Strategic Analysis of Aquatic Plant Management in Wisconsin

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To the Reader

This document is a strategic analysis of aquatic plant management (APM) in Wisconsin, as authorized under s. NR 150.10 of the Wisconsin Administrative Code, consistent with s. 1.11(2)(e) and (h) of Wisconsin Statutes and the Wisconsin Environmental Policy Act. The analysis addresses topics of interest identified through a public scoping process. The purpose of this and other strategic analyses is to inform decision-makers and the public of alternative courses of action and the anticipated effects of these alternatives on the quality of the human environment. Strategic analyses rely in part on the professional judgement and expertise of subject area specialists within the department. They are not intended to be exhaustive scientific studies and do not advocate for particular alternatives.

The strategic analysis document summarizes current information on APM, including known and possible environmental impacts, applicable regulations, economic considerations, and potential alternative approaches for the future. It does not establish department policy for the review of specific APM projects or proposals. Rather, it is intended to serve as an informational resource to help decision-makers and the public to better understand the topic, and to aid in the crafting of future policy.

The scope of the analysis was limited to APM. This includes APM for controlling aquatic invasive plant species (AIS) but does not include AIS prevention, such as boater outreach and education. AIS prevention is covered by the Wisconsin Aquatic Invasive Species Management Plan, which will be finalized and released sometime in 2019 (visit https://dnr.wi.gov/topic/invasives for updates). Although much of the strategic analysis focused on lakes, APM activities are conducted in a variety of environments, including wetlands, marinas, shoreline areas and stream banks, right-of-ways, private and non-private ponds, and areas of exposed lakebed, among others. Many of the concepts described in this document apply to APM in these and other semi-aquatic or 'wet' environments.

The department initiated this strategic analysis in September of 2016. A public comment period on the proposed scope of the analysis was held from October 18 through November 16, 2016 with comments received from 20 individuals. Sources of information used to conduct the analysis included interviews with stakeholders, department staff, tribal representatives and other states' natural resource agencies, as well as scientific literature, APM codes and statutes, and personal/historical experience of APM in the state. As part of the analysis, a list of management alternatives was developed for consideration and discussion by APM stakeholders and decision-makers (see Chapter 8). The department also organized an APM Study Group consisting of nine non-department APM stakeholders, who reviewed and provided input on a preliminary draft of the analysis. Their feedback has been incorporated into this document with the aim of being as factual, objective, and inclusive of various considerations as possible.

The department sought public input on a draft of this document between December 11, 2018 and January 25, 2019 and received public comments from 45 individuals and organizations, as well as the Great Lakes Indian Fish and Wildlife Commission. A summary of the comments received, along with the department's responses, can be found in the response to public comments document.

Table of Contents

To the Reader ii
Table of Contents iii
List of Figures vii
List of Tables vii
Glossary viii
Acronyms and Abbreviations x
Common and Scientific Names of Species in this Report xi
Executive Summary xiv
1. Legal Authority for Aquatic Plant Management in Wisconsin 1
   1.1. Statutory Authority 1
   1.2. Administrative Rules 2
   1.3. Related Authority and Policy 4
   1.4. Wild Rice 5
   1.5. Discussion 6
2. Aquatic Plant Management in Wisconsin – Past and Present 8
   2.1. History of Aquatic Herbicide Use 8
   2.2. Non-Chemical Approaches and Integrated Pest Management 14
   2.3. DNR Staff Workload 17
   2.4. Strategic Management and Research 17
   2.5. Data Management and Accessibility 18
   2.6. DNR Grants and Aquatic Plant Management 19
3. Aquatic Plant Management Beyond Lakes and Ponds 21
4. Economic Considerations 23
   4.1. Costs 23
   4.2. Benefits 26
   4.3. Distribution and Opportunity Costs 29
5. Aquatic Plant Management Stakeholders and Collaborators 31
6. Stakeholder Views on Aquatic Plant Management 34
   6.1. Stakeholder Interview Process 34

6.2. Interview Findings 35
6.2.1. Management Goals 35
6.2.2. Management Considerations 36
6.2.3. Suggestions for Improving Aquatic Plant Management in Wisconsin 38
6.2.4. Other Aquatic Plant Management-Related Concerns 40
7. Current Practices and Research Implications 42
7.1. Aquatic Plants and Beneficial Use Impairment 42
7.2. Management of Non-Native Aquatic Plant Species 42
7.3. Strategies for Managing Non-Native Aquatic Plants 45
7.4. Implications of Recent Findings on Herbicide Use in Aquatic Environments 46
7.5. Hybrid Watermilfoil and Herbicide Resistance 50
7.6. Management Planning, Integrated Pest Management, and Adaptive Management 52
7.7. Cause for Variation in Management Strategies Statewide 55
7.8. The Importance of Understanding the Relationship between Aquatic Plants and Water Quality 56
8. Management Alternatives 58
8.1. Collaboration 59
8.2. Department Resources and Workload 65
8.3. Public Outreach and Communications 71
8.4. Program Tracking and Evaluation 76
8.5. Integrating New Information 78
8.6. Consistency in Evaluating Permit Applications 83
8.7. Grants 88
8.8. Watershed Health, AIS Prevention, Enforcement, Overall Emphasis, and Other Topics 94
Supplemental Chapters 100
S.1. Aquatic Plant Management in Other States 100
S.2. Ecology and Ecosystem Services of Aquatic Plants 108
S.2.1. Aquatic Ecosystems and the Value of Aquatic Plants 108
S.2.2. Ecology of Aquatic Plants in Wisconsin 121
S.2.3. Ecosystem Services of Aquatic Plants 121
S.2.4. Climate Change and Aquatic Ecosystems 124

S.3. Wisconsin’s Toolbox for Aquatic Plant Management ... 126
S.3.1. Management Techniques Not Allowed in Wisconsin ... 127
S.3.2. Management Techniques for which Permits are Not Issued by Wisconsin DNR’s Aquatic Plant Management Program ... 127
S.3.3. Herbicide Treatment ... 128
S.3.3.1. Submersed or Floating, Relatively Fast-Acting Herbicides ... 132
Diquat ... 132
Flumioxazin ... 135
Carfentrazone-ethyl ... 137
S.3.3.2. Submersed, Relatively Slow-Acting Herbicides ... 139
2,4-D ... 139
Fluridone ... 144
Endothall ... 147
Imazamox ... 150
Florpyrauxifen-benzyl ... 152
S.3.3.3. Emergent and Wetland Herbicides ... 154
Glyphosate ... 154
Imazapyr ... 156
S.3.3.4. Herbicides Used for Submersed and Emergent Plants ... 158
Triclopyr ... 158
Penoxsulam ... 160
S.3.4. Physical Removal Techniques ... 162
S.3.4.1. Manual and Mechanical Cutting ... 162
S.3.4.2. Hand Pulling and Diver-Assisted Suction Harvesting (DASH) ... 164
S.3.4.3. Benthic Barriers ... 164
S.3.4.4. Dredging ... 166
S.3.4.5. Drawdown ... 167
S.3.5. Biological Control ... 171
S.3.6. Cyanobacteria and Algae Management ... 174
S.3.6.1. Alum Treatment ... 175
S.3.6.2. Barley Straw ... 176

S.3.7. Attempted Starry Stonewort Control using Copper-based Herbicides ... 178
S.3.8. Understudied Management Techniques ... 178
S.3.8.1. Dyes ... 178
S.3.8.2. Planting of Aquatic Plants ... 180
S.3.8.3. Fire ... 181
References ... 183
Appendix A. Authority for Aquatic Plant Management ... 236
Appendix B. Overview of the Aquatic Plant Management Permitting Process ... 238
Appendix C. Recent Statewide Strategic Efforts Toward Control and Containment of Non-Native Phragmites and Other Non-Native Species ... 243
Appendix D. Stakeholder Interview Questions ... 247
Appendix E. Detailed Summary of and Quotes from Stakeholder Interviews ... 249
E.1. Management Goals ... 249
E.2. Management Considerations ... 251
E.3. Suggestions for Improving Aquatic Plant Management in Wisconsin ... 262
E.4. Other Aquatic Plant Management-Related Concerns ... 273
Appendix F. APM Resources ... 277

List of Figures

Figure 2.1. Copper sulphate and sodium arsenite use for APM in Wisconsin lakes (1950-1969). 10
Figure 2.2. Department issued ch. NR 107 and ch. NR 109 permits (2008-2018). 12
Figure 2.3. Acres of department approved chemical and non-chemical management (2008-2018). 13
Figure 2.4. Amount (a) and acreage (b) of 2,4-D applied to Wisconsin waterbodies (2008-2016). 13
Figure 2.5. Growth in the scale of APM treatments with 2,4-D in Wisconsin (2008-2016). 14
Figure 6.1. Location of various stakeholder categories. 35
Figure 7.1. Percent of littoral zone (a) and surface area (b) with Eurasian watermilfoil............................ 44
Figure 7.2. Managed versus unmanaged Eurasian watermilfoil populations. 46
Figure 7.3. Concentration and exposure time graph for 2,4-D. 47
Figure S.2.1. Change in plant and algae population as a function of nutrient levels. 109
Figure S.2.2. Diagram of various lake trophic states. 110
Figure S.2.3. Seasonal periods of mixing and stratification in a temperate lake. 112
Figure S.2.4. Visualization of the habitat zones of a waterbody. 113
Figure S.2.5. Phosphorus-enriched versus unenriched water. 114
Figure S.2.6. Examples of lakes with clear (a) and turbid water (b) 115
Figure S.2.7. Generalized lake food web for submerged aquatic plant systems. 118
Figure S.2.8. Links between ecosystem services and human well-being. 122
Figure A.C.1. Non-native phragmites records in each of Wisconsin's 72 counties. 244
Figure A.C.2. Native and non-native phragmites records and control (2014-2017)................................ 245

List of Tables

Table 2-1. Dates of U.S. EPA approval for pesticides employed in APM. 11
Table 8-1. Alternatives related to collaboration between DNR staff and APM partners, stakeholders 63
Table 8-2. Alternatives related to department resources and workload. 69
Table 8-3. Alternatives related to public outreach and communications. 74
Table 8-4. Alternatives related to program tracking and evaluation. 77
Table 8-5. Alternatives related to integrating new APM-related information into APM practice. 81
Table 8-6. Alternatives related to consistency in evaluating APM permit requests. 86
Table 8-7. Alternatives related to the department's Surface Water Grants program. 91
Table 8-8. Alternatives related to other aspects of APM. 98
Table S.1-1. Comparison between eighth states' aquatic plant management (APM)............................. 107
Table A.B-1. APM permit requirements for tribal and non-tribal entities on and off reservations. 240

Glossary

Word or Phrase	Definition
anthropogenic	relating to, or resulting from the influence of human beings on nature
beneficial use impairment	a situation in which aquatic plants prevent beneficial water use activities, including angling, boating, swimming or other navigational or recreational water use activity (this definition is derived from ch. NR 109's definition of "beneficial water use activities" and in this document it does not refer to "beneficial use impairments" as defined in Great Lakes Areas of Concern)
eutrophic lake	a lake with ample nutrient supply and high primary productivity
herbicide tolerance	the inherent ability of a species to survive and reproduce after herbicide treatment; implies that there was no selection or genetic manipulation to make the plant tolerant; it is naturally tolerant (WSSA 1998)
herbicide resistance	the inherited ability of a plant to survive and reproduce following exposure to a dose of herbicide normally lethal to the wild type; resistance may be naturally occurring or induced by such techniques as genetic engineering or selection of variants produced by tissue culture or mutagenesis (WSSA 1998)
hypereutrophic lake	a lake with an overly abundant nutrient supply and dominated by free-floating phytoplankton and algae
invasive species	a species likely to cause economic or environmental harm or harm to human health
large-scale treatment	an herbicide treatment exceeding 10 acres in size or 10% of the area of a waterbody that is 10 feet or less in depth (from ch. NR 107)
littoral zone	an area in a waterbody where there is enough light penetration to allow for aquatic plants to grow
macrophyte	a plant large enough to be seen without magnification
mesocosm	an outdoor experimental system that examines the natural environment under controlled conditions
mesotrophic lake	a lake with moderate nutrient supply and primary productivity
mode of action	the specific mechanism by which the active ingredient of a pesticide exerts a toxic effect
non-native species	a species not indigenous to Wisconsin (from ch. NR 40)
oligotrophic lake	a lake with low nutrient supply and primary productivity
pelagic zone	an area in a waterbody where light does not penetration to the bottom
periphyton	microscopic organisms attached or clinging to plants and other objects
phytoplankton	free-floating microscopic photosynthetic organisms
primary productivity	energy or biomass produced through photosynthesis by aquatic plants and phytoplankton
private pond	a body of water located entirely on the land of an applicant, with no surface water discharge or a discharge that can be controlled to prevent chemical loss, and without access by the public (from ch. NR 107)
small-scale treatment	an herbicide treatment generally less than 10 acres in size, or where impacts are anticipated to occur on a localized, not lakewide scale
stratified lake	a waterbody where a temperature gradient (thermocline) prevents warmer,

	top waters from readily mixing with cooler, bottom waters
thermocline	a vertical temperature gradient in a waterbody designated by a warmer upper water layer and a cooler bottom layer
trophic state	general definition of lake condition based upon level of biologically useful nutrients
waterbody	a “Water of the State” as described below
waters of the state	all lakes, bays, rivers, streams, springs, ponds, wells, impounding reservoirs, marshes, watercourses, drainage systems and other ground or surface water, natural or artificial, public or private, within Wisconsin or its jurisdiction, including territorial portions of Lake Michigan and Lake Superior (s. 281.01(18), Stats.)
zooplankton	free-floating microscopic animals and immature stages of larger animals

Acronyms and Abbreviations

Abbreviation	Meaning
AIPC	AIS Prevention and Control (grant)
AIS	aquatic invasive species
APM	aquatic plant management
CET	concentration and exposure time
cHAB	cyanobacterial harmful algal bloom
CISMAs	Cooperative Invasive Species Management Areas
CLMN	Citizen Lake Monitoring Network
DASH	diver assisted suction harvesting
DATCP	Department of Agriculture, Trade, and Consumer Protection
DAT	days after treatment
DEC	Department of Environmental Conservation (the New York DEC)
DEEP	Department of Energy and Environmental Protection (the Connecticut DEEP)
DEP	Department of Environmental Protection (the Maine DEP)
DEQ	Department of Environmental Quality (the Michigan DEQ)
DNR	Department of Natural Resources (the Wisconsin DNR unless otherwise noted)
DOE	Department of Ecology (the Washington DOE)
DOT	Department of Transportation
EPA	Environmental Protection Agency
EWM	Eurasian watermilfoil
FIFRA	Federal Insecticide, Fungicide and Rodenticide Act
FTE	Full-term employee
GLIFWC	Great Lakes Indian Fish and Wildlife Commission
GLRI	Great Lakes Restorative Initiative
HAB	harmful algal bloom(s)
IPM	Integrated Pest Management
LTE	limited-term employee
NPDES	National Pollution Discharge Elimination System
OHWM	Ordinary High Water Mark
ppb	parts per billion
ppm	parts per million
RBF	Recreational Boating Facilities
SWIMS	Surface Water Integrated Monitoring System
USACE ERDC	United States Army Corps of Engineers Engineer Research and Development Center
USFWS	United States Fish and Wildlife Service
WPDES	Wisconsin Pollution Discharge Elimination System

