Review of the Massachusetts DWSP Watershed Forestry Program

DWSP Science and Technical Advisory Committee[1]

Paul K. Barten, Mark S. Ashton, James K. Boyce, Robert T. Brooks, John P. Buonaccorsi,
John L. Campbell, Scott Jackson, Matthew J. Kelty, David I. King, Chi Ho Sham,
John E. Tobiason, and Mary L. Tyrrell[2]

November 2012

[1] Massachusetts Division of Water Supply Protection, Department of Conservation and Recreation, Executive Office of Energy and Environmental Affairs.
[2] Stephen DeStefano will be added as a co-author when the U.S. Geological Survey internal review process is completed.

Table of Contents

1 – Introduction	1
2 – System Description and Management Context	12
3 – Watershed Forest Management Principles and Practices	22
4 – Active versus Passive Watershed Forest Management	31
5 – Review of Silvicultural Methods for Watershed Forest Management	43
6 – Forest Management and Water Quality Monitoring	58
7 – Findings, Conclusions, and Recommendations	69
8 – References	74

1 – Introduction

When Secretary of Energy and Environmental Affairs, Ian Bowles, and Department of Conservation and Recreation Commissioner, Richard Sullivan (now Secretary of EOEEA), announced the Forest Heritage Plan in April 2010, they called for the Massachusetts Division of Water Supply Protection (DWSP) to reconvene an existing team of science and technical advisors to review the principles of the Office of Watershed Management's forestry program. This group of experts was asked to review possible changes to the program. DWSP and DCR will subsequently seek community input through public meetings with its legislatively mandated watershed advisory committees after the review is presented. Fourteen scientists representing a wide range of specialties related to forest and watershed management agreed to serve on the DWSP Science and Technical Advisory Committee (STAC).

The 2010 Forest Heritage Plan states:

> *Before new FY2011 timber sales on DCR Water Supply Protection forests are finalized, DWSP will have the existing Science and Technical Advisory Committee (STAC) conduct a review of the scientific principles that guide existing Land Management Plan objectives. The STAC will also analyze DWSP proposed changes to implementation on issues such as opening sizes and retention standards. Resulting recommendations will be reviewed by the existing public Advisory Committees and appropriate changes or clarifications to Land Management Plans and future watershed forestry projects implemented. DCR will defer any new timber sales for FY11 until this review is concluded. Habitat management practices will be reviewed in coordination with the Division of Fish and Wildlife (DFW) as part of a broader statewide effort.*

The statement of task for the DWSP STAC (July 2010) is:

> *Prior to October 30, 2010, this committee will review the principles guiding current Land Management Plan objectives and forest management practices for the Quabbin, Ware River, Wachusett, and Sudbury watersheds, develop draft recommendations for refinements in these objectives and practices to be presented to the public for comment, and deliver final recommendations in a report to DCR Commissioner Sullivan.*[3]

STAC Background

The first meeting of the Quabbin Science and Technical Advisory Committee (QSTAC) was convened in the fall of 1996. This committee included forest, wildlife, and natural resource researchers and managers from several University of Massachusetts Amherst departments, Harvard Forest, the

[3] The October 30, 2010 target date proved to be untenable in light of the scale, complexity, and history of DWSP system, and in light of the other responsibilities of the volunteer committee.

USDA Forest Service, Mount Holyoke College, Amherst College, the Institute of Ecosystem Studies, US Geological Survey, Massachusetts Audubon Society, the New England Small Farms Institute, the MA Natural Heritage and Endangered Species Program, Hampshire College, and several state agencies. Other scientists were added over time. Paul Barten and Thomas Snowman served as co-chairs.

The committee was formed to address major natural resources and watershed management issues, changes in the Quabbin Reservoir Land Management Plan, and to advise the agency in the development and implementation of scientific research at the Quabbin Reservoir. The committee met annually from 1996 through 2000, and sub-groups have been called upon occasionally to address current issues. In addition to general advice, the committee assisted in:

- Setting research priorities
- Developing standards for research quality assurance and control
- Subwatershed modeling
- Determining appropriate sizes for regeneration openings
- Identifying lands reserved from management
- Management considerations for the Pottapaug Natural Area, and
- Debating the management response to hemlock woolly adelgid.

The STAC was expanded in May 2010 to encompass the entire system and complete the statement of task; it was re-convened in June 2010 and chaired by Paul Barten, Professor of Forest Resources at UMass Amherst. Dr. Barten's background is in hydrology, forest management, and watershed management. As noted earlier, he co-chaired QSTAC with Thomas Snowman (DWSP Natural Resources).[4]

All QSTAC members were asked to serve on the DWSP STAC; several declined this invitation. New members were appointed to fill gaps left by retirements. Others were added to provide new expertise and new perspectives (Table 1.1).

[4] In addition to QSTAC, Dr. Barten served on the Massachusetts Forester Licensing Board (2001-2004), chaired the Massachusetts Forestry Committee that completed comprehensive revisions to the M.G.L. Chapter 132 Forest Cutting Practices Act regulations, 2005-2007. [DCR did not act on the proposed revisions after they were submitted in July 2007.] He served on National Research Council (NRC) committees assessing the New York City water supply system (1997-2000) and conservation of Atlantic salmon in Maine (2002-2004). He chaired the NRC committee assessing the hydrologic effects of a changing forest landscape (2006-2008) and was project co-leader (with Eric Seaborn, DCR) for the assessment of the forest resources of Massachusetts (de la Cretaz et al. 2010) mandated by the 2008 Farm Bill and the USDA Forest Service.

Table 1.1 – Massachusetts DCR Division of Water Supply Protection Science and Technical Advisory Committee, 2010-12

Member	Expertise	Title and Affiliation
Paul Barten (Chair)	Forestry, hydrology, watershed management	Professor, University of Massachusetts Amherst, Dept of Environmental Conservation
Mark Ashton	Silviculture, forest ecology, forest regeneration, adaptability of forests to changes in climate	Professor and Director of Forests, Yale University School of Forestry & Environmental Studies
James Boyce	Environmental economics	Professor, University of Massachusetts Amherst, Dept of Economics
Robert Brooks	Wildlife research biology, ecology, hydrology, and effects of harvesting on ephemeral and riparian habitats	Research Scientist, USDA Forest Service Northern Research Station Amherst, MA
John Buonaccorsi	Biometrics; previous work with DWSP on deer population and tree regeneration sampling	Professor, University of Massachusetts Amherst, Dept of Math and Statistics
John Campbell	Biogeochemical cycling in northeastern forested watersheds	Research Scientist, USDA Forest Service, Northern Research Station, Hubbard Brook Experimental Forest
Stephen DeStefano	Wildlife ecology, population dynamics, habitat relationships, and human-wildlife interactions	Research Professor and Unit Leader, US Geological Survey Massachusetts Cooperative Fish and Wildlife Research Unit
Scott Jackson	Conservation biology, vernal pools, amphibians, biological conservation, impacts of roads	Director, Natural Resources & Environmental Conservation, University of Massachusetts Amherst Extension
Matthew Kelty	Silviculture, forest ecology, stand dynamics, managed vs. unmanaged forests, regeneration	Professor, University of Massachusetts Amherst, Dept of Environmental Conservation
David King	Forest wildlife habitat management, neotropical migrant birds, effects of silviculture and roads	Research Scientist, USDA Forest Service Northern Research Station, Amherst, MA
Tom Lautzenheiser	Community ecology, field naturalist, plants, reptiles, amphibians, butterflies, landscape interpretation	Regional Scientist Massachusetts Audubon Sanctuary Management Planning
Chi Ho Sham	Source water protection, hydrology, geomorphology, water quality	Vice President, The Cadmus Group, Inc. and Chair of the American Water Works Association Source Water Protection Committee
John Tobiason	Civil and environmental engineering, transport and transformation of pollutants in natural and engineered drinking water systems	Professor, University of Massachusetts Amherst, Dept of Civil and Environmental Engineering, Water Resources Program
Mary Tyrrell	Sustainable forestry/forest policy	Executive Director, Yale University, Global Institute of Sustainable Forestry, School of Forestry & Environmental Studies

Watershed Advisory Committees

There are two public advisory committees created by the legislature to monitor and review DWSP watershed issues. Both the Quabbin Watershed Advisory Committee and the Ware River Watershed Advisory Committee, designed by the legislature to include a broad range of watershed stakeholders, have been involved in forestry and land management plan development since the 1980s. They conduct public meetings that are posted on the DCR website. Both committees will review STAC's recommendations and work with DCR to determine if changes are needed to the approved land management plans.

Management Context for DWSP Forests

The geography and characteristics of the forests managed by the DWSP as an integral part of the water supply system for Boston and 40 smaller communities are described in more detail in section 2 of this report and in exhaustive detail in the Quabbin, Ware, and Wachusett Land Management Plans. It is often observed that Massachusetts is fortunate to have a large proportion of forest land (~60% of the landscape) even though it is the third most densely populated state in the U.S. (Figure 1.1). In contrast, during the 18^{th} and 19^{th} centuries 60 to 90 percent of the landscape was cleared for agriculture or cut for firewood, lumber and other building and industrial raw materials (e.g., "box board"), charcoal, or tanbark. Less than one percent of Massachusetts' original forest remains – in small isolated areas, primarily in the Berkshires. Sweeping social, technological, economic, and political changes led to farm abandonment and re-location of wood-using industries in the late-1800s and early-1900s. This allowed the forest to naturally regenerate to the familiar even-aged oak, white pine, and (or) mixed deciduous forests that now dominate the landscape (Box 1). The 1938 hurricane and subsequent salvage operations led to the establishment of another age class over large areas of Massachusetts.

When in the early-1900s it became clear to engineers, planners, and water commissioners that the Wachusett Reservoir (once the largest drinking water reservoir in the world) would no longer be sufficient to meet Boston's exponential increases in population and demand, they looked west to the Ware River and Swift River valleys. By 1920, public health officials and engineers (many of whom gained experience via the design and construction of the New York, New Haven, and other water supply systems) clearly understood the benefits of "source isolation" – protecting water quality and favorably influencing streamflow quantity and timing by maintaining or restoring large areas of forest (Figure 1.2). In most cases, like the Wachusett Reservoir before recent land and conservation easement purchases, this watershed protection forest was limited to a modest strip of land around the reservoir(s). The conscious realization that "more [forest] is better" and the fleeting opportunity to purchase large areas of land during the Great Depression, led to the protection of a large portion of the Quabbin and Ware watersheds. These forests are neither "accidental" nor "wilderness" (Barten et al., 1998 after Conuel 1981) although this myth persists in the popular press and media (Figure 1.3).

Figure 1.1 – Google Earth (2010) image of the Quabbin (west side of image), Ware (center), and Wachusett (east side of image) watersheds and adjacent areas, Massachusetts.

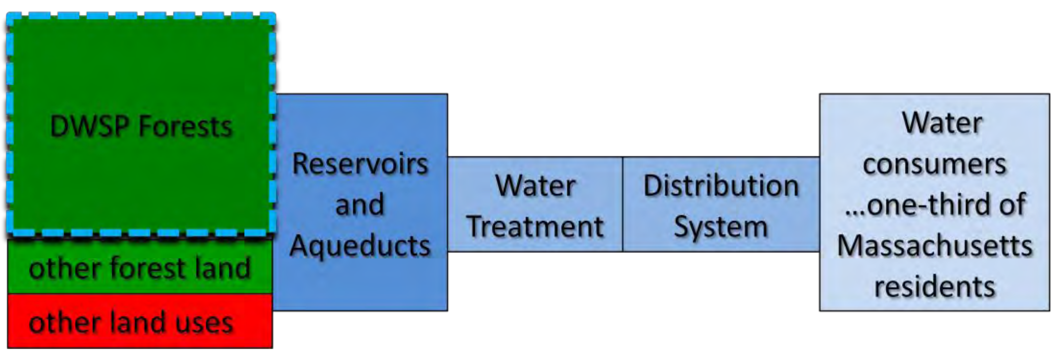

Figure 1.2 – Simple schematic diagram of the DWSP/MWRA water supply system. Water treatment includes disinfection to kill pathogens (bacteria, giardia, etc.), fluoride addition, and pH and water chemistry adjustment to prevent corrosion in the water distribution system. Filtration is not required.

Q is for QUABBIN

The creation of the Quabbin Reservoir in central Massachusetts came with a cost: The sites of four communities in the Swift River Valley were drowned out of existence when it was built in the 1930s. In their place came two huge earthen dams and a new body of fresh drinking water for metro-Boston residents: a reservoir capable of holding 412 billion gallons. But what was originally an engineering marvel is now a place of wonder for nature lovers, spanning 39 square miles, with 181 miles of shoreline. In the decades since Quabbin was created, the valley has undergone a slow transformation back to a place without mankind, a place of deer and muskrats, hemlocks and hardwoods. Fall, especially, brings a brilliant palette of color, and solitude. You may visit, but you may no longer stay here. And that's part of Quabbin's beauty. For more on hiking near the reservoir, as well as the area's history, go to: *mass.gov/dcr/parks/central/quabbin.htm* —*I.A.*

From the Enfield Lookout on Quabbin Hill in Ware, Massachusetts, the stunning landscape and pristine waters of Quabbin Reservoir stretch before you.

YANKEE | 101

"In the decades since Quabbin was created, the valley has undergone a slow transformation back to a place without mankind, a place of deer and muskrats, hemlocks and hardwoods."

Figure 1.3 – Q is for Quabbin, in: "Autumn A to Z: 26 New Ways to See Fall," *Yankee Magazine*, September/October 2012, 78-108, Q is for Quabbin on pages 100-101.

The Quabbin Forest [Wilderness] Debate

A 56,000 acre public forest surrounding a 24,000 acre artificial lake in southern New England, near the sprawling edge of the Boston-Washington megalopolis, cannot fail to attract the attention of many people and organizations. Hence, it is not surprising that the contrast between the beauty of the Quabbin forest and reservoir and the short-term unsightliness of harvesting operations (e.g., as documented by the Massachusetts Forest Watch and other groups) has generated heated controversy—especially since very few people knew that timber harvesting had been happening there for 50 years. Fewer still know the Quabbin Forest was the first Forest Stewardship Council-certified public land in North America or understand the significance of this third-party certification. When urban and suburban residents are confronted with photographs of stumps, slash, and mud, the illusion of preservation is shattered, and, naturally, they ask how and why this could happen on a "pristine" state forest? It is ironic that a forest that has been actively managed since the 1960s is immediately assumed to be a wilderness by visitors admiring the view from the Enfield or North New Salem lookouts as evidenced by the quotation in Figure 1.3 and many other examples.

This emotionally charged debate defines the daunting challenge faced by the DWSP, the Massachusetts Water Resources Authority, Watershed Advisory Committees, elected and appointed leaders, and this Committee: to assemble, evaluate, and accurately communicate objective information about the management of these unique and extraordinarily valuable watershed protection forests (Quabbin, Wachusett, and Ware). It may seem old-fashioned but Gifford Pinchot's 1905 staff directive to the fledgling U.S. Forest Service is, we believe, an appropriate frame of reference for decisions about the future of DWSP forests (…especially the frequently omitted clause that precedes "the greatest good"):

"...where conflicting interests must be reconciled, the question will always be decided from the standpoint of the greatest good of the greatest number in the long run."

Acute Natural Disturbances in Southern New England

The first U.S. Secretary of Energy, James R. Schlesinger, cogently summarized the country's approach to energy as follows: "We have only two modes—complacency and panic."[5] In many respects this review centers on the need to avoid complacency about the potential for acute natural disturbances that could change the structure and function of the Quabbin, Wachusett, and Ware watershed forests in a matter of hours (Figures 1.4, 1.5, and 1.6). Recall the reaction to the ice storm of December 2008, the tornado in June 2011, the uncertain path of Hurricane Irene (and subsequent damage in parts of New York and Vermont) in August 2011, the late-October snow storm of 2011, and Hurricane Sandy in November 2012, and the lessons learned about (1) emergency preparedness, (2) the need for backup power generation capability

[5] http://www.nytimes.com/2005/07/12/business/worldbusiness/12oil.ready.html?pagewanted=all

for hospitals, communications systems, emergency services, and (3) the recrimination about deferred tree trimming and hazard tree removal along power, cable, and telephone lines.

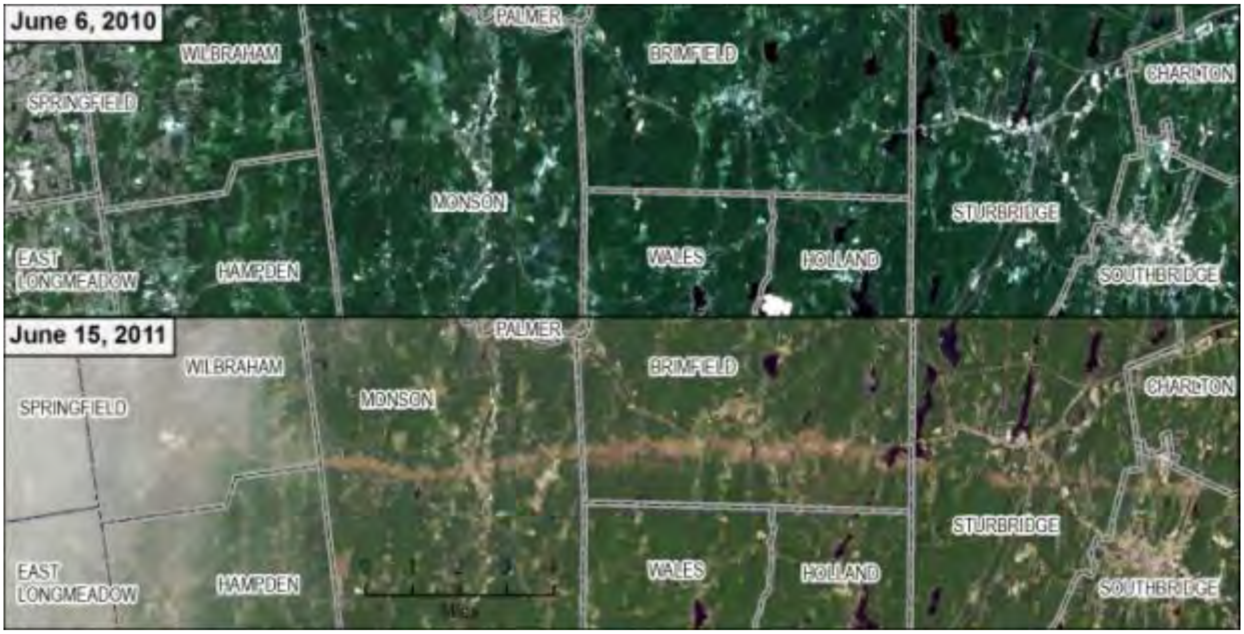

Figure 1.4 – Landsat 5 Thematic Mapper scenes showing tornado damage (8,500 acres) in western Massachusetts. Data source: USGS GLOVIS.

Figure 1.5 –Tornado damage along the Mill River in Springfield, MA, June 2011, 70 to 90 mph winds

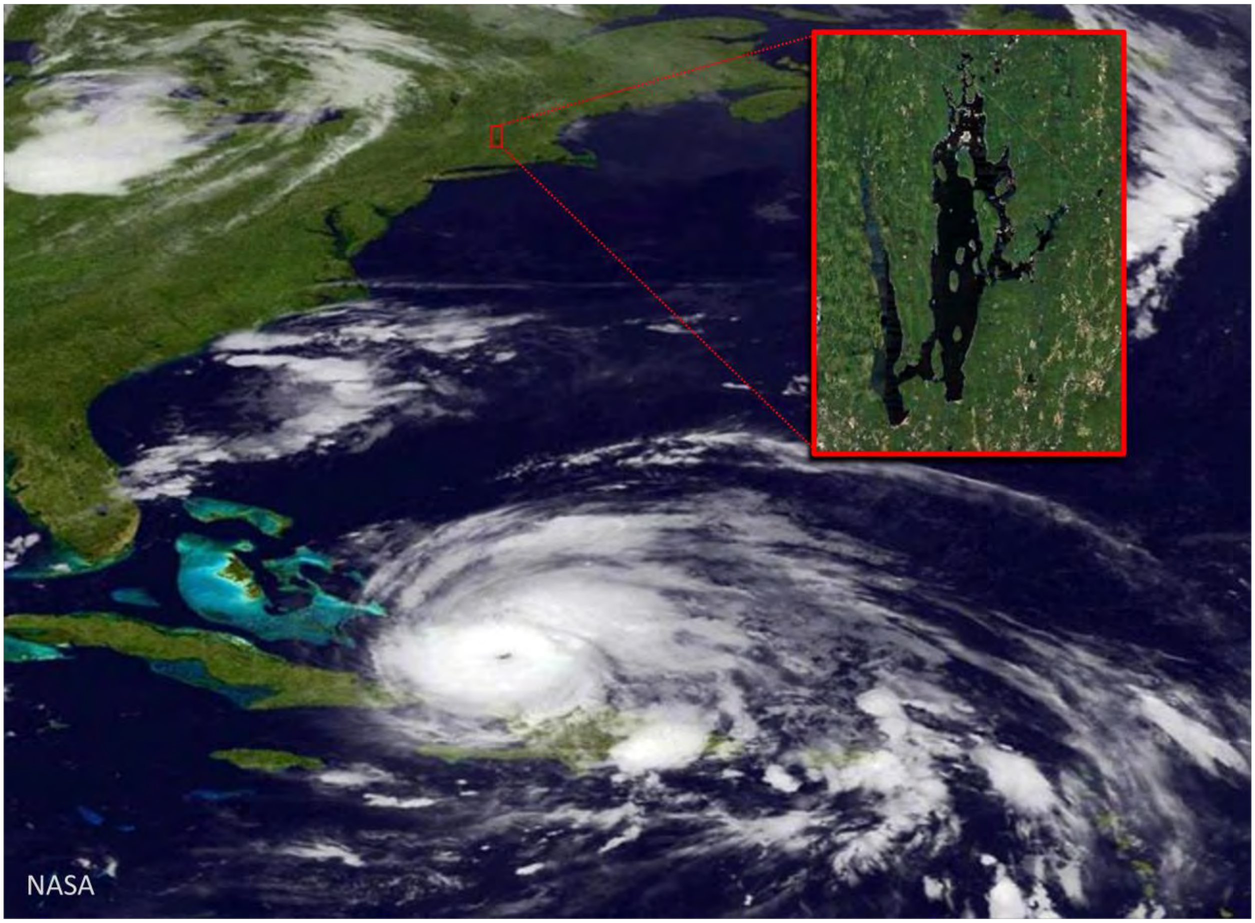

Figure 1.6 – Hurricane Irene, position on August 24, 2011; the diameter of this system ranged from 200 to 600 miles between August 21 and 29. The maximum storm strength reached Category 3. The dimensions of the red box are ~14 miles (E-W) and ~20 miles (N-S). Animation of the time series of satellite images and other information about this hurricane can be found at: http://www.nasa.gov/mission_pages/hurricanes/archives/2011/h2011_Irene.html

Box 1: The Hydrologic Effects of Land Use Change: Insights from the Harvard Forest Models (Fisher Museum, Harvard Forest, Petersham, Massachusetts and Foster and O'Keefe 2000). Paul K. Barten, University of Massachusetts Amherst, 2005©

	*Pre-settlement forest, circa 1710* The mixed species, uneven-aged forest shown in this diorama depicts the conditions encountered by many European settlers. Rain and snowmelt took a labyrinth path through many layers of vegetation, undisturbed forest soils, beaver ponds, and wetlands before reaching streams and rivers. This is the reference condition for changes in streamflow, soil erosion, and sediment delivery caused by forest clearing, agricultural land use, the fur trade, mill dams, and channel alteration.
	*Early settlement, circa 1740* It is unlikely that the small scale changes (isolated settlers clearing 2 or 3 acres per year) led to measurable landscape-scale changes in streamflow and sediment delivery. These small, scattered openings certainly affected microclimate and streamflow and water quality in small tributaries but probably did not, at least initially, reach the threshold of forest clearing (change in evapotranspiration, ET) that would increase water and sediment yield and stream channel erosion.
	*Peak of agricultural development, ca. 1840* By this time 60 to 90% of the forest in the Northeast was cleared for cropland and pasture. Water yield probably increased by 50% or more as a direct result of soil compaction, channel alteration, wetland drainage, and reduced ET. Even larger increases in soil erosion and sediment delivery occurred. Earlier and more rapid snowmelt led to disastrous spring floods. Compare this scene with the primeval forest and Native American farming and burning.

