little value and interest at the time that the Commonwealth is more solvent and prepared to once again undertake protective management.

Accordingly, a limited and selective management program to control vegetation growth in and around archaeological sites and historic buildings and structures is recommended. As a general site stabilization and preservation technique, vegetation management will entail:

- Removal of most small to medium sized brush, saplings, and trees from on, and within archaeological features (i.e., cellar holes and their foundation walls, channelized stream beds, mill dams, and historic buildings.
- Removal shall be by cutting as close to the ground as feasible. Vegetation should not be pulled, or otherwise dislodged in a manner that would affect root systems.
- While manual removal may often be the best technique, in some cases where the terrain is sufficiently level and stable, feller-bunchers may be appropriate. These machines have a long reach that limits the need to bring equipment too close to the structure. They pick the tree up, thus there is no concern about the direction of the fall. The tracks tend to distribute the machine's weight, thereby limiting compaction of buried deposits.

In most cases, OWM staff should perform the vegetation management around historic sites. However, there may be private loggers/contractors who are well known to OWM foresters, are particularly skilled and careful, and could be allowed to undertake the work. At sites that are imminently threatened, and which otherwise fall within a proposed silvicultural operation, it may be prudent to allow the private contractor to perform the selective cutting around historic sites. Contracts could include clauses that direct the logger to take extra care and precautions around cellar holes and foundations. Vegetation management will in most cases require periodic and cyclical treatment depending on the nature of the growth, the condition, and significance of a specific site.

5.5.3 Long Range Cultural Resource Management Initiatives

The following is a list of important initiatives that should be undertaken when funds and staffing are available:

- Inventory historic sites. Identify by age, owner, activities, and buildings. This data has been compiled on more than 45,000 acres at Quabbin and will be used to help list priorities for vegetation management efforts and improve the review of silvicultural operations. Future inventories will cover the remaining OWM lands.
- Enter known prehistoric sites into the GIS mapping system.
- Map areas sensitive for prehistoric sites based on site location criteria and enter into GIS.
- Conduct archaeological sampling of Red Pine Plantations, which were primarily planted on previously cultivated land, to determine the nature of sub-surface disturbance and survival factor for prehistoric sites.
- Develop educational signage and displays on Native American land use of the region. (Note: The Avery Collection, a small but informative artifact collection, could easily be incorporated into an exhibit).
- Encourage local universities to conduct *archaeological field schools* on watershed lands to further test and refine site location criteria.

6 Research, Inventory, and Monitoring Needs

6.1 Introduction

OWM has supported a wide variety of watershed research, through access to its properties, directed management activities, and/or limited direct funding. While the research budget at OWM is not constant, the value of contiguous, undeveloped watershed properties generally behind secure gates or patrolled on a regular basis has attracted many researchers who bring their own funding. In addition, OWM watershed properties have provided fertile settings for a wide range of graduate theses. Although some of this research has primarily benefited the researcher, the vast majority has informed OWM managers and improved or supported watershed management practices.

Listed below is a variety of research, inventory, or monitoring needs in the general areas of forests and forestry, wildlife, and cultural resources. Most of these are identified as needs across the whole OWM watershed system while others are specific research needs for the Sudbury watersheds. These are listed in part to direct OWM's own efforts in the coming decade, but also as a specific reference for potential researchers who are looking for a project that would address a real need of the OWM.