Common and Scientific Names of Species in this Report

Common Name	Scientific Name
American bulrush	*Schoenoplectus americanus*
American lotus	*Nelumbo lutea*
black crappie	*Pomoxis nigromaculatus*
bluegill	*Lepomis macrochirus*
blue-winged teal	*Anas discors*
bog smartweed	*Polygonum setaceum*
*Brazilian waterweed	*Egeria densa*
*brittle naiad	*Najas minor*
broadleaf arrowhead	*Sagittaria latifolia*
broadleaf cattail	*Typha latifolia*
common bladderwort	*Utricularia vulgaris*
*common carp	*Cyprinus carpio*
common three-square bulrush	*Schoenoplectus pungens*
common waterweed	*Elodea canadensis*
common loon	*Gavia immer*
coontail	*Ceratophyllum demersum*
*curly-leaf pondweed	*Potamogeton crispus*
dotted duckweed	*Landoltia punctata*
*Eurasian watermilfoil	*Myriophyllum spicatum*
*European frog-bit	*Hydrocharis morsus-ranae*
European water-clover	*Marsilea quadrifolia*
*fanwort	*Cabomba caroliniana*
fathead minnow	*Pimephales promelas*
flat-stem pondweed	*Potamogeton zosteriformis*
*floating marsh pennywort	*Hydrocotyle ranunculoides*
*flowering rush	*Butomus umbellatus*
Fries' pondweed	*Potamogeton friesii*
giant bulrush	*Schoenoplectus californicus*
*giant hogweed	*Heracleum mantegazzianum*
*giant reed	*Arundo donax*
*giant salvinia	*Salvinia molesta*
*grass carp	*Ctenopharyngodon idella*
*hairy willow herb	*Epilobium hirsutum*
hardstem bulrush	*Schoenoplectus acutus*
horned pondweed	*Zannichellia palustris*
horsetail	*Equisetum hyemale*
hybrid cattail	*Typha × glauca*
*hybrid watermilfoil	*Myriophyllum spicatum* x *sibiricum*
*hydrilla	*Hydrilla verticillata*
Illinois pondweed	*Potamogeton illinoensis*

*Indian swampweed	*Hygrophila polysperma*
*Japanese hops	*Humulus japonicus*
*Japanese knotweed	*Fallopia japonica [Polygonum cuspidatum]*
*Japanese stiltgrass	*Microstegium vimineum*
*java waterdropwort	*Oenanthe javanica*
large-leaf pondweed	*Potamogeton amplifolius*
largemouth bass	*Micropterus salmoides*
leafy pondweed	*Potamogeton foliosus*
*lesser celandine	*Ranunculus ficaria*
long-leaf pondweed	*Potamogeton nodosus*
manyflower marsh-pennywort	*Hydrocotyle umbellata*
milfoil weevil	*Euhrychiopsis lecontei*
*narrow-leaf cattail	*Typha angustifolia*
needle spikerush	*Eleocharis acicularis*
*non-native phragmites	*Phragmites australis* subsp. *australis*
northern watermilfoil	*Myriophyllum sibiricum*
*oxygen-weed	*Lagarosiphon major*
*parrot feather	*Myriophyllum aquaticum*
*perennial pepperweed	*Lepidium latifolium*
perfoliate pondweed	*Potamogeton perfoliatus*
pickerelweed	*Pontederia cordata*
*purple loosestrife	*Lythrum salicaria*
purple loosestrife biocontrol beetles	*Galerucella calmariensis*, *G. pusilla*, *Hylobius transversovittatus*, *Nanophyes marmoratus*
rainbow trout	*Oncorhynchus mykiss*
red-necked grebe	*Podiceps grisegena*
reed canary grass	*Phalaris arundinacea*
ribbon-leaf pondweed	*Potamogeton epihydrus*
clasping-leaf pondweed	*Potamogeton richardsonii*
fern pondweed	*Potamogeton robbinsii*
sago pondweed	*Stuckenia pectinata*
sheepshead minnow	*Cyprinodon variegatus*
slender naiad	*Najas flexilis*
small pondweed	*Potamogeton pusillus*
smallmouth bass	*Micropterus dolomieu*
softstem bulrush	*Schoenoplectus tabernaemontani*
*southern cattail	*Typha domingensis*
southern naiad	*Najas guadalupensis*
spiny softshell turtle	*Apalone spinifera*
squarestem spikerush	*Eleocharis quadrangulata*
*starry stonewort	*Nitellopsis obtusa*
stiff pondweed	*Potamogeton strictifolius*
swamp smartweed	*Polygonum hydropiperoides*
variable-leaf watermilfoil	*Myriophyllum heterophyllum*

variable-leaf pondweed	*Potamogeton gramineus*
spatterdock	*Nuphar variegata*
walleye	*Sander vitreus*
water celery	*Vallisneria americana*
*water chestnut	*Trapa natans*
*water hyacinth	*Eichhornia crassipes*
*water lettuce	*Pistia stratiotes*
water marigold	*Bidens beckii*
water net	*Hydrodictyon reticulatum*
water stargrass	*Heteranthera dubia*
Watercress	*Nasturtium officinale*
Watermeal	*Wolffia columbiana*
Watershield	*Brasenia schreberi*
water-thread pondweed	*Potamogeton diversifolius*
white-stem pondweed	*Potamogeton praelongus*
white sucker	*Catostomus commersonii*
white water crowfoot	*Ranunculus aquatilis*
white waterlily	*Nymphaea odorata*
wild rice	*Zizania palustris*
*yellow floating heart	*Nymphoides peltata*
*yellow iris	*Iris pseudacorus*
yellow perch	*Perca flavescens*
yellow pond-lily	*Nuphar advena*
*zebra mussel	*Dreissena polymorpha*

Note: * indicates an invasive species, as identified under Wisconsin Administrative Code Chapter NR 40.

Executive Summary

The following is a summary of the full strategic analysis document, organized by chapters.

1. Legal Authority for Aquatic Plant Management in Wisconsin DNR

The Wisconsin Department of Natural Resources (department) is responsible for regulating the management of aquatic plants growing in the surface waters of the state. This authority has evolved over time from the state government directly controlling "aquatic nuisances" in the 1940's and 1950's, to a regulatory program permitting shoreline and wetland property owners, lake districts and associations, and other organizations to manage aquatic plants and other nuisance-causing organisms. Over time, the program has become more ecologically focused with an increasing emphasis on protecting ecosystems and controlling invasive plant species.

Statutory Authority

According to s. 23.24, Stats., the scope of management activities that may be regulated under an APM permit include the quantity, species, area, methods, and timing of management. The scope of activities needing a permit include anyone seeking to:

1. Introduce non-native aquatic plants into waters of this state (s. 23.24 (3) (a) 1)
2. Manually remove aquatic plants from navigable waters (s. 23.24 (3) (a) 2)
3. Control aquatic plants in waters of this state by the use of chemicals (s. 23.24 (3) (a) 3)
4. Control aquatic plants in navigable waters by introducing biological agents, by using a process that involves dewatering, desiccation, burning, freezing, or by using mechanical means (s. 23.24 (3) (a) 4)

This statute also allows the department to require a plan for how aquatic plants will be managed as part of an application for a permit and provides the department with rule authority to set fees for permits.

Administrative Rules

Ch. NR 107, Wis. Admin. Code ("Aquatic Plant Management") regulates the use of chemicals for the management of aquatic plants and control of other aquatic nuisance-causing organisms. It sets application requirements, permit standards, exemptions and fees. The purpose section notes that a "balanced aquatic plant community is recognized to be a vital and necessary component of a healthy aquatic ecosystem" and allows for the management of "nuisance-causing" aquatic plants with sound ecosystem management and minimized loss of ecological values. The rule also directs that high value plant species be protected from adverse, long-term or permanent changes when chemical treatments are conducted and lists a dozen species that are known to offer these values. NR 107 was repealed and re-created in 1989 and has not been revised since. Minor editorial corrections were made in 2000.

Ch. NR 109, Wis. Admin. Code ("Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations") regulates non-chemical management activities, including: introduction of aquatic plants, manual removal, burning, and use of mechanical control or plant inhibitors. It has the same general purpose as ch. NR 107 recognizing the value of native aquatic plants to a healthy ecosystem, but adds that management will also be conducted in "a manner consistent with sound ecosystem management, shall consider cumulative impacts, and shall minimize the loss of ecological values in the body of water." Chapter NR 109 also allows for the department to require a plan as an application requirement and identifies the required plan elements. Chapter NR 109 was created in 2003 and has not been revised.

Related Authority and Policy

Chapter NR 40, Wis. Admin. Code ("Invasive Species Identification, Classification, and Control") classifies non-native invasive species as either prohibited or restricted, to assist in the management of these species, including control, prevention, information and education, and grant funding. Enabled under s. 23.22, Stats., part of the invasive species program includes a cost-sharing grant program for the control of aquatic invasive species (AIS). Although it does not impact the authority of APM permitting, it does incentivize local organizations and governments to conduct projects to control aquatic invasive plant species, putting the department in both the role of regulator and financier of APM in some instances.

Federally, APM activities utilizing pesticides fall within the jurisdiction of the U.S. Environmental Protection Agency (EPA) under the Federal Insecticide, Fungicide and Rodenticide Act (FIFRA) and the Clean Water Act. FIFRA requires the registration of pesticides, establishes record-keeping requirements, and provides for delegation, state cooperation, aid, and training. In Wisconsin, the Department of Agriculture Trade and Consumption Protection (DATCP) is the delegated authority, registering pesticides and training and certifying chemical applicators under ch. ATCP 29, Wis. Admin Code. The department works cooperatively with DATCP on treatment supervisions, record retention, and enforcement.

Under the Clean Water Act, most pesticide applications in public waters also require a Wisconsin Pollution Discharge Elimination System (WPDES) permit. A WPDES permit is required for all open water herbicide treatments except for private ponds. One condition of the WPDES permit directs applicants to apply herbicides following Integrated Pest Management (IPM) principles. Additionally, some non-chemical APM activities are regulated by the Waterways and Wetlands Section of the department, under ch. 30, Stats.

Discussion

The evolution of APM in Wisconsin has outpaced some of the provisions of the current administrative rules, potentially leading to the application of outdated requirements and approaches. One of the most significant changes in recent years has been the introduction of planning activities into the overall APM program. Over time, aquatic plant managers in both the public and private sectors, as well as lake organizations have adopted planning as a valuable component of effective APM, giving rise to expanded expertise in the private sector. In many of the state's more heavily-used waterbodies, planning for water quality improvement and APM now are conducted together, leading to approaches that are more holistic than the traditional nuisance control.

The AIS grant program established under ch. NR 198, Wis. Admin. Code has subsidized not only the increased scale of AIS control but also expanded APM planning and evaluation activities. In the last decade, the increased emphasis on management evaluation has led to a greater understanding of the use of chemicals and their efficacy and selectivity in aquatic plant control.

2. Aquatic Plant Management in Wisconsin – Past and Present

The recognition of excessive plant growth as a management problem was first reported in urban areas as early as the mid-1850's. Only more recently have aquatic plants and algae been recognized as vital components of aquatic ecosystems, providing essential habitat and food resources for fish and wildlife populations. When aquatic plants and algae respond to excess nutrients, natural fluctuations, or are invasive, their density and frequency can be problematic for some recreational uses. In some cases, fish, wildlife, property values, and even human health are affected. As the view of aquatic plants has changed over time from being strictly a nuisance to that of a natural resource requiring management, the department has increasingly worked with other state agencies, tribal governments, academia, industry, municipalities, lake associations, sporting clubs, and other enthusiasts to balance the needs of the ecosystem with a range of public concerns and expectations for the waterbodies of the state.

History of Aquatic Herbicide Use

In the early 1900's, APM was primarily conducted by cities and counties to alleviate nuisance plant and algae populations caused by pollution that occurred prior to the development of wastewater treatment technology. Wisconsin's long history of managing aquatic plant communities with herbicides began with harsh chemicals, such as copper- or arsenic-based compounds, which are now banned or greatly restricted. The period from 1969 through the 1980's saw an increase in the availability and use of organic-chemical pesticides such as 2,4-D, endothall, glyphosate, and triclopyr in Wisconsin, although copper was still in use. These organic herbicides became recognized as effective tools for aquatic nuisance control and are still widely used to manage aquatic plants and algae.

The number of APM permits sought and issued has increased over time. Likely contributing factors include increases in shoreline development and recreational activities, increases in the types of herbicides available, the regulation of non-chemical APM activities, and the emergence and spread of invasive species. Over the last ten years, the increase in permit numbers appears to have been driven by the proliferation of constructed ponds. There also appears to have been an increasing trend in the total acreage where chemical and non-chemical management has occurred.

Non-Chemical Approaches and Integrated Pest Management

Starting in the early 1970's, mechanical harvesting became a popular management tool for nuisance aquatic plant control. As the number of management methods has increased, there has been a recognition of the benefits of combining multiple control methods to achieve management goals. In additional to mechanical harvesters, other non-chemical management approaches include benthic barriers, dredging, and unsupervised mechanical weed rollers. In the 1980's water-level fluctuation was determined to be another APM approach that could be used to encourage beneficial aquatic plant growth and aid in restoration of native aquatic plant communities.

Diver Assisted Suction Harvesting (DASH) has recently become a popular control method for invasive plant populations that may be too small for effective control by other means. DASH utilizes divers to uproot and remove vegetation. The diver then hand feeds the plants into a vacuum hose which transports the plants to the surface where they are collected and properly disposed of on shore.

Since the 1990's, Wisconsin's APM program has also used organisms (biocontrol) to manage a select few invasive species. Biological controls are used worldwide, though the use of biocontrol agents that are not native to the ecosystem in which they are used can sometimes cause more harm than good. In Wisconsin, rigorous testing must be completed before any method of biocontrol is used.

DNR Staff Workload

The overall amount of time that department staff spend on APM permitting and planning has remained relatively constant despite an increase in the number of APM permits processed. In recent years, more of this time been dedicated to APM planning than permitting. APM program revenue is collected from application fees, which range from $20 for a private pond to maximum of $1,270 for lake treatments over 50 acres. Fees cover about half the total program cost with the remainder funded by state taxes.

Strategic Management and Research

Strategic management and planning are more effective than nuisance-control approaches for maintaining healthy aquatic plant communities and controlling AIS. Department staff track APM activities and monitor aquatic plant communities to better understanding natural patterns and trends in plant communities. The department has collaborated with partners on several management case studies, which are particularly useful when field trials for a given management approach are lacking. As case studies accumulate, conclusions can be drawn about the selectivity, efficacy, and non-target effects of management. These studies have shown how quickly herbicides dissipate, how plant abundance can fluctuate naturally over time, and how lake type, stratification, pH and other environmental factors can affect herbicide efficacy and the severity of non-target effects. This work is crucial in informing individual management actions as well as development of effective APM strategies for the state.

Data Management and Accessibility

The department maintains a database of APM permits and treatments from 2008 to the present. Since 2017, APM permit applicants have been able to submit their applications and chemical treatment records online. The department also has an aquatic plant survey database that includes data from over 1,600 surveys on approximately 800 lakes, plus long-term data from annual surveys of a subset of managed and unmanaged lakes monitored since 2005. This database can be used to describe local and statewide patterns in aquatic plant communities, allowing a better understanding of the natural context for management. In the near term, the APM database will be integrated into the department's Surface Water Integrated Monitoring System allowing access to anyone with a computer and a user account. Eventually, all APM permits, treatment records, and aquatic plant survey data will be integrated.

DNR Grants and Aquatic Plant Management

Most of the financial burden for APM falls to lake districts, lake associations, and to a lesser extent, cities and villages. Many lake districts and associations are formed explicitly to finance APM. Surface Water Grants support APM activities primarily through "AIS Prevention and Control Grants" and "Lake and River Planning Grants." Lake and River Planning Grants can provide assistance for collecting information on aquatic plant communities and developing management plans as a first step in APM projects.

While planning grants often target broader issues, AIS Prevention and Control Grants explicitly target invasive species. The $4 million per year grant program supports prevention, planning, early detection, and response to AIS, and the on-going management of established AIS populations, as well as AIS-related research. About 70% of the funding relates to invasive aquatic plants. The department's Recreational Boating Facilities (RBF) program also distributes cost-sharing grants for equipment used for cutting and removing aquatic plants in public water ways. Examples include mechanical harvesters, conveyors, transport barges, and harvester repair.

3. Aquatic Plant Management Beyond Lakes and Ponds

Aquatic plant management also occurs in wetlands, along riparian corridors, in roadside rights-of-way, and other semi-aquatic or 'wet' environments. While these systems are not fully-aquatic, some APM activities within them still fall under the jurisdiction of chs. NR 107 and 109. Aquatic plant management in wetlands and other semi-aquatic environments is typically aimed at controlling brush and invasive species, and restoring habitat, as opposed to improving recreational or navigational access. APM in wetland environments also presents some unique challenges. Unlike public navigable waters, most wetlands and stream banks in Wisconsin are privately owned, so managers must often work with land owners to organize and conduct plant control activities.