	*Old field white pine, circa 1910* This diorama depicts two (before and after) hydrologic conditions. Immediately before white pine stands were clearcut, ET in these dense, even-aged stands probably reached an all time high; snow accumulation was reduced and melt was delayed by several weeks. Immediately after the pine was cut the abrupt changes in ET and snow accumulation and melt, along with soil disturbance, would have caused an equally abrupt increase in water and sediment yield.
	*Hardwood regeneration, circa 1915* The scattered deciduous trees left by loggers, coupled with seed sources from adjacent areas, and the moderate, well-watered climate of the Northeast once again led to rapid reforestation. Like the period after farm abandonment (ca. 1850), the hydrologic recovery was rapid (3 to 5 years) as fast growing, early-successional species converted water and nutrients to biomass and again reduced water yield and erosion. Habitat conditions favored the rapid increase in whitetail deer and ruffed grouse populations.
	*Hardwoods reach pole size, circa 1930* Young, vigorous forests continued to stabilize the water balance and allow the land to recover from two centuries of intensive use. As leaf area, litter layer and organic horizon thickness, and the infiltration capacity of soils increased, the stability of the water balance was reinforced. Consider, however, the cumulative differences in forest structure (even-aged) and composition (fewer species) over 200 years. The hemlock woolly adelgid is now causing the loss of Eastern hemlock from these century-old forests.
	*Forest conversion, 1950 to present* This photograph represents the fate of many forests and farms in the Northeast. Although the area of forest has doubled since the late-1800s, the human population has increased by two- or three-fold. More importantly, settlement patterns, sprawl, and forest fragmentation facilitated by the automobile and highway network have steadily increased our per capita ecological footprint. All the old (circa 1840) symptoms are returning: erratic streamflow patterns, increased sediment loads, channel instability, and water quality degradation.

2 – System Description and Management Considerations

The DWSP/MWRA water supply system is an engineering achievement of the first order.[6] In its present configuration it has supplied clean water to Boston and many smaller communities (totaling about one-third of the population of Massachusetts) since the 1940s (Figure 2.1). As noted in the introduction and emphasized throughout this report, the integral role of forests as the living filter for this system is extraordinarily valuable. Considering the potential costs of more extensive water filtration and treatment puts the value of these watershed forests in perspective.

The Texas Water Development Board (2005) estimated the annual operation and maintenance (O&M) cost for a 200 million gallon per day (MGD) system (equivalent in size to the MWRA system) would range from $33 million to $42 million. Black and Zaklikowski (HDR, Inc., 2009) estimated annual O&M costs for direct filtration and conventional treatment of 200 MGD at $13 million and $16 million, respectively. In other words, the DWSP watershed forests and source water protection program are avoiding O&M costs in the neighborhood of $20 million per year—over and above the avoided upfront capital costs of building a enhanced filtration and treatment plant. The estimated cost of treating 1.2 billion gallons per day (six times the daily MWRA volume) for New York City would be $8 to $10 billion to construct the facility and approximately $1 million per day for O&M (http://www.dec.ny.gov/lands/25599.html). Extrapolating from this ratio, the approximate capital cost of building a treatment plant for metropolitan Boston capable of delivering 200 MGD would be an additional $500 million. These numbers provide a rough indication of the value of the Commonwealth's watershed forest assets.

[6] The history and characteristics of the system is described in detail on the MWRA and DWSP websites, in DWSP management plans, and in many other documents and sources.

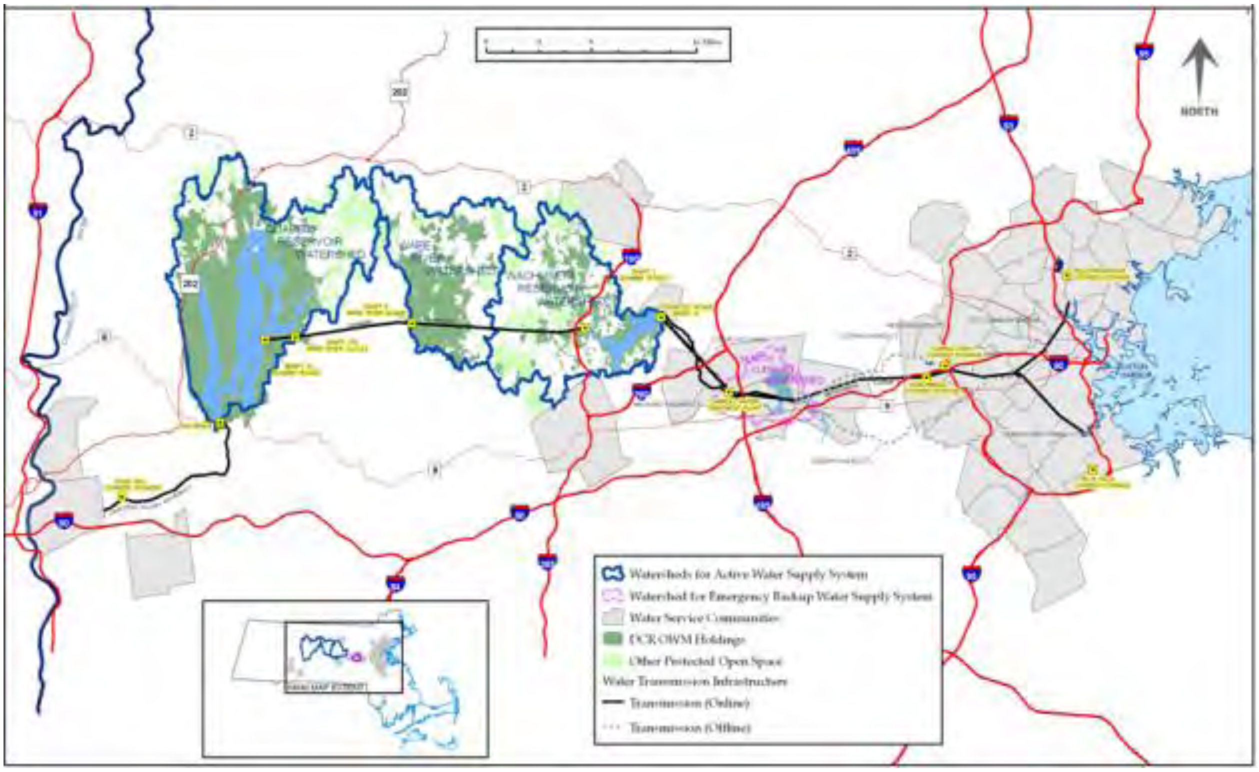

Figure 2.1 – Massachusetts DCR Division of Water Supply Protection and Massachusetts Water Resources Authority system map. Source: DWSP GIS Group

The Quabbin, Ware, and Wachusett watersheds are the focus of this review and report. The Sudbury Reservoir is still managed by the DWSP but its water is no longer used for municipal supply. The largest component of the system, the Quabbin Reservoir and Forest, is notable for its sheer size and for the unusually large proportion of the watershed that is permanently protected from development. More than six times larger in volume than the Wachusett Reservoir (which itself has a more favorable daily use to available storage ratio than many water supply systems), the Quabbin Reservoir has unusually high quality water and it can be blended with water that enters the system from the more developed Wachusett watershed. This gives rise to the notion that the Quabbin is *so* large that its assimilative capacity is, for all practical purposes, inexhaustible. This is a weak and imprudent assumption, especially during a prolonged drought (e.g., 1966-1970). As Professor Emeritus Peter Black at the SUNY College of Environmental Science and Forestry in Syracuse is fond of noting, American attitudes about water supply are governed by the hydro-illogical cycle *"…drought …concern …rain …apathy"* [repeat]. Table 2.1 summarizes the key storage, use, and time dimensions of the system. Although few Massachusetts residents (and others across the northeastern U.S.) remember the regional drought of the 1960s, the influence of an extreme event on a system that usually operates flawlessly in the background of daily life is plainly evident in Figure 2.2.

Table 2.1 — Division of Water Supply Protection/Massachusetts Water Resources Authority water supply system attributes.

	Quabbin	Ware	Wachusett	System
Watershed area (acres)	119,940	61,740	74,890	256,570
Reservoir area (acres)	24,576	River intake	4,160	28,736
Reservoir capacity (billion gallons)	412	River intake	65	477
System at maximum storage				
Mean daily water use (million gallons per day; MGD)				200
System capacity ÷ mean annual withdrawal				6.5 years
Safe Yield[1] (million gallons per day; MGD)				300
System capacity ÷ Safe Yield				4.3 years
Continuous Stage 1 Drought Emergency (February 1966 through February 1970)[2]				
Average Quabbin volume (billion gallons) …53.5%	220	River intake	65	285
Mean 1966-70 volume ÷ mean annual withdrawal				**3.9 years**
Mean 1966-70 system volume ÷ Safe Yield				**2.6 years**

[1] Safe Yield is the maximum quantity of water that could be delivered on a sustained (though not indefinite) basis during a prolonged drought

[2] Wachusett Reservoir is kept at or near capacity with water from the Quabbin

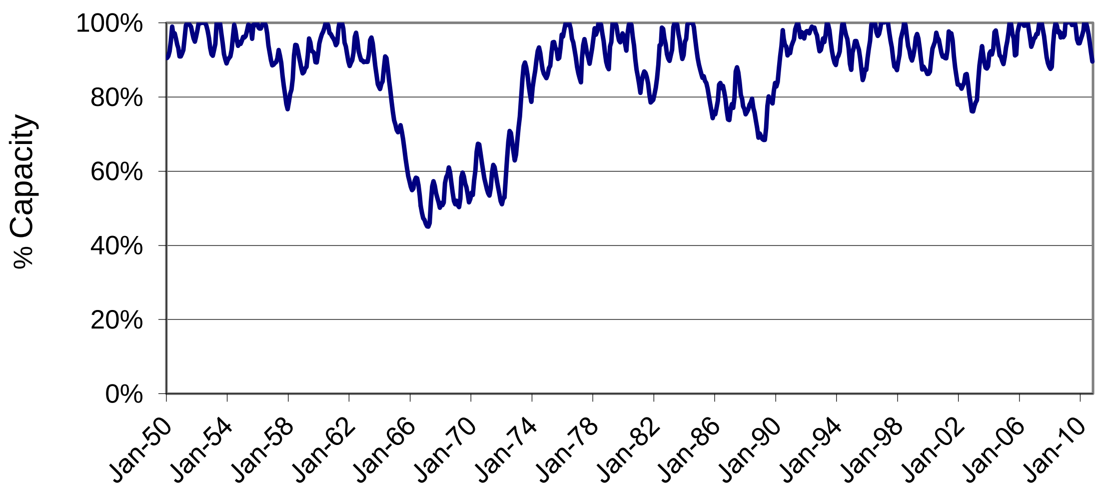

Figure 2.2 — Quabbin Reservoir storage volumes (percentage of 412 billion gallon maximum capacity) from January 1950 to present. A continuous Stage 1 Drought Emergency occurred from February 1966 through February 1970 and for six months between October 1971 and March 1972. The minimum storage volume of record is 45.1% in March 1967.

The links between land cover and land use and streamflow and water quality are well established (Calder 2005; de la Cretaz and Barten 2007; National Research Council 2008). There is, of course, variation from site to site, region to region, and year to year (in relation to climate) but patterns and trends have been clearly demonstrated through a combination of monitoring and modeling. Two general land cover classes, % forest and % developed, and more specific metrics such as % impervious area, have proven to be useful indices.

When forest land is converted to residential, commercial, industrial, and transportation uses (in sum, developed land), what was once a pollutant sink (i.e., a place that can detain and assimilate many pollutants) becomes a potential stormwater and pollutant source. The principal reason for the change is the addition of impervious surfaces (roads, rooftops, driveways, parking lots, highly compacted soils, etc.) that prevent water from entering the soil. This limits or eliminates the time and opportunity for beneficial biological, chemical, and physical processes that naturally filter and protect water quality. Riparian forests—the last line of defense before overland or shallow subsurface flow enters streams, rivers, wetlands, lakes, and reservoirs—are arguably the most important ecosystems in the watershed in relation to water supply protection. They also are key corridors for wildlife movement with rich and diverse habitat values and high biological diversity (both plants and animals).

As noted earlier, Table 2.2 shows that the Quabbin and Ware watersheds have unusually favorable land cover characteristics. In contrast, the Wachusett Reservoir watershed is slowly approaching key thresholds for all three metrics noted above. If not for the effective long-term source water protection efforts and substantial investments by the Commonwealth, NGOs, and community groups, the filtration waiver made possible by the consistently high quality water—delivered from the system as a whole—would not have been issued or renewed. In other words, even if distilled water entered the Wachusett Reservoir from the Quabbin and Ware, the quality of the blended water is ultimately dependent upon local (Wachusett) watershed characteristics. Recent changes in the New York City water supply system are noteworthy.

New York City is spending an enormous sum of money to construct a treatment plant (coagulation, clarification, filtration, disinfection) for the water from the circa 1850 East-of-Hudson system (10% of daily supply). This is because development has decreased water quality below the threshold or mixing ratio where water from the larger Catskill (completed in the 1920s, now 40% of daily supply) and Delaware Systems (completed in the 1960s, now 50% of daily supply) can be reliably used to reach EPA standards after the three sources are combined. (The old maxim—"dilution is the solution to pollution"—is no longer viable.) It follows, for both metro-Boston and New York, that decreases in water quality from the larger (almost fully forested) parts of the system (the Quabbin Reservoir and Catskill and Delaware Reservoir systems, respectively) would present new and very expensive public health challenges.

Why does this matter? It matters because change occurs slowly …one building lot at a time. Furthermore, the Nashua River watershed, within which the Wachusett Reservoir watershed is a major component (tributary or sub-watershed), scored near the very top of a list of 540 large watersheds (in the 20-state Northeastern Area of the U.S. Forest Service) that are vulnerable to forest conversion and water quality degradation by 2030 (Gregory and Barten 2008; Barnes et al. 2009; de la Cretaz et al. 2010). The reasons for assigning high priority to source water protection include:

1. the excellent condition of the watershed,
2. the proximity to Boston and other employment centers,
3. US Census Bureau population growth projections for 2030, and
4. the high proportion of private forest land in the watersheds (Table 2.3).

Furthermore, a dollar invested in prevention typically buys *much* more than a dollar of mitigation. This realization is motivating rapid advances in the emerging field of "ecosystem services." Clearly, the conservation and stewardship of forests, both public and private, should continue to be a high priority for DWSP, DCR, and their many partners. The vulnerability study cited above use 2030 as an end date because source water protection requires time, dedicated effort, and sufficient human and financial resources. It always has, it always will.

Table 2.2 — Division of Water Supply Protection/Massachusetts Water Resources Authority water supply system, areas and percentages for key watershed and land cover attributes

	Quabbin		Ware		Wachusett		System	
	acres	%	acres	%	acres	%	acres	%
Watershed area	119,940	*100*	61,738	*100*	74,891	*100*	256,568	*100*
Reservoir area	24,576	*20*	0	*0*	4,160	*6*	28,736	*11*
Non-reservoir area[1]	95,363	*80*	61,738	*100*	70,731	*94*	227,832	*89*
The land cover percentages that follow are calculated with non-reservoir area — the entire contributing area for streamflow and groundwater inputs to the Quabbin and Wachusett Reservoirs and the Ware River intake.								
Forest area[2]	85,538	*90*	50,770	*82*	51,405	*73*	187,713	*82*
Non-forested wetlands[3]	3,002	*3*	2,352	*4*	1,216	*2*	6,570	*3*
Agricultural and open[4]	3,393	*4*	3,123	*5*	5,577	*8*	12,093	*5*
Developed Land[5]	2,160	*2*	3,320	*5*	10,548	*15*	16,028	*7*
Impervious surface[6]	1,350	*1.4*	1,621	*2.6*	4,061	*5.7*	7,032	*3.8*

[1] This category includes all land, streams, wetlands, developed areas, etc., upstream of the Quabbin and Wachusett Reservoirs and the Ware River intake. (Watershed area – Reservoir area = Non-reservoir [contributing] area; based on DWSP GIS watershed and reservoir data layers)
[2] Forest area includes evergreen, deciduous, and mixed forest and wooded wetlands.
[3] Non-forested wetlands are derived from the MassGIS non-forested wetland cover (2005).
[4] Agricultural and open land includes the following MassGIS land covers (2005): brushland/successional, cropland, nursery, open land, orchard, and pasture.
[5] Developed land includes all MassGIS 2005 land covers categories that include impervious surfaces and potential anthropogenic pollution sources: cemetery, commercial, golf course, industrial, junkyard, mining, powerline/utility, recreational, residential, transitional, transportation, urban public/institutional, and waste disposal.
[6] Impervious surface estimates are derived from April 2005 spatial data compiled by the Sanborn Map Company, integrated with the 2007 Executive Office of Transportation roads layer by MassGIS. It includes all constructed surfaces such as buildings, roads, parking lots, brick, asphalt, and concrete. It also includes compacted soils or surfaces related to mining and unpaved parking lots.

Table 2.3 — Protected forest land and open space in the DWSP/MWRA water supply system.

	Quabbin		Ware		Wachusett		System	
	acres	%	acres	%	acres	%	acres	%
Watershed area	119,939	100	61,738	100	74,891	100	256,568	100
Reservoir area	24,576	20	0	0	4,160	6	28,736	11
Land area[1]	95,363	80	61,738	100	70,731	94	227,832	89
The land cover percentages that follow are calculated with non-reservoir area — the entire contributing area for streamflow and groundwater inputs to the Quabbin and Wachusett Reservoirs and the Ware River intake.								
All protected lands[2]	67,870	71	31,216	51	30,774	43	129,860	57
Forest area[3]	85,538	90	50,770	82	51,405	73	187,713	82
Protected forest[2]	62,776	74	27,243	54	25,883	50	115,902	62
DCR DWSP Reserve forest[4]	5,915	7	3,100	6	271	0.5	9,286	5

[1] includes all land, streams, wetlands, developed areas, etc., upstream of the Quabbin and Wachusett Reservoirs and the Ware River intake. (Watershed area – Reservoir area = Land area; based on DWSP GIS watershed and reservoir data layers)

[2] MassGIS protected open space layer; private forest land enrolled in Chapter 61 is *not* included since these parcels may be sold and converted to non-forest uses after the 10 year enrollment period ends.

[3] Forest area includes evergreen, deciduous, and mixed forest and wooded wetlands

[4] DCR DWSP forest land excluded from forest management through designation as a "reserve." These include the western Quabbin Park, the Pottapaug Natural Area, all islands, the Cunningham Pond Reserve, and the Poutwater Pond Nature Preserve.

Harvesting Intensity and Imputed Motives on DWSP Forests

The STAC discussed several common statements about the intensity of and motivation for harvesting operations by the Division of Water Supply Protection. Statements that "logging is unsustainable" (annual harvest is greater than annual growth) and that "they are in it for the money" are not supported by forest inventory and financial data (Tables 2.5 and 2.6). The Quabbin Forest has one of the most complete and extensively analyzed continuous forest inventory (CFI) programs in North America. Established by Fred Hunt in 1960 and re-measured at ten (sometimes five) year intervals, more than 300 plots on a half mile grid are used to quantify a large number of parameters. As summarized in Table 2.4, total growth between 1960 and 2000, over and above harvesting, was 400 million board feet. The 2010 shows another increase because (1) the forest continues to mature, (2) recent tree mortality caused by insects and diseases has been modest, and (3) harvest areas and volumes have remained right around the average of earlier decades (until harvesting operations were suspended in April 2010).

Table 2.4 – Quabbin Forest board foot (BF) volumes by species in 1960 and 2000

Tree species	BF Volume 1960[1]	BF Volume 2000[1]
White pine	50,920,000	230,058,000
Hemlock	11,914,000	39,266,000
Red pine	1,398,000	23,806,000
Other evergreens	1,574,000	5,316,000
Sugar maple	2,134,000	5,783,000
Red maple	7,544,000	27,799,000
Red oak	20,877,000	115,407,000
Black oak	8,437,000	28,810,000
Scarlet oak	3,240,000	497,000
White oak	7,001,000	14,151,000
Yellow birch	1,427,000	4,107,000
Black birch	2,332,000	12,402,000
Paper birch	858,000	3,576,000
White ash	2,650,000	13,458,000
Other deciduous	4,759,000	2,864,000
TOTAL	127,065,000	527,300,000[2]

[1]Both time series are based on 55,520 acres, the agency ownership at Quabbin in 1960.
[2]Growth in excess of [net] harvesting 1960 to 2000 was 400,235,000 board feet.

Table 2.5 – Harvest unit area and total revenue for the DWSP system (Quabbin, Ware, Wachusett, Sudbury Forests; 83,300 acres of managed forest with 9,300 acres of reserves) by decade.

Decade	Harvest unit area[1] (acres)	Revenue[2]
1980-89	16,867	$2,429,607
1990-99	13,329	$4,498,730
2000-09	14,212	$6,940,762
Annual average 1980-2009	1,480	$462,303

[1] Harvest unit area is based on the outer perimeter of the timber sale and includes both treated *and* untreated areas, the openings (~1/3) and residual trees (~2/3).
[2] Not adjusted for inflation.

Harvesting revenues have increased in relation to the size and value of the trees and the transition from thinning to regeneration treatments. They also have increased as a result of the thinning and stand improvement treatments (by design and as expected) that enhanced the growth rate of the most valuable and vigorous trees. Another major influence on revenue is the volatile nature of timber markets as global demand for building materials and furniture waxes and wanes. That said, recent regeneration harvests of straight, sound, large-diameter logs command a much higher price (10 to 100 times) than an equal volume from the firewood and pulpwood sales of the 1960s-80s.

An “in it for the money” approach would jeopardize the filtration waiver by US EPA and many other forest benefits and values. The purpose of watershed management and source protection efforts is to minimize costs not to maximize timber revenue. The DWSP, MWRA, and other water suppliers are, therefore, “in it for the sustained cost savings.” The operation and maintenance costs alone for an expanded water filtration and treatment plant would exceed timber harvesting revenues by one or two orders of magnitude.