6.2 Forest Research Needs

1. ***Monitoring of Forest Management Activities:*** OWM policy of "no measurable impact upon stream water quality from forest management activities" creates a need to establish a standard approach for measuring compliance. Streams should be monitored to assess any short-term water quality changes associated with active logging conducted on OWM lands. Monitoring should involve upstream and downstream and/or paired watershed sampling before planned operations, during active logging, and following the completion of the operations. Monitoring efforts should focus on storm event testing. Parameters should include pH, temperature, dissolved oxygen, turbidity, suspended solids, total particulates, total and fecal coliform, and nutrients. Based on this fieldwork, specific recommendations could be made outlining a low cost, statistically valid method of monitoring logging operations on a more wide-scale basis. Recommendations for adjustments in current Conservation Management Practices would be made, if necessary, based on this research.
2. ***Analysis of Optimal Riparian Vegetation:*** While the opportunity to shift species composition on the watersheds is limited by site, seed, overstory conditions, etc., it would be valuable to complete an investigative literature review and/or field study to determine the water quality benefits/detriments associated with each of the common tree/shrub species. While species selection for an entire watershed should be based primarily on site suitability and species stability, in areas directly adjacent to tributaries and reservoir shorelines, a species' direct impact on water quality may have a measurable benefit. One result of this work would be to generate a model of the ideal riparian forest for various sites. Models developed recently to quantify the buffering effects of riparian forest should be examined for applicability to the Sudbury watersheds and other OWM forests.
3. ***Invasive Plant Species:*** Many different invasive plant species are currently established on and adjacent to OWM properties on the Sudbury watersheds. Control of these species is important to the establishment of tree regeneration and the maintenance of native plant diversity. To begin to address this issue, a survey of invasive plant species on the watershed and the extent of their spread should be conducted and digitized, in part to establish an historical reference point for future distribution of these species. Once priorities have been established for control, further research needs to be conducted on the feasibility of mechanical controls and/or the relative benefits and threats associated with chemical or biological controls.

4. ***Evaluation of Sudbury Access Roads:*** Given that roads are a potential source of pollution and sedimentation on watershed lands, a systematic evaluation of the Sudbury road system would be valuable. This project would include a watershed-wide mapping of road conditions to identify trouble spots including testing for sediment transport during storm events. Part of this project would involve locating the most appropriate model for sizing culverts and utilizing GIS to routinely size culverts and design roads that will withstand 50-year storms. The results of this study would be useful in the decision making process when planning new road construction on newly acquired property as well as improving the current road network.

5. ***Analysis of Sudbury forest age structure:*** Section 2.4.1 describes the origin of most of the Sudbury forest as plantations dating to the years from 1907 to 1947. Since DWSP will be managing the forest for a balanced age structure, a careful analysis of the current distribution of age classes needs to be made. Similar work is ongoing at the Wachusett Reservoir, and will be extended to the Sudbury when that is complete. This will involve recording years of origin in a GIS layer table for all stands mapped on DWSP lands. Plantation ages can be determined from old records, while all other stands will need to be sampled in the field. All openings made as a result of silvicultural operations will also be included in this layer. Thus a complete picture of the age structure will be available for analysis and guidance of future silviculture. This work will be completed by DWSP foresters.

6.3 Wildlife Research Needs

Very little wildlife research or monitoring has been conducted on the Sudbury watersheds. Occasional monitoring of certain species has occurred, but limited resources and personnel have prevented extensive monitoring efforts. Much more work is needed. The following projects represent a few areas where technical data would assist in managing wildlife resources more effectively.

1. ***Biological Surveys and Inventories:*** In order to minimize or avoid negative impacts of land management activities on wildlife and critical habitats, all proposed activities are reviewed by the wildlife biologist. However, a single biologist is responsible for all watersheds within OWM and it would be impossible to physically inspect the hundreds of proposed acres. OWM must rely on records of known occurrences of critical habitat or species. Although new information is added as it becomes available, the database is far from complete. Biological surveys conducted by qualified persons can provide critical additional information that will aid OWM efforts to protect these resources during land management activities. For example, Cedar Swamp is listed as an Area of Critical Environmental Concern, yet there is little natural resource information about it. An in-depth biological survey of the area would prove useful. Gathered information should be incorporated into GIS data layers.

2. ***Routine Monitoring Activities:*** Routine monitoring programs for selective species will continue during this management period. These surveys include monitoring potential common loon nesting around the watershed, Canada goose breeding surveys, and occasional breeding bird surveys. Other surveys (permanent breeding bird surveys, locating rare and endangered species) may be conducted if resources and personnel are available.