The department relies heavily on collaboration with partners, such as non-profit organizations and Cooperative Invasive Species Management Areas (CISMAs), for management of stream-bank and wetland invasive species. Funding availability has also been a challenge for wetland invasive plant control. Because of the unique challenges associated with wetland plant management, the department has organized statewide strategic control efforts for some wetland invasive plant species.

4. Economic Considerations

Chapter 4 discusses whether and to what extent the economic benefits of APM outweigh its costs and how these benefits and costs are distributed among different stakeholders and the public. Due to data limitations and the fact that many of the costs and benefits of APM do not have traditional market values, it is impossible to answer this question definitively, although it is possible to gain some useful insights based on the data that are available and relevant recent economic studies.

Costs

The cost of APM in Wisconsin includes public and private spending on chemical and mechanical control, planning, evaluation, and technical assistance, plus economic damages that may be caused by APM activities. Total spending on APM is estimated at roughly $9.3 million a year. The majority of funding for APM comes from the department's segregated Water Resources Account funded through a motorboat fuel sales tax. Additional funding comes from a mixture of property taxes, association membership fees, private spending and other sources.

Benefits

Spending on APM generates direct and indirect sales, income, and employment among APM service providers, suppliers, and other businesses that provide goods and services to people employed directly or indirectly in APM. Approximately 60 companies with offices in Wisconsin employ 300 to 350 full and part-time workers to provide one or more APM services. This does not include APM workers employed by lake districts, state and local agencies, or non-profit organizations.

Beyond this, APM can provide substantial economic benefits by helping to maintain the ecological, aesthetic and recreational value of public and private waterbodies, including the potential to maintain or improve water-based tourism and shoreline property values. The results of a national household survey suggest that the average household in Wisconsin is willing to pay around $9 a year for an APM program to minimize the scenic, natural, health-related, economic, navigational, and recreational impacts of aquatic invasive plants, or roughly $22 million totaled across all households in the state.

Distribution, and Opportunity Costs

There may be situations in which funds spent on certain APM activities could have provided a greater economic return had they been spent on alternative approaches. In such cases, the difference between the actual economic benefit of the APM activities conducted and the likely benefit of the alternatives foregone constitute an opportunity cost. While such costs are difficult to estimate, it may be useful to consider them when evaluating alternative APM approaches or strategies.

5. Aquatic Plant Management Stakeholders and Collaborators

Wisconsin's APM activities are conducted by a diverse group of stakeholders and partners, including state agencies, lake associations and districts, non-profit organizations, outdoor sporting groups, private sector service providers and manufacturers, colleges and universities, Native American Tribes, local and federal government, individuals, tourism-related businesses, and others. Department staff work closely with all these stakeholders and partners.

6. Stakeholder Views on Aquatic Plant Management

There is a wide range of perspectives on aquatic plants and how they should be managed. Riparian property owners, recreational boaters, anglers, wildlife enthusiasts, and other stakeholder groups value different aspects of the waterbodies they frequent. These differences often result in conflicting views on what constitutes a successful APM outcome or even the need for APM in the first place.

Stakeholder Interview Process

Individuals representing various APM stakeholder groups in Wisconsin were interviewed. There were three sets of questions: one for stakeholders actively conducting APM activities, one for stakeholders not actively involved in APM, and another for department APM staff. In total, 12 department APM staff and 53 individual stakeholders representing 48 organizations from Wisconsin's lake-rich ecoregions were interviewed. Interviews were conducted between December 2016 and April 2017. Interviewees included representatives from: lake organizations, private APM and consulting companies, county government offices, outdoor sporting groups, tribal entities, a riparian landowner, a boat rental company, and a sailing club.

Interview Findings

Aquatic plant management goals are consistent across stakeholder groups and department APM staff. There is a general desire to "keep lakes natural and healthy." Individuals involved in management are generally aware of how seasonal timing, target species, waterbody characteristics, potential development of herbicide resistance, and concentration and exposure times can influence management. Stakeholders are generally more accepting of APM for non-native than native plants, but perspectives on when APM is warranted differ regardless of whether the target species is native or non-native. There is also variability in how stakeholders consider the negative ecological tradeoffs of APM. Interviewees identified several benefits of, and barriers to, integrated pest management (IPM) implementation.

Suggestions for Improving Aquatic Plant Management in Wisconsin

The predominant areas of the department's APM program that stakeholders identified as needing improvement include staff availability, collaboration and communication with private service providers, public outreach, research efforts and implementation, consistency, grants, and fees.

Other Aquatic Plant Management-Related Concerns

Other topics that arose in the stakeholder interviews included AIS prevention, nutrient reduction, potential policy changes, the general direction and focus of the department's APM program, and ways to address emerging issues such as new AIS and climate change, as well as concerns over current communication and messaging related to Eurasian watermilfoil and common AIS.

7. Current Practices and Research Implications

Aquatic Plants and Beneficial Use Impairment

Perceptions of what constitutes a beneficial use impairment are based on an individual's desired lake use. There is no standardized definition of nuisance or beneficial use impairment that can accommodate differences in stakeholder perceptions and management goals. This, along with physical differences among waterbodies, can lead to inconsistent implementation of APM across the state. There are several potential goals of APM and it is often difficult for stakeholders to agree on common goals. Even when a common goal is agreed upon, expectations of success in management outcomes may differ. The use of consistent terminology for describing different management outcomes or degrees of success may improve communication and consistency in APM implementation.

Management of Non-Native Aquatic Plant Species

Ecological rationale for APM includes, but is not limited to, native species displacement by non-native species, containment of invasive aquatic plants to a given waterbody, and the avoidance of stunted fisheries from overly dense aquatic plant populations. Scientific understanding of non-native species' impacts across the landscape has greatly evolved in the past 10-15 years. The department and others in government, academia, non-profits, and the private sector have worked to communicate the potential for invasive species to cause ecological harm.

Strategies for Managing Non-Native Aquatic Plants

When a new non-native species is detected in a waterbody, rapid responses are often implemented to try to eradicate the new population before it has a chance to spread. If successful, eradication can lead to cost savings. However, at eradication attempts are often unsuccessful. Having an adaptive management plan that identifies how management strategies should evolve after eradication attempts fail can avoid excess spending. Shifting management goals to keeping the plant population below a certain threshold may be more attainable and cost-effective.

Another strategy for addressing a new non-native plant population is to conduct regular monitoring to observe trends in abundance and impacts. Continual monitoring of plant populations can help to determine when management is warranted based on individual site management goals. Successful adaptive APM requires collaboration between permit applicants, service providers, department staff and other stakeholders to appropriately address each management scenario.

Implications of Recent Findings on Herbicide Use in Aquatic Environments

Herbicide treatment is the most commonly employed control technique for APM in Wisconsin. The herbicide's effectiveness on the target species as well as potential non-target impacts is dependent on the herbicide product used and the concentration (C) and exposure time (ET) at which that herbicide is in contact with the plants. Achieving adequate CET in aquatic scenarios can be quite challenging due to wind and water movements. Recent aquatic herbicide research can help guide management decisions regarding target and non-target species, waterbody type, and treatment scale.

There is no single, accepted threshold at which management of aquatic plants should move from a localized, small-scale approach to a large-scale or whole-lake approach. Acceptable impact levels may depend on the target species. Less selective management strategies with greater non-target impacts may be warranted for species that are newer to the region, relatively isolated, and likely to have large adverse ecosystems effects. Management strategies should protect pristine and/or diverse ecosystems.

Hybrid Watermilfoil and Herbicide Resistance

The hybridization of native and non-native milfoil has drawn considerable attention. Recent studies present evidence of herbicide resistance in some hybrid populations. This potential exists for other aquatic plant species as well. Overreliance and repeated use of a single herbicide or mode-of-action is a likely cause of herbicide resistance. Multifaceted control strategies and the incorporation of IPM into management practice can help to reduce the risk of herbicide resistance and maintain the long-term efficacy of APM, leading to future cost-savings. Research on different APM techniques and combinations of techniques could help support the incorporation of IPM into APM. Disseminating new practices will require working with APM stakeholders and recognizing situational and value differences.

Management Planning, Integrated Pest Management, and Adaptive Management

Eradication of invasive species is very rare unless the species is found very early after introduction and the population is small and isolated. Management of Eurasian watermilfoil and curly-leaf pondweed using large-scale herbicide treatments can sometimes greatly reduce the abundance of a target species; however, they are unlikely to completely eradicate the target species and can have substantial effects on non-target native species. Ongoing investment in management is usually necessary to maintain population reductions. Small-scale herbicide management often provides only short-term relief and will necessitate annual input of additional management effort.

The department offers technical assistance and funding for organizations to develop comprehensive surface water management plans. Incorporation of IPM should be included in the planning process for APM, as this is a condition of WPDES permits. IPM can help prevent the development of herbicide resistance, while increasing management success. After plans are approved by the department, organizations become eligible for cost-sharing to implement eligible management strategies. Grants are available for AIS early detection and response, prevention, established population control, and management evaluation activities.

Monitoring allows evaluation of APM efficacy and non-target effects. It is important that data are collected in a standardized and repeatable way before, during, and after management to allow for evaluation of efficacy, longevity, and non-target impacts. Ideally, multiple years of pre- and post-APM data will be collected to account for natural variation and to document recovery over time. Most APM projects, however, occur on waterbodies without pre- and post-management data because of the cost.

Cause for Variation in Management Strategies Statewide

Because each waterbody is unique, management strategies should be tailored and should carefully consider the balance between protection and restoration. Making APM more consistent across the state is challenging due to ecological differences, disturbance history, and social needs.

The Importance of Understanding the Relationship between Aquatic Plants and Water Quality

When developing an APM strategy, it is important to consider the relationship between water quality and aquatic plants. Excessive nutrients in lake sediments, particularly nitrogen and phosphorus, go hand-in-hand with excessive plant growth. Nutrient management can be a key tool in IPM and strategic management. While stakeholders may not view high plant biomass as beneficial, lakes that support a healthy population of aquatic plants can better accommodate additional nutrients.

8. Management Alternatives

Chapter 8 presents a set of potential alternatives to the status quo in APM. These alternatives are based on suggestions made by stakeholder interviewees, reviews of the scientific literature, and additional discussions with APM stakeholders and department staff. Every alternative suggested by stakeholder interviewees is included. The chapter also includes summary tables listing all the alternatives, including whether they would require changes to Wisconsin administrative code and/or statute and references to supporting information. Individual alternatives are grouped into eight broad categories:

- Collaboration
- Department resources and workload
- Public outreach and communications
- Program tracking and evaluation
- Integrating new information
- Consistency in evaluating permit applications
- Grants
- Watershed health, AIS prevention, enforcement, overall emphasis, and other topics

Collaboration

Thirteen alternatives were identified in this category. Stakeholders suggested that the department should increase its commitment to collaboration to help ensure that permitting decisions consider all relevant ecological and socio-economic information, pursue sound science, and maintain positive and fruitful partnerships.

Department Resources and Workload

Ten alternatives were identified in this category. Stakeholders called for more one-on-one interaction, check-ins, shorter permit review times, and reduced turnover among department staff. Department staff reported being overwhelmed with their workloads, which involve balancing APM duties with responsibilities related to other programs.

Public Outreach and Communications

Eight alternatives were identified in this category. Stakeholders have expressed the need for the department to improve the APM program's rapport with the public, to better distribute information on the ecological tradeoffs associated with APM and AIS prevention, to provide better direction on how to navigate the APM process, and to reach out to stakeholder groups not directly involved in permitting.

Program Tracking and Evaluation

Two alternatives were identified in this category. Self-evaluation and self-assessment are integral to organizational success. Without basic knowledge of how the department's APM program is currently operating, it will be difficult to assess how well the program meets its goals in the future. Some examples include the number of permits issued and received, treatment details for each permit and money spent by permittees on APM activities.

Integrating New Information

Eight alternatives were identified in this category. Recent work has led to a better understanding of the efficacy and limitations associated with various APM techniques, potentially leading to substantial cost savings and improved outcomes for natural resources and APM stakeholders. The capacity to support continued evaluation of management efforts has decreased. Stakeholders expressed concerns about an uninformed APM program, including the department's ability to respond to emerging issues such as new AIS and changing climate among others.

Consistency in Evaluating Permit Applications

Seven alternatives were identified in this category. APM permit applications are evaluated by department staff who understand that certain aspects of review the same regardless of the project. At the same time, each lake is unique and permit conditions may be added that address a lake's specific physical, chemical or biological components. Staff consider the system's treatment history, recreational uses, stakeholder goals, and any relevant information on ecological tradeoffs.

Grants

Ten alternatives were identified in this category. The department's surface water grants program is critical to stakeholders actively involved in conducting APM activities. Administrative code revision for the grant program (ch. NR 198, Wis. Admin. Code) is currently underway. While planning for and educating people about all aquatic plants is an eligible activity for all surface water grants, only invasive species are eligible for control grants. There are several ways in which stakeholders have suggested the grants program could be improved or revised.

Watershed Health, AIS Prevention, Enforcement, Overall Emphasis, and Other Topics

Ten alternatives were identified in this category. Several stakeholders suggested APM shift toward approaches which address preventing some of the causes of invasive species and excessive plant growth. Suggestions include improved nutrient management, establishing management classifications for lakes, increasing prevention and enforcement, and changing legal definitions and regulations.

Supplemental Chapters

Aquatic Plant Management in Other States

Programs in seven other states were investigated to provide context for and comparison to Wisconsin's APM program. Information on state APM programs was collected through interviews with agency staff, a multi-state meeting on APM, and review of online program materials. States were generally chosen due to their abundance of water resources and proximity to Wisconsin while others provide contrast to Wisconsin's APM program. All states reviewed have permitting processes for APM activities. Information about the APM programs in these states is summarized in Table S.1-1.

Ecology and Ecosystem Services of Aquatic Plants

The ecology of aquatic ecosystems must be understood to support and protect healthy surface waters. In general, healthy waters have biological communities that are in a natural condition with water that is unpolluted and where human disturbance is low. These waterbodies are often resilient to natural events that affect them and can perform important ecological functions like nutrient cycling, oxygen production, and decomposition. The physical, chemical, and biological environment in a given aquatic ecosystem depends on natural patterns in geology, topography, climate, vegetation, and history.

Wisconsin's Toolbox for Aquatic Plant Management

There are many strategies and tools available to manage aquatic plant communities. Some methods can be selectively applied to a particular species, while others are non-selectively applied to the overall plant community. Many aquatic plant and algae management techniques will have effects on non-target elements of the ecosystem. It is important to balance the benefit of management with any possible ecological, economic, or social costs. Reviews of the most common APM techniques, relevant caveats, and suggestions for appropriate and effective use are included. Lists of susceptible and tolerant plant species are given for many of the management techniques. Only species for which control efficacy has been evaluated using each technique are listed. Other species are likely to be tolerant or susceptible to each management technique. Generally, only plants native to Wisconsin, plants found in states adjacent to Wisconsin, or non-native plants regulated under ch. NR 40, Wis. Admin. Code are included in the discussions of species susceptibility and tolerance.

1. Legal Authority for Aquatic Plant Management in Wisconsin

The Wisconsin Constitution declares that all navigable waters "shall be common highways and forever free" and that the state has jurisdiction over those waters. Derived from the Public Trust Doctrine, Article IX of the Wisconsin State Constitution implies that the state is responsible for maintaining the waterways for all its inhabitants.