A summary of the most recent forest inventory with the Quabbin continuous forest inventory [CFI] network of 323 plots (representing 51,680 acres and including repeat measurements of more than 10,000 trees [living, dead, or harvested] clearly shows that growth exceeded harvest and natural mortality by a substantial margin (Table 2.6). The negative values for some species are attributable to insect and disease mortality and associated salvage operations (e.g., red pine scale, ash dieback) and natural succession (e.g., white birch).

Table 2.6 –Total volume (cubic feet) of live trees in 2000 and 2010 on 323 permanent inventory plots on the Quabbin Forest.

SPECIES	2000 Total	mortality	cut	2010 ingrowth	2010 Total	Net Change (ingrowth-mortality /cut+new)	
White pine	40,257,000	1,196,000	2,702,000	485,000	45,857,000	5,599,000	14%
Red oak	26,870,000	268,000	438,000	115,000	33,754,000	6,884,000	26%
Red maple	15,054,000	1,057,000	1,029,000	378,000	15,615,000	561,000	4%
Hemlock	8,985,000	212,000	139,000	216,000	10,950,000	1,965,000	22%
Black oak	7,849,000	268,000	677,000	32,000	8,628,000	779,000	10%
Black birch	5,659,000	284,000	365,000	293,000	6,355,000	696,000	12%
White ash	4,536,000	521,000	189,000	29,000	4,426,000	-110,000	-2%
Red pine	3,901,000	104,000	1,422,000	0	2,789,000	-1,112,000	-29%
White oak	3,834,000	134,000	260,000	16,000	4,159,000	326,000	8%
Sugar maple	2,126,000	82,000	34,000	30,000	2,446,000	320,000	15%
White birch	1,770,000	399,000	132,000	23,000	1,430,000	-340,000	-19%
Hickory	1,728,000	116,000	11,000	18,000	1,838,000	110,000	6%
Yellow birch	1,722,000	119,000	13,000	34,000	1,934,000	212,000	12%
Chestnut oak	596,000	77,000	0	12,000	594,000	-3,000	0%
Red spruce	483,000	2,000	0	1,000	604,000	121,000	25%
Black cherry	345,000	39,000	26,000	18,000	302,000	-43,000	-12%
Larch	287,000	2,000	0	0	298,000	11,000	4%
Scarlet oak	279,000	0	0	6,000	435,000	155,000	56%
Poplar	255,000	29,000	0	0	261,000	6,000	2%
Beech	196,000	47,000	0	5,000	202,000	6,000	3%
Pitch pine	77,000	18,000	0	0	66,000	-11,000	-14%
Black gum	51,000	0	0	1,000	71,000	20,000	39%
White spruce	44,000	0	0	5,000	55,000	11,000	25%
Other species	26,000	4,000	7,000	5,000	20,000	-6,000	-23%
Elm	21,000	0	1,000	1,000	28,000	7,000	33%
Basswood	16,000	0	0	5,000	28,000	12,000	75%
Other spruce	7,000	0	0	0	11,000	4,000	57%
TOTALS	**126,974,000**	**4,978,000**	**7,445,000**	**1,728,000**	**143,156,000**	**16,180,000**	**13%**

3 – Watershed Forest Management Principles and Practices

In his acceptance speech for the 2007 Nobel Peace Prize (shared with ~1,000 members of the Intergovernmental Panel on Climate Change [IPCC]), Vice President Al Gore lamented that *"…science thrives on uncertainty and politics are paralyzed by it."* This leaves managers and regulators with the unenviable task of making and implementing decisions that are scientifically sound, operationally practical, *and* socially acceptable. Whether they opt for an active or a passive management approach (a choice discussed in Section 4), they and their organizations must accept the consequences of their decisions. This is especially daunting when a decision based on scientific principles, operational experience, and their professional judgment is in direct contradiction with conventional wisdom and public opinion. In the case of the active management of DWSP forests, wide ranging aesthetic sensibilities in relation to timber harvesting and the 4 C's of 21st century journalism (conflict, controversy, contradiction, and colorful language) are added to the decision space.

A worksheet based on the charge to the committee and the extant DWSP land management plans was used to identify and better define the key gaps between theory and practice early in the STAC review process (Table 3.1). This section draws upon comprehensive reviews by Satterlund and Adams (1992), Brooks and others (2003), Ice and Stednick (2004), Calder (2005), de la Cretaz and Barten (2007), the National Research Council (2000, 2004, 2008), Creed and others (2011 a,b), and others (Section 8) to discuss these gaps and the core principles of the DSWP land management plans for the Quabbin, Ware, and Wachusett forests. An explanation and discussion of each of the 10 principles presented in the worksheet follows.

Table 3.1 – Summary of STAC members' responses to a worksheet completed in preparation for the second meeting. (Some members elected not to complete the worksheet or rate all the principles.)

A = there is sufficient certainty about this principle, and from what I know about its application on DWSP watersheds, I have no major concerns.
B = there is sufficient certainty regarding this principle yet I am uncomfortable with its application by DWSP. I would like to learn more and discuss potential changes in DWSP objectives and forest management practices.
C = there is significant uncertainty regarding this principle such that I do not think it should be applied on DWSP properties until it is clarified by research and monitoring.

Principle	A	B	C
1. Forested watersheds yield higher quality water than non-forested cover types	8	-	-
2. Paired watershed studies have demonstrated that until approximately 20-30% of a watershed forest is cut, there is generally no measurable increase in water yield, and furthermore that water yield generally returns to or below the pre-harvest baseline within 3-10 years.	3	3	1
3. A forest including stands of younger, aggrading stands will capture and retain more of the available nutrient pool than one exclusively composed of mature stands.	5	3	-
4. A forest (stand or landscape) with a diverse mix of species will better resist insects or disease outbreaks than one that is relatively homogenous in composition.	6	1	1
5. Larger openings allow for the full range of shade tolerance and allow established regeneration to grow freely. However, there may be a threshold size above which the mineralization and transport of nutrients may temporarily exceed the regenerating forest's uptake.	3	4	-
6. In larger openings, retention of scattered trees or small groups helps to maintain ecosystem structure and function (e.g., seed sources, nutrient cycling, wildlife habitat features), influence microclimate (e.g., shading patterns and soil temperature), and reduce the aesthetic impact of timber harvesting (…retaining vertical structure, screening long sight lines, etc.).	4	3	1
7. Unmanaged deer populations, especially under mature oak forests with high acorn production, will increase to densities and herd sizes that severely limit forest regeneration.	7	1	-
8. Certain wildlife species, including a number of neotropical migratory birds, prefer or require early successional habitat (ESH; herbaceous plants, shrubs, young trees) for feeding, nesting, and/or cover. Timber harvesting can generate this habitat type.	7	1	-
9. Invasive species that are capable of rapid, unchecked expansion can compromise biological diversity, limit the regeneration of native species, and, consequently, have an unfavorable influence on water resources.	4	3	1
10. While careless logging methods can degrade water quality, the diligent application of M.G.L. Chapter 132 (Forest Cutting Practices Act) and state-of-the-science Best Management Practices can avoid, prevent, or mitigate adverse effects on forest vegetation, soils, wildlife, and aquatic ecosystems, and water resources.	8	-	-

Note: Eight STAC members completed the worksheet before the second meeting. One respondent did not indicate a choice for principle 2; another respondent did not indicate a choice for principle 5.

1. Forested watersheds versus other land uses and land covers

The quality of water emanating from forest ecosystems exceeds that of other land covers and land uses for a host of inter-related reasons. The first may be self-evident, but the presence of forests means the potential pollutants (fertilizers, pesticides, metals, hydrocarbons, etc.) associated with other land uses (i.e., residential, industrial, commercial, agricultural, etc.) are largely absent. Forests also have a distinctive set of hydrological, edaphic, and ecological characteristics that help to regulate and moderate streamflow (Figure 3.1) and maximize nutrient uptake (relative to other land covers and land uses). These characteristics and functions include:

i. Leaf litter and organic layer;
ii. high infiltration capacity;
iii. high porosity and permeability;
iv. long residence times for water in the soil;
v. deep-rooted, long-lived vegetation;
vi. effective uptake and assimilation of nutrients and other potential pollutants;
vii. stabilization and protection (via rooting) of soils, slopes, and stream banks; and
viii. microclimate amelioration (the active surface for radiant energy exchange is the forest canopy not the soil surface during the growing season).

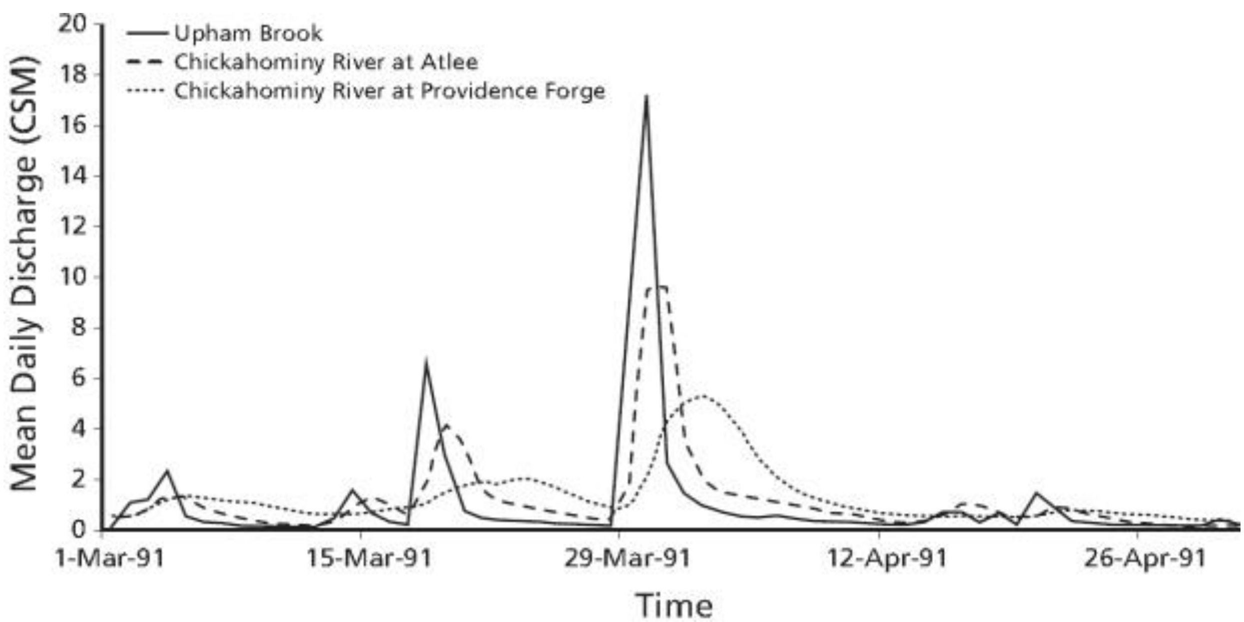

Figure 3.1 – Normalized mean daily discharge ([ft^3/sec]/mi^2) for three gaging stations in the Chickahominy River watershed, Virginia, used by Focazio and Cooper (1995). Solid line = Upham Brook (urbanized, 38 mi^2); Dashed line = Chickahominy River at Atlee (residential, 62 mi^2); Dotted line = Chickahominy River at Providence Forge (rural, but includes Upham and Atlee subwatersheds, 252 mi^2). The period from 29 March to 12 April 1991 corresponds to "Storm 4" in Figure 8.6. Data source: http://waterdata.usgs.gov/va/nwis/discharge? (de la Cretaz and Barten, 2007: 219)

2. What is the response threshold for streamflow?

Since the first paired watershed experiments were undertaken a century ago (Ice and Stednick 2004), a key objective has been the identification of a threshold for harvesting treatments above which the change in streamflow, relative to the control or reference watershed, can be attributed to the treatment (e.g., thinning, strip cuts, clearcutting, clearcutting followed by herbicide application). Changes in streamflow volume and timing are the net result of changes in the water balance, energy balance, soil water storage, subsurface flow rates, and overland flow rates (if excessive soil compaction has initiated this pathway). In other words, if the residual trees are unable to use the same volume of water and nutrients (via enhanced growth, increased leaf area, reduced competition for sunlight, water, and nutrients) the "surplus" will make its way to the stream. If careless logging has compacted and rutted soils, especially in riparian areas, and initiated overland flow, the movement of water, sediment, and nutrients is no longer regulated by the forest.

Every review and synthesis of the forest hydrology and watershed science literature has wrestled with this key question (Sopper and Lull 1967; Anderson et al. 1976; Bosch and Hewlett 1982; Swank and Crossley 1988; Ice and Stednick 2004; National Research Council 2008). An apparent threshold that emerges from scores of paired watershed experiments is 20 to 30 percent (area treated *or* biomass removal) (Figure 3.2). However, the threshold for the treatment response could be as low as 5 or 10% if the watershed in question had very steep slopes, shallow and highly permeable soils (i.e., short residence times and rapid subsurface flow rates), impermeable bedrock, an evergreen forest, or a non-uniform temporal distribution of precipitation (e.g., high intensity, long duration rain events and/or rapid rates of snowmelt). The threshold for the treatment response could be 40 to 50% if the watershed in question had very gentle slopes, deep and highly permeable soils, a deciduous forest, or a uniform temporal distribution of precipitation (with relatively frequent, low intensity rain events and extended periods of snowmelt). This potential variation in watershed characteristics and responses is a key reason why site-specific monitoring is needed (discussed in Sections 6 and 7).

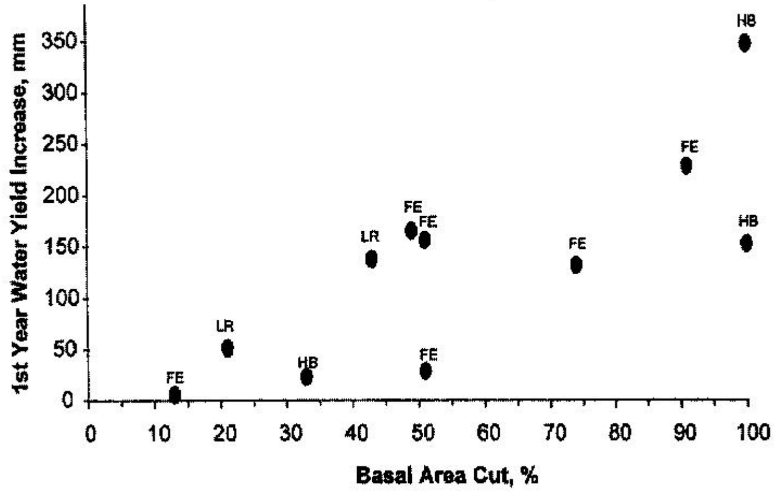

Figure 3.2 –First year (post treatment) water yield increase in relation to biomass removal (FE = Fernow, West Virginia, HB = Hubbard Brook, New Hampshire, LR = Leading Ridge, Pennsylvania) (Hornbeck and Kochenderfer 2004). Note: the HB experiment that produced a 350 mm increase was a 100% clearcut followed by three years of herbicide treatment—completing eliminating the influence of living forest vegetation on the water balance.

3. Young aggrading forests retain more nutrients

The logistic (S-shaped) growth curve—from ecology and silvics—is the scientific underpinning for the principle that young, aggrading forests retain more nutrients (reviewed in Barnes et al. 1998; Kimmins 1997; Smith et al. 1997). At early stages of stand development, especially with a diverse species mix that includes fast-growing early successional species, biomass accumulation increases at an increasing rate. After several decades of rapid growth, increased competition, and subsequent decreases in the number of trees per unit area the logistic growth curve reaches an inflection point. Height and volume growth continues at a decreasing rate until a comparative equilibrium is reached or natural disturbance re-sets the stand back to an earlier condition.

4. A forest or stand with a diverse mix of species is more resistant to insects and diseases

Since many insects and diseases that kill trees are specialized organisms it stands to reason that monocultures or a limited species mix (e.g., white pine and red oak) are more vulnerable to loss than stands or forests comprised of more species, more seed sources, more regeneration mechanisms, and so on. This is no more complicated than the risk management principles in investment and finance or the redundant systems paradigm in engineering, communications, and health care.

5. Large openings and microclimate

The undesirable changes (with respect to watershed forest management and water quality protection) in radiant energy loading, soil moisture, soil temperature, and decomposition, nutrient cycling, and evaporation rates embedded in this principle are scientifically plausible. However, the potential for spatial and temporal variation is so large that a general principle is difficult to support. In any case, since geometric patch cuts (the focal point of the present controversy and cause of harvesting moratorium) are unlikely to be used in future operations, this principle may focus on a moot point. Simple modifications of silvicultural practices (e.g., retaining some mature trees, adapting the opening shape and orientation to slope and aspect, thinning the residual stand along the edge of the opening) can favorably influence microclimate and the appearance of the harvest unit without reducing the diversity of shade tolerant, mid-tolerant, and shade intolerant tree and shrub species that naturally regenerate in the opening (Smith et al. 1997).

6. and 8. Forest management and the conservation of biological diversity

The conservation, perpetuation, and management of wildlife populations are important goals to many state and federal agencies, non-governmental organizations (NGOs), and large and varied segments of the public. Goals and objectives for wildlife populations and habitats are prominent features of the Land Management Plans (LMPs) for the Wachusett, Ware River, and Quabbin watersheds. The methods that are applied to wildlife populations range from active management of beavers, muskrats, gulls, and Canada geese to prevent or deter their activities in the Pathogen Free Zone near the aqueduct intake structures, to a hunt to control deer numbers on the watershed to prevent over browsing of understory vegetation and allow forest regeneration, to the protection and maintenance of vernal pools in an undisturbed state. The key caveat, however, is that the protection of the watershed and the water supply are the highest priorities and take precedence over other goals and objectives, including those for wildlife, recreation, carbon sequestration, and historical and cultural values. Although important, these additional objectives need to be compatible with the maintenance of water quality in the near- and long-term.

The words “wildlife” and “biodiversity”, like many terms, can have different meanings to different people. Our use of these terms here takes on a broad, inclusive, and holistic approach. People often place different values on different species (e.g., what is worth more, a bluebird or a mosquito?), yet when viewed as a *community* of living organisms, ideas about differential values become less useful or meaningful. Because our emphasis is on the entire living community of organisms, we use the term biodiversity to make it clear that we want to address issues related to all native organisms: vertebrate and invertebrate animals, plants, fungi, and microbes.

Forest Communities as a Continuum

Biodiversity in New England includes a diverse array of species. Many of these species use some form of forest vegetation as habitat. Our knowledge of the forest habitat requirements of terrestrial vertebrates (amphibians, reptiles, birds, and mammals) is substantial. Although still incomplete, it is much more comprehensive than what is currently known for the vastly more diverse array of invertebrates. In New England, upwards of 260 species of terrestrial vertebrates use some form of forest vegetation as habitat, including 21 amphibians, 18 reptiles, 161 birds, and 60 mammals (DeGraaf and Yamasaki 2001). DeGraaf and Yamasaki’s (2001) book on New England wildlife provides perhaps the most extensive and comprehensive picture of wildlife-habitat relationships in New England, in the form of both narratives and habitat matrices. It thoroughly characterizes the forest composition and structure used and preferred by each of the 260 species.

There are at least two major components of forest vegetation that combine to form habitat for a wide variety of animal species: vegetation species composition and vegetation structure. While both components are critical, many forest ecologists agree that forest structure (i.e., the size and density of trees, age classes of trees, percent canopy cover, amount of vertical [height] diversity, presence of key components such as openings, snags, and logs, etc.) is largely responsible for determining the presence, abundance, and distribution of species in forested landscapes (DeStefano 2002; DeStefano and Haight 2002).

It is the mix of structural diversity in a forest, from openings with herbaceous plants and tree seedlings, to patches of early young woody growth and pole-sized saplings, to areas of mid-aged stands, and finally to late seral stages or old-growth, that creates the conditions required for diversity among species (biological diversity) and for the varied life history stages within a species (life history diversity). Creating some structural diversity for protection of the forested watershed against catastrophic events such as hurricanes, as discussed elsewhere in this report, can also serve to create structural diversity for wildlife. In southern New England, however, important habitat issues for forest wildlife are focused at the two ends of the forest continuum: young woody growth (early successional forest) and older forest or old-growth (late seral stage forest). After 60 to 90% of southern New England was cleared for agriculture in the 1700s and 1800s, and much of the subsequent forest regeneration is now even-aged, both very young and very old forests are under-represented across the region's landscape today.

Forest Structure and Wildlife Habitat

An analysis of the habitat matrices provided by DeGraaf and Yamasaki (2001) shows that a majority of New England's amphibians, reptiles, birds, and mammals that use forest habitat require a wide variety of structural stages—50 to 70% of all species of forest wildlife need a diversity of forest structure to fulfill their life history needs (DeGraaf et al. 2006; DeStefano 2011). Some species may breed in older forest, but at least some of the food they require is found in younger forest (e.g., northern goshawks). Alternatively, several species may breed in young forest, but require older forest for winter food and cover (e.g., ruffed grouse). A very large proportion of New England's wildlife species (126 terrestrial vertebrate species, or 48%) use the full spectrum of forest ages and structure, from areas with young and vigorously growing seedlings and herbaceous growth up through and including older forest with large trees and closed canopy (e.g., such diverse species as spotted salamanders, northern black racers, wood thrushes, and woodland voles).

A significant number of species (20-24% overall), particularly birds, not only require early successional stages, but can be considered obligate early successional users (e.g., American kestrels, eastern kingbirds, brown thrashers, prairie warblers, several swallow species, least shrews, cottontail rabbits, meadow jumping mice, and long-tailed weasels to name a few). Several other species (8-25% overall) require late seral stage forest. Stands of older, large trees with well-developed canopies and diverse vertical structure, which also provide important habitat components such as large standing (snags) and downed (logs) dead wood, provide the structure required for these species (e.g., most woodpecker species, great crested flycatchers, cerulean warblers, flying squirrels). In addition, older forest can provide for the special needs of several species, such as large trees to form cavities for a few species of waterfowl (e.g., wood ducks, common goldeneyes, mergansers) and nesting substrate for many species of raptors.

DeGraaf et al. (2006) noted that species associated with mature forest, such as pileated woodpeckers and American fisher, are common throughout much of New England, while species associated with early successional forest, such as field sparrows, eastern towhees, and New England cottontail rabbits are uncommon. Ironically, the latter species were once thought of as “generalists” because they were so abundant a century ago. They are actually habitat specialists, requiring young regenerating forests for their continued existence. Early successional and late seral stage forests also provide habitat for a *much* wider range of biodiversity, which include invertebrates (e.g., a diverse array of butterflies and moths), plants (e.g., a diverse array of wildflowers), fungi, and microbes.

As noted earlier, there is a preponderance of mid-sized, even-aged forest throughout much of southern New England. In the continuum of forest ages and structures, it is the opposite ends of the spectrum—young forest and old forest—that are uncommon in the forested landscape. By increasing this kind of diversity in forest structure, even in a very modest and very conservative way, we can achieve diversity in the forest ecosystem and the wide range of species that use forests as habitat.

7. Unmanaged deer herds limit forest regeneration

This topic is thoroughly discussed in the current (and earlier) versions of the Quabbin Land Management Plan and the research papers and reports cited therein. The interested reader is referred to those documents.