6.4 *Cultural Resources Research Needs*

The principal research need for the continued protection of cultural resources within OWM properties on the Sudbury Reservoir watersheds is to inventory, accurately map, and digitize all known historic cultural sites. This inventory would be modeled after the multi-phased historic site inventory that was completed for the Quabbin Reservoir watershed in 1995-96. The Quabbin inventory was completed by graduate students and faculty of the Boston University Department of Archaeology in collaboration with the OWM staff archaeologist. The process involved integration of geographical and descriptive information from a variety of cartographic and historical resources, including historic OWM Real Estate Plans and a series of maps dating as far back as 1794. Information from these sources was used to complete a database and map record for several hundred sites. Many of these sites were subsequently field checked for current condition. Locational information was entered in OWM's GIS so that important sites can be identified when management activities are proposed for areas within OWM's properties. This process greatly enhances the ability of managers to protect historic cultural resources.

7 Public Involvement

7.1 *Public Input in Formulating Watershed Management Plans*

Public input represents an important part of OWM's management planning process. This input is provided in several ways, including through the Wachusett/Sudbury Watershed System Advisory Committee, local experts in resource management, and the general public. The goals of OWM's public input process are:

- To understand the broad range of public issues and concerns regarding forest and wildlife management at OWM's watersheds so that OWM can better integrate the concerns of the public into protection strategies for maintaining watershed integrity.
- To improve the understanding of the technical aspects of forest and wildlife management on OWM watersheds and to generate creative program ideas.
- To educate the public regarding the purposes and goals of OWM with regard to its watershed management program in order that the public will better understand the program chosen in managing the forest and wildlife resources at Sudbury.
- To gain support for the implementation of the watershed management program selected by OWM so that it may be implemented smoothly.

Throughout the public input process, OWM will stress that its primary legislative mandate is the delivery of sufficient quantities of pure water to present and future generations of water users of the system. This mandate is much narrower than that of most public land managing agencies. Therefore, it is important that the public understand that management alternatives that do not adequately support OWM's primary mandate will not be considered viable. While OWM considers secondary values of its watershed such as passive recreation, environmental research, natural areas, and wildlife management, these values will only be encouraged and enhanced where they do not impair the primary mandate of OWM. Occasional conflicts may arise between state and federal laws (e.g., rare and endangered species, wetlands, and historic sites) and prudent watershed management. These conflicts will be examined on a case by case basis to ensure that the requirements of laws protecting non-water supply resources are met while still protecting the water supply.

Chapter 372, Acts of 1984 states that the Division of Watershed Management shall prepare watershed management plans each five years that provide for forestry, water yield enhancement, and recreation. The legislation further states that these plans shall be prepared with the participation of the appropriate watershed advisory committee and a professional forester and that public hearings be held to discuss these watershed management plans. Two committees, the Quabbin Watershed Advisory Committee (there is now also a Ware River Advisory Committee) and the Watershed System Advisory Committee (for Wachusett and Sudbury), were also formed by this legislation, although the Watershed System Advisory Committee is not currently active (OWM is currently attempting to reactivate this committee by communicating with the represented towns). The Sudbury Watershed Advisory Committee is technically a standing sub-committee of the above Watershed Advisory Committee.

Due to the technical nature of this plan, input has been sought from appropriate watershed management, forest, and wildlife experts outside of OWM to improve the technical presentations in this plan. As this plan is modeled after the policies and recommendations contained in the MDC's 1995

Quabbin Land Management Plan, the public and technical review of that plan has assisted in the drafting of this document. For example, in completing the Quabbin Land Management Plan, the MDC held a one day discussion with hydrology and forest ecology experts from Harvard Forest, University of Massachusetts and S.U.N.Y College of Environmental Sciences and Forestry to consider the general approach OWM had taken with regard to forest watershed management in the Quabbin plan. The Quabbin plan was also reviewed in May, 1994 at a Watershed Workshop to which more than 60 representatives of various environmental organizations and interest groups were invited and again at two two-day conferences in the fall of 1996 and 1997 by the Quabbin Science and Technical Advisory Committee, composed of land management experts from the around the northeast.

After review of the draft Sudbury Land Plan by interested groups, OWM will make the plan available to the local community and will present the final draft of the plan at a public hearing. With the comments it receives, OWM will produce the final plan.