Much of this authority and responsibility falls on the Wisconsin Department of Natural Resources (department) and this includes regulating the management of aquatic plants growing in those waters. This authority has evolved over time from the state government directly controlling "aquatic nuisances" in the 1940's and 1950's, to a regulatory program permitting riparian and wetland property owners and their local organizations or governments to manage aquatic plants and other nuisance-causing organisms. Over time the program has become more ecologically focused with an increasing emphasis on protecting ecosystems and controlling invasive plant species. These regulatory powers generally apply to the "Waters of the State" (as defined in s. 281.01 (18), Stats.) which covers all "lakes, bays, rivers, streams, springs, ponds, wells, impounding reservoirs, marshes, watercourses, drainage systems and other ground or surface water, natural or artificial, public or private," within the state or its jurisdiction including territorial portions of Lake Michigan and Lake Superior. The following is a summary and a brief analysis of the general authority and policy for aquatic plant management (APM). Links to complete statutory language and administrative codes can be found in Appendix A.

1.1. Statutory Authority

Historically, the department conducted or was otherwise directly involved in most aquatic plant management and drew its authority from s. 281.17 (2), Stats.:

> "The department shall supervise chemical treatment of waters for the suppression of nuisance-producing organisms that are not regulated by the program established under s. 23.24 (2), Stats. It may purchase equipment and may make a charge for the use of the same and for materials furnished, together with a per diem charge for any services performed in such work. The charge shall be sufficient to reimburse the department for the use of the equipment, the actual cost of materials furnished, and the actual cost of the services rendered."

Today, the department conducts APM with additional authority from s. 23.24 (2), Stats., which requires the department to:

1. Implement efforts to protect and develop diverse and stable communities of native aquatic plants (s. 23.24 (2) (a) 1)
2. Regulate how aquatic plants are managed (s. 23.24 (2) (a) 2)
3. Administer and establish by rule procedures and requirements for the issuing of aquatic plant management permits (s. 23.24 (2) (a) 4)

Section 23.24, Stats., also requires the department to identify Eurasian watermilfoil (*Myriophyllum spicatum*), curly-leaf pondweed (*Potamogeton crispus*), and purple loosestrife (*Lythrum salicaria*) as invasive species and prohibits their distribution by any person(s). The department can add other species to the list by rule if the species has the ability to cause significant adverse change to desirable aquatic habitat, to significantly displace desirable aquatic vegetation, or to reduce the yield of products produced by aquaculture. Drawing on this and other authorities for species classification, including s. 23.22, Stats., the department promulgated ch. NR 40, Wis. Admin. Code, "Invasive Species Identification, Classification, and Control" in 2009, which established a comprehensive regulatory system for listing invasive species that includes many other non-native aquatic plants and algae (see Chapter 1.3).

According to s. 23.24, Stats., the scope of management activities that may be regulated under an APM permit include the quantity, species, area, methods, and timing of management. The scope of activities needing a permit include anyone seeking to:

1. Introduce non-native aquatic plants into waters of this state (s. 23.24 (3) (a) 1)
2. Manually remove aquatic plants from navigable waters (s. 23.24 (3) (a) 2)
3. Control aquatic plants in waters of this state by the use of chemicals (s. 23.24 (3) (a) 3)
4. Control aquatic plants in navigable waters by introducing biological agents, by using a process that involves dewatering, desiccation, burning, freezing, or by using mechanical means (s. 23.24 (3) (a) 4)

Section 23.24, Stats., allows the department to require a department-approved plan for how aquatic plants will be managed as part of an application for a permit, and also provides the department with rule authority to set fees for permits. Section 23.24 (4), Stats. contains limited exemptions from the permit requirement and authorizes the department to create rules to waive the permit requirement in other limited instances. Section 23.24 (5), Stats. contains penalties for introducing or controlling aquatic plants without a permit and for distributing invasive aquatic plants.

1.2. Administrative Rules

The statutes are implemented under two sets of rules: ch. NR 107, Wis. Admin. Code, "Aquatic Plant Management" and ch. NR 109, Wis. Admin. Code**, "**Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations." Chapter NR 107 was repealed and recreated in 1989 following the completion of an Environmental Assessment that was developed to guide the program through changing perspectives and laws on the use of chemicals for APM, an outgrowth of the National Environmental Policy Act (NEPA) and Federal Insecticide, Fungicide and Rodenticide Act (FIFRA), and growing environmental awareness. Chapter NR 107 has changed little since promulgation. Chapter NR 109 was promulgated in 2003 in response to changes made to s. 23, Stats., and other statutes relating to aquatic plants that expanded the scope of the law regarding invasive species. There was intent to merge both codes into one set of APM policies but that was never fully initiated.

Chapter NR 107 establishes procedures and requirements for permitting the use of chemicals for the management of aquatic plants and control of other aquatic nuisance-causing organisms. It sets forth the requirements of an application and the standards for approving and denying a permit, codifies exemptions and establishes a fee schedule. The purpose highlights that a "balanced aquatic plant community is recognized to be a vital and necessary component of a healthy aquatic ecosystem" and allows for the management of "nuisance-causing" aquatic plants in a manner consistent with sound ecosystem management and where the loss of ecological values is minimized. All chemical herbicides sold and used in Wisconsin must be registered and labeled by the U.S. Environmental Protection Agency (EPA) and licensed by the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP). While DATCP does not have any specific regulations on the sales of aquatic herbicides, sales of any pesticide in Wisconsin must comply with the general requirements in s. ATCP 29.41, Wis. Admin Code. There are no currently registered aquatic herbicides that are listed as restricted use pesticides (RUPs) which would require certification to purchase. Chemical applications must be conducted by an applicator certified by DATCP (with some limited exceptions).

Chapter NR 107 also directs that high value plant species be protected from adverse, long–term or permanent changes when chemical treatments are conducted and s. NR 107.08 (4) lists a dozen species that are known to offer these important values. Treatments over 10 acres in size or greater than 10% of the area of the waterbody that is 10 feet or less in depth are defined as "large-scale". Treatments that fall below these criteria are generally described as "small-scale". Additional information about the waterbody being treated, as well as evidence that the public has been notified of the proposed treatment, is required as part of the permit application for large-scale treatments. Treatments within a lake or reservoir are identified as being allowed for areas up to 150 feet from shore along developed shorelines, public parks, or areas beyond 150 feet in navigation lanes.

Chapter NR 109 establishes procedures and requirements for issuing APM permits for other non-chemical management activities, including: introduction of aquatic plants, manual removal, burning, and use of mechanical control or plant inhibitors. It has the same general purpose as ch. NR 107 in that it recognizes the value of native aquatic plants to a healthy ecosystem, but ch. NR 109 adds that management will also be conducted in "a manner consistent with sound ecosystem management, shall consider cumulative impacts, and shall minimize the loss of ecological values in the body of water." It also implemented amendments to s. 30.07, Stats., that prohibited the launching of watercraft or placement of equipment with attached aquatic plants or zebra mussels (*Dreissena polymorpha*) by expressly including equipment used in APM. The prohibitions of s. 30.07, Stats. have been complemented in ch. NR 40, Wis. Admin Code, which includes regulations related to the transport of all invasive species, the removal of aquatic plants and animals from boats and equipment, and the draining of water from boats and equipment.

Procedures and requirements for ch. NR 109 permits are very similar to those of ch. NR 107, including the intent to protect the same dozen high value plant species. Nuances include requirements to follow stipulations incorporated by *Lac Courte Oreilles v. Wisconsin*, protecting wild rice (*Zizania palustris*) within the Ceded Territory which encompasses approximately the northern third of Wisconsin. Chapter NR 109 does not use the vague terminology to control "nuisance-causing plants", instead using the more specific phrase "impairment of beneficial water use activities" which are defined as, "angling, boating, swimming or other navigational or recreational water use activity." Hereafter, the situation in which aquatic plants impair beneficial water use activities is referred to as "beneficial use impairments."

Chapter NR 109 also allows for the department to require a plan as an application requirement for an enforceable part of a permit and identifies the elements that must be included in a plan to be approvable. The term invasive species is first used in ch. NR 109, codifying the aforementioned changes in aquatic plant laws. Along with s. 23.24, Stats, ch. NR 109 also designates Eurasian watermilfoil, curly-leaf pondweed, and purple loosestrife as invasive, though this has little relation to the rest of the rule.

Control of other aquatic organisms are permitted through the APM program such as mosquitos, aquatic insects, and rough fish. If the product applied for control is a pesticide, the permit is processed through ch. NR 107. If the product applied is a growth inhibitor (e.g., alum, dyes, or lime), it is processed through ch. NR 109.

Only NR 109 includes a specific provision for enforcement which references the Department's general authorities under s. 23, 30 and 31, Stats.

Department Manual Code 3261 "Procedures for Processing Permits for Aquatic Plant Management for Non-DNR Projects at Regional Offices" establishes staff roles and responsibilities in administering ch. NR 107. However, this manual code has only been updated once in 2008 since it was originally created in 1994.

1.3. Related Authority and Policy

In 2009, DNR promulgated ch. NR 40, Wis. Admin. Code, "Invasive Species Identification, Classification, and Control" using s. 23.22 (2) (a), Stats., and other authorities. It classifies non-native terrestrial and aquatic invasive species as either prohibited or restricted with the intention to assist in the management of these species, including control, prevention, information and education, and grant funding. The ch. NR 40 rule overlaps into the transportation of invasive species provisions of ch. NR 109, but is much more comprehensive. The three invasive species identified in ch. NR 109 are considered "restricted" under ch. NR 40, meaning they are established in the state and containment and control, as opposed to eradication, are the statewide objectives of management. However, local eradication may be an acceptable goal if the species is new to a waterbody and has a spatially limited population.

Part of the invasive species program enabled in the early 2000's under s. 23, Stats., included a cost-sharing grant program for the control of aquatic invasive species (AIS). This program has a $4 million annual appropriation and is implemented through ch. NR 198, Wis. Admin. Code, "Aquatic Invasive Species Prevention and Control Grants." Though it does not impact the authority of APM permitting, it does impact aquatic plant management statewide by financially incentivizing local organizations and governments to conduct projects to control aquatic invasive plant species, putting the department in both the role of regulator and financier of APM in some instances. Previously limited by local funds the advent of generous state cost-sharing, up to 75% for the cost of a project, dramatically increased the magnitude and frequency at which APM can take place. Grant funds are split more or less evenly between prevention and control activities and may also be used for the development of management plans.

Federally, APM activities utilizing pesticides fall within the jurisdiction of the U.S. EPA under the FIFRA and the Clean Water Act. FIFRA requires the registration of pesticides, establishes record-keeping requirements, and provides for delegation, state cooperation, aid, and training. In Wisconsin, DATCP is the delegated authority, registering pesticides, and training and certifying chemical applicators under ch. ATCP 29, Wis. Admin. Code. The department works cooperatively with DATCP on treatment supervisions, record retention, and enforcement.

In 2010, the U.S. Supreme Court declined the industry's request to review the Sixth Circuit Court of Appeal's decision in *The National Cotton Council of America, et al. v. EPA*, upholding the lower court's determination that pesticides should be regulated as a pollutant and their application to surface waters subject to regulation under the Clean Water Act requiring a National Pollution Discharge Elimination System (NPDES) permit. Under Wisconsin's delegated authority, this decision meant that most applications in public waters also required a Wisconsin Pollution Discharge Elimination System (WPDES) permit. Soon after this decision, the department developed a WPDES general permit that is issued concurrently with a ch. NR 107 permit to provide statewide coverage for individual applicators. A WPDES permit is required for all open water herbicide treatments (however, private ponds are exempt from some provisions of the WPDES general permit). Under ch. NR 102, Wis. Admin. Code, "Water Quality Standards for Wisconsin Surface Waters", the WPDES general permit does not cover discharges to "Outstanding Resource Waters" or "Exceptional Resource Waters"; an individual permit is needed for chemical APM in these waters. The general permit does not cover activities that conflict with wetland protection requirements according to ch. NR 103, Wis. Admin. Code, "Water Quality Standards for Wetlands."

One of the conditions of the WPDES permit directs applicants to apply herbicides following Integrated Pest Management (IPM) principles. The U.S. EPA defines IPM as "an effective and environmentally sensitive approach to pest management that relies on a combination of common-sense practices. IPM programs use current, comprehensive information on the life cycles of pests and their interaction with the environment. This information, in combination with available pest control methods, is used to manage pest damage by the most economical means, and with the least possible hazard to people, property, and the environment."

Additionally, some non-chemical APM activities are regulated by the Waterways and Wetlands Section of the department, under ch. 30, Stats.

To assist the public in understanding and complying with aquatic plant management laws and rules, numerous informational and education publications and fact sheets have been developed, most with the assistance of University of Wisconsin's Extension program. Appendix F contains a listing of the most recent and commonly used resources.

1.4. Wild Rice

As an important social, cultural, and ecological resource, wild rice (*Zizania palustris*) is one of the few plants that has specific statutory protection. Section 29.607, Stats. regulates the harvesting of wild rice seeds in order to prevent overharvesting. Under NR 19.09 (1) (b), the department may only approve the removal of wild rice plants if the overall wild rice resource in a lake will not be substantially affected and only when removal is necessary to allow access to the lake by a riparian property owner.

In addition, there are specific legal requirements related to wild rice and the six Chippewa Bands within the Ceded Territory, encompassing approximately the northern third of Wisconsin. As part of a 1989 settlement in *Lac Courte Oreilles v. Wisconsin*, a Stipulation for Wild Rice requires that the department consult with the Voigt Task Force, representing the Chippewa, before taking any action that may reasonably be expected to impact wild rice abundance or habitat. For projects located on or near wild rice waters, documentation must be reviewed to determine whether impacts may occur. As a result, a process was developed for working with the Chippewa on proposed projects, including APM, that could potentially impact wild rice and to determine when consultation is required.

The department is conducting a strategic analysis on wild rice management in the state. For more information see https://dnr.wi.gov/topic/EIA/WRMSA.html.

1.5. Discussion

The evolution of aquatic plant management and aquatic plant law has surpassed some of the provisions of the current rules, potentially leading to the application of outdated requirements and approaches for effective management. This transformation seeks an approach that aims to be more comprehensive, involving strategic invasive species management and integrated pest management. However, previous management approaches embedded in ch. NR 107 that only envision small treatments to shoreland areas and navigational lanes can limit better management techniques that consider the broader ecosystem and long-term management goals. For example, the restrictions to shoreland and limited treatment areas for nuisance relief run counter to large-scale or regionwide control options that may be required for effectively managing a population of an invasive plant. Also, management intervention may be warranted before an invasive plant becomes a nuisance or causes a use impairment. Determination of a nuisance is subjective and therefore leads to difficulty making consistent permit decisions across varying conditions statewide. The newer terminology in ch. NR 109, “impairment of beneficial water use activities” may be as subjective as the language related to ‘nuisance’. In addition, the classification and listing of invasive species and the resulting regulations in ch. NR 40 are much more comprehensive than the provisions of ch. NR 109. Future APM policy will need to more completely incorporate the policies of ch. NR 40. Regardless, any future rewrite of APM policy will need to address these and other dualities, incorporate the superseding aspects of ch. NR 40, and establish a clear link to the grant program in ch. NR 198 as well.

One of the most significant changes in recent years was the introduction of planning activities to the aquatic plant management program. This was supported by enhanced monitoring technology and the adaption of standardized monitoring methods (i.e., Hauxwell et al. 2010) to evaluate efficacy and non-target impacts. Over time, aquatic plant managers in the public and private sectors, along with lake organizations, have accepted planning as a valuable component of good aquatic plant management, giving rise to expanded expertise in the private sector to help fill this niche. Planning for water quality improvement now runs parallel to aquatic plant management planning in many of the state's more heavily used waterbodies, leading to more holistic or comprehensive approaches than traditional nuisance control. The integration of watersheds and the focus on the whole ecosystem creates a foundation for future APM policy to continue to evolve. Implementing IPM into the broader activities of waterbody protection and improvement is a component of effective APM.

The AIS grant program established under ch. NR 198 has subsidized not only the increased scale of control but also expanded APM planning and evaluation activities. Within the last decade, the increased emphasis on management evaluation has led to a greater understanding of the use of chemicals and their efficacy and selectivity in aquatic plant control. Much of this strategic analysis draws from recently gained knowledge and strives to relate it so that it can be used in future improvements to APM policy and management. It is important that the department continues to collaborate with partners on planning, monitoring and evaluation and adapt the results into effective management approaches and related regulations.