9. Invasive species management

Invasive species (plants, animals, insects, diseases) are an ever-present concern for any forest, managed or unmanaged. A particular concern for southern New England forests are non-native invasive insects and pathogens which are causing mortality or decline of many tree species. The list includes species-specific pests such as beech bark disease, hemlock woolly adelgid (*Adelges tsugae*), and emerald ash borer (*Agrilus planipennis*); Asian longhorned beetle (*Anoplophera glabripennis*) which has a long list of trees it will attack, particularly maples (*Acer* spp.); as well as cyclical outbreaks of gypsy moth (*Lymantria dispar*) which feeds on many species, particularly oaks (*Quercus* spp.). A good review of invasive forest pests and pathogens in eastern North America can be found in Lovett and others (2006).

The main effects of defoliation and mortality from insects and pathogens are increased gap formation, increased nutrient cycling, more standing snags and dead wood, and in some cases species extirpation from affected areas. The increased gap formation can facilitate spread of invasive plants into the interior forests. This is also true for gaps created by management activities.

Silvicultural treatments with the goal and effect of increasing species and age class diversity can potentially increase the resilience of forest function and processes in the face of invasive insects and pathogens. Management plans should take into consideration the risk of spread of invasive plants and include actions to prevent such spread, including minimizing edge environments, taking precautionary measures so that seeds are not spread on boots/clothing/equipment, and close monitoring of gaps created either by tree defoliation/mortality due to insects and pathogens or management activity.

DWSP has two representatives on MIPAG (http://www.massnrc.org/mipag/), a regional working group and also participates in the IPANE process (http://www.eddmaps.org/ipane/).

10. Effectiveness of forestry BMPs

A comprehensive review and archive of project reports about the form, function, and effectiveness of best management practices (BMPs) to protect water quality can be found on the USDA Forest Service Northeastern Area website: http://www.na.fs.fed.us/watershed/bmp.shtm. Other reviews include Ice and Stednick (2004), de la Cretaz and Barten 2007, and the National Research Council (2008).

4 – Active versus Passive Watershed Forest Management

A limited and literal interpretation of STAC's statement of task would yield a short report based on the principles discussed in the preceding section with the addition of brief narrative and assessment of silvicultural methods. This approach would duck the overarching question, which is, should the DWSP forests be managed (noting that large areas have already been reserved from active management) *or* should they be designated, in their entirety, as large reserves? As emphasized throughout this review, this choice should be considered and a decision made in the context of the water supply system.

The test case or condition for a water supply system is the uncommon (low probability) yet plausible combination of events that imposes maximum stress on its resistance and resilience. This would be analogous to the standard engineering practice of designing for the maximum load imposed on a bridge or a building, the stability of a large commercial aircraft after the failure of one or more engines, et cetera. For the DWSP/MWRA system this test case is a hurricane that blows down the majority of the mature trees in a predominantly even-aged forest during a time period when the reservoir system has been subjected to a prolonged drought (e.g., the 1960s or the 1980s). Because the forest is the green infrastructure for the MWRA system and water must be supplied—day in, day out—to more than 2 million people, this is reasonable and prudent contingency planning and scenario analysis. The extensive damage caused by the 1938 hurricane (when the forest was younger with shorter trees that were less susceptible to wind damage) and the hardships associated with the 1966-70 drought emergency (when the Quabbin Reservoir was at 45 to 55% of capacity) serve as fair warning. Put them together—with the IPCC climate scientists forecasting a greater frequency and severity of extreme events—and the potential for 5 to 10 years of crisis management is no longer a remote, hypothetical possibility. In the words of Al Sample (2008), Director of the Pinchot Institute for Conservation, has everyone responsible for the DWSP/MWRA system carefully and systematically considered how to "avoid the unmanageable and manage the unavoidable"? Will the highway bridge bear the weight of a grossly overloaded truck during rush hour traffic? Will the plane be able to land safely with one engine? Will the DWSP/MWRA water supply system meet the daily needs of more than two million people …come what may?

Since we know the forest will recover from natural and anthropogenic disturbance (…as evidenced by the natural regeneration after agricultural abandonment, changes in forest composition after chestnut blight, and forest regeneration after hurricanes, ice storms, insect outbreaks, etc.), why worry? There are at least three operational reasons for concern. *First*, natural regeneration of forests takes **time** – three to five years before the new leaf area and biological activity stabilize the water balance and related soil erosion, channel erosion, sediment transport, and biogeochemical processes are restored to the approximate pre-disturbance conditions. (Planting trees would only be cosmetic.) *Second*, the time needed for the site selection, design, permitting, financing, construction, and start-up of additional water treatment facilities to would take even longer (probably 10 to 15 years). *Third*, safe, clean, potable water must be delivered day in, day out for the $\geq$ 1,000 days it takes for the forest to recover or the $\geq$ 3,000 days it takes to bring additional water treatment on line. Recall that under drought conditions the system's turnover rate (water "in" becoming water "out") decreases from more than five years to about two or three years—less than the maximum recovery rate of the forest. To be sure, a major hurricane would bring 5 to 15 inches of precipitation and help to refill reservoirs, albeit with lower quality water since turbidity, suspended solids, and nutrient and organic matter loading would all increase. One may recall when 20+ inches of rainfall in a few weeks "ended" the 2007 drought-of-record in the southeastern U.S. with record flooding (after reservoirs for Atlanta, Birmingham, and other municipalities had fallen to an unprecedented 30-day supply). At the point when water supply systems were on the brink of failure they were driven to the opposite end of the operational spectrum by torrential rains and the consequent failure of many wastewater treatment plants in the region. A combination of the biological, physical, and chemical capacity and the skill, experience, and dedication of the water utilities' operators prevented a public health catastrophe (e.g., a waterborne disease outbreak in Atlanta). New reservoirs and enhanced water and wastewater treatment facilities are now being designed, financed with municipal bonds and sales taxes, and built throughout the Southeast.

Denver Water will spend an estimated $40 million of rate-payer fees to remove sediment from one of its reservoirs after a high severity wildfire incinerated most of the forest cover in that watershed. Not long after this incident, Denver Water announced a $33 million agreement[7] with the USDA Forest Service to help pay (50:50 cost share) for forest management actions (thinning, fuel load reduction, clearing firebreaks, prescribed burning, etc.) designed to reduce the likelihood and severity of wildfires. Very large areas of pine forest have been killed by a native pine beetle after probable climate change effects. Warmer winters and limited snow cover have substantially accelerated insect infestation and tree mortality rates. Of course, warmer winters and less snow cover have also reduced water yield to the reservoirs. Elsewhere in the western U.S., the water level of Lake Mead (the water and hydroelectric power supply for Las Vegas) has decreased below the drought of record in 1956, leaving engineers with no short-term alternative except the unsustainable necessity of lowering the intake to access water from the "conservation pool."

The recent examples from Atlanta, Birmingham, and Denver (all three are roughly equivalent in size to the DWSP/MWRA system) serve as sobering reminders of the fiscal, social, and political implications and challenges of the active management versus passive management decision. They underscore the need for robust contingency plans. In the weeks and months after the next severe hurricane in southern New England, the inevitable question will be "…is the water supply safe?" Even if the answer is a confident and resolute "yes", comprehensive water quality data will be needed to convince and reassure a skeptical public. If the answer is "yes, *but* it might be a good idea to buy a filter and boil your drinking water …just to be on the safe side" or "no, but we're working on it," the next shouted questions will be WHY? and WHO is responsible? The hue and cry about logging operations on DWSP land will pale in comparison to the interviews, investigative reporting, and hearings that will follow.

[7] http://www.ecosystemmarketplace.com/pages/dynamic/article.page.php?page_id=7706&section=home

The flow chart or decision tree in Figure 4.1 is one way to consider whether an active or a passive approach is best suited to avoid the unmanageable and manage the unavoidable. The allure of a "wilderness" area in Massachusetts is strong. The potential risks and consequences for the DWSP/MWRA system seem remote and theoretical (just like they did in Atlanta and Denver in the 1990s). A wilderness designation seems straightforward, uncomplicated, even cautious—the forestry equivalent of "less is more." In contrast, active management in the form of logging operations to deliberately change the structure of the forest seems unnecessary, rash, even antithetical, to the whole notion of a watershed protection forest. The marked contrast between the appearance and appeal of these philosophies underscores why an objective comparison, not aesthetics, should form the basis of management decision-making, especially in a water supply system that relies on the forest to provide high quality water.

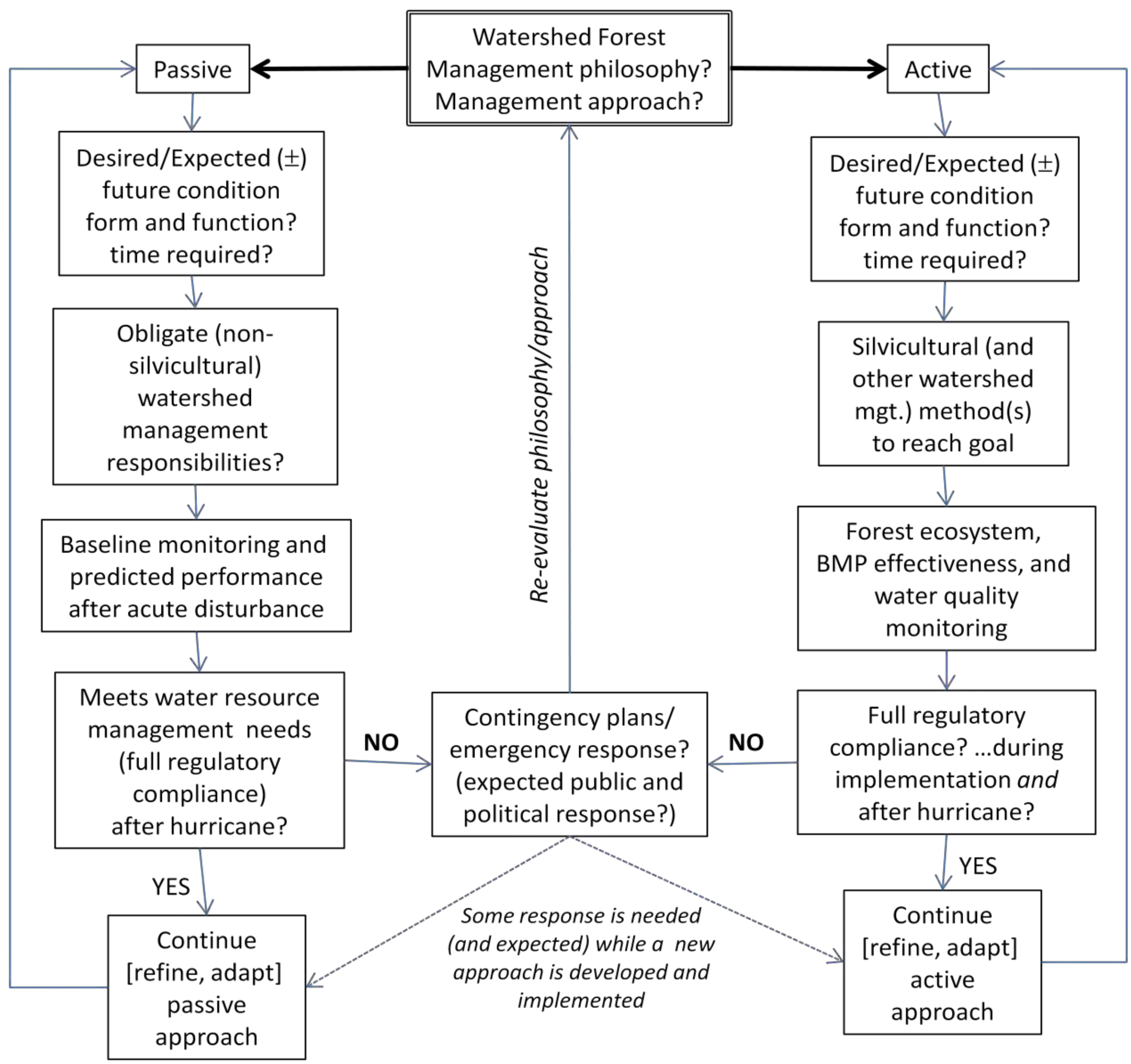

Figure 4.1 – A flow chart comparing active and passive watershed forest management approaches for DWSP/MWRA water supply system (and other similar systems).

The photographs and species lists in Figure 4.2 show the two ends of the forest stand condition spectrum on the Quabbin Forest. There are also even-aged mature stands with more structural and species diversity and two-aged stands (primarily from thinning operations and regeneration harvests).

Unmanaged stands (even-aged with no understory vegetation)

Eastern white pine, Eastern hemlock, black birch – no understory vegetation

Managed stands with three or more height classes resulting from thinning and regeneration cuts

↓ ↓ ↓

Northern red oak	Eastern white pine	Eastern white pine
Black oak	Black oak	Northern red oak
White oak	White oak	Black oak
Scarlet oak	Scarlet oak	White oak
Eastern White pine	Red maple	Scarlet oak
Pitch pine	Black birch	American beech
Eastern hemlock	Gray birch	Red maple
Red maple	Paper birch	Shagbark hickory
Black birch	American chestnut	Paper birch
Gray birch	American Beech	Black cherry
Paper birch	Pignut Hickory	Blue beech (ironwood)
American Chestnut	Quaking aspen	American chestnut

Figure 4.2 – Comparison of unmanaged and managed stands on the Quabbin Forest at opposite ends of the species composition and structural (height) diversity spectrum.

Figure 4.3 shows many of the natural disturbances that influence the structure and function of forests in southern New England. The spatial extent, outcome, and ecological implications of these disturbances can vary substantially in relation to site, soil, and stand characteristics. For example, the large foliar area (“sail”) and lower wood strength of mature evergreen species typically makes them more vulnerable to wind damage than mature leafless deciduous trees in the same stand. In other cases, some insects and diseases focus on particular tree species while others are generalists. Water stress—either too much or too little—may amplify the effects of insects, diseases, or a combination thereof. The extent to which active management or a reserve designation influences the net result of natural disturbances over the long term is usually related to the age, species, density, and structural diversity of the forest. The rate or time scale at which natural disturbances change a forest may vary from minutes (e.g., a hurricane or microburst) to years (e.g., hemlock woolly adelgid) to decades (e.g., beech bark disease). The stress imposed on the “forest filter” and the water supply system is, therefore, directly related to type, total area, rate, and cumulative effect of the disturbance(s) in relation to the resistance and resilience of the forest.

Canopy gap formation

Wet snow	Ice	Windthrow	Lightning

Stand- to landscape-scale

Category II hurricane, 1991	Microburst storm, 1989	Gypsy moth outbreak, 2000	Regional ice storm, 2008

Figure 4.3 – Some natural disturbances on the DWSP watershed forests (typical of southern New England). The catalog of insects and disease effects is much more extensive.

The sequence of photos in Figure 4.4 shows the general appearance of and typical response to active management on DWSP lands. The companion figure (4.5) is graphical summary of how agricultural use, farm abandonment, reservoir construction, forest management, and the establishment of reserves has influenced the Quabbin Forest from 1800 to present, then projected through 2050.

During and immediately after harvesting operations

Three to five growing seasons after harvesting (two age and height classes)

Fifteen to thirty years after harvesting (deciduous and evergreen species, diverse heights and ages)

Figure 4.4 –Time series of DWSP silvicultural methods (thinning, small group selection cuts, and patch cuts) and consequent changes in age, species, and structural diversity.

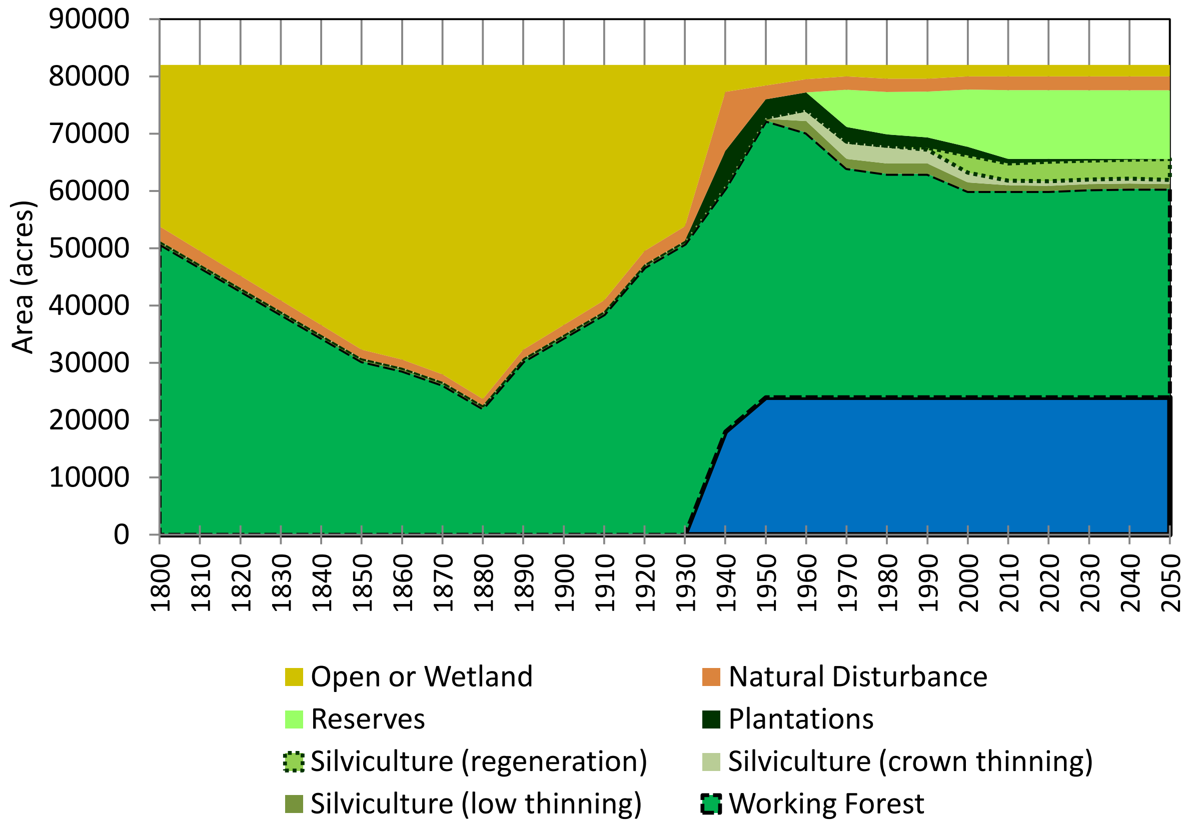

Figure 4.5: Land cover and land use on the DWSP landholdings in the Quabbin Reservoir watershed, 1800 to 2050 (2010 to 2050 is a projection of the current management plan). The blue component of the graph is the 24,000 acre Quabbin Reservoir.

At the second STAC meeting a key part of our discussion focused on the need for a side-by-side comparison of the overall effects of continuing the current management approach until the goal of three age classes (regeneration and saplings, intermediate and mid-canopy trees, and mature trees, including a substantial number of large "legacy" trees when they are present in the stand) is met versus the permanent designation of the DWSP forests as a reserve. To that end, (1) long-term forest inventory data (1960 to present at 10-year intervals), (2) average growth rates for evergreen and deciduous trees on average or median sites, and (3) detailed GIS data about the area of each major forest age cohort were used to produce Figures 4.6 and 4.7 for the Quabbin Forest (equivalent patterns and trends would apply to the Ware and Wachusett Forests). The Quabbin Forest age cohorts or classes include:

- mature (~140 years old), even-aged stands that originated on abandoned agricultural land,
- mature (~70 years old), even-aged stands that regenerated after the 1938 hurricane,
- two-aged stands where regeneration harvests have already occurred in one third of the total stand area, and
- (future) three-aged stands after a second round of regeneration cuts when current regeneration reaches intermediate size (~2040).

Small-scale natural disturbances (forming canopy gaps as shown in Figure 4.3) would accelerate the diversification of the forest (whether managed or unmanaged) at an average rate of approximately one (1) percent per year.

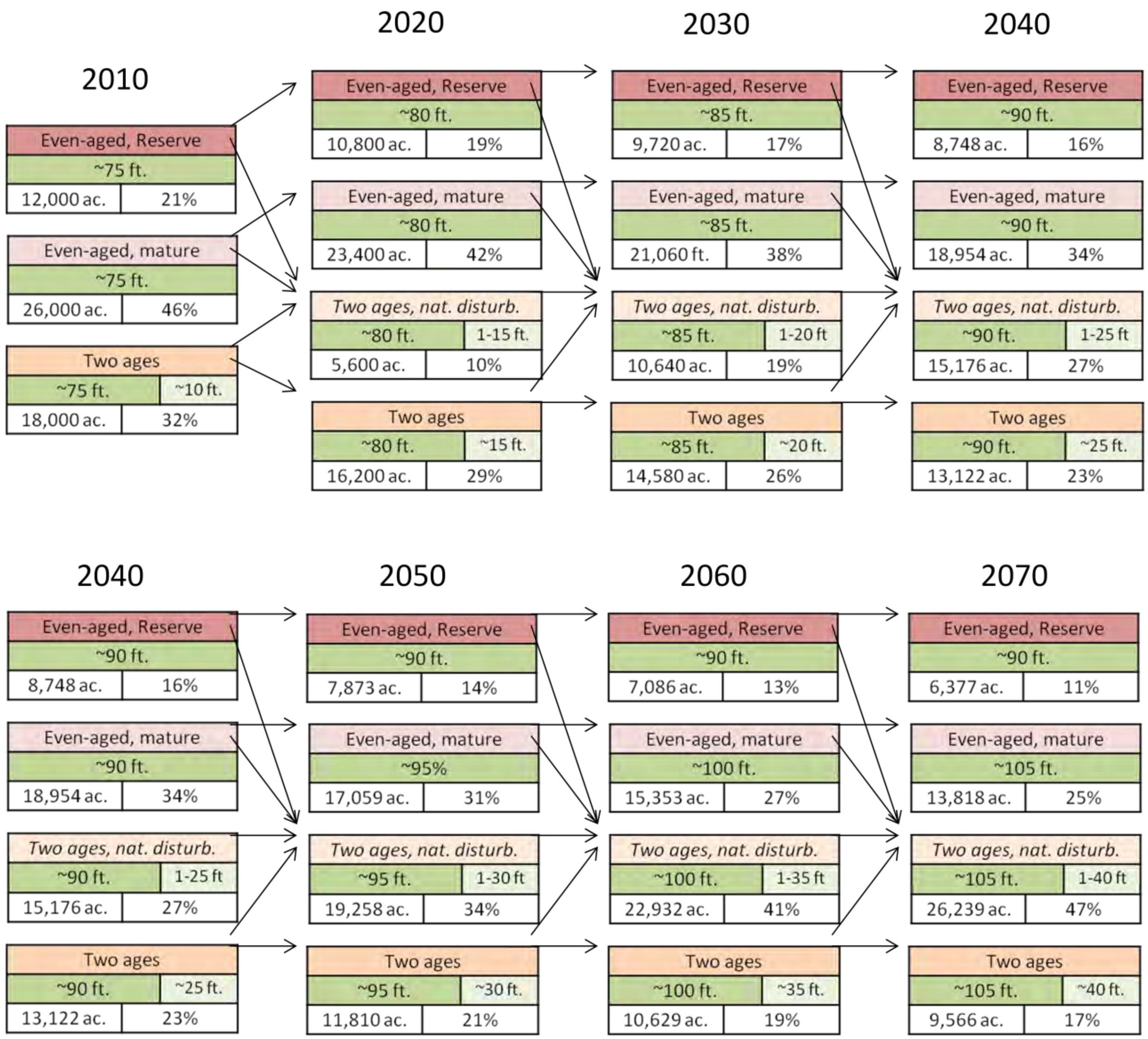

Figure 4.6 — Unmanaged forest — Generalized forest stand type (e.g., even-aged, two ages after regeneration cuts, two ages after natural disturbance), age range, total area (acres), and percentage (%) of Quabbin Forest over time if silvicultural operations are permanently suspended and the forest is designated as a reserve. The cumulative effect of natural disturbance (e.g., canopy gap formation and associated natural regeneration) is depicted at an average annual rate of one percent. (Note: 2040 is repeated in the upper and lower sections of the figure.)