7.2 Regular Revisions to the Sudbury Land Management Plan

Watershed management is a developing science. In order to accommodate new findings in the field, and to adapt management policies based on local experience, OWM will revise and update this plan in five years. OWM will compile the revisions to the plan, together with a summary of the management which has occurred during this time and present this information to the Sudbury Watershed Advisory Committee. Local officials and the general public will also be invited to this review meeting. At the meeting, OWM will also outline planned watershed land management activities for the remaining five year period of the plan. At that time information gained from relevant ongoing OWM research, new professional literature, and comments from the general public can be incorporated into the remaining five year period.

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9 Glossary of Terms

Listed in alphabetical order below are terms and definitions that OWM uses throughout various watershed land management plans. Specific sources of definitions are shown in parenthesis, where applicable.

age class: (from Society of American Foresters, 1971. Terminology of forest science, technology, practice, and products.) one of the intervals, commonly 10 years, into which the age range of tree crops (and sometimes other vegetation) is divided for classification or use.

aggradation: (from Bormann and Likens, 1979. Pattern and process in a forested ecosystem.) in Northern Hardwoods, a period of more than a century when the ecosystem accumulates total biomass reaching a peak at the end of the phase; preceded by the reorganization phase and followed by the transition phase.

advance regeneration: in silvicultural terms, young trees that have become established naturally in a forest, in advance of regeneration cutting; may become established following "preparatory" cuts.

allogenesis: changes in an ecological community primarily through periodic, acute, external (exogenous) disturbances, such as storms. These changes generally reset the successional progression of the community.

area inch; acre inch: used to describe changes in water yield from a given area of land; for instance, if a change in vegetation results in an increase of one acre inch in water yield, this translates to 43,560sq ft x 1/12ft = 3,630 cubic feet per acre; 3,630ft^3 / 7.5 gals per ft^3 = 484 gallons additional yield per acre. Area inch is translated to percent water yield increase by dividing area inch by total inches of yield. For example 40 inches of precipitation generally yields 50%, or 20 inches of discharge, therefore a 2 area inch increase in yield on this watershed is a 10% increase (2/20).

autogenesis: changes in an ecological community primarily through the regular, internal processes of growth, competition, and senescence, which are general endogenous (within community) forces that result in a steady successional progression of the community.

basin; sub-basin: the land area from which all water flows to a single, identified water source, such as a stream, a river, or a reservoir. Sub-basin is used to refer to the basin of a tributary or lower *order* stream (the higher the order, the greater the area drained).

basal area: the area in square feet of the cross section of a tree taken at 4.5 feet above the ground.

"beaver pipe"; flow control pipe: generally a length of culvert that is extended into a beaver pond and at or near the top of the beaver dam, in order to maintain the pond level at a particular level.

Best Management Practices, BMPs: in natural resources management, refers to a set of standards that have been designed for an activity, and often a region, to protect against degradation of resources during management operations.

biological diversity (biodiversity): a measure, often difficult to quantify, of the variety and abundance of plant and animal species within a specified area, at the genetic, species, and landscape level of analysis. The 1992 UN Convention on Biological Diversity defined biodiversity as "the variability among living organisms from all sources including, inter alia, terrestrial, marine and other aquatic ecosystems and the ecological complexes of which they are part; this includes diversity within species, between species and of ecosystems".

biomass: (SAF) the total quantity of living organisms of one or more species per unit area (species biomass) or of all the species in a community (community biomass)

conservation restriction; conservation easement; CR: a legal agreement between a landowner and another party whereby the landowner deeds the rights to development of the property to the other party, but retains ownership of the land and other rights to its use. Specific agreement varies, but the general result is to protect land from conversion to new uses without requiring transfer of ownership; OWM also limits or retains the right to approve certain agricultural and silvicultural practices in its CRs.

Continuous Forest Inventory (C.F.I.): an extensive method of forest inventory in which permanent sample plots are remeasured at periodic intervals to determine forest growth and condition; OWM's CFI is composed of 1/5 acre permanent plots, located on a 1/2 mile grid, and remeasured every 10 years.

cutting cycle: the frequency with which silvicultural cuttings are conducted in any given area; cutting cycle is a subunit of "rotation," which is determined either by the maximum life of the existing overstory, or by a predetermined maximum age imposed on the area.