2. Aquatic Plant Management in Wisconsin – Past and Present

The recognition of excessive plant growth as a management problem is not new. Indeed, excessive plant and algae growth was reported in urban areas as early as the mid-1850's. Only more recently have aquatic plants and algae been recognized as vital components of aquatic ecosystems, providing essential habitat and food resources for fish and wildlife populations that ultimately affect multi-billion-dollar sport fish, hunting, and tourism industries. However, when aquatic plants and algae respond to excess nutrient inputs, natural fluctuations, or are invasive species, their density and frequency can become problematic for some recreational uses. In some cases, fish, wildlife, property values, and even human health are affected. As the view of aquatic plants has changed over time from being strictly a nuisance to that of a natural resource that requires management, the department has increasingly worked in partnership with other state agencies, tribal governments, academia, industry, municipalities, lake associations, sporting clubs, and other enthusiasts to balance the needs of the ecosystem with a range of public concerns and expectations for the waterbodies of the state.

2.1. History of Aquatic Herbicide Use

In the early 1900's, aquatic plant management (APM) was primarily conducted by cities and counties to alleviate nuisance plant and algae populations caused by pollution that occurred prior to the development of wastewater treatment technology. Municipal raw sewage discharges caused odiferous algae blooms that plagued urban areas. Early on, plants and algae caused taste and odor problems for ice cut in the winter to be used for summer refrigeration and consumption. Wisconsin's long history of managing aquatic plant communities with herbicides began with harsh chemicals, such as copper- or arsenic-based compounds, which are now banned or usage greatly restricted.

In 1918, the City of Madison began using copper sulfate to control excessive algae blooms. By 1925, the City was using copper to reduce algae populations throughout Lake Monona. In 1926, the City began using sodium arsenite for aquatic plant control. Soon many lakes were being treated to control aquatic plants and algae. For example, in 1938, shortly after Lake Nepco (Wood County) was created by damming the Four-mile Creek, greater than 100 acres of the lake was treated with copper sulfate. The large-scale application of this heavy metal-containing chemical was considered good aquatic plant management practice at the time, while it is now classified as 'highly toxic' by the U.S. EPA and is known to persist in the environment.

In a few rare cases, treatments were conducted in cooperation with partners; for example, the Lake Nepco treatment occurred in collaboration with the Nekoosa Edwards Paper Company, the Wood County Board, Wood County Park Commission, and the Water Regulatory Board of Wisconsin. However, the vast majority of chemical treatments were not regulated, and few records exist of the amount of chemical used, much less its efficacy or impacts to other organisms.

The growing demand for aquatic plant and algae control and concomitant concern about the adverse effects of these treatments expressed by outdoor sporting groups led to Governor La Follette's 1938 executive order establishing an interdepartmental Aquatic Nuisance Control subcommittee, under the

Committee for Water Pollution Control. The subcommittee was to review the problem of aquatic plant and algae control in Wisconsin waters to resolve the technical difficulties and society's concern with chemical controls. The subcommittee's work resulted in the development of a permit system to regulate aquatic plant and algal control activities for the first time in Wisconsin's history. The Committee for Water Pollution Control later became part of the Wisconsin Conservation Department, which in 1968 became the present-day Wisconsin Department of Natural Resources.

In 1941, the Wisconsin legislature passed an act that authorized the Committee for Water Pollution Control to supervise chemical treatment of waters for the suppression of algae, aquatic plants, schistosomes (the parasites that cause swimmer's itch), and other nuisances. This act also gave the Committee authority to buy management equipment, lease that equipment to sponsors, and charge customers for aquatic plant management services. Demands on the Committee for leased management equipment quickly surpassed the supply, and by 1949 the leasing of state equipment ceased.

By 1950, treatments of algae or aquatic plants were permitted in over 100 lakes in Wisconsin. Most of these treatments occurred in southeastern Wisconsin near major population centers, although some northern lake treatments were permitted as well. Inorganic compounds remained the most popular treatments used. Copper- and arsenic-based products were the primary pesticides applied to control plants, algae, and snails. From 1950 through 1969, copper sulphate and sodium arsenite treatments were permitted in 129 and 167 lakes, respectively. Over this 20-year period, 1,585,094 pounds of copper sulphate for algae control and 2,010,332 pounds of sodium arsenite for plant control (about 1,145,889 lbs. of arsenic) were reportedly applied (Figure 2.1; Lueschow 1972). Because pesticides with arsenic (or arsenite) as the active ingredient do not deteriorate and instead accumulate in the environment, they were prohibited in Wisconsin in 1969. Arsenical pesticides can remain in sediments for decades or even centuries, affecting the ecosystem for a very long time (WDNR 2014). For waterbodies which were historically treated with sodium arsenite, sediment removed during dredging should be chemically tested to determine whether the sediment is hazardous waste, and how it should be handled with respect to human and ecological health. Prolonged use of any active ingredient that does not deteriorate (e.g., copper, chromium, etc.) is likely to lead to similar sediment toxicity.

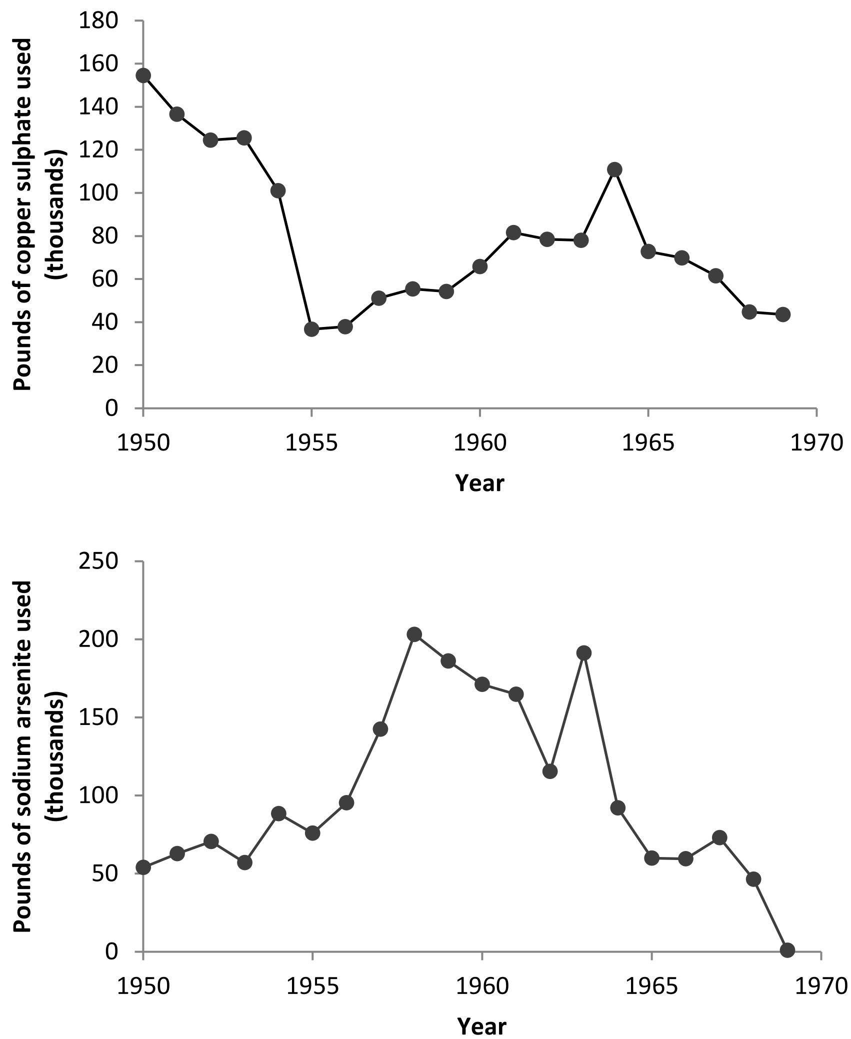


Figure 2.1. Copper sulphate and sodium arsenite use for APM in Wisconsin lakes (1950-1969).

Note: A total of over 1.5 and 2 million pounds of copper sulphate and sodium arsenite, respectively, were applied to these lakes during this period. The use of copper- or arsenic-based compounds for APM has since been prohibited or greatly restricted in Wisconsin.

The time period of 1969 to the 1980's saw an increase in the availability and use of organic-chemical pesticides in Wisconsin, although copper was still in use. The common names of some of these products are: 2,4-D, endothall, glyphosate, and triclopyr. These organic herbicides became recognized as effective tools for aquatic nuisance control and are still widely used to manage aquatic plants and algae. The number of different pesticide formulations for aquatic plant management has continued to increase over the last two decades (Table 2-1). Technological advances combined with the demand for herbicides, and the growing industry formed around aquatic plant management have led to more options for chemical control.

Table 2-1. Dates of U.S. EPA approval for pesticides employed in APM.

Common Name	Original Year of EPA Approval
2,4-D	1946
Endothall	1968
Glyphosate	1974
Triclopyr	1979
Bti*	1983
Diquat	1986
Fluridone	1986
Bsp*	1991
Sodium carbonate peroxyhydrate	2002
Imazapyr	2003
Imazamox	2008
Penoxsulam	2009
Flumioxazin	2010
Bispyribac sodium	2011
Florpyrauxifen-benzyl	2017

* These pesticides are used for controlling insect populations rather than APM.

The number of APM permits sought and issued has increased over time (Figure 2.2). In 1986, 347 APM permits were issued for herbicide treatment of private and non-private waterbodies throughout the state (WDNR 1988), while 1,717 chemical and non-chemical permits were issued in 2018. There are several factors that have likely contributed to the increase in permits over time, including increases in riparian development and recreational activities, types of herbicides available, regulation of non-chemical APM activities, and the emergence and spread of invasive species.

In the last ten years, the increasing trend in permit numbers appears to have been largely driven by APM in private ponds. This could be due to an increase in the number of private pond owners conducting chemical and non-chemical APM activities or increased compliance by private pond owners who were previously unaware an APM permit was needed for aquatic plant and algae management activities. The department has been able to gain compliance by private pond owners primarily through education and outreach, and by working with non-profit and private industry partners, requiring only minor enforcement actions. While private ponds are considered waters of the state, private pond permits are likely for management at smaller localized scales and the department recognizes there is less public interest in APM on private ponds.

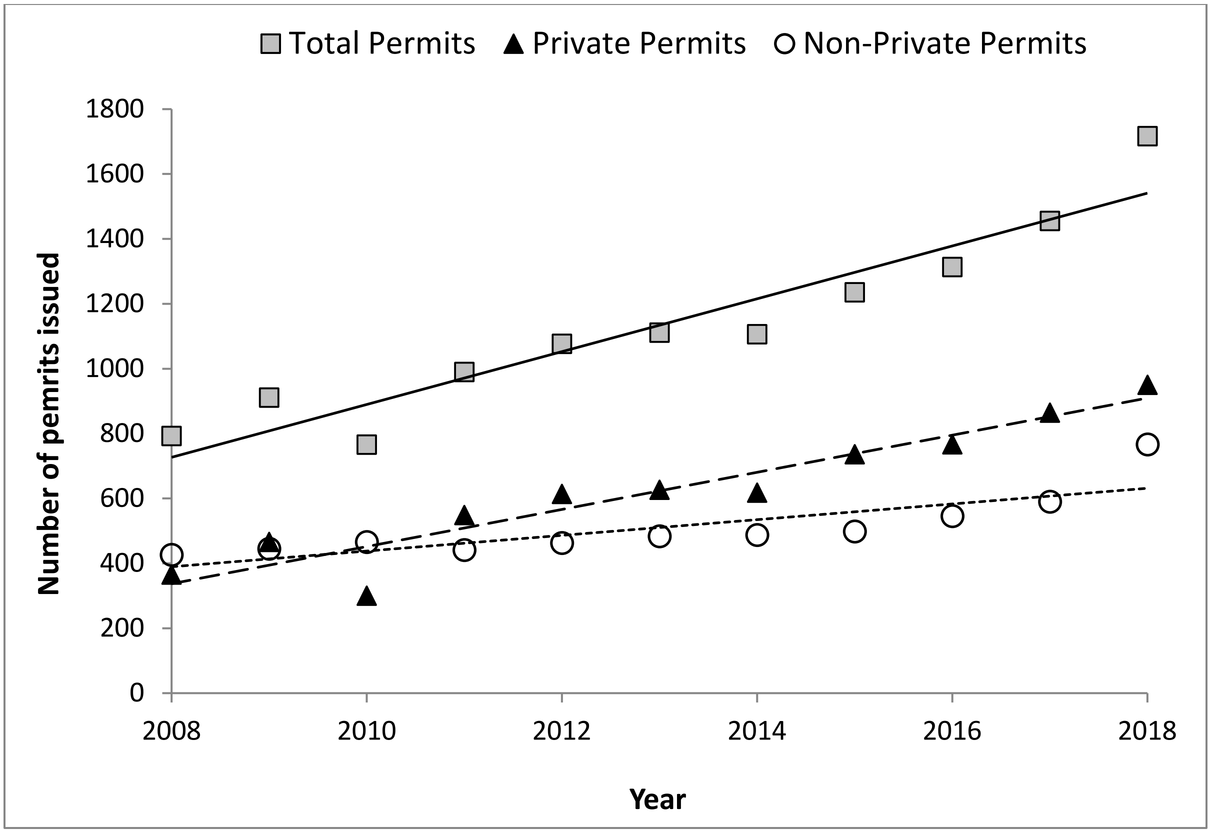


Figure 2.2. Department issued ch. NR 107 and ch. NR 109 permits (2008-2018).

Note: Private permits refer to permits for private ponds and non-private permits apply to all permits other than those for private ponds. The department began to collect permit information in a central database in 2008.

There also appears to have been an increasing trend in the total acreage where chemical and non-chemical management has occurred over the past 10 years (Figure 2.3). Several factors could be contributing to this trend. A department lead statewide effort to treat non-native phragmites (*Phragmites australis* subsp. *australis*) in 2015 resulted in a dramatic spike in acres managed in that year; this point in Figure 2.3 is an outlier which skews the trendline upward. Second, the increasing trend in total number of permits (described in Figure 2.2) should, logically, be correlated with an increase in acres managed over time. Additionally, a shift in the department's APM program toward more strategic management may also be contributing to the increasing trend in acres managed, as some management strategies may benefit from large-scale APM activities, as described in Chapter 6 of this strategic analysis.

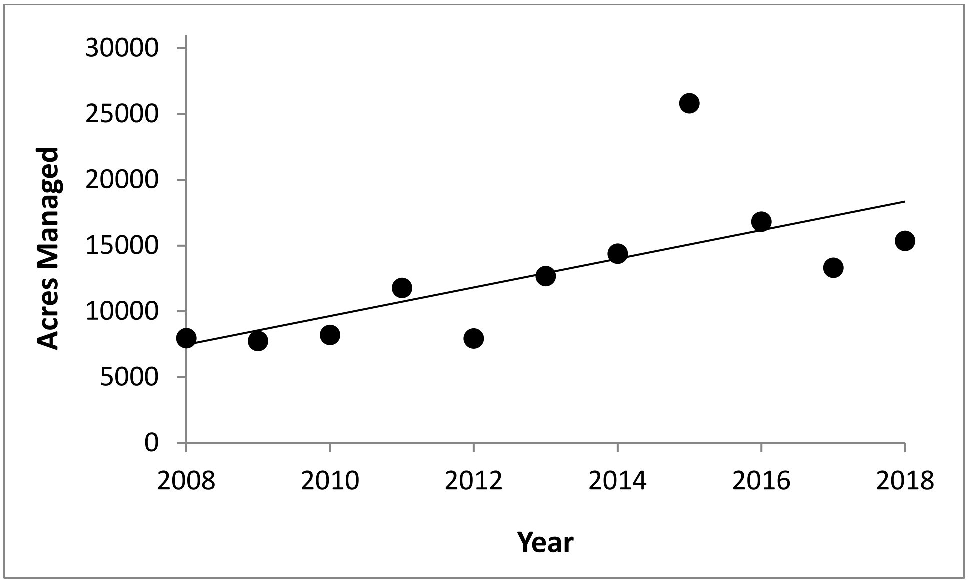
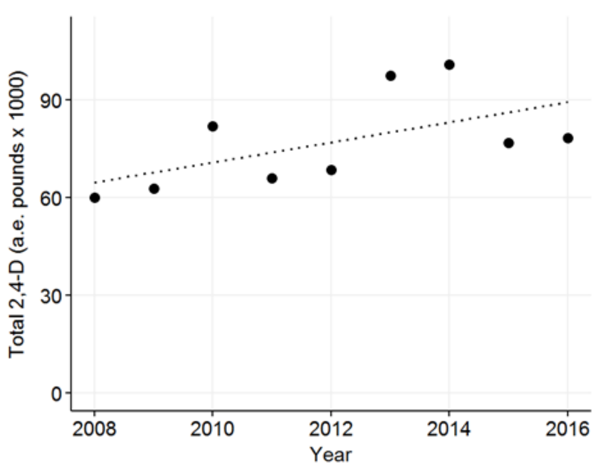


Figure 2.3. Acres of department approved chemical and non-chemical management (2008-2018).