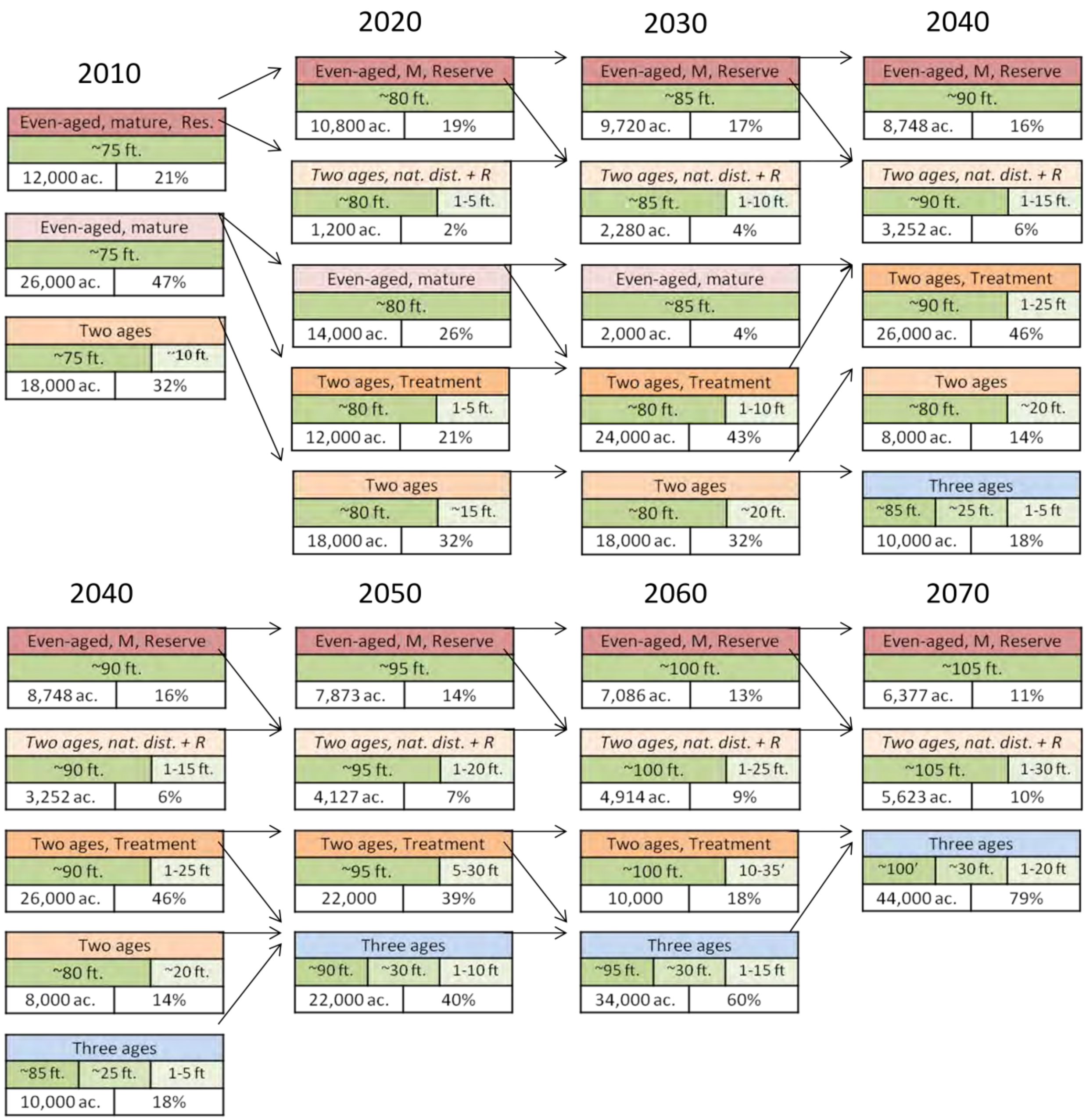

Figure 4.7 — Managed forest — Generalized forest stand type (e.g,. even-aged, two ages, three ages), age range, total area, and percentage of Quabbin Forest over time with the implementation of the current management plan (*i.e.,* approximately 400 acres of openings per year comprising about one-third of each harvest unit). This influences a total of 12,000 acres per decade (4,000 acres cut, 8,000 acres of mature trees after first cutting cycle; 4,000 acres cut, 4,000 acres intermediate-age trees, 4,000 acres of mature tree after second cutting cycle). The cumulative effect of natural disturbance is depicted at an average annual rate of 1% only as it influences the 12,000 acres of reserves already designated in the Quabbin Land Management Plan. Natural disturbance would occur in the managed stands as well—further increasing the diversity of ages, heights, and species and accelerating progress toward the overall management goal (Note: 2040 is repeated in the upper and lower sections of the figure.)

A side-by-side graphical comparison of the time series if a harvesting moratorium is made permanent (top graph) *or* active management is resumed (bottom graph) is presented in Figure 4.8. The results of the analysis which has substantial bearing upon the decision to continue active management or to permanently suspend active management on Quabbin and other DWSP forests are summarized in Table 4.1. Age is the surrogate for tree height; age classes are also the surrogate for height and structural diversity. These are the two forest characteristics that will have the greatest influence on vulnerability to damage and rate of recovery of the forest from the next hurricane. An event comparable to the 1938 hurricane has a probability of occurrence of about one percent in any given year.

As discussed in section 3, scores of paired watershed experiments have shown that reducing forest cover by 20 to 30% leads to measureable increases in the volume and rate of streamflow. The size of the streamflow (both annual water yield and peak discharge) increase, and the number of growing seasons needed for the regenerating forest to restore the water balance and streamflow regime to pre-disturbance conditions, is directly proportional to the extent of the forest change. Many site-specific factors influence the associated changes in water quality and channel stability. However, since water (especially overland and shallow subsurface flow) is the prime mover for nutrients and sediment, some water quality degradation is inevitable in the near term when the 20 to 30% threshold is exceeded.

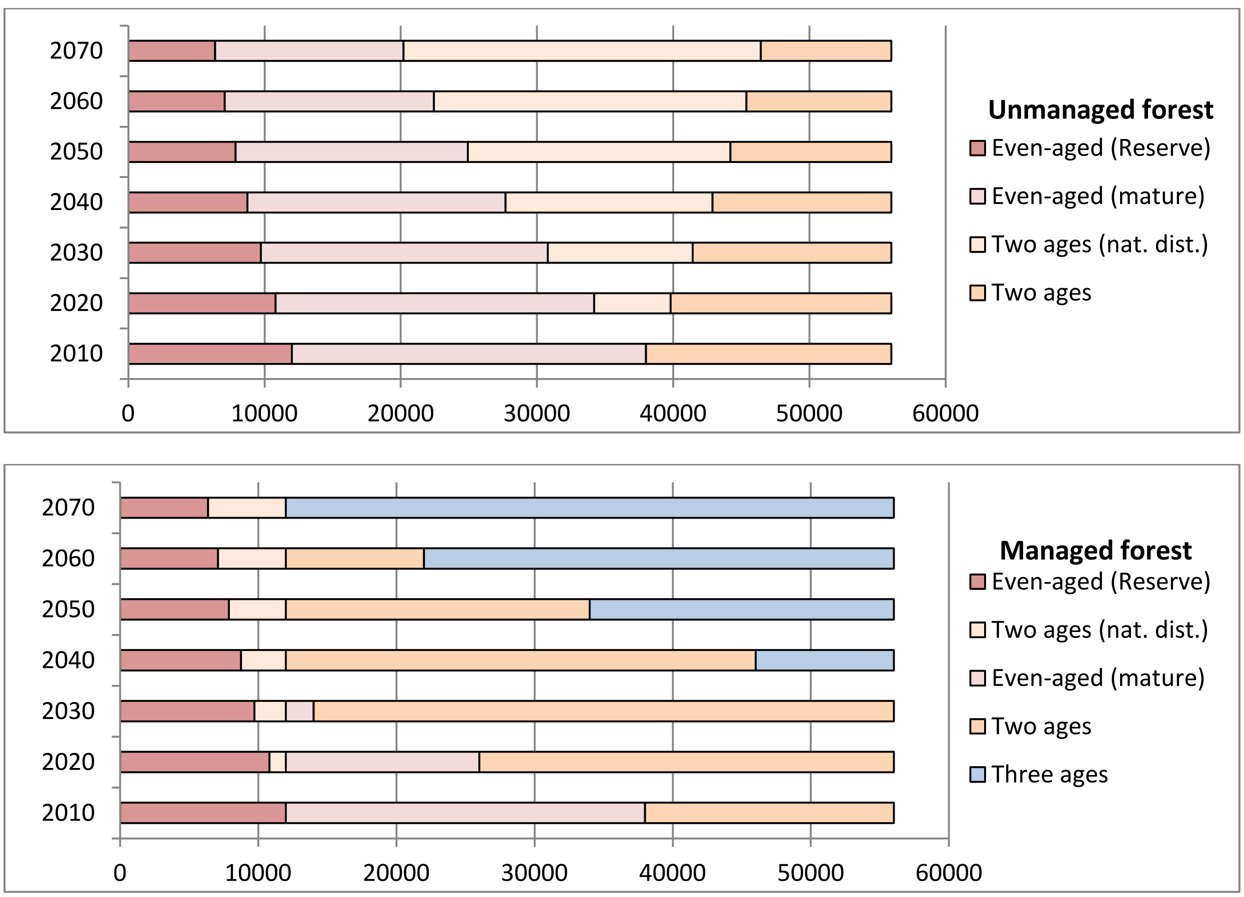

Figure 4.8 – Graphical summary of generalized age class distributions versus area (acres) for the Quabbin Forest, 2010-2070, derived from Figure 4.6 and Figure 4.7, respectively.

Table 4.1 — Summary of the approximate proportional changes in age class distribution and corresponding height range derived from Figure 4.7 (Managed watershed forest [with 12,000 acres of reserves]) and Figure 4.6 (Unmanaged watershed forest designated as reserve).

Managed Watershed Forest		Proportion (%) of Quabbin Forest area (56,000 acres)						
Age range* (years)	Height range** (feet)	*2010*	*2020*	*2030*	*2040*	*2050*	*2060*	*2070*
60-200	55-105	89	81	74	66	58	51	44
30-60	35-80	-	-	-	6	13	20	26
0-30	0-40	11	18	26	28	29	29	30
Unmanaged Watershed Forest		Proportion (%) of Quabbin Forest area (56,000 acres)						
60-200	55-105	89	87	85	82	81	80	79
30-60	35-80	-	-	-	11	12	13	13
0-30	0-40	11	13	15	7	7	7	8

* Age ranges correspond to the mature, intermediate, and young forest age classes in the DWSP land management plans.

** Height ranges for the most common tree species on the Quabbin Forest, northern red oak (site index 50) and eastern white pine (site index 70), on average productivity sites. The 1938 hurricane (Category III) caused significant damage to white pine and other evergreens greater than 34 feet tall and oaks and other deciduous trees greater than 74 feet tall.

The 1938 hurricane (category 3) blew down 50 to 70% of the mature trees in its path. Consider that historical precedent in relation to the current ("2010") and future conditions summarized for both management approaches in Table 4.1. It also is necessary to consider what could or should happen in the forest in the aftermath of hurricane.

After the immediate emergency has passed, the attention of the forestry and natural resources staff will turn to storm damage assessment. A combination of aerial and ground surveys and GIS analyses will quantify the extent of the forest disturbance and the associated management watershed implications (short term and long term). After the road network is cleared of downed trees the question will turn to salvage operations. Traditionally, almost reflexively, foresters propose salvage operations to recover valuable timber and reduce the assumed risk of wildfire in the jumble of downed trees (with foliage and small branches drying in the sun). This is always controversial since some members of the public will call for an immediate "clean-up" while others will advocate for no action and strict observance of a wilderness designation (if one is extant).

The management philosophy (passive or active) and associated level of risk chosen by the Division of Water Supply Protection, Massachusetts Water Resources Authority, and Executive Office of Energy and Environmental Affairs is the key, long-term question for the water supply system and watershed protection forest. Ultimately, this decision should consider the proportion or percentage of the Quabbin Forest that will already have young and/or intermediate aged trees if a major hurricane occurs in 2020, 2030, or 2040 (Figure 4.9).

The decision to suspend active management on the Quabbin Forest would mean that decades of low intensity natural disturbance (~1% of the forest per year) would be required to approach the optimal 70% threshold of forest areas with two or more age and height classes. In other words, by 2070 more than 30% the forest would still be comprised of mature, even-aged stands (with little or no structural [height] diversity). These areas would be subject to blowdown during the next hurricane and the associated increases in streamflow and nutrient output during 3 to 5 subsequent growing seasons.

A decision to re-start and sustain the active management of the Quabbin Forest would lead to the establishment of two age classes on ~70% of the area by 2025 and two or three age classes on more than 80% of the forest by 2040. If the irregular shelterwood method (discussed in detail in the next section of the report) is used for a substantial portion of the regeneration cuts, the effect of the silvicultural treatment would extend to the majority of the stand, not just the regeneration in the regularly spaced and sized patch cuts. As a result, the rapid response of young and intermediate trees in the aftermath of damage to the mature overstory trees could be reasonably expected to minimize changes in streamflow and water quality.

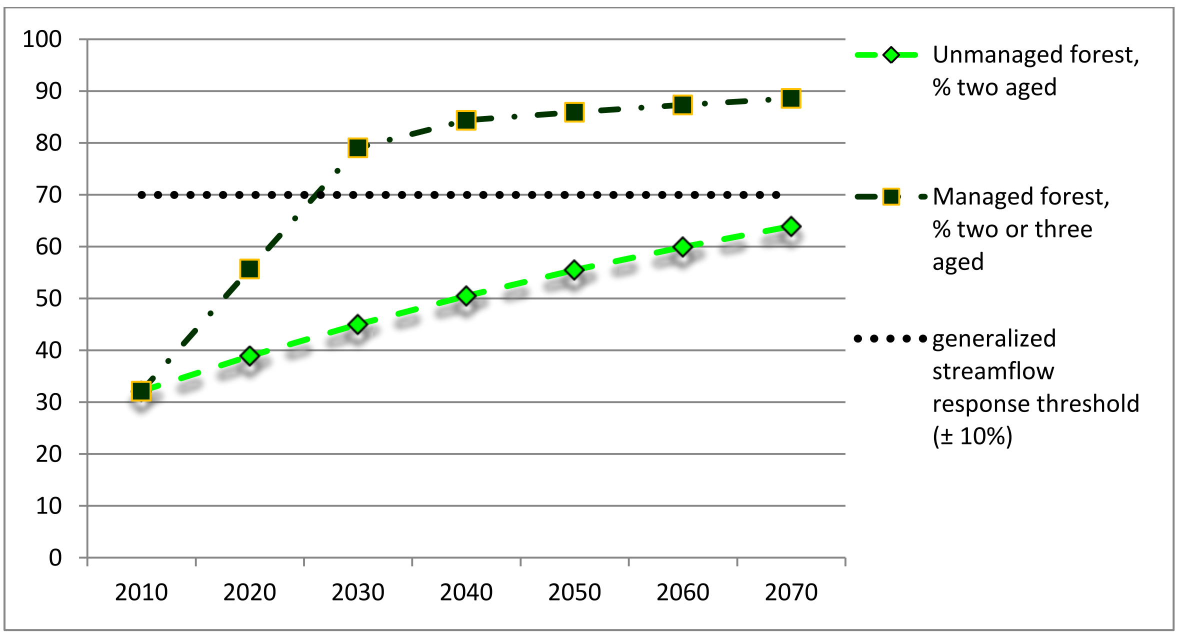

Figure 4.9 — A comparison of the percentage of the Quabbin Forest area (56,000 acres) with young and/or intermediate aged trees (summarized from Figures 4.6 and 4.7) in relation to the general threshold for streamflow increases.

As noted throughout this report, in New England, a hurricane is the "stress test" for a watershed protection forest and water supply system (Figure 1.6). Table 4.1 and Figures 4.8 and 4.9 provide managers, policy-makers, and decision-makers with a sense of the relative risk and possible outcomes of this landscape-scale forest disturbance in relation to the choice of management approach.

5 – Review of Silvicultural Methods for Watershed Forest Management

If the policy decision is made to re-start active management on DWSP lands, the most appropriate method(s) for implementing that decision should be clearly identified. As a practical matter, the decision to re-start management will not be made without reasonable assurance that (1) active management is the preferred approach, (2) the goals and objectives (encompassing a range of forest benefits and values) of the existing or revised LMP can be met, (3) water quality can be maintained, (4) a repetition of the current controversy can be avoided, and (5) related issues and concerns can be fairly and effectively addressed.

Focusing on Viable Options

The STAC considered and discussed an extensive range of possible management options (Table 5.1). The desirable and undesirable biophysical and operational outcomes of each management option were discussed in relation to goal of maintaining streamflow and water quality across a wide range of climatic conditions. The desirable and undesirable sociopolitical and economic outcomes of each management option were also considered and discussed. Taken together, the outcomes associated with each management option were used to reach a general consensus about the findings, conclusions, and subsequent recommendations of the STAC.

Table 5.1 – <u>Possible</u> management options for the Massachusetts DWSP System
1. Maximum utilization of wood resource, open to almost all recreational uses.
2. Minimum standards of Forest Cutting Practices Act and other applicable MA regulations.
3. "North Quabbin" silvicultural approach (patch cuts) within the current LMP.
4. "South Quabbin" silvicultural approach (irregular shelterwood cuts) within the current LMP.
5. Revert to earlier LMP 1960s to 1990s silvicultural approach (thinning).
6. No silviculture, limited vegetation and wildlife management, and additional public access restrictions.
7. Minimal vegetation and wildlife management and minimal public access.
8. Complete restriction of forest management, access, and use.

Four management options (Table 5.1, options 1, 2, 7, and 8) were deemed to be inappropriate or infeasible for the DWSP/MWRA system. Option 1 runs contrary to the charter of the DWSP and would be violate a host of Massachusetts environmental laws and regulations. Option 2 is not viable because meeting the *minimum* standards of M.G.L. Chapter 132 – the Forest Cutting Practices Act – would not be an acceptable performance standard for forest management on a public water supply (for this or any other water supply system in Massachusetts). At first glance, the additional access and use restrictions noted in option 7 may not seem unreasonable for an important public water supply. However, the new access restrictions, enhanced security, and other precautions that were implemented after the September 11, 2001 terrorist attacks have already addressed this contingency. More restrictions would be controversial, to say the least, especially since the security precautions needed to meet 21st century challenges have already been implemented. Option 8 is a more extreme, and therefore even more unlikely, version of option 7.

Management Options 3, 4, 5, and 6

A combination of satellite images, aerial and ground level photography, and a field tour were used to ensure STAC members could clearly visualize and objectively discuss the viable management options:

- 3 – patch cuts in the Prescott, New Salem, and Petersham ("North Quabbin") blocks (Figure 5.1),
- 4 – irregular shelterwood cuts in the Hardwick and Pelham ("South Quabbin") blocks (Figures 5.2 and 5.3),
- 5 –circa 1960-1990 thinning in many parts of the Quabbin Forest (visible in Figures 5.1 and 5.2), and
- 6 – no silvicultural treatment (Figure 5.4).

While the focus was on the Quabbin Forest, the analyses and results also apply to the Ware and Wachusett Forests. As discussed in the preceding sections, the Wachusett Reservoir and public and private forest land in its watershed is a critically important component of the water supply system.

A **patch cut** removes most or all of trees in ~0.5 to ~2 acre openings over less than half of a harvest unit. (Cutting more than half the stand is typically called "patch retention.") The patch cut method recently implemented on DWSP lands removed trees on up to one third of a harvest unit (Figure 5.1). A 0.5 acre opening, if square, is approximately 150 x 150 feet or about 1.5 mature tree heights in size. A two acre opening, if square, is approximately 300 x 300 feet or about three mature tree heights in size. Because the sun rises in the east, tracks across the southern sky, and sets in the west, the shade generated by the mature trees surrounding the opening varies substantially around the periphery, ranging from: (1) maximum shade on the southern edge, (2) morning and mid-day sun on the western edge, (3) mid-day and afternoon sun on the eastern edge, and (4) full sun in the center and northern portion of the opening. The duration of direct sunlight is a function of the size of the opening, topography, and the height of the adjacent mature trees. Some light reaches the opening through canopy gaps and small spaces between the crowns of trees in the adjacent uncut forest. Variations in microclimate (e.g., solar radiation, wind speed, soil moisture, air temperature, soil temperature) in different parts of the opening result in a wide range of shade tolerant, mid-tolerant, and shade intolerant tree (and herbaceous plant) species regeneration. The particular species composition that becomes established in any given opening is also influenced by seed sources, soil characteristics (e.g., land use history, fertility, water holding capacity, thickness), and terrain features (topography, slope, and aspect, i.e., N, S, E, W orientation). In general, of all the options considered in this review, patch cuts leads to the greatest habitat diversity and most abundant food and cover resources for wildlife species. This, however, is a secondary objective or side benefit when the primary goal is to maintain or enhance a watershed protection forest.

Figure 5.1 – Google Earth image (altitude = 4,771 feet) of a patch cut in the Petersham Block of the Quabbin Forest. The results of earlier thinning operations are evident in the northwest and southeast corners of the image. Note the relatively uniform height and density of the tree canopy in the uncut portions (two-thirds) of the harvest unit.

An abrupt vertical edge between the cut and uncut portion of the stand makes some of the residual trees (that were formerly part of dense forest canopy) more vulnerable to wind, ice, and snow damage. Most trees survive and thrive at the edge of the patches. Reduced competition for light, water, and nutrients and the renewed growth and development of their crown accelerates their growth and seed production relative to the trees that are wholly within the uncut areas. Thinning the trees around the periphery of the patch ("feathering the edge") may or may not reduce mortality but is more representative of natural disturbances effects than an abrupt cut/uncut boundary. Similarly, retaining small groups of trees with the opening can mimic the more random patterns of natural disturbance and reduce the jarring appearance of the treatment by interrupting sight lines and better mimicking the results of natural disturbance (e.g., wind damage from microburst storms, substantial ice damage, etc.). It usually takes several growing seasons (with additional growth and root system development, microclimate changes as regeneration fills the opening, etc.) until the full effects of the treatment on bordering trees are evident. At the stand or harvest unit level, the patch cut regeneration method nominally meets the objective of regenerating one third of the area. It creates a somewhat geometrically arranged area ("checkerboard pattern") of mature and young trees. Patch cuts like those shown in Figure 5.1, have little resemblance to typical natural disturbance patterns.