Cryptosporidium: A coccidian protozoan parasite found in humans and various wild and domestic animals that can be transmitted via water and often causes serious intestinal illness. While the epidemiology and transmission of *Cryptosporidium* are similar to *Giardia*, its oocysts are smaller that the cysts of other protozoa, and thus may be more difficult to remove from water supplies.

diameter at breast height; DBH: the diameter of a tree, outside the bark, taken at 4.5' above the ground, generally in inches and fractions.

diverse/diversity: in this plan, the term is most often used to refer to forest composition, and refers to both height or size diversity in trees, seeking a minimum of three distinct layers (understory, midstory, and overstory), and to diversity of species composition, with a general goal of avoiding monocultures and working to include components of hemlock, pine, oak, birch, and maple throughout the forest.

disturbance-sheltered: areas that based on slope and aspect are physically "sheltered" from the influence of a catastrophic New England hurricane blowing from the southeast, based on a model developed at the Harvard Forest; the most sheltered areas are steep slopes facing northwest.

edge effect: this term has traditionally been used to describe the increased richness of flora and fauna found where two habitat types or communities meet. More recently, the term has also been used to refer to the increased predation and brood parasitism that often occurs near these boundaries.

endogenous disturbance: disturbance that originates within the ecological community. For example, a single tree that succumbs to a root-rot fungus and falls to the ground, breaking off several other trees on the way, creates an endogenous disturbance. While the proximal cause of the treefall may be wind or accumulation of snow and ice, the primary cause is still considered endogenous in this instance. (see exogenous disturbance below)

even-aged: (SAF) an area of forest composed of trees having no, or relatively small, differences in age. NOTE: By convention the maximum difference admissible is generally 10 to 20 years, though with rotations of 100 years or more, differences up to 30% of the rotation may be admissible.

exogenous disturbance: disturbance that originates from forces outside of the ecological community. For example, storms that carry high winds can cause large-scale treefall well in advance of normal senescence and decay. The cause of the disturbance is therefore considered exogenous. (see endogenous disturbance above)

feller-buncher; feller-buncher-processor: logging machines that grasp a tree to be cut or "felled," sever it at the stump with either a saw or hydraulic shears, and directionally drop it to the ground. Some machines can accumulate, or "bunch" several trees before releasing them. The most complex machines are also capable of delimbing and sawing trees into predetermined lengths (processing).

forest canopy: (SAF) the more or less continuous cover of branches and foliage formed collectively by the crowns of adjacent trees and other woody growth.

forest fragmentation: the separation of a previously contiguous forested area into discontinuous patches or "fragments." These fragments are less useful to wildlife that require large contiguous habitats. Fragmentation by suburban development is likely to be detrimental to "deep woods" species, while the simple break imposed by an access road is not often an impediment.

forwarder: a logging machine used to "forward" logs from the woods to a landing. A forwarder differs from a skidder in that the logs are hydraulically loaded onto the machine and carried, rather than skidded through the woods.

G.I.S.: Geographic Information System - a computer-based analysis and mapping system for spatially-linked data sets.

***Giardia*:** A protozoan parasite found in humans and various wild and domestic animals that can be transmitted via water and often causes serious intestinal illness.

hurricane exposure ("exposed," "intermediate," "sheltered"): generally used in OWM management plans to mean physical exposure of a site to catastrophic hurricane winds, those coming from the southeast. Research at the Harvard Forest in Petersham, MA provides a model of the impact of this typical New England hurricane, which includes slope and aspect. Actual damage will depend on the type and size of vegetation present.

intermediate cut: cutting of trees in a stand during the period between establishment and maturity. Objectives may include the improvement of vigor by reducing competition or the manipulation of species composition. Regeneration may occur following intermediate cuts, but it is incidental to the objectives.