Note: The spike in 2015 is attributed to the large-scale treatment of non-native phragmites (*Phragmites australis* subsp. *australis*) near the shores of Lake Michigan, for which the department was the applicant. Over 15,000 acres of non-native phragmites were treated in an attempt to restore native vegetation.

2,4-D is the most frequently used herbicide for management of submersed aquatic plants in Wisconsin. The total number of waterbody acres treated with 2,4-D has remained relatively constant over time, but the total amount of active ingredient applied has increased (Figure 2.4). In addition, the average percentage of each waterbody treated has increased from approximately 7 to 10% since 2008 (Figure 2.5). These findings indicate that on average, across the state, treatment size relative to lake size is increasing as 2,4-D treatments are being conducted on more smaller waterbodies.

a.



b.

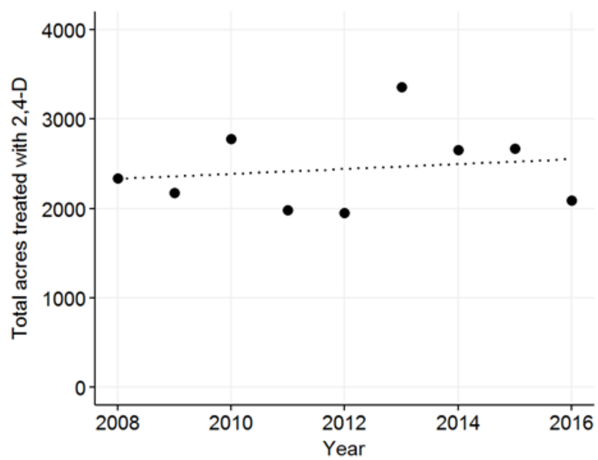


Figure 2.4. Amount (a) and acreage (b) of 2,4-D applied to Wisconsin waterbodies (2008-2016).

Note: Based on maximum reported acreage treated per waterbody.

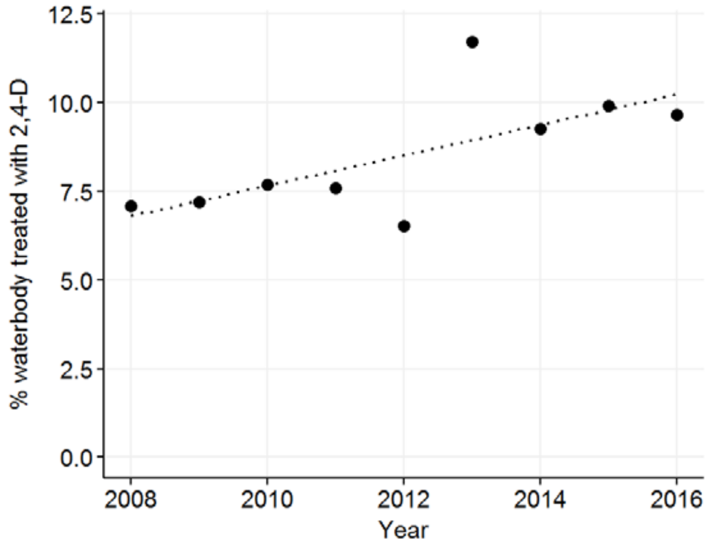


Figure 2.5. Growth in the scale of APM treatments with 2,4-D in Wisconsin (2008-2016).
Note: Reported here is the mean percentage of lake surface treated per waterbody.

2.2. Non-Chemical Approaches and Integrated Pest Management

There are many APM techniques other than herbicide application that have played a part in the evolution of APM in Wisconsin. In the early 1970's, mechanical harvesting started to become a more popular management tool for nuisance aquatic plant control. As manufacturing of aquatic plant harvesters in Wisconsin increased, so did availability and use. Lake groups and municipalities took advantage of the immediate and apparent reductions in nuisance populations afforded by mechanical harvesting. As the number of management methods diversified, some people recognized the benefits of combining multiple control methods to achieve management goals. A brief discussion of the history of non-chemical APM follows, while technical information on the use of the most commonly employed APM approaches can be found in Supplemental Chapter S.3 of this strategic analysis.

In 1977, Chapter 274 lead to the creation of the Wisconsin Waterways Commission (WWC). The Commission is comprised of five members, with each member covering a specific geographic area of the state and acting as a resource for knowledge about their respective area's water recreation issues. The Commission may fund studies to determine the need for recreational boating facilities, approve financial aid to local governments for recreational boating projects (including the acquisition of aquatic plant harvesters), and recommend administrative rules for the recreational facilities boating program. One of the first APM activities supported by the WWC was mechanical harvesting. The WWC assisted many municipalities with the purchase of harvesters such that by the mid 1980's, about 75 lakes had harvesting programs.

In additional to mechanical harvesters, there are other mechanical devices for APM. For example, unsupervised mechanical harvesters, such as those that mount to piers or roll along the lake bed use repetitive motion to erode or remove plants. Although these devices may be permitted, they pose greater risk for harming non-target organisms. When rollers run over the lake bed, they compact sediment, kill macroinvertebrates, destroy fish spawning beds, and/or restrict navigation. Thus, devices of this nature are often reviewed by the Waterways and Wetlands Section for ch. 30, Stats. compliance. Similar devices that attach to a pier and do not rest on the lakebed may be eligible for ch. 30 General Permits if the local APM coordinator approves.

Recognizing that aquatic plant species respond differently to different stressors, resource managers and researchers in the 1980's found that water-level fluctuation is another APM approach that could be used to encourage beneficial aquatic plant growth and even aid in restoration of native aquatic plant communities. Large pools of the Mississippi River were managed by manipulating water levels to encourage water celery (*Vallisneria americana*) growth to increase food sources for waterfowl. Other water-level manipulations were conducted to decrease aquatic plants that favor vegetative fragmentation as a means of spreading, such as coontail (*Ceratophyllum demersum*) and the invasive species Eurasian watermilfoil (*Myriophyllum spicatum*). Generally, species that spread chiefly by vegetative means decrease in density and frequency following water-level manipulations, especially when these plants are thoroughly desiccated and frozen during winter drawdowns. Since the 2010's, water-level manipulation has become more common as a large-scale management tool to shift entire aquatic plant communities towards higher-value species.

Diver Assisted Suction Harvesting (DASH) has more recently become a popular method of control for aquatic invasive plant populations that may be too small to be effectively controlled by other chemical or mechanical means. DASH utilizes divers to physically uproot and remove aquatic invasive vegetation from a waterbody. Instead of a diver or snorkeler coming to the surface to dispose of invasive plants, the entire plant is hand fed from the diver's hands into a vacuum hose that transports the plant to the surface. At the surface the plant is captured in holding bins or bags and then properly disposed of. DASH can be more selective and reduce invasive species spread relative to other approaches if only the target plant is removed, and all fragments are collected, though research is needed on the efficacy, selectivity, and costs of this approach. There are several companies in Wisconsin and surrounding states that offer these services. Some lake groups have integrated this method with other control options and some have even built their own DASH units.

Beginning in the 1990's, Wisconsin's APM Program has also utilized biological organisms (biocontrol) to manage a select few species. Biological controls are used worldwide, though the use of biocontrol agents that are not native to the ecosystem in which they are used can sometimes cause more harm than good. For example, due to their harmful non-target impacts on lake ecology, the use of grass carp (or white amur; *Ctenopharyngodon idella*) has been illegal in Wisconsin since the 1970's. Grass carp can decimate plant populations, but also resuspend sediments, elevate nutrient levels, and can generate algal blooms. However, the use of grass carp is still permitted in some neighboring states and since these fish have been known to migrate over 1,000 miles, they still pose some risk to Wisconsin despite statewide regulation.

In Wisconsin, rigorous testing must be completed before any method of biocontrol is used. A good example in the APM Program is the use of *Galerucella* beetles to control invasive purple loosestrife (*Lythrum salicaria*). These beetles are native to Europe, where purple loosestrife originates, and in their native environment, the species keep each other's populations well balanced. After very careful long-term testing it was found that the *Galerucella* beetles only feed on purple loosestrife and will not survive without the plant. Unlike the multi-colored Asian lady beetles introduced in the south to control aphids in fruit tree orchards, *Galerucella* beetles will not reproduce to nuisance population sizes. As such, since 1994, the department has built a very successful program that utilizes *Galerucella* beetles to control invasive purple loosestrife in Wisconsin.

Other organisms, such as the native watermilfoil weevil (*Euhrychiopsis lecontei*) are being studied as a potential management tool to control Eurasian watermilfoil. For the past two decades, numerous studies have been conducted but there are few conclusive results regarding the weevil's efficacy. Research continues to evaluate what environmental conditions are needed to support or augment weevil populations for their use as a viable management option.

The promulgation of ch. NR 109, Wis. Admin. Code, in 2003, required nearly all plant control methods to go through a permitting process. In response to stories of the unintended consequences of APM activities (like those associated with grass carp), one of the goals of ch. NR 109 was to regulate further APM activities to reduce the risk of negative outcomes. The ability to regulate APM actions allows managers to support the implementation of various management techniques, which is consistent with the concepts of integrated pest management (IPM) as well as required by Wisconsin Pollution Discharge Elimination System (WPDES) permits.

Integrated pest management is essentially a science-based decision-making process that combines diverse treatment approaches, frequent monitoring, and adaptive strategies. IPM is intended to ensure the efficacy of management over the long-term while ensuring the lowest-possible risk to beneficial ecological functions. Decisions are informed by thorough planning and monitoring efforts, during which all permissible plant management techniques are considered based on their potential to control target plant species while reducing non-target impacts and risks to human health and the environment. Lake management or APM plans can use IPM approaches, and good plans can pave the way for science-based management for years to come. Once a plan is formally adopted by the applicant and approved by the department, implementation is guided through the requisite permitting process. Chapter NR 109 allows the department to write multi-year permits when the permitted actions follow and approved plan.

While an IPM strategy is being employed in Wisconsin in the sense that permitees must consider use of a range of possible aquatic plant control techniques during the decision-making process, further research on the efficacy of different techniques and combinations of techniques across a range of ecological conditions is critical for successful incorporation of IPM into APM practice. For example, studies have evaluated the efficacy of combining chemical and non-chemical approaches for control of starry stonewort (*Nitellopsis obtusa*; Glisson et al. 2018). Another study examined the compatibility of an insect, a fungus, and the herbicide imazamox for hydrilla (*Hydrilla verticillata*) control (Cuda et al.

2016). More studies evaluating non-chemical plant control techniques, combinations of non-chemical techniques, chemical and non-chemical techniques, and rotations of different types of herbicides under a variety of ecological conditions could provide APM professionals with a broader range of management options that have been shown to be successful.

2.3. DNR Staff Workload

The APM "program" is staffed statewide by a combination of full-time and limited-time employees (FTEs and LTEs). Work activity is highly seasonal and varies considerably across regions of the state. 'APM permitting' and 'APM planning' (i.e., activities associated with management planning, evaluation, and technical assistance) are the two main activities department staff use to record time spent on APM-related activities.

A 2015-16 department-wide work effort analysis determined that the equivalent of approximately 6 staff (FTE and LTE combined) are used to run the program. This analysis did not include other work activities related to APM such as staff time spent on the review and administration of AIS Prevention and Control Grants. Despite an increase in the number of APM permits processed, that level of staffing has remained consistent from 2012 to present. It should be noted that beginning in 2014 the department began moving to centralized permit in-take and electronic permitting that has likely improved efficiency.

APM program revenue is collected from the permit application and acreage fees paid by the permit applicants. Fees range from $20 for a private pond to maximum of $1,270 for a lake treatment exceeding 50 acres in size. APM fees are distributed to support LTE assistance to the Districts or Central Office, allocated roughly proportional to the number of permits received. Concurrent with the increased number of permits processed, revenue increased by 40% from FY 2012 to FY 2016 ($105,250 to $147,465, respectively).

The regulated community has registered concerns citing a desire for additional professional full-time staff to run the APM program (see Chapter 6 and Appendix E). When the department shifts its focus to restructuring the APM program, a more accurate and current work effort and revenue analysis should be conducted to ensure the new program is "right-sized" and adequately staffed.

2.4. Strategic Management and Research

The department and its partners recognize that maintaining a healthy aquatic plant community and controlling AIS can be achieved more effectively through strategic management and planning, as opposed to the historical nuisance control approach described in Chapter 2.1. Active management conducted using science-based decision-making and best professional judgment may lead to suppression of invasive species populations (Kujawa et al. 2017). However, limiting a population to a smaller size than it would be naturally requires ongoing control effort, with accumulating risk and cost. The timeline for managing many AIS populations is indefinite.

To this end, additional research is needed to better understand the long-term effects of even strategic management. However, aquatic plant control research is rarely conducted in academic settings. While the department has become a leader in evaluating APM activities to support effective management, the recent realignment process has shifted department priorities away from applied research, which may present challenges in enhancing future APM practices.

Department staff track APM activities and monitor aquatic plant communities to inform strategic management. Understanding natural patterns and trends in aquatic plant communities can help set more realistic and ecologically-valid management goals. While there are many aquatic plant sampling methodologies that have been developed and used over time (i.e., transect surveys, biomass surveys, SCUBA surveys, quadrat surveys, etc.), the department has utilized a standardized and repeatable point-intercept based sampling methodology from 2005 to present (Hauxwell et al. 2010). The protocol uses a point-based sampling design, with sites located on a geo-referenced sampling grid laid out on the surface of lakes. Standardized monitoring grids are developed by the department based on site specific characteristics such as lake size, lake depth, and shoreline complexity (Mikulyuk et al. 2010). Sites are sampled from a boat using a double-sided rake, and information on depth, substrate, plant abundance, and species identification are recorded at each sampling location. The consistent statewide effort of monitoring aquatic plant communities using a standardized methodology results in an enhanced ability to understand and manage them. For example, monitoring data are used to assess the relative health of a plant community and guide management actions. Treatment results can be compared from lake to lake and the condition of the state's aquatic plant community can be tracked over time. In addition, these data can be used to assess how management is affecting non-target native plant populations.

The department has also collaborated with partners on several management case studies. These studies are particularly useful when data on field trials for a given management approach are lacking. As case studies accumulate, information can be compiled to draw conclusions about the selectivity, efficacy, and non-target effects of management. These studies have shown how quickly herbicides dissipate, how plant abundance fluctuates naturally over time, and how lake type, stratification, pH and other environmental factors can affect herbicide efficacy and the severity of non-target effects. This work is crucial in informing individual management actions as well as development of effective APM strategies for the state and is only possible with a consistent monitoring method.

2.5. Data Management and Accessibility

The department currently maintains a database of APM permits issued and treatment records from 2008 to the present. Presently, APM permit applicants can electronically submit their applications and chemical treatment records through a web-based application. Since 2017, applications for APM activities on both private and non-private waterbodies can be submitted this way. Prior to 2011, permittees submitted applications and sent treatment records to regional department staff, who independently compiled regional data. From 2008 to 2011, the electronic records were sent to Central Office staff who were tasked with aggregating all regional data. Coupled with centralized permit intake, creation of a centralized electronic database in 2014 drastically reduced inefficiencies and simultaneously provided access to a comprehensive APM dataset. Permits and treatment records prior to 2008 are currently housed in paper format at regional department offices.