The committee also discussed alternative methods of patch cutting with variably-shaped, more randomly [i.e., less geometrically] distributed openings, retention of legacy trees, and less emphasis on a rigid "one third cut, two thirds retained" stand structure. In other words, the majority of the committee did not favor the elimination of this method from the set of silvicultural methods that could be used, on suitable sites, for active management.

An **irregular shelterwood cut** is a hybrid of several silvicultural methods (Raymond et al. 2009) that was adapted by Quabbin foresters to meet the primary watershed forest management goals. It has proven to be an effective way to regenerate about one third of the harvest unit while emulating natural disturbance patterns and adapting to the particular opportunities and challenges presented by each site (Figure 5.2). This treatment approach begins with two important questions:

1. What are the smallest openings that will reliably yield diverse regeneration? …and
2. How should the stand characteristics and prior treatments (one or more thinning operations) guide the process of increasing the species and structural diversity in this area?

It combines patches (ranging from ~one quarter to two acres – with a median size of ~one acre) and small groups (about three to five mature trees) to create the conditions needed for natural regeneration. This method also employs single tree selection to reduce shading of seedlings and saplings already present in the stand. Finally, the deliberate retention of large "legacy" trees throughout the stand is a distinguishing feature. These trees will be retained even if subsequent management takes place in these stands.

Since most harvesting operations are now mechanized (using a feller-processer to fell and de-limb the tree then cut it to log lengths and a forwarder to lift and carry the logs to road for stacking or direct loading on a truck) the equipment access lanes wind through the stand, favoring the terrain that is most resistant to soil compaction, avoiding sensitive areas (e.g., depressions, organic soils, etc.) and steep continuous slopes, and moving parallel to the terrain contours to the maximum extent possible. The lateral reach of many feller-processers is long enough to cut trees that are 20 to 30 feet away from the access lane. This limits the area of the harvest unit over which the machine travels. In addition, the operator can de-limb trees in the path of the machine, protecting the soil with a brush mat of foliage and branches during and after harvest. The same technique can (and should) be used during patch cut or thinning operations to avoid soil compaction and reduced infiltration capacity for rain and snowmelt.

Figure 5.2 – Google Earth image (altitude = 4,771 feet) of an irregular shelterwood cut (2008) in the Hardwick Block of the Quabbin Forest. The results of earlier thinning operations are evident along the east (right) side of the image. The results of an earlier cut can be noted in the northwest quadrant of the image, immediately adjacent to the most recent harvest. Note the contrast with the even-aged stand on the east side of the harvest area, where the thinning occurred.

Figure 5.3 – The 2008 irregular shelterwood cut shown in Figure 5.2 during the DWSP STAC's July 2010 field tour.

A mature, **unmanaged,** even-aged stand is shown in Figure 5.4. This stand on Mt. Zion, once a hilltop in the Swift River valley, originated from natural regeneration after farm abandonment or the 1938 hurricane. A careful review of this 2010 aerial photograph shows the net result of small-scale natural disturbances and stand development processes—canopy gaps formed when individual trees die—on a 70- to 140-year old even-aged stand. The uniformity of the tree canopy is indicative of the absence of an acute disturbance such as high velocity winds or a major insect or disease outbreak.

Figure 5.4 – Google Earth image (altitude = 4,771 feet) of Mt. Zion, an even-aged forest area that has not been managed. Note the relatively uniform height and density of the tree canopy. Canopy gaps created by the death of individual trees can be seen (more evident in Figure 5.5a at 1,260 ft.) along with a more irregular canopy on the hilltop near the center of the scene (probably the result of repeated gypsy moth infestations, drought conditions, and thin, stony soils). A beaver meadow is visible at the top of the image.

Thinning is an intermediate treatment not a regeneration method (Figure 5.5). The primary aim of all thinning methods (e.g., low, crown, free, etc.) is to reduce, at least temporarily, the competition for light, water, and nutrients among trees in order to enhance the growth of the residual or "crop" trees. (It is directly analogous to thinning a row of carrot or bean seedlings a few weeks after germination in a vegetable garden. Even at that early stage of growth it is possible to identify the most vigorous plants, carefully remove the weaker adjacent plants, and in so doing improve the crop yield for the growing season.) The functional definition of "improvement" (both biological and economic) is directly related to the subsequent rate of growth, size at maturity, or a combination thereof.

The effects of competition for light, water, and nutrients on the density and relative size of trees are evident in forests at early stages of development (i.e., the sapling stage in even-aged stands). Micro-site variations in soil fertility, soil thickness, and water availability and genetic variation among trees also influence their rate of growth and form. These site and genetic characteristics also influence their resistance to insects, diseases, and other stressors such as air pollution. Foresters use crown classes (dominant, co-dominant, intermediate, and suppressed) as key means of describing the natural variation between trees and evaluating likely changes in stand and forest structure. Dominant trees are the largest, most competitive individuals. Their growth in height and volume outpaces all other (subordinate) trees in the stand unless their additional height becomes a liability by exposing them to greater risk of a lightning strike or wind damage. Co-dominants are the average and above-average trees which comprise most of the tree canopy. Intermediate trees have been less successful than their co-dominant and dominant neighbors. They have smaller crowns, less foliage, slower height growth, and smaller diameters than the co-dominants. Unless something changes in their immediate vicinity (i.e., one or more neighboring trees dies) they will eventually fall farther behind and become suppressed (sometimes called “overtopped”) trees. Suppressed trees may persist in the forest for years, even decades, especially if they are a shade tolerant species, but in most cases they are destined to become woody debris on the forest floor. As this woody debris slowly decomposes and releases nutrients, it contributes to the growth of the remaining trees and other forest vegetation.

Two forms of thinning (low thinning and crown thinning) were used on DWSP forests (1960s through the 1990s) before the transition to regeneration cuts. Low thinning (sometimes called “thinning from below”) removes the intermediate and suppressed trees, making some of the water and nutrients they used available to the residual trees. The harvested trees were typically used for firewood, pulpwood, or low quality, small diameter sawlogs. As the names connotes, crown thinning (Figure 5.5, option 5) removes intermediate and weak co-dominant trees and reduces stand density—at the level of the crown canopy—to enhance the growth of the remaining co-dominant and dominant trees. In the process, small openings are created in the canopy and more light is admitted to the forest floor. As a result, some natural regeneration occurs until enhanced growth rates close the canopy gaps (typically in 3 to 5 years) and once again shade the forest floor. This sequence of events and site conditions favors the establishment of shade tolerant species and may provide a fleeting opportunity (two or three growing seasons) for mid-tolerant species to germinate or sprout. Shade intolerant trees (e.g., paper birch, black cherry, quaking aspen, and other species which normally regenerate and grow in full sun) have little or no chance of establishment. Although thinning leads to some regeneration its principal aim is, as noted earlier, to improve the vigor, health, and volume grow rate (height growth is limited by site productivity and genetic and physiological characteristics) of the residual trees and the stand as a whole. The irregular shelterwood cut regeneration method described earlier tries to protect and “release” the regeneration that may be present from earlier thinning treatments. In contrast, a simple patch cut may inadvertently destroy some these seedlings and saplings or subject them to a drastic and ultimately lethal change in microclimate (full or partial shade and moist soils is abruptly changed to full sun, dry surface soils, and desiccating heat and wind).

Most people regard thinning to be more aesthetically palatable, during and immediately after harvesting operations, than regeneration cuts. If the logging is skillfully and carefully done (especially during the dormant season on dry, frozen, or snow-covered soil) a thinning operation may go unnoticed. In contrast, it is hard to miss the startling, short-term change brought about by most regeneration methods—with the necessary objective of increasing the amount of sunlight that reaches the forest floor. As the second- and third-growth forests across most of the DWSP lands matured during the 1960s through the 1990s, thinning was an appropriate and effective silvicultural method. Before the deer population was reduced to average densities (from 30 to 50 animals per square mile to state-wide average of 5 to 10 animals per square mile) by controlled hunting, regeneration cuts had little or no likelihood of success. The combined effect of deer and moose browsing on forest regeneration is challenging, but still within manageable bounds on DWSP lands.

In sum, discontinuing the use of regeneration cuts and returning to earlier thinning methods on DWSP forests would, no doubt, enhance the growth rate and value of crop trees, lead to the establishment of some shade intolerant regeneration, and mollify some critics. However, thinning would do little to meet the primary objective of the current watershed forest management plan — increasing structural and species diversity. The primary, sometimes subtle, difference between a heavy crown thinning (Figure 5.5b) and an irregular shelterwood cut (Figure 5.5c) is size, shape, and spatial distribution of the canopy gaps. A regeneration cut deliberately influences the amount of sunlight reaching the forest floor and the length of time this change will persist. The consequent difference in the species diversity of the regeneration, the range of heights and ages, and the vertical structure of the forest can be substantial.

Figure 5.5 –Comparison of watershed forest management options (altitude = 1,260 feet). Clockwise from upper left: (a) no treatment, Mt. Zion; (b) Crown Thinning, Prescott; (c) Irregular shelterwood cut, Hardwick; (d) Patch cut, Prescott

Hydrologic Considerations

The review, comparison, and discussion of Options 3, 4, 5, and 6 was completed with the consideration of their potential hydrologic effects. To that end, three sites (all immediately adjacent to the Quabbin Reservoir) were used as a simple, comparable visual reference (Figures 5.6, 5.7, and 5.8). All three sites have relatively uniform, planar (neither concave nor convex) slopes that helped us to consider and discuss the management options on an equal basis, without the confounding effects of major differences in terrain and soil characteristics. The dashed lines superimposed on the aerial photographs, perpendicular to the contours, simply represent the pathway of overland flow (if it occurred on compacted or frozen soil) and shallow subsurface flow (through the root zone).

The central question is which management option (3—patch cuts, 4—irregular shelterwood cuts, 5—thinning, or 6—no treatment) is best suited to avoiding short term effects of active management while maximizing the protective influence of the forest over the long term? There are three figures, not four, because in the opinion of the STAC perpetual thinning of DWSP forests may just be management for management's sake. At the stand level and landscape scale thinning would accelerate and guide natural successional processes in an even-aged forest without substantially influencing its overall structure and function in the aftermath of an acute disturbance (i.e., hurricane or a major insect/disease outbreak) since, as discussed earlier, the objective of thinning is not to foster natural regeneration but to enhance growth of mature trees. Hence, it would largely be "care and tending." This would require human and financial resources that could otherwise be invested in enhanced source water protection in the Wachusett watershed, in particular, and the conservation and stewardship of private forest land in all three watersheds, in general.

Some of the flow paths in Figure 5.6 intersect one or more patches while others only come in contact with the even-aged forest between the patches. If frozen or compacted soil within the patches leads to the generation of overland flow (and soil erosion) during rain and snowmelt events, the uncut forest between patch(es) and the nearest water body must effectively control the short-term increases in the water yield and sediment and nutrient transport (3 to 5 growing seasons). The same, of course, can be said for the irregular shelterwood cut treatment. Yet here, the functional difference between the two regeneration methods is apparent. Consider, for example, a 1,000 foot flow path (transect) from the ridgeline to the reservoir that intersects three, evenly-spaced, one-half acre (150 x 150 ft) patches and the uncut forest in between. Water on this flow path is moving, alternately, between uncut and cut areas, mature and young trees, and protected and exposed soil. An adjacent flow path may intersect one or two patches …another may extend entirely through the uncut mature forest all the way from the ridgeline to the reservoir. It was duly noted by several committee members that changing the style and implementation of patch cuts (from a relatively simple geometric layout to a more variable, land-form based approach) could avoid or mitigate these risks and potential problems.

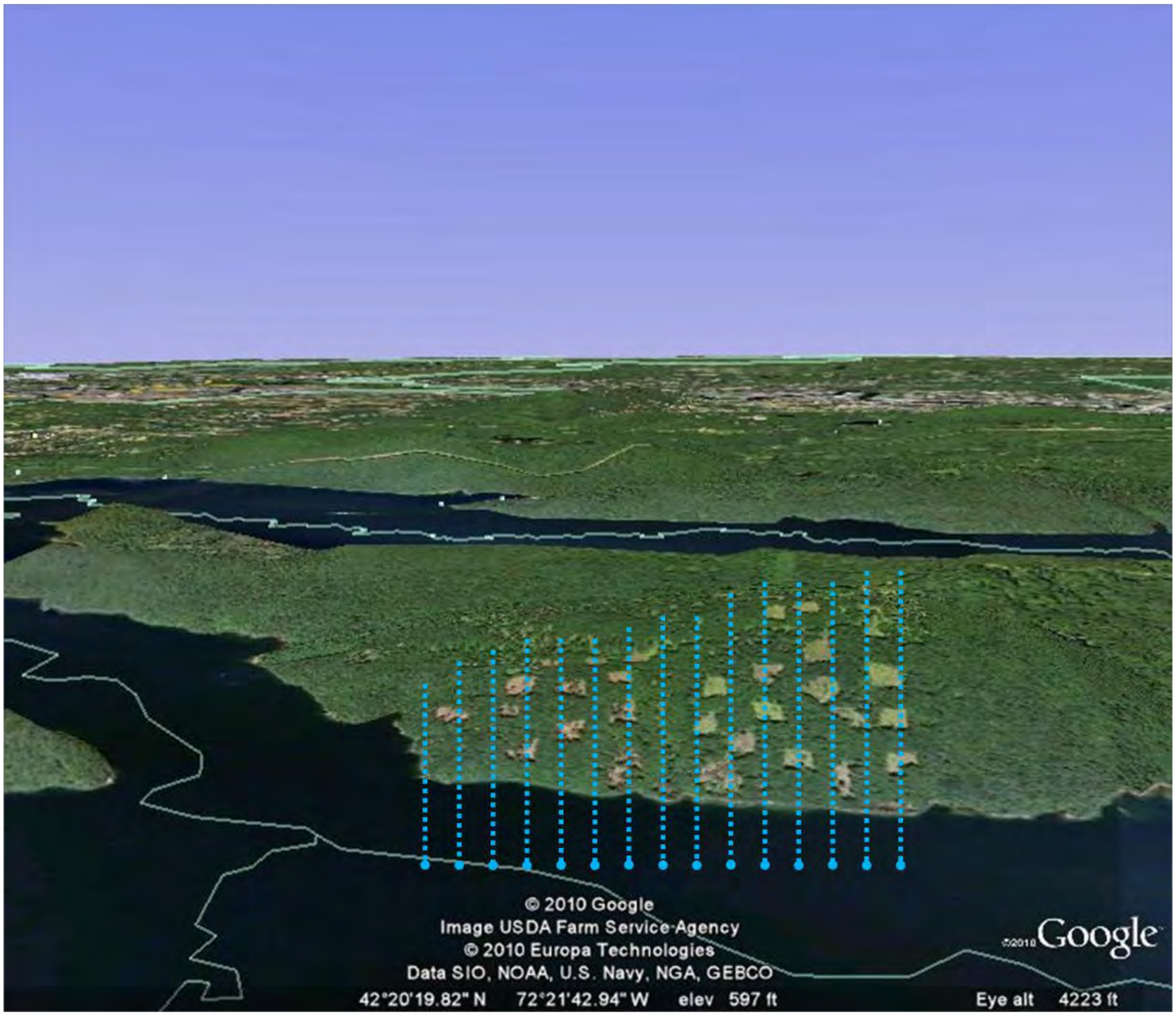

Figure 5.6 – Google Earth image (altitude = 4,223 feet; oblique viewing angle; 2X vertical exaggeration; identical to Figures 5.7 and 5.8) of patch cut on the Prescott Block of the Quabbin Forest. Regularly spaced flow paths (dashed blue lines), perpendicular to the slope contours, are superimposed on the image.

In contrast, <u>every</u> 1,000 foot flow path or transect through the irregular shelterwood cut would intersect access lanes and openings of varying sizes, with small areas of exposed soil, and encounter a wide variety of trees (ranging from seedlings, saplings, poles, and the mature canopy). The size or spatial scale of these features is 10's of feet, not 100's of feet as in the patch cut. The overall character of the flow path or transect is highly varied for the irregular shelterwood cut (Option 4) versus an alternating series of homogeneous patches (Option 3) or 1,000 feet of relatively uniform conditions in an unmanaged, even-aged stand (Option 6).

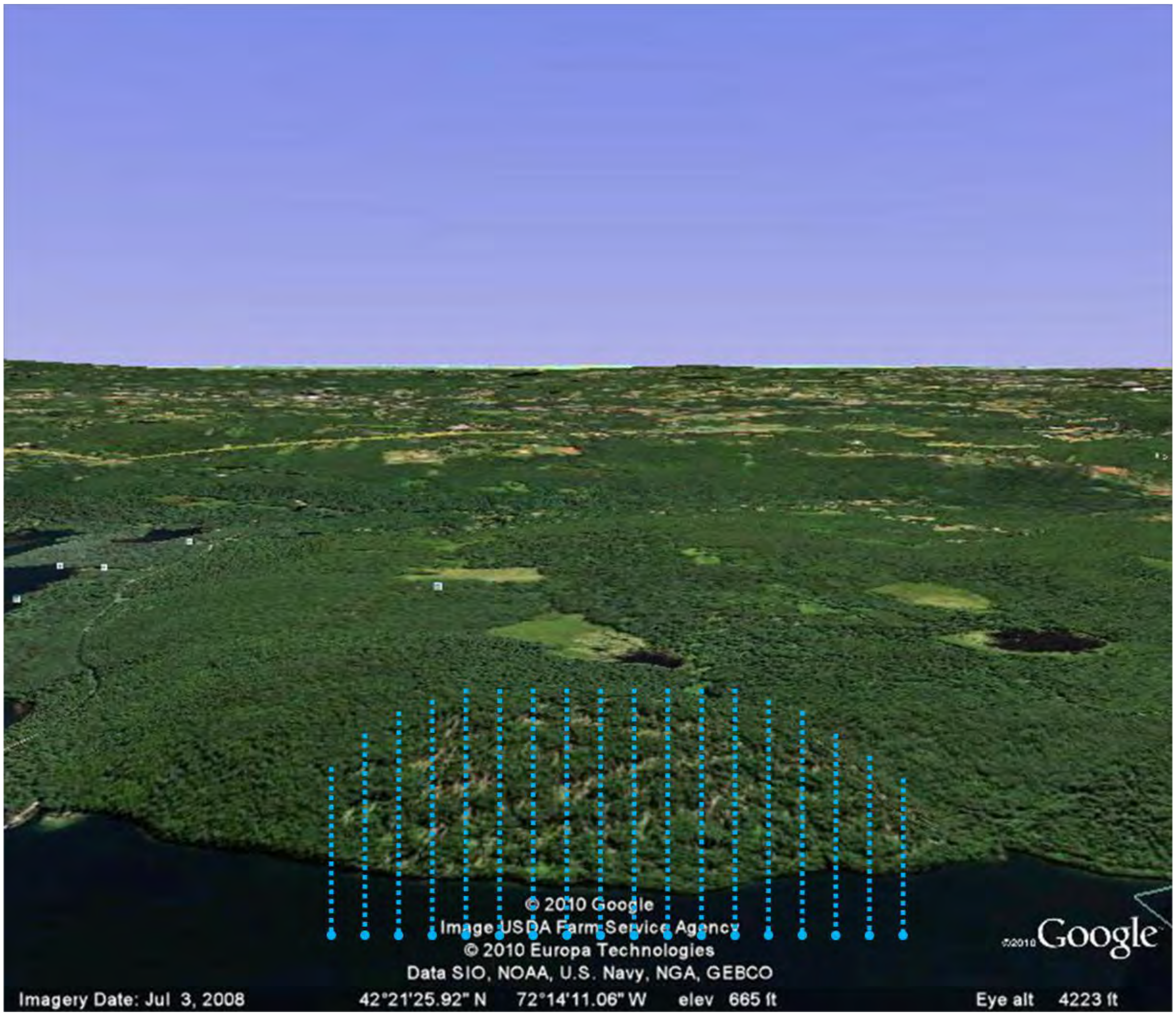

Figure 5.7 – Google Earth image (altitude = 4,223 feet; oblique viewing angle, identical to Figures 5.6 and 5.8; 2X vertical exaggeration) of irregular shelterwood cut on the Hardwick Block of the Quabbin Forest. Regularly spaced flow paths (dashed blue lines), perpendicular to the slope contours, are superimposed on the image.

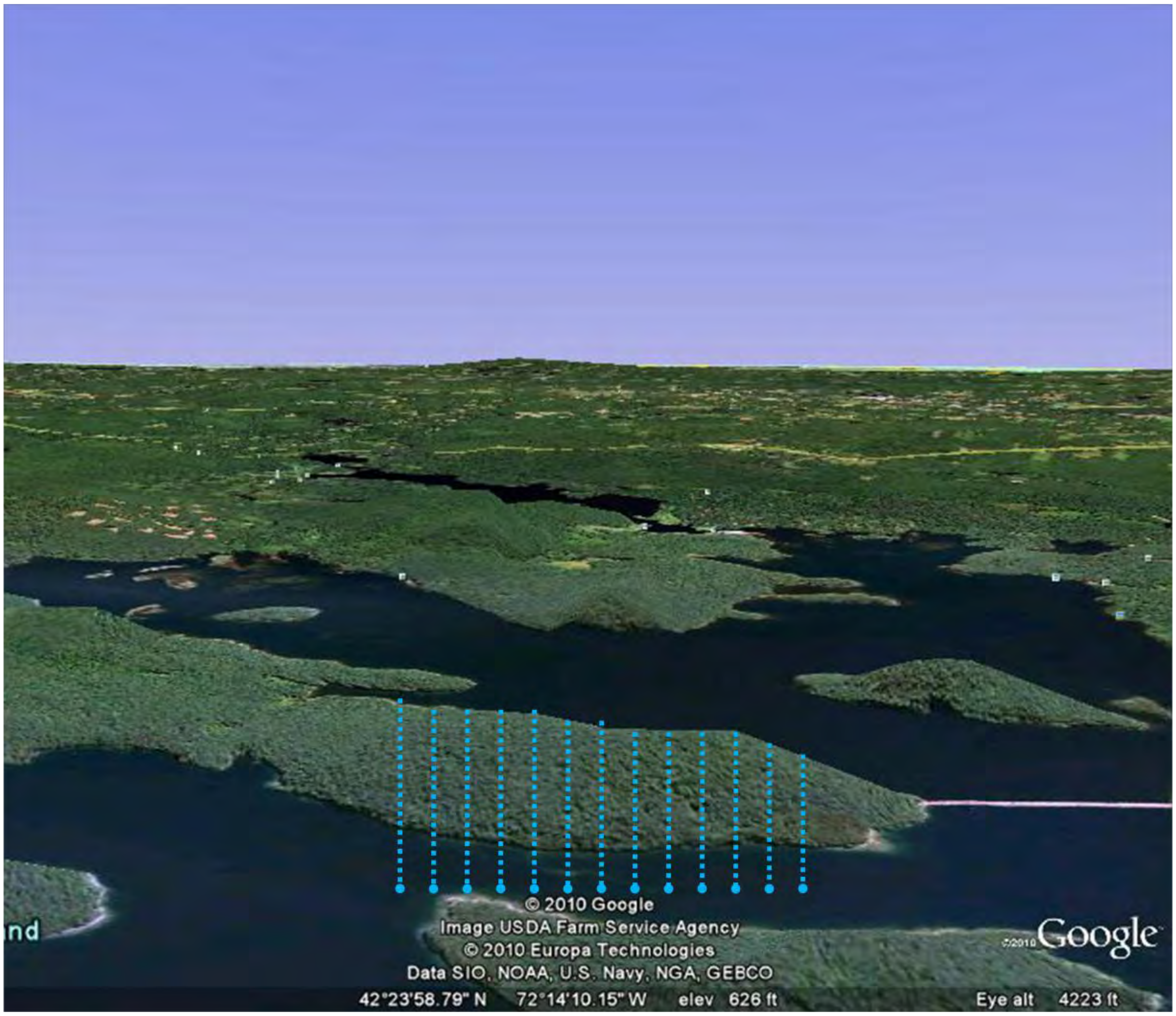

Figure 5.8 – Google Earth image (altitude = 4,223 feet; oblique viewing angle, identical to Figures 5.6 and 5.7; 2X vertical exaggeration) of an unmanaged even-aged stand on Mt. Zion, Quabbin Forest. Regularly spaced flow paths (dashed blue lines), perpendicular to the slope contours, are superimposed on the image.