irregular shelterwood: similar to the shelterwood silvicultural system except that overstory removals are protracted, taking as long as half the rotation, so that the resulting new stand is quite uneven-aged (wide intervals between the oldest and youngest trees) and mimics the multi-storied effect of strictly uneven-aged systems.

log landing; landing: a clearing of variable size to which logs, pulp, and/or firewood are skidded or forwarded during a logging operation, in order to facilitate their processing or further transport by truck.

mast: the fruit and seeds of trees and shrubs. Mast constitutes an important food source for many wildlife species.

milacre: one-thousandth of an acre**.**

mineral soil: any soil consisting primarily of minerals (sand, silt, and clay), rather than organic matter.

multi-storied or multi-layered forest: a forest containing a distinct understory, midstory, and overstory. From a watershed perspective, these layers provide, respectively, immediate response to disturbance, vigorous uptake of nutrients, and deep filtration of air-borne and precipitative pollutants.

naturally managed: the results of a deliberate decision to allow natural disturbances and processes prevail by adopting a minimal management approach that protects forests from development or other land use changes and possibly human-caused fire, but which includes vegetation management only where it clearly counteracts a negative result from previous human disturbances.

old-growth: various definitions, but one definition in Massachusetts is that old-growth must contain at least four acres in which the dominant trees are late-successional species, have reached at least half the potential maximum age of the species with a few trees at or near that age (e.g., birches/maples at 300 years or hemlocks at 400), have late-successional tree regeneration present, and show little or no evidence of human or large-scale natural disturbance during the current stand's development.

preparatory cutting: (SAF) removing trees near the end of a rotation so as to open the canopy and enlarge the crowns of seed bearers, with a view to improving conditions for seed production and the establishment of natural regeneration.

protected: refers to areas of the watershed that, according to the Harvard Forest model of hurricane disturbance, would suffer minimal damage from the recurrence of a hurricane similar to that of 1938, due primarily to topography and orientation.

protection forest: (SAF) an area, wholly or partly covered with woody growth, managed primarily to regulate stream flow, maintain water quality, minimize erosion, stabilize drifting sand, or to exert any other beneficial forest influences

regeneration: recently established tree growth, generally smaller than one inch dbh; also, the process of establishing this growth, as in "bring about the regeneration of a forest area".

regeneration cut: (SAF) any removal of trees intended to assist regeneration already present or to make regeneration possible.

riparian: pertaining to the bank of a stream or other water body; (SAF) vegetation growing in close proximity to a watercourse, lake, swamp, or spring, and often dependent on its roots reaching the water table.

rotation: in conventional forestry, rotation is (SAF) the planned number of years between the formation or regeneration of a crop or stand and its final cutting at a specified stage of maturity. In the selection system of uneven-aged management, however, the concept of a rotation is replaced with the average age of trees removed to initiate regeneration.

salvage; salvage cutting: the removal of trees damaged by fire, wind, insects, disease, fungi, or other injurious agents before their timber becomes worthless. In some situations, the motivation is the reduction of fuel loading and fire hazard. Sanitation cutting is related, but is a proactive removal of diseased or highly susceptible trees in order to slow or halt the spread of a disease or other destructive agent.

seep: a wet area, generally associated with groundwater seepage, which is important to wildlife because it remains unfrozen, and generally uncovered, during periods when the ground is otherwise snow-covered, which makes it easier for wildlife to forage for seeds.

shelterwood: (SAF) mostly even-aged silvicultural systems in which, in order to provide a source of seed, protection for regeneration, or a specific light regime, the overstory (the shelterwood) is removed in two or more successive shelterwood cuttings, the first of which is ordinarily the seed cutting (though it may be preceded by a preparatory cutting) and the last of which is the final cutting, while any intervening cuttings are termed removal cuttings. Note that where adequate regeneration is already present, the overstory may be removed in one cutting, resulting in a method referred to as a one-cut shelterwood.

silviculture: (SAF) generally, the science and art of cultivating (i.e., growing and tending) forest crops, based on a knowledge of silvics (the study of the life history and general characteristics of forest trees and stands, with particular reference to environmental factors affecting growth and change). More particularly, silviculture is the theory and practice of controlling the establishment, composition, constitution, and growth of forests.