Additionally, the department has a separate aquatic plant survey database which includes plant community data from over 1,600 individual point-intercept surveys on approximately 800 unique lakes. It also includes long-term data from plant surveys conducted on an annual basis on a set of managed and unmanaged lakes which the department has been monitoring since 2005. This database can be used to describe both local and statewide patterns in aquatic plant communities, allowing a better understanding of the natural context in which management occurs.

To further reduce inefficiencies in the future, the APM database is being integrated into the department's Surface Water Integrated Monitoring System (SWIMS) database. While technologically challenging and time-intensive, incorporation of these data into SWIMS has been a long-term goal for the APM program. Incorporation of APM data into SWIMS will provide wider access to the data, as anyone with access to the SWIMS database will be able to independently view and download APM data without having to submit a data request to the department. In the long-term, the APM permit, treatment record, and aquatic plant survey data should be integrated.

Although the permit application process has been streamlined and APM data is now stored in a centralized, more accessible location, there are still some issues that present obstacles for department staff and stakeholders wishing to make full use of the data. One overarching issue is that herbicide treatment records have not always received quality assurance checks to make sure they accurately capture treatment details, including whether management occurred and if the management action followed permit conditions. Furthermore, in situations where multiple chemicals were applied, permit and treatment data do not record whether the treatment areas overlapped, meaning that the APM data might over- or under-estimate treated acreage each year. For biologists and lake associations to make full use of the data, it is necessary to ensure that future permits and records adequately and clearly capture all the relevant details of the management techniques implemented.

2.6. DNR Grants and Aquatic Plant Management

Much of the financial burden of aquatic plant management falls to lake districts, lake associations, and to a lesser extent, cities and villages (see Chapter 4.1). Many lake districts and associations were formed specifically to finance APM. Excluding private ponds, lake districts and lake associations comprise the majority of APM permit applicants. These organizations, along with local governments and some other non-profit organizations are eligible to compete for financial assistance from the state to support certain APM and AIS management activities. Cost-share funding is available through the department's Surface Water Grants and Recreational Boating Facilities programs. These programs are funded, in turn, by an annual transfer of revenue from the state's motor vehicle fuel tax (see Chapter 4.3).

Surface Water Grants support APM activities primarily through "AIS Prevention and Control Grants" and "Lake and River Planning Grants". While primarily focused on water quality, Lake and River Planning Grants can aid with collecting information on aquatic plant communities and developing management plans that are a necessary first step in an aquatic plant management project. In 2018, the department funded 58 planning projects, awarding nearly $950,000 to qualified Wisconsin organizations, though only a portion of this addressed aquatic plants. Locally, grant sponsors must provide at least a 33% local match for planning projects, which can be either cash or donated labor and services. In 2018, this cost-sharing leveraged more than $620,000 dollars in matching funds from lake and river associations, local governments and non-profit groups for planning activities.

While planning grants often target broader issues related to waterbody and aquatic plant management, the AIS Prevention and Control Grants explicitly target invasive species. The AIS grant program is allocated approximately $4 million annually to support prevention, planning, early detection of and response to AIS, established AIS population control, the maintenance and containment of AIS, as well as AIS-related research projects. AIS grants require a 25% local match. Activities may include work related to invasive fish and invertebrates, as well as invasive aquatic plants, so it is difficult to determine the portion of funding dedicated to APM. However, a conservative estimate is that 70% of all annual funding, or approximately $2.8 million, is somehow related to aquatic plants. While Eurasian watermilfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*) are the most commonly targeted plant species in grant applications, funds are also used for managing invasive wetland species such as non-native phragmites (*Phragmites australis* subsp. *australis*) and purple loosestrife (*Lythrum salicaria*). As described in Chapter 1, most of the planning and control work funded by these grants is conducted by private consultants and professional herbicide applicators.

Much of the department's AIS grant funding goes to applications for Eurasian watermilfoil control. For example, in a single year of the grant program (2015-2016), chemical treatments of Eurasian watermilfoil comprised 81% of the department's expenditures in the AIS Established Population Control (ACEI) funding category. The total requested assistance for the ACEI category amounted to over $1.79 million, with more than $1.45 million of that assistance supporting chemical treatment of Eurasian watermilfoil. In addition, this figure does not account for further grant funding supporting Eurasian watermilfoil population assessment and management planning, supplied through the AIS Education, Prevention, and Planning grant category. Curly-leaf pondweed was the second most targeted species. Dredging and most mechanical harvesting activities are not currently eligible activities under ACEI grants because they are considered too expensive and routine short-term maintenance activities, respectively.

In addition to state financial assistance provided by the Surface Water Grants program, the department's Recreational Boating Facilities (RBF) program distributes cost-sharing grants for which the purchase of equipment to cut and remove aquatic plants in public waterways is eligible. Examples of equipment which has been purchased in this way include mechanical harvesters, conveyors, transport barges, and harvester repair. The costs of this equipment can exceed $100,000. In addition, to be eligible for RBF funding, grant applicants need to have an APM harvesting plan approved by the department. Cost-sharing for development of qualifying management plans is available through Surface Water Grants. RBF funds are the only state source for financing control of native aquatic plant species. Since 2014, the program has had a policy of funding harvesters and equipment at less than 50% of total costs. RBF program contributions from 2014-2018 have varied between 20-35%. Between 2015 and 2017, the RBF grant program was allocated $2.9 million annually. Out of this allocation, approximately $1.2 million was awarded for mechanical plant removal equipment.

3. Aquatic Plant Management Beyond Lakes and Ponds

Much of the above discussion is focused on APM in lakes and ponds but APM also occurs in wetlands, along riparian corridors, in roadside right-of-ways, and other semi-aquatic or 'wet' environments. While these systems are not fully-aquatic, some APM activities within them still fall under the jurisdiction of chs. NR 107 and 109, Wis. Admin. Code.

Management goals of APM in wetlands and other semi-aquatic environments may differ from the goals of APM in lakes. APM is less often conducted for recreational or navigational relief from nuisance aquatic plant growth. Instead, APM in these environments is typically conducted for the purposes of brush and invasive species control and habitat restoration.

APM in wetland and riparian environments also presents some unique challenges. While navigable waters are a public resource, most wetlands and stream banks in Wisconsin are privately owned. In most of these cases, managers must work with private land owners to organize and conduct plant control activities. Wetland invasive plants, such as Japanese hops (*Humulus japonicus*), non-native narrow-leaf and hybrid cattails (*Typha angustifolia; Typha × glauca*), reed canary grass (*Phalaris arundinacea*), phragmites (*Phragmites australis* subsp. *australis*), Japanese knotweed (*Fallopia japonica*), lesser celandine (*Ranunculus ficaria*), and java water dropwort (*Oenanthe javanica*) have variable means of propagation and dispersal that are difficult to address. Wind and water dispersal can make population control and preventing the spread of wetland and riparian invasive plant species particularly difficult.

The department relies heavily on collaboration with partners, such as non-profit organizations and Cooperative Invasive Species Management Areas (CISMAS), for management of stream-bank and wetland invasive species. The department will occasionally conduct AIS control and work with property owners directly, but partners lead the effort in most cases. Contractors are also hired to conduct wetland mitigation work. Like APM activities initiated by property owners in a lake setting, APM activities initiated by the department, conservation groups, and other partners for AIS control or restoration work must also be approved through the appropriate permit process before implementing.

Funding availability has also been a challenge for wetland and riparian invasive plant control. Fragmented property ownership, grant sponsorship and local match requirements, as well as permitting processes have sometimes been stumbling blocks for department staff and partners seeking to control high-priority wetland and riparian AIS populations. In these instances, efforts have sometimes had to rely on funding from the department's Division of Forestry or other funding sources to support control activities. In some cases, the funds were never obtained, and the control work has not been done. These challenges highlight the need for increased collaboration across department programs to better accommodate wetland and riparian projects.

Because of the unique challenges associated with wetland and riparian plant management, the department has organized statewide strategic control efforts for some of these invasive plant species. In the past few years, the department applied for and utilized federal grant funding to coordinate control of many non-native phragmites and reed manna grass (*Glyceria maxima*) populations on public and private properties throughout the state. In the coming years, the department will continue with strategic, federally-funded control work on the invasive species lesser celandine (*Ranunculus ficaria*), giant hogweed (*Heracleum mantegazzianum*), hairy willow herb (*Epilobium hirsutum*), and starry stonewort (*Nitellopsis obtusa*). More information on these efforts can be found in Appendix C.

4. Economic Considerations

This chapter discusses some of the economic considerations of aquatic plant management (APM) in Wisconsin. The overarching question is whether and to what extent the economic benefits of APM – as it is currently practiced in the state – outweigh its costs, and how these are distributed among different stakeholders and the public. Given the limited amount of statewide data available and the fact that many of the costs and benefits of APM do not have traditional market values, it is not possible to answer this question definitively. Some insights, however, can be gained from Wisconsin Department of Natural Resources (department) data on permitting, budget, and grants, as well as relevant economic studies that have been conducted in recent years in Wisconsin and elsewhere.

4.1. Costs

The cost of APM in Wisconsin includes public and private expenditures on chemical and mechanical treatments, equipment and supplies, planning and evaluation, management, and technical assistance – plus any economic damages that may be caused by treatments. Total statewide spending on APM is estimated at roughly $9.3 million a year. Of this, approximately half ($4.8 million) is spent by the department, while the remainder ($4.5 million) is spent by a combination of lake districts, lake associations, local governments, conservation and outdoor groups, other state agencies, federal agencies, property owners' associations, and individual property owners.[1] These values should be viewed as *rough estimates* since the various estimates that comprise them (described below) have a wide range of precision and accuracy. For example, the $215,000 that the department spends annually on APM-related permitting is based on detailed budget codes (Chapter 2.3), whereas the estimated $2.8 million in cost-share grants that the department awards each year for the control and management of aquatic invasive plants is based on a conservative estimate that 70% of all funding awarded under the AIS Prevention and Control program is related to aquatic plants (Chapter 2.6).

<u>Department Spending on APM Activities</u> (rough total = $4.8 million per year)

- **Permitting.** During Fiscal Year (FY) 2017, the department spent just over $215,000 on staff time and expenses related to the review, issuance and tracking of individual permits for chemical and mechanical treatments (see Chapter 2.3).
- **Planning and Management.** During FY 2017, the department spent $228,000 on staff time and expenses related to APM planning and management. This includes technical assistance and evaluation, as well as planning and management, but does *not* include all the administration of cost-share grants for APM. The administration of these grants falls under multiple department budget codes and is therefore not tracked as a single activity (see Chapter 2.3).

[1] These estimates do not include APM expenditures by tribal governments. The department does not issue permits for (or track) APM treatments conducted by tribal members in tribal waters (Appendix B).

- **Grants for Lake and River Planning.** In FY 2017, the department awarded an estimated $200,000 in cost-share grants to lake districts and associations, local governments, and other groups for lake and river planning activities related to APM, such as aquatic plant inventories (see Chapter 2.6).
- **Grants for Aquatic Plant Harvesters.** Between 2015 and 2017, the department provided $550,000 a year in cost-share grants to lake districts, local governments, and lake associations to purchase harvesting equipment under the Recreational Boating Facilities grant program (see Chapter 2.6).
- **Grants for the Control of Aquatic Invasive Plants**. As a *rough estimate*, the department provides $2.8 million a year to lake districts and associations, local governments, and other eligible entities for APM planning, treatment, evaluation and research, under the AIS Prevention and Control program. This represents 70% of the total amount granted under this program, which also includes AIS prevention and education, as well as non-plant related activities (see Chapter 2.6).
- **Chemical Treatments**. As a *rough estimate*, the department spends $790,000 a year on chemical treatments conducted by staff and department contractors, including related planning and evaluation. These treatments are carried-out by multiple programs within the department using a variety of funding sources and accounts, including fishing and hunting licenses and stamps. It is therefore difficult to estimate how much the department spends on these treatments overall. The estimate provided here is based on the total acreage of treatments permitted to internal programs between 2015 and 2017, relative to the total acreage of treatments permitted to lake districts during the same period.[2]

<u>Stakeholder Spending on APM</u> (rough total = $4.5 million per year)

- **Lake Districts.** As a *rough estimate*, the 240 or so lake protection and rehabilitation districts in the state spend a combined $1.875 million a year on APM (not including department cost-share). This figure is based on an analysis of lake district tax revenue conducted by UW-Extension Lakes and an estimate that lake districts spend approximately one-quarter of their revenue on APM-related activities (Eric Olson [UW-Extension], personal communication, April 4, 2018).[3]

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[2] To calculate this estimate, all treatment permits (chemical and mechanical) issued by the department between 2015 and 2017 were categorized by stakeholder group (including the department, for its own treatments). For each group, the total annual acreage permitted for treatments was multiplied by $325, which is the estimated dollar amount that lake districts spend on APM *per-acre*, not including cost-share grants from the department.

[3] Using data from the Wisconsin Department of Revenue, UW-Extension Lakes found that lake districts take in approximately $7.5 million in taxes a year. They estimate that roughly one-quarter of this revenue is spent on APM (Eric Olson, personal communication, April 4, 2018). This estimate is supported by the results of a recent survey of lake associations in Minnesota conducted by Concordia College (Ibrahim et al. 2017). In that study, lake association leaders were asked what percentage of association funds are typically allocated to each of 14 different activities. Of the activities listed, only one corresponds (in part) with APM: '*writing/implementing lake management plans*'. On average, lake association leaders reported spending 60% of their funds on a combination of the 13 non-APM activities. Of the remaining 40%, they reported spending 9% on lake management plans and 31% on 'other' activities. Given the otherwise exhaustive list of non-APM activities presented in the survey, APM activities are assumed to account for at least half the combined spending on lake management plans and 'other' activities.

- **Lake Associations.** As a *rough estimate*, the 550 or so non-profit lake associations in Wisconsin spend $955,000 a year on APM (not including department cost-share). This estimate is based on the total acreage of APM treatments permitted by the department to lake associations between 2015 and 2017, relative to that permitted to lake districts during the same period.[4]
- **Non-Profit Conservation Groups.** As a *rough estimate*, non-profit conservation and outdoor groups, separate from lake associations, spend $545,000 a year on APM (not including department cost-share). This estimate is based on the total acreage of APM treatments permitted by the department to such groups between 2015 and 2017, relative to that permitted to lake districts during the same period.[4]
- **County and Municipal Governments.** As a *rough estimate*, county and municipal governments spend $435,000 a year on APM (not including department cost-share). This estimate is based on the total acreage of APM treatments permitted by the department to these units of government between 2015 and 2017, relative to that permitted to lake districts during the same period.[4]
- **Residential Property Owners.** As a *rough estimate*, residential property owners spend $365,000 a year on APM, mostly for the chemical treatment of private ponds.[5] This estimate is based on the total acreage of APM treatments permitted by the department to residential property owners, property managers, and property owners' associations (not including lake associations) between 2015 and 2017, relative to that permitted to lake districts during the same period.[4]
- **Commercial and Institutional Property Owners**. As a *rough estimate*, commercial and institutional property owners spend $225,000 a year on APM, mostly for the chemical treatment of private ponds.[5] This estimate is based on the total acreage of APM treatments permitted by the department to commercial and institutional property owners between 2015 and 2017, relative to that permitted to lake districts during the same period.[4]
- **State and Federal Agencies.** As a *rough estimate*, state and federal agencies (not including the department) spend $80,000 a year on APM. These include the Wisconsin Dept. of Transportation, U.S. Fish and Wildlife Service, and the National Park Service, among others. This estimate is based on the total acreage of APM treatments permitted by the department to these agencies between 2015 and 2017, relative to that permitted to lake districts during the same period.[4]

[4] To calculate this estimate, all treatment permits (chemical and mechanical) issued by the department between 2015 and 2017 were categorized by stakeholder group. For each group, the total annual acreage permitted for treatment was multiplied by $325, which is the estimated dollar amount that lake districts spend on APM *per-acre*, not including cost-share grants from the department.