The real test of the management options and the watershed protection forest comes during the two to three years after a hurricane. When a large proportion of the mature trees (e.g., 50 to 70%) are blown down on each of the transects described above, the younger trees that are already established on the site would respond immediately to the increases in soil water content and nutrients (from increased rates of decomposition) and re-establish the water balance and pre-disturbance nutrient cycling processes. The regeneration in the patches (option 3) will continue to grow vigorously. However, greater rates of water and nutrient movement along the transect will impose even greater reliance on the intervening uncut areas. Without an understory of young trees (advance regeneration) already in place, the ability of these patches to assimilate increased water and nutrient loading during the two or three years required for post-hurricane regeneration to become established would be less effective than the mature forest was before the hurricane. (Again, an alternate form of patch cuts could minimize this risk or potential problem.) In contrast, the young trees and mid-story trees that are distributed along the entire transect through the irregular shelterwood cut (option 4) will respond immediately. Post-hurricane regeneration will add to the rate at which the water balance and nutrient cycling processes are restored. The rate at which the unmanaged forest (option 6) recovers is largely dependent upon the rate of post-hurricane regeneration, species composition, prevalence of sprouting, etc. In all three cases (options 3, 4, 5, and 6), the enhanced growth response of any moderately damaged or undamaged mature trees will hasten the recovery.

6 – Forest Management and Water Quality Monitoring

All community water supplies (i.e., water systems serving at least 15 service connections used by year-round residents or at least 25 year-round residents) are required to establish and maintain a water quality monitoring program as a requirement of the federal Safe Drinking Water Act (SDWA) and its amendments. The US EPA and designated state agencies (e.g., Massachusetts Department of Environmental Protection [DEP]) work with water utilities (in this case, the Environmental Quality staff of the Division of Water Supply Protection (DWSP) of the Massachusetts Department of Conservation and Recreation (DCR) and their counterparts at the Massachusetts Water Resources Authority [MWRA]) to design and implement a monitoring network. The water utility collects, analyzes, reviews, reports, and archives water quality data as part of routine operations. When violations occur, the water utility, DEP, and other government agencies take appropriate follow-up actions. These typically include: (1) taking additional samples to verify and isolate the problem or violation, then (2) implementing mitigation, remediation, and enforcement actions as needed.

A wide range of water quality metrics are used to characterize the quality of reservoir tributary inflows and reservoir withdrawals for water supply (Table 6.1). MWRA characterizes the withdrawals for drinking water supply to demonstrate compliance with requirements for fecal coliform and turbidity to maintain the waiver of filtration treatment. DWSP and MWRA collect watershed and reservoir performance monitoring data to identify potential water quality concerns (e.g., high bacteria levels in tributaries, or specific algal species in the reservoir that cause taste and odor problems) and to manage operation of treatment facilities (e.g., disinfectant dosing).

Samples are taken—usually at a fixed frequency (i.e., weekly or biweekly intervals)—across a network of monitoring stations (Figures 6.1, 6.2, and 6.3). During the last several decades, the number of parameters measured has increased and the threshold concentrations have decreased (below which the utility is in compliance, above which corrective actions to address the violation are needed) as laws and regulations have been amended. Similarly, the expected accuracy and precision of laboratory work has increased. In sum, the work of compliance monitoring has become more costly and labor-intensive while, in many cases, financial and human resources have not increased proportionately.

Some water quality monitoring stations are located at obvious places (e.g., where principal tributaries flow into the reservoir, at aqueduct intakes, etc.). Others are dispersed throughout the watershed in strategic locations in order to detect potential point source (e.g., accidental or illegal industrial discharges) and nonpoint source pollutants (e.g., sediment, fertilizer, and road salt from dispersed activities such as agriculture and logging) in a timely manner. Many of the DWSP monitoring stations are located near the transition from private to public land. This is based on the assumption that land use change and management practices on private land are a greater concern than management activities on public land (e.g., Figure 6.3, points 2, 4, and 5; Figure 6.4, points 6, 7, and 8; Figure 6.5, numerous points).

Collecting, transporting, processing, and analyzing samples in order to generate accurate and consistent (precise and replicable) data and information is time consuming and expense. It is necessary, therefore, to weigh the costs and benefits of each new sampling site and/or water quality metric before the network or scope of sampling is increased. Another important consideration is the need for long-term records in order to assess time trends and detect inter-annual changes. Sustaining the sampling effort on what once were called "barometer watersheds" or "benchmark sites" often yields greater insight than short-term efforts on sites that are monitored for two or three years, then discontinued. The latter approach makes it difficult, if not impossible, to separate random inter-annual variation from changes in streamflow and water quality caused by incompatible land use(s).

For the purposes of this review and the prospects for improvement in the coordination and integration of the environmental quality and watershed forest management activities of the DWSP, it is important to make a distinction between compliance monitoring and performance monitoring. (These terms can be interpreted literally but some explanation could be helpful.) As noted earlier, compliance monitoring is used to ensure conformity with or fulfillment of legal or regulatory requirements. In intent and design it is analogous to quality control procedures in a manufacturing plant. For example, does every 100th toaster reaching the end of the assembly line work satisfactorily—yes or no? Performance monitoring extends this approach by systematically examining components, mechanisms, or processes. Returning to the simple example, a performance monitoring approach would test the components of the toaster throughout the manufacturing process. This would detect and address problems (…with product design, materials, and/or assembly methods) to minimize the number of toasters that fail the final inspection.

Table 6.1 –Water quality sampling in the DWSP/MWRA system to protect public health and meet Federal and State regulatory requirements.

Initial water quality monitoring Quabbin and Ware: 1938-1990 Wachusett: early-1900s-1988	Contemporary water quality monitoring Quabbin and Ware: 1990 to present Wachusett: 1988 to present	Number of permanent water quality sampling stations (Locations in Figures 6.1, 6.2, and 6.3 for Quabbin, Ware, and Wachusett, respectively)
• bacteria • Temperature • pH • Conductivity • Alkalinity • Nitrate-nitrogen • Turbidity • Total phosphorus	• Temperature • pH • Specific conductance • Dissolved oxygen • Alkalinity • Turbidity • Fecal coliform • Total coliform • E. coli • Nitrate-nitrogen • Nitrite-nitrogen • Ammonia • Total Kjeldahl nitrogen • Total suspended solids • Total silica • Total phosphorus • Total organic carbon • UV-254 • Calcium • Metals	Quabbin = 8 Ware = 8 Wachusett = 34 Sampling interval is biweekly, with weekly and event-based samples at some stations Additional short-term (typically 2 to 3 years) monitoring stations are deployed in relation potential nonpoint source pollutant sources in the watersheds – in cooperation with Massachusetts DEP

Table 6.2 – Stream gaging stations maintained in cooperation with the US Geological Survey

Watershed	Gage name	Gage ID	Record	Years
Quabbin	East Branch Swift River at Hardwick	01174500	1937 to present	74
	West Branch Swift River at Shutesbury	01174565	1983-85, 1995 to present	2, 16
	Swift River at West Ware	01175500	1912 to present	99
Ware	Ware River at Barre	01173000	1928 to present	83
Wachusett	Stillwater River at Sterling	01095220	1994 to present	17
	Quinapoxet River at Holden	01095375	1997 to present	14
	Nashua River at Clinton	01095505	2007 to present	4
	Gates Brook	01095434	Dec 2011 to present	1

As currently configured, the water quality [compliance] monitoring network does not explicitly address the questions associated with performance monitoring that addresses harvesting operations. In other words, a long time series of “clean” samples at the aqueduct intake, or at the confluence of a major tributary with the reservoir does not necessarily capture the effects (positive *or* negative) from forest harvesting operations. If nonpoint source pollution occurred, the localized deposition of sediment and transformation of nutrients somewhere between the harvesting site and the monitoring station would mean the short-term, subwatershed-scale effect would not be detected using the fixed compliance monitoring stations. Such sediment and nutrients that are temporarily detained in a transient state would be ready to move during subsequent storm events (perhaps years later) when the cause-effect or source-sink relationship is no longer evident.

Another difference—and potential confounding effect—between compliance and performance monitoring relates to sampling frequency. Fixed frequency sampling (i.e., samples are collected at all sites on the first and third Monday of each month) may, or may not capture the effects of rain and snowmelt events and associated changes in streamflow and water quality. A major storm immediately after the sampling run would, of course, go undetected. Alternatively, if the sampling run happened to occur at the beginning of storm event (on the rising limb), or after the streamflow hydrograph has peaked (on the recession limb) the data will reflect those transient conditions. If, by random chance, the majority of the compliance monitoring data were collected during dry weather (baseflow) periods, occasional storm event samples appear to be “outliers” and can be difficult to interpret.

Compliance monitoring focuses on the concentration (e.g., milligrams per liter) of water quality constituents in relation to regulatory standards, as required. Performance monitoring links concentration data (mass per unit volume; Table 6.1) and streamflow discharge data (volume per unit time; Table 6.2) to determine export rates from the site or activity in question and the corresponding import or loading rates to the receiving water (reservoirs in this case). Multiplying concentration and discharge (mass/volume *x* volume/time = mass/time) and comparing the result to an undisturbed reference site can show whether management activities such as timber harvesting are generating significant changes in tributary loadings. This is especially important when these short-term impacts could be avoided or prevented with different silvicultural methods or best management practices (including things as simple as “stop work” provisions for wet weather in the timber sale contract). It is also important to note that event-based sampling (of key metrics) supersedes fixed frequency sampling when compliance monitoring is augmented with performance monitoring. This does not mean that elaborate research methods must be used. Automated equipment at strategic locations and more frequent grab samples can suffice. It also does *not* mean that more sampling stations are needed. Focusing the total sampling effort (e.g., a budget for 5,000 samples per year) on fewer stations could yield more useful information than spreading the same number of samples over two or three times the number of sites …and lengthening the sampling interval in consequence. This depends upon the spatial and temporal variability of natural and anthropogenic disturbance, subwatershed characteristics, weather patterns, and, ultimately, water quality.

The long-term monitoring, research, and hydrodynamic modeling efforts conducted by faculty and graduate students from the Department of Civil and Environmental Engineering at the University of Massachusetts Amherst—in cooperation with the DWSP—is a useful prototype for the enhanced monitoring efforts described in this report. Over many years, this cooperative work has helped to characterize watershed inputs and the hydrodynamics of the reservoirs, which in turn has been used to assess risks to water quality and evaluate possible management strategies. One example is the impact of gulls and geese on fecal coliform levels and the need prevent them from roosting near the aqueduct intakes in order to maintain water quality. Another example is the assessment of the level and duration of impacts from potential contaminant spills. Watershed monitoring data are important in the evaluation of potential impacts on reservoir water quality.

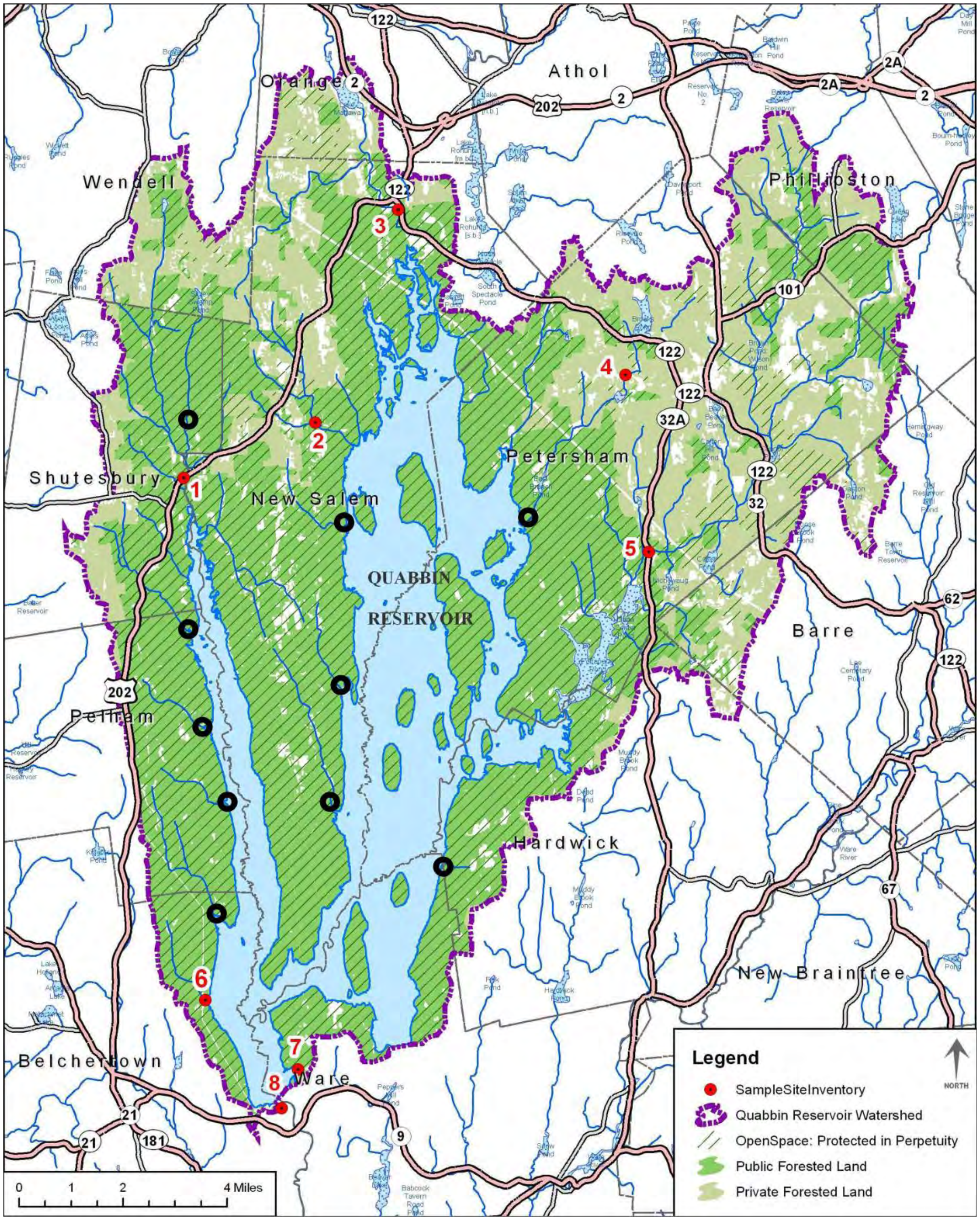

Figure 6.1 – Long-term water quality sampling stations (numbered red circles) and potential [example] water quality sampling stations to assess forest management effects (**open circles**) on the Quabbin Reservoir watershed, Massachusetts.

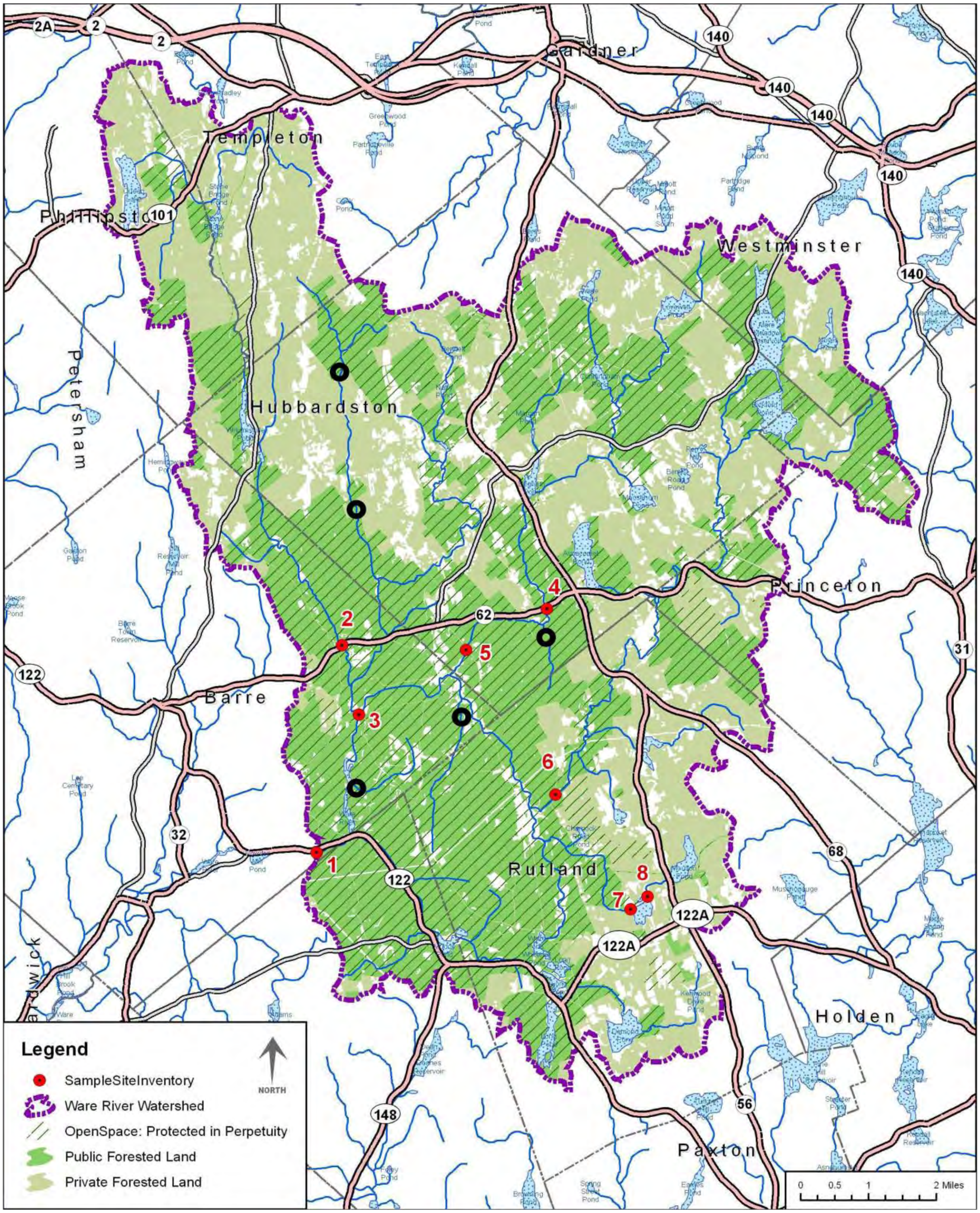

Figure 6.2 – Long-term water quality sampling stations (numbered red circles) and potential [example] water quality sampling stations to assess forest management effects (**open circles**) on the Ware River watershed, Massachusetts. The two northernmost example sites illustrate “above and below” sampling to quantify the effects, if any, of different management regimes on public and private forest land.

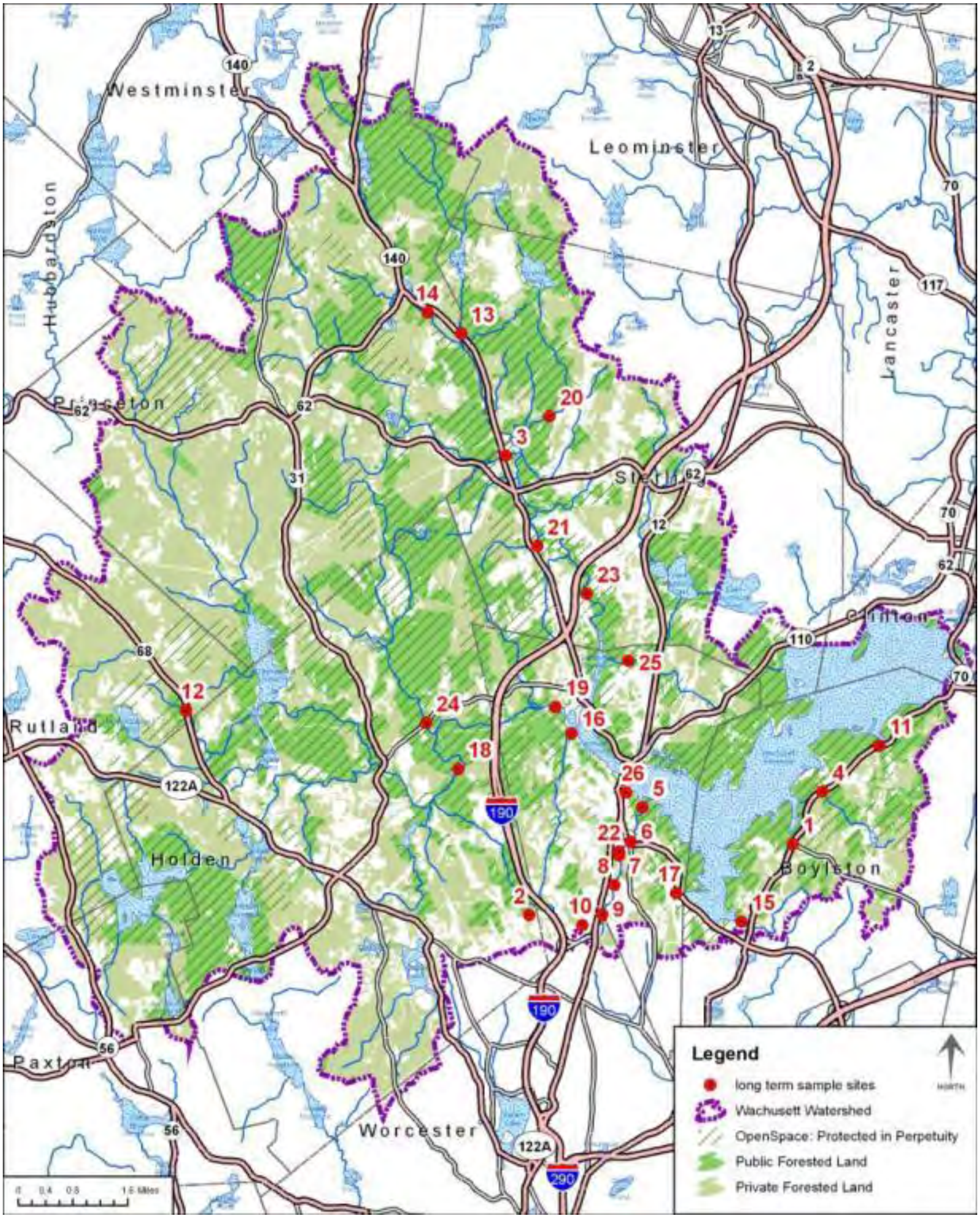

Figure 6.3 – Long-term water quality sampling stations (numbered red circles) on the Wachusett Reservoir watershed, Massachusetts. (A larger map scale would be required to show additional water quality sampling sites to assess forest management effects.)