site: in forestry, the combination of environmental factors that affect the ability of a species to grow and persist, including at least soil characteristics, aspect, altitude and latitude, and local climate. Sites are often classified by the ability of specific trees to grow on them.

site index: the ability of a given site to grow a given species. As height growth is generally not density dependent, a common forestry site index is the height to which a given species will grow on the site in fifty years (so that a site with a Red Oak site index of 65 will grow Red Oak to that height in fifty years).

site preparation: in silviculture, any of a variety of treatments of a site that are intended to enhance regeneration success. A common goal of these treatments is to remove enough of the accumulated organic layers above the mineral soil so as to expose that soil and enhance the ability of seeds that fall on it to germinate and grow. The simple skidding of logs is an incidental, and often sufficient, site preparation.

site-suited: species that have evolved to take advantage of a particular type of site. Where species are planted on other sites, they may succumb prematurely to disturbance or disease. Red pine grows and persists well on deep, sandy soils, where root rots are less common, but may become excessively prone to wind and or root rotting diseases on the moist agricultural soils on which they were typically planted.

skidder: logging machine used to "skid" logs from the woods to a landing or a forwarder road. Logs are either winched by cable to the skidder (cable skidder), or lifted on one end by a hydraulic grapple (grapple skidder), and then dragged.

stand: (SAF) a community of trees possessing sufficient uniformity as regards composition, constitution, age, spatial arrangement, or condition to be distinguishable from adjacent communities.

steady state: (Bormann and Likens, 1979. p.4) "For the ecosystem as a whole, over a reasonable period of time gross primary production equals total ecosystem respiration, and there is no net change in total standing crop of living and dead biomass".

stocking: in forestry, the extent to which a site is occupied by trees compared to the maximum occupation possible at a given stand age; a relative measure of stand density. Most commonly measured as basal area per acre, stocking is often related directly to crown closure, as a site is considered fully occupied when crown closure is complete (when each crown has grown to touch all adjacent ones). As crowns can be of very different sizes among species and tree ages within stands, average diameter (dbh) and total number of trees of a "fully stocked" site is variable.

stream order: a classification of streams within watersheds. Small streams at the uppermost level of stream systems are labeled "first-order"; two first-order streams join to form a "second-order" stream; two second-order streams join to form a "third-order" stream; etc.

succession: (SAF) the gradual supplanting of one community of plants by another, the sequence of communities being termed a "sere" and each stage "seral." Succession is "primary" (by "pioneer species") on sites that have not previously borne vegetation, "secondary" after the whole or part of the original vegetation has been supplanted; "allogenic" when the causes of succession are external to and independent of the community (e.g., a storm, or climate change), and "autogenic" when the developing vegetation is itself the cause. "Early succession" generally refers to the pioneer stages and species that follow disturbance, while "late succession" refers to stages and species that occur as an area continues to develop undisturbed for long periods.

thinning: an intermediate silvicultural treatment, generally with the goal of altering the forest composition and/or improving the growing conditions for the residual trees, regardless of associated regeneration effects. Most thinnings leave stands considered to be fully stocked, i.e., capable of fully occupying the site a short while after the thinning has been completed.

turbidity: a water quality measure that is most commonly derived by measuring the proportion of a given amount of light that is deflected by suspended/dissolved sediments in a water sample, giving an indirect measure of these sediments. Most common unit is the nephelometric turbidity unit, NTU.

uneven-aged: (SAF) a forest, crop, or stand composed of intermingling trees that differ markedly in age. By convention, a minimum difference between tree ages of 25% of the rotation age is generally accepted. Some texts require a minimum of three distinct age classes for a stand to qualify as "uneven-aged."

vernal pool: a temporary body of fresh water that provides crucial habitat for several vertebrate and many invertebrate species of wildlife, but does not support fish populations.

wetland: generally refers in OWM land management plans to areas defined as "wetlands" by M.G.L. C.131 § 40 (the "Wetlands Protection Act") and 310 C.M.R. 10.00 (the "Wetlands Protection Regulations"), updated as these are revised.