Figure 6.4 –Example of "above and below" water quality monitoring in relation to forest management activities (irregular shelterwood cuts, Pelham block, Quabbin Forest).

The reference condition for streamflow and water quality can be characterized using a nearby watershed with similar characteristics (i.e., a "paired watershed" approach). More commonly, sampling stations can be established immediately upstream ("above") and downstream ("below") the management activity (Figure 6.4). Collecting and analyzing samples from these sites for a sufficient time period (e.g., 1 to 3 years) before the management activity occurs establishes the "baseline" conditions. The combination of "above and below" *and* "before, during, and after" sampling of key metrics such as discharge, turbidity, total suspended solids, total organic carbon, nitrogen, phosphorus, and calcium can reliably quantify the effects (if detectable and separable from natural variations in streamflow and water quality) of management actions such as timber harvesting.

Streamflow and water quality sampling could be combined with best management practice (BMP) effectiveness monitoring by DCR Service Foresters (Figures 6.5 and 6.6 and Welsch et al. 2006). This integrated approach would cover the spectrum of stand, site, sub-watershed, and watershed effects. Massachusetts was one of 12 states in the 20-state U.S. Forest Service Northeastern Area where the regional BMP monitoring protocol was developed, tested, and validated over a two year period. Several DCR Service Foresters were part of the pilot test and were fully prepared to train other service foresters and DWSP foresters, natural resources, and environmental quality staff.

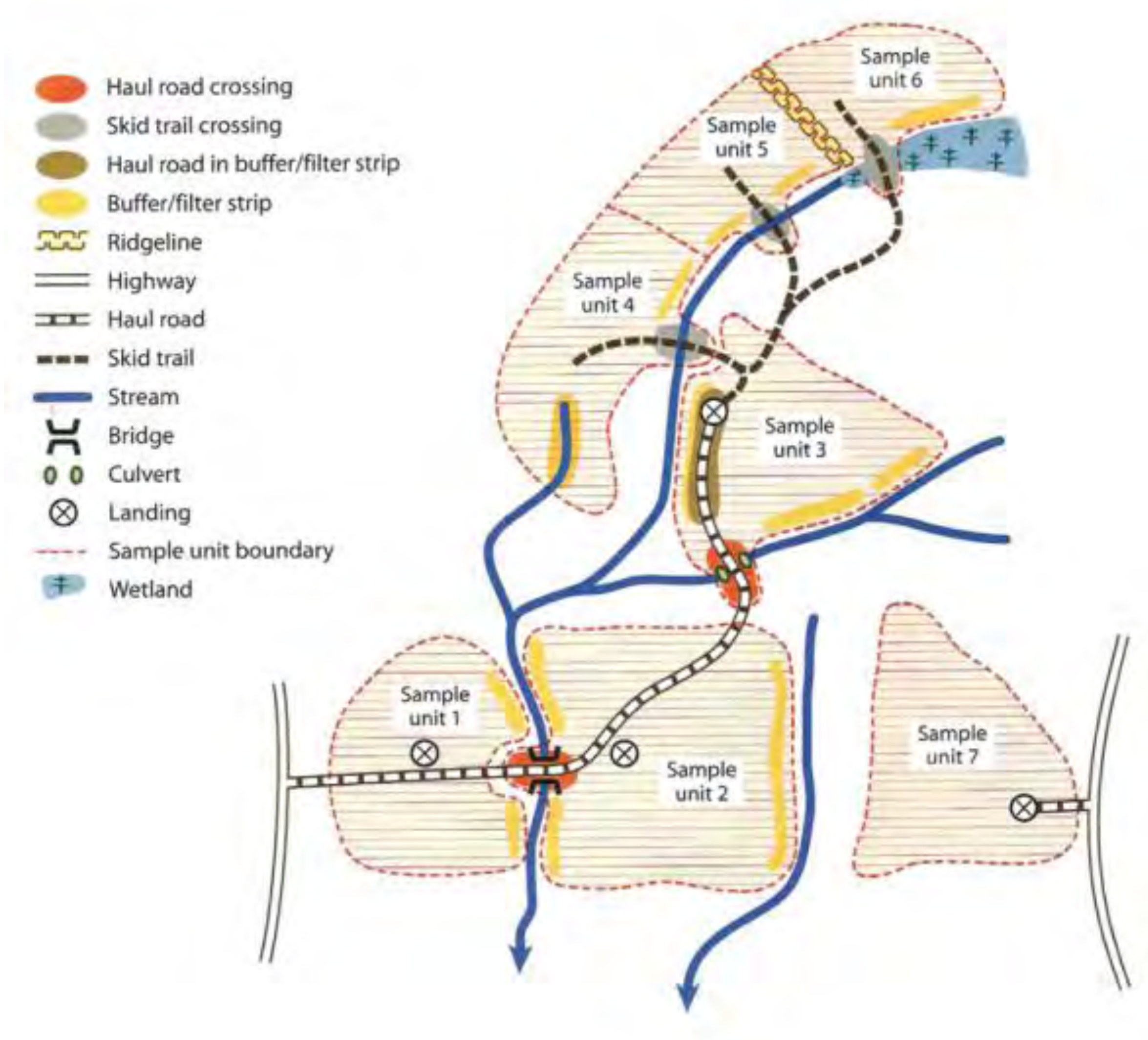

Figure 6.5 –Definition sketch for sample unit delineation using harvest area boundaries, ownership boundaries, and stream or wetland crossings, US Forest Service Northeastern Area BMP monitoring protocol (Welsch et al., 2006)

Figure 6.6 – Identification of approach areas. Approach Area "A" is always on the left when looking downstream. US Forest Service Northeastern Area BMP monitoring protocol (Welsch et al., 2006), Photo: Maine Forest Service.

7 – Findings, Conclusions, and Recommendations

The findings, conclusions, and recommendations of the DWSP Science and Technical Advisory Committee are enumerated in this section.

1. The forests managed by the DWSP on behalf of the Commonwealth of Massachusetts are a vitally important component of the water supply system for more than two million people in Boston and 40 smaller communities. This differentiates DWSP lands from other public lands with a less direct influence on public water supplies. These forests, reservoirs, treatment works, aqueducts, and distribution systems are irreplaceable assets that warrant the highest attainable standards of management – whatever the guiding philosophy may be – with the goal of continuous improvement.

2. The general controversy about active management of DWSP lands—particularly in relation to the Quabbin Forest—has been brewing for decades. A wide range of people and groups have questioned the advisability of active management of the deer population, forest vegetation, and recreational access. The recent Forest Futures Visioning Process on other DCR state forests and parks focused attention on DWSP management practices (including silvicultural methods, the timing and operational control of harvesting operations, and the implementation of Best Management Practices to protect water quality) — especially the geometric patch cuts in the New Salem, Prescott, and Petersham blocks of the Quabbin Forest. This heightened attention and concern happened to coincide with the recent transition from relatively innocuous thinning treatments to much less photogenic regeneration treatments. Most people are unpleasantly surprised by any kind of logging, especially when its purpose is unknown, unclear, or misrepresented. Few people have the opportunity to observe forest change over time. Few people ever see a before-during-after time series of photographs. Without a time series of photographs and the corresponding forest inventory data it is difficult to objectively describe the purpose and long-term outcomes of harvesting and silviculture. As a result, opinions are formed solely on the basis of stumps, slash, and exposed soil and the stark contrast with the adjacent mature forest. This ephemeral condition changes dramatically in a few growing seasons especially if the harvesting operation is well planned, carefully implemented, and well supervised.

3. Active management of DWSP forest land to increase the diversity of heights, ages, and species in what is currently a predominantly even-aged forest is a reasonable and prudent way to prepare for and minimize the adverse effects of natural and anthropogenic disturbance on streamflow and water quality. Increasing the diversity of heights, ages, and species is an inherently conservative approach that accelerates the restoration of many pre-settlement forest characteristics and conditions.[8] A diversity of heights, ages, and species maximizes the resistance and resilience of the forest in relation to hurricanes, tropical storms, insects, and diseases. It also is a buffer against the uncertainty associated with global climate change and the unintended consequences of global trade (e.g., Asian long-horned beetle).

---

[8] A complex mosaic of mixed species, uneven-aged stands …to the extent possible after exotic insects and diseases eliminated chestnut and elm, 19th century agriculture altered soil characteristics and microtopography, and overhunting and habitat loss extirpated many wildlife species.

Watershed management agencies throughout the U.S. have emulated and adapted the approach developed on DWSP lands (e.g., Baltimore, Denver, Hartford, New Haven, New York, Portland, Providence, etc.). In addition, active management was endorsed by the Forest Stewardship Council (an international consortium of NGOs founded in 1993) when the Quabbin Forest became the first green-certified public land in North America.

4. Other forest benefits and values such as wildlife habitat restoration or enhancement should be carefully integrated with the primary watershed protection objective and the DWSP mission. However, maintaining water quality, streamflow regimes, and stream channel stability over the long term should be the primary objective for the DWSP (in compliance with all applicable laws and regulations) not just "first among equals" or one of many uses or values (i.e., the 1960s-vintage multiple use management paradigm). Adaptive management for multiple benefits and values should be the norm for 21st century forestry on DWSP and other DCR lands. It is an attainable goal and well-founded strategy.

5. The implicit assumptions in DWSP plans about the short-term effects of active management on streamflow and water quality should be explicitly tested. The willingness and ability to test working hypotheses is a cornerstone of an adaptive management approach. Enhanced monitoring is also needed to restore the trust and confidence of the public, regulatory agencies, and policy makers in the DWSP.

6. The length and complexity of the land management plans for the Quabbin, Ware, and Wachusett watersheds (341, 205, and 216 pages, respectively) are a reflection of (i) the scale and complexity of the ecosystem and infrastructure, (ii) management planning and decision-making in the light of scientific uncertainty and operational experience, (iii) their evolution through multiple versions since 1960, (iv) extensive stakeholder input, (v) the guidance and requirements of regulatory agencies and policy-makers …and a host of other factors. As a result, it is very difficult for interested parties (e.g., new members of this or other committees, members of the public, newly appointed leaders and policy-makers, the media, etc.) – *and* all DWSP and MWRA staff members – to develop a clear and complete understanding of the background information, management context, ecological and operational constraints, goals, objectives, activities, and performance metrics that are summarized in these documents. This unintentional obstacle to a shared understanding and a "systems view" has produced confusion, apprehension, and mistrust. Different interpretations of the plans by members of the forestry staff are evident in different parts of the same watershed (Quabbin) and across the Quabbin, Ware, and Wachusett watersheds. This inconsistency is one of the key reasons why the DWSP watershed forestry program landed in the court of public opinion, where there is little hope of compressing 762 pages into a 45 second news report or 300-word website summary.

7. The Quabbin Reservoir does *not* have an infinitely large assimilative capacity. The persistent myth that 412 billion gallons of water will dilute or absorb *any* shock or stress (e.g., the effects of a severe hurricane, catastrophic insect outbreak, high intensity wildfire in the aftermath of a hurricane or insect outbreak, etc.) is a high risk assumption for any system but especially for an unfiltered water supply. The test of a water supply system comes when an uncommon (low probability) yet plausible combination of events imposes maximum stress on its resistance and resilience. A hurricane (e.g., 1938,

category 3 event) that blows down 50% to 70% of an even-aged forest upstream of a reservoir system that has been subjected to a prolonged drought (e.g., 1966-70, Quabbin at 45 to 55% of capacity) is a plausible test case or design scenario. The oceans and the atmosphere are substantially larger than the Quabbin Reservoir yet most people now recognize that even their assimilative capacity is finite.

8. The high profile calls for the designation of the Quabbin Forest as a "biosphere reserve" (R. Hubley, Massachusetts Audubon, QSTAC, 1990s) or as a "Wildland" (Foster et al. 2005, 2010) do not describe how "passive management" would be implemented. Neither proposal explains how this designation would equal or exceed the efficacy of the current plan and risk management approach. Both proposals assert that active management is, at best, unnecessary. In other words, the decision to "let Nature take its course" is the most prudent and conservative way to maintain or enhance the function of this watershed protection forest. This notion is very appealing to the general public and many policy makers. However, a *laissez-faire* approach is at odds with the time-tested principles and practices of water supply management. While it may be a reasonable option for some other state forests and parks, greater caution and clarity is warranted before a second-growth, even-aged forest—the green infrastructure of this water supply system—is designated as a biosphere reserve, wildland, or "wilderness" area. A passive management approach is also at odds with the diversification and risk management principles that have guided engineering, medicine, sustainable agriculture, responsible financial investment, and many other fields for decades or centuries.

9. The heated controversy about harvesting and other management activities has diverted attention from the time-sensitive challenge of building on the success of forest and open space conservation and nonpoint pollution control efforts in the Wachusett Reservoir watershed (mid-1980s to present). This watershed and reservoir is the critically important source of water prior to treatment and distribution to the metropolitan Boston region of the DWSP/MWRA system. The Wachusett watershed stands at the threshold of land use and land cover changes with the potential to adversely (and permanently) alter streamflow regimes and water quality. Now is the time (in spite of the current fiscal challenges) to make focused and continued investments which build upon decades of diligent source water protection. Exploring prospects for payments for ecosystem services or enhanced conservation easements on private forest lands is especially important and timely during the current downturn in the real estate market.

Recommendations

The following recommendations are based upon one or more the findings and conclusions in the preceding section. The data, information, and observations presented in earlier sections are also reflected in the proposed actions and changes.

1. Develop a 20 to 30 page illustrated plain-language summary of the DWSP system and management plans for a *"Scientific American"* audience in collaboration with the DCR, EEOEA, and MWRA Public Affairs offices. Develop a 4-page system and plan overview document for the same audience; it also should serve as a briefing document for visitors. Both documents should be readily accessible on the DCR website. The 4-page overview should be small enough to disseminate as an email attachment.

2. Continue and enhance source water protection efforts in the Wachusett Reservoir watershed in collaboration with other DCR offices (e.g., the Forest Legacy Program, Service Forestry), private landowners, local communities and service clubs, NGOs (e.g., Nashua River Watershed Association, The Nature Conservancy, Wildlands & Woodlands), schools, colleges, and universities. Systematically explore new approaches such as those in development by the Trust for Public Land, Portland Water District (Maine), Chesapeake Bay Program, Denver Water, and many others to identify promising ways to sustain and enhance the DWSP program (Webb 2012).

3. Re-start active management of DWSP forests using the silvicultural methods, harvest planning, and marking and layout techniques employed on the Hardwick and Pelham blocks of the Quabbin Forest and the Wachusett Forest (i.e., site specific adaptation of the irregular shelterwood method) as a the primary approach to the diversifying stand structure and species composition. Large openings with irregular boundaries and other site-specific ecological features (which clearly differentiate them from the controversial geometric patch cuts that led to the harvesting moratorium) could be implemented with conservative BMPs and strict operational control on hydrologically remote areas to create early successional habitat and enhance biological diversity. This recommendation should not be construed as an endorsement of traditional even-aged management methods that, first and foremost, focus on timber values not watershed protection, wildlife habitat enhancement, or other goals and objectives that are much more likely to—in concert with the other recommendations—restore and sustain public trust. Simply put, silvicultural methods that are inherently controversial should be set aside when they jeopardize the watershed forest management program as a whole. Since these watersheds must be protected and managed in perpetuity, patience, not efficiency, is the key measure of forest stewardship. At the other end of the management and successional continuum, silvicultural methods (i.e., specialized thinning techniques) to deliberately accelerate the development of old-growth characteristics in appropriate stands should be considered.

4. Monitor the effectiveness of BMPs to protect water quality using the USDA Forest Service Northeastern Area regional protocol[9] in cooperation with DCR Service Foresters. Establish a camera post and aiming marker on each harvest site and use annual (or seasonal) photographs to document progress of forest regeneration and change. This should be augmented with sampling and analyses to quantify regeneration. Make these photographs, regeneration data summaries, and an interactive map available on the DWSP website that is updated on a regular basis (e.g., quarterly). This high level of transparency will foster a renewed sense of public trust.

5. Monitor the hydrologic and water quality effects (e.g., turbidity, total suspended solids, nitrogen, calcium, stream water level and velocity, etc.) of active management using a team effort by the forestry, natural resources, environmental quality, and DCR service forester staffs. Water quality monitoring sites should be established in relation to a reasonable number of harvesting operations using a "before and after" and "above and below" or paired watershed approach (before and after on reference and treatment sites). The financial and human resources needed to design, implement, and sustain monitoring should be added to current staffs and budgets if needed.

[9] http://www.na.fs.fed.us/watershed/bmp.shtm

8 – References

Anderson, H.W., M.D. Hoover, and K.G. Reinhart. 1976. Forests and water: Effects of forest management on floods, sedimentation, and water supply. USDS Forest Service General Technical Report PSW-18, Washington, DC.

Askins, R. A. 2001. Sustaining biological diversity in early successional communities: the challenge of managing unpopular habitats. *Wildlife Society Bulletin* 29:407-412.

Barnes, B.V., D.R. Zak, S.R. Denton, and S.H. Spurr. 1998. *Forest Ecology.* Fourth Edition, John Wiley & Sons, NY, 774 pages.

Black, B. and A. Zaklikowski., 2009. Cost for Municipal-Type ASR Source Water Treatment Systems. HDR, Incorporated Technical Memorandum 86502 to IRZ Consulting LLC, 21 pages.

Bosch, J.M., and J.D. Hewlett. 1982. A review of catchment experiements to determine the effect of vegetative changes on water yield and evapotranspiration. *Journal of Hydrology* (55):3-23.

Brooks, K.N., P.F. Ffolliott, H.M. Gregersen, and L.F. DeBano. 2003. *Hydrology and the Management of Watersheds*. Third Edition, Iowa State University Press, Ames, 574 pages.

Calder, I.R., 2005. *Blue Revolution: Integrated Land and Water Resource Management.* Second Edition, Earthscan, London, 353 pages.

Creed, I, G. Sass, F. Beall, J. Buttle, D. Moore, and M. Donnelly. 2011a. Hydrological principles for conservation of water resources within a changing forested landscape. Sustainable Forest Management Network, University of Alberta, Canada, State of Knowledge Report, 80 pages.

Creed, I, G. Sass, F. Beall, J. Buttle, D. Moore, and M. Donnelly. 2011b. Scientific theory, data, and techniques for conservation of water resources within a changing forested landscape. Sustainable Forest Management Network, University of Alberta, Canada, State of Knowledge Report, 136 pages.

D'Amato, A., and P. Catanzaro. No date(a). A forest manager's guide to restoring late-successional forest structure. University of Minnesota and University of Massachusetts Extension Service, St. Paul, MN and Amherst, MA, 8 pages.

D'Amato, A., and P. Catanzaro. No date(b). Restoring old-growth characteristics. University of Massachusetts Extension Service, Amherst, MA, 20 pages.

de la Crétaz, A.L., and P.K. Barten., 2007. *Land Use Effects on Streamflow and Water Quality in the Northeastern United States.* CRC Press/Taylor & Francis Group, Boca Raton, FL, 319 pp.

de la Crétaz, A.L., L.S. Fletcher, P.E. Gregory, W.R. VanDoren, and P.K. Barten. 2010. *An Assessment of the Forest Resources of Massachusetts.* University of Massachusetts Amherst and Massachusetts Department of Conservation and Recreation, 274 pp.

DeGraaf, R.M. and M. Yamaski. 2001. *New England Wildlife: Habitat, Natural History, and Distribution.* University Press of New England, Hanover, NH, 482 pages.

DeGraaf, R.M., M. Yamaski, W.B. Leak, A.M. Lester. 2005. *Landowner's Guide to Wildlife Habitat: Forest Management for the New England Region.* University of Vermont Press, Burlington, published by University Press of New England, Hanover, NH, 111 pages.

DeGraaf, R. M., M. Yamasaki, W. B. Leak, and A. M. Lester. 2006. *Technical Guide to Forest Wildlife Habitat Management in New England.* University Press of New England, Hanover, NH, 305 pages.

DeStefano, S. 2002. Regional and national issues for forest wildlife research and management. *Forest Science* 48:181-189.

DeStefano, S. 2011. Forest structure as a component of habitat for New England wildlife. Unpublished manuscript, USGS Massachusetts Cooperative Fish and Wildlife Research Unit, University of Massachusetts, Amherst, MA, 14 pages.

DeStefano, S., and R. G. Haight, eds. 2002. *Forest Wildlife-Habitat Relationships: Population and Community Responses to Forest Management.* Society of American Foresters, Bethesda, MD, 275 pages.

Hornbeck, J.W., and J.N. Kochenderfer. 2004. A century of lessons about water resources in northeastern forests. Chapter 2, In: Ice and Stednick 2004., pages 19-31.

Ice, G.G., and J.D. Stednick., 2004. *A Century of Forest and Wildland Watershed Lessons.* Society of American Foresters, Bethesda, MD, 287 pages.

Kimmins, J.P., 1997. *Forest Ecology: A Foundation for Sustainable Management.* Second Edition, Prentice Hall, Upper Saddle River, NJ, 596 pages.

Lovett, G.M., C.D. Canham, M.A. Arthur, K.C. Weathers, and R.D. Fitzhugh. 2006. Forest ecosystem responses to exotic pests and pathogens in eastern North America. *Bioscience* 56(5): 395-405.

Massachusetts Audubon Society. 2011. *State of the Birds: Documenting Changes in Massachusetts' Birdlife*. Massachusetts Audubon Society, Lincoln, MA, 60 pages.

National Research Council., 2008. *Hydrologic Effects of a Changing Forest Landscape.* Water Science and Technology Board, National Academies Press, Washington, DC., 180 pp.

National Research Council., 2004. *Atlantic Salmon in Maine.* Environmental Studies and Toxicology and Ocean Science Boards, National Academies Press, Washington, 275 pp.

National Research Council., 2000. *Watershed Management for Potable Water Supply: Assessing New York City's Approach.* Water Science and Technology Board, National Academies Press, Washington, DC, 549 pp.

Raymond, P., Bedard, S., Roy, V., Larouche, C., and Tremblay, S. 2009. The irregular shelterwood system: review, classification, and potential application to forests affected by partial disturbances. Journal of Forestry 107:405-413.

Satterlund, D.R., and P.W. Adams., 1992. *Wildland Watershed Management.* Second Edition, John Wiley & Sons, NY, 436 pp.

Smith, D.M., B.C. Larson, M.J. Kelty, P. M. Ashton. 1997. *The Practice of Silviculture: Applied Forest Ecology.* 9th Edition. John Wiley & Sons, NY, 537 pages.

Sopper, W.E., and H.E. Lull (Editors). 1967. Forest Hydrology: Proceedings of a National Science Foundation Advanced Science Symposium. Pergamon Press, NY.

Swank, W.T., and D.A. Crossley (Editors). 1988. Forest Hydrology and Ecology and Coweeta. Springer-Verlag, New York, NY.

Texas Water Development Board. 2005. Appendix 4C: Cost Estimating Procedure. 16 pages. http://www.twdb.state.tx.us/

Webb, A.A., 2012. Payments for watershed services and other market-based approaches to forest management. Gottstein Trust Fellowship Report. Australian Forest Products Industries, Clayton South, Australia, 126 pages.