[5] Of the total acreage of APM treatments permitted by the department to residential, commercial, and institutional property owners, between 2015 and 2017, nearly 70% was for private ponds. Unlike APM conducted for larger waterbodies by lake districts and other stakeholder groups, APM for private ponds does not typically include planning or other non-treatment activities. On the other hand, individual property owners are not eligible for cost-share grants from the department and do not have the same economies of scale that other groups do. As, such, their out-of-pocket costs are assumed to be comparable with other stakeholder groups on a per-acre basis.

In addition to APM expenditures, nearly all APM treatments carry some risk of adverse impacts to aquatic resources, which in turn may cause economic damages. Non-selective chemical and mechanical treatments can cause damage to non-targeted plants, while the removal of aquatic plants in general can negatively impact invertebrates and fish populations (see Supplemental Chapters S.3.3 and S.3.4). Interviews and mail-in surveys of some 3,200 recreational visitors to Lake Guntersville in Alabama found that the hypothetical reduction of aquatic invasive plants to below a 20% coverage would make the lake a considerably less desirable destination for anglers, while making it more desirable to other recreational users (Bergstrom et al. 1996). In some cases, the large-scale removal of aquatic plants can also lead to decreased water quality and clarity, as aquatic plant beds play an important role in nutrient cycling and sediment control (see Supplemental Chapter S.2). The economic premium placed on water clarity has been shown by a study of sale prices of lakefront properties in northern Wisconsin lakes (Kemp et al. 2017), as well as a survey of anglers on Delevan Lake in Walworth County (Eiswerth et al. 2008). A lack of data and relevant studies, however, make it impossible to isolate and quantify economic damages caused directly by APM. Future research in this area would be useful.

4.2. Benefits

APM provides a variety of direct and indirect economic benefits. Public and private spending on APM generates sales, income, and employment among businesses, public agencies, and non-profit organizations that provide APM services. Roughly 60 businesses with headquarters or regional offices in Wisconsin provide one or more APM services. Together, these businesses employ 300 to 350 full and part-time workers to provide these services. This is based on a review of businesses that are licensed to apply aquatic pesticides in the state by the Wisconsin Department of Agriculture, Trade, and Consumer Protection (DATCP), coupled with a review of 'applicators' listed on APM permits issued by the department, and a series of discussions with vendors at the 2018 Wisconsin Lakes Partnership Convention.[6] These figures do not account for APM workers employed by lake districts, non-profit organizations, the department, or other state and federal agencies. According to the U.S. Bureau of Labor Statistics (BLS), as of May 2017, individuals employed as 'Pesticide Handlers, Sprayers, and Applicators [for] Vegetation' in Wisconsin earned an average of $35,000 a year, while those employed as

[6] DATCP-issued licenses do not distinguish between the application of aquatic herbicides and pesticides (e.g., for mosquito control). Businesses that apply aquatic herbicides were identified by searching licensed companies' advertised services and matching their names to herbicide applicators in the department's chemical permits database. This review identified 35 businesses with offices in the state that applied herbicides in Wisconsin waters and wetlands between 2015 and 2017. A review of department non-chemical permits from the same period identified 22 additional entities that *only* conduct non-chemical treatment. A comparison of DATCP-licensed businesses versus certified applicators (individuals), plus discussions with vendors attending the 2018 Wisconsin Lakes Partnership Convention, suggest that APM businesses employ 5 or 6 people, on average, including seasonal staff, while a few environmental consulting firms employ one or more specialists who may provide APM-related services but do not conduct treatments.

‘Forest and Conservation Technicians’ (a separate category that likely includes APM field work) earned $38,000 (BLS 2018). Recent postings for seasonal operators of aquatic plant harvesters in Dane County reported an hourly wage equivalent to $32,600 a year. For those categories most likely to include APM evaluation and planning, average annual salaries in Wisconsin in 2017 were $46,820 for ‘Environmental Science and Protection Technicians’ and $60,450 for ‘Environmental Scientists Specialists’ (BLS 2018).

As with any industry, spending on APM services generates not only direct benefits, but also *indirect* and *induced* sales, income, and employment among APM suppliers (e.g., herbicide retailers) as well as any businesses that provide consumer goods and services to individuals who are directly employed in APM or by APM suppliers. (In the case of aquatic plant harvesters, department cost-share grants provide direct benefits to APM suppliers.[7]) While APM is a just a tiny fraction of the state’s economy, data on those sectors of the economy that are most likely to include APM services suggest that spending on these services has a comparatively large ‘multiplier effect’. According to the input-output modeling system IMPLAN, every $1 million spent in Wisconsin on ‘support activities for agriculture and forestry’ (including herbicide application) directly supports 21 jobs, plus another $820,000 in sales and 6 jobs in other industries (IMPLAN 2016). In addition, every $1 million spent on ‘environmental and other technical consulting services’ directly supports 13 jobs, plus another $1.12 million in sales and 9 jobs in other industries (IMPLAN 2016).

More broadly, the outcomes of APM can provide substantial economic benefits by helping to maintain or restore the ecological, aesthetic and recreational value of public and private waterbodies. The recreational value of Wisconsin’s lakes and rivers is reflected by the fact that there are over 600,000 registered boats in the state – more than one for every ten residents. In a typical year, the department issues over 800,000 resident fishing licenses and 100,000 non-resident licenses, with anglers spending more than 15 million ‘fishing days’ in the state. Boating and fishing, as well as swimming and other recreational activities, generate sales and employment in sporting goods, groceries, restaurants, and lodging, as well other goods and services. APM can support these industries by controlling populations of overabundant aquatic plants that could otherwise curtail recreational activities, while managing for native populations that maintain or enhance those activities. To date, however, there have been almost no empirical studies on how APM effects these values. A ‘bioeconomic’ analysis of 13 lakes in Florida projected that APM could increase the annual economic benefits generated by anglers visiting those lakes by up to $5 million (Adams and Lee 2007).

[7] As noted in Chapter 4.1, the department provides $550,000 a year, on average, in cost-share grants to lake districts, local governments and lake associations for the purchase of aquatic plant harvesting equipment, under the Recreational Boating Facilities (RBF) program. Two Wisconsin-based companies manufacture and sell mechanical harvesters to public and private entities in and outside of Wisconsin. RBF grants have been used to purchase harvesters from these companies.

According to the Wisconsin Department of Tourism (2018), visitors to the state generated over $20 billion in total sales in 2017, supporting over 195,000 jobs. While the extent to which this activity is related to the state's lakes and other surface waterbodies is unknown, it is likely to be substantial. Wisconsin ranks second among U.S. states as a recreational fishing destination, behind Florida, with an estimated 6.7 million of the state's 21.3 million annual fishing days in 2011 accounted for by non-resident anglers (USFWS 2018). A number of Wisconsin communities depend on lake-based recreation, tourism, and vacation homes for their economic development, most notably in the lake-rich Northern Highlands region in and around Oneida and Vilas Counties (Carpenter et al. 2007). In a study sponsored by the Oneida County Lakes and Rivers Association, analysts reported that tourists and seasonal residents spend nearly $200 million a year in the county. Over three-quarters of the property value assessed by the county is in waterfront property, of which nearly three-quarters is owned by seasonal residents (Noel and Alexander 2017).

One of the more frequently-cited economic benefits of APM is the potential to limit declines in shoreline property values that may be caused by nuisance aquatic plants. The connection between property values and Eurasian watermilfoil (*Myriophyllum spicatum*) has been the focus of several studies. Economists at UW-Madison analyzed ten years of sales data for properties around 172 lakes in Vilas County. Controlling for parcel-specific variables (such as lot size, frontage, and the distance to commercial centers) as well as lake-specific variables (such as clarity and sportfish populations), the researchers found that land values[8] were 13% lower, on average, following watermilfoil invasion compared to non-invaded lakes (Horsch and Lewis 2009). Economists at UW-Oshkosh analyzed two and a-half years of data for shoreline properties around 413 lakes across 17 counties in north-central Wisconsin and found that watermilfoil invasion lowered sales prices by 4.5% (Johnson and Meder 2013). Similar studies in other states also found watermilfoil-related declines, including a 19% reduction on invaded lakes in King County, Washington (Olden and Tamayo 2014) and a 13% reduction on invaded bays around Coeur d'Alene Lake, Idaho (Liao et al. 2016).

A limitation of these studies has been their narrow focus on the presence (or absence) of Eurasian watermilfoil, as opposed to measures of plant abundance for milfoil and/or other species. In a study that is arguably more relevant to APM, economists found that the *combined density* of watermilfoil and other aquatic plants had a negative effect on property values around four lakes and one pond in Vermont (Zhang and Boyle 2010). Controlling for other variables, the authors of that study reported that increased plant density corresponded with a stepwise decrease in average sales price from 1 to 16%. These and the previous studies' results indicate that APM treatments can have a positive effect on

[8] Land value is the value of a property minus the value of improvements; e.g., the house, garage, etc. In this study, this was estimated as the sale price of the property minus the tax-assessed value of the house.

shoreline property values, although a more ideal study would analyze the effect of actual *APM treatments*, as opposed to the density of invasive aquatic plants.

A broader method of estimating the economic benefits of APM is to survey households on how much they would be willing to pay for it. In 2006, economists at the University of Minnesota-Duluth conducted a nationwide survey of randomly-selected households asking how much they would be willing to pay for "a trusted public or private wildlife organization" to delay or otherwise minimize the scenic, natural, health-related, economic, navigational, and recreational impacts of different types of aquatic invasive species (McIntosh et al. 2010). As part of this study, 1,400 households received a version of the survey that focused solely on aquatic invasive plants. On average, households were willing to pay $74 for an unspecified program that would maintain low-level impacts for one year, under a scenario in which *all* waterbodies within a two-hour drive of their homes had already been invaded. Assuming households' willingness to pay for such a program is directly proportional to the percent of waterbodies invaded, which is estimated to be at least 10% in Wisconsin,[9] the average respondent would be willing to pay $7.40 for one year of a statewide APM program focused on invasive plant control. This figure is conservative since respondents from the Midwest Census Region, which includes Wisconsin, were reported as being willing to pay more on average than those in other parts of the country (McIntosh et al. 2010). Multiplying household willingness-to-pay ($9.16 in 2018 dollars) by the number of households in Wisconsin (2.38 million) provides a rough estimate of the economic benefit of APM in the state, were it focused only on the control of invasive plants. At $22 million a year, this estimate is more than double the estimated $9.3 million spent annually on APM in general (see Chapter 4.1).

4.3. Distribution and Opportunity Costs

Not surprisingly, the nationwide survey described above found that households located on waterfronts are, on average, willing to pay more to delay or minimize the impact of aquatic invasive species than other households. A similar finding was reported for people who believe that significant AIS-related impacts are likely to occur in waterbodies within their area, along with people who belong to conservation groups (McIntosh et al. 2010). As these results suggest, different groups have different economic stakes in the ecological, aesthetic and/or recreational quality of waterbodies.

As described in Chapter 4.1, total statewide spending on APM is estimated at roughly $9.3 million a year. Of this, nearly 40% ($3.6 million) is supported by various types of cost-share grants awarded by the department to lake districts, lake associations, and other eligible entities. These grants come out of the department's Water Resources Account, which in turn is funded by an annual transfer from the state's motor vehicle fuel tax revenue. The amount transferred into this account each year approximates the

[9] This is a conservative estimate, based on an analysis of lake survey data conducted by Latzka (2015).

amount of fuel tax paid by all recreational motorboat users in Wisconsin.[10] Individuals who pay property taxes to lake districts and/or dues to voluntary lake associations fund another 30% ($2.8 million) of annual APM spending in the state. The remaining 30% of annual APM spending is funded by state and federal income taxes, contributions to non-profit conservation groups, county and municipal property taxes, and the direct purchase of APM goods and services by property owners.

As with any resource management activity, there may be situations in which funds spent on APM activities could have provided a greater economic return on investment had they been spent on alternatives to APM in general (e.g., AIS education and prevention), alternative APM approaches (e.g., more emphasis on planning), and/or alternative locations (e.g., waterbodies in earlier stages of invasion). In such cases, the difference between the actual economic benefit of the APM activities conducted and the likely benefit of the alternatives foregone constitute an 'opportunity cost'. While such costs are difficult if not impossible to estimate, it may be useful to consider them, at least conceptually, when evaluating alternative APM approaches or strategies. The lack of research on this question, as well as others previously noted in Sections 4.1 and 4.2, could help to inform the direction of future research conducted by resource economists at academic institutions and elsewhere.

[10] The amount of fuel tax revenue transferred into the department's Water Resource Account is calculated by first multiplying the motor vehicle fuel tax that would have been paid on 50 gallons of gasoline on April 1st of the previous fiscal year by the number of motorboats registered in the state as of January 1st of the previous fiscal year. The final amount is calculated by multiplying the initial result by 1.4. In recent years, this formula has resulted in annual transfers of around $13 million (Wisconsin Legislative Fiscal Bureau 2017).

5. Aquatic Plant Management Stakeholders and Collaborators

In the state of Wisconsin, aquatic plant management (APM) activities are conducted by a diverse group of stakeholders and partners, including state agencies, lake organizations, outdoor sporting groups, other nonprofit and non-governmental organizations, commercial APM service providers and manufacturers, colleges and universities, Native American Tribes, local government, federal agencies, individual citizens, tourism-related businesses, and others. APM stakeholder groups in Wisconsin are described below.

Department staff work closely with lake organizations (associations and districts) when permitting APM management actions in lakes and streams. Outside of individual permit applications for the treatment of private ponds, lake organizations are the most common applicants for APM permits. There are currently about 550 lake associations and 240 lake districts operating across 920 lakes in Wisconsin. These lake organizations can share information about lake issues with members, develop management plans, apply for grants, and collaborate with other stakeholders and the department on lake management projects and decisions, including those related to APM. Lake districts also have taxing and limited regulatory authority. For more information, see UW-Extension's guide for lake organizations (https://www.uwsp.edu/cnr-ap/UWEXLakes/Pages/organizations/default.aspx).

There are 11 federally-recognized Native American Tribes in the state of Wisconsin, all of whom are sovereign and retain the right to govern themselves, define their own membership, manage tribal property, and regulate tribal business and domestic relations. Their sovereignty also establishes a government-to-government relationship between the tribes and state and federal government. The northern third of Wisconsin encompasses the Wisconsin Ceded Territory, which is land that was ceded to the United States by six bands of Lake Superior Chippewa (Ojibwe) in 1837 and 1842. Members of these Chippewa Bands retained certain off-reservation hunting, fishing, and gathering rights within the Ceded Territory. These rights must be considered when conducting APM activities within the Ceded Territory. These six and an additional five Ojibwe Tribes in Michigan and Minnesota are represented by the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) for off-reservation activity that is related to their hunting, fishing and gathering rights. In collaboration with GLIFWC and the six Chippewa Bands, the department has a review process designed to help evaluate proposed APM actions and potential impacts to treaty reserved rights (e.g., wild rice (*Zizania palustris*)). Territories of several other Native American Tribes are within Wisconsin's borders. These include the Forest County Potawatomi Community, the Ho-Chunk Nation, the Menominee Indian Tribe of Wisconsin, the Oneida Nation and the Stockbridge-Munsee Community. All these tribes have environmental or natural resources departments with whom the department may collaborate on APM activities when appropriate (see Appendix B for additional information).

In addition, the department follows protocols, policies and Executive Order #39 in efforts to collaborate with the tribes of the state. Executive Order #39 affirms the government to government relationship between the State and Tribal Governments located within the state. These resources, along with the consultation policy, guide the department on respectful and cooperative discussion designed to occur prior to a decision being made or an action being taken.

Private professional service providers are also key partners in planning, conducting, and evaluating APM actions. These private professionals may conduct APM actions, provide recommendations to permit applicants, prepare APM permit applications for clients, develop APM plans, monitor aquatic plant communities, evaluate control activities, and assist in management decision-making. Plant control services may include herbicide application or physical plant removal approaches. The department collaborates and communicates with APM service providers by hosting or attending seminars, meetings, and conferences.

The department also collaborates with manufacturers of APM products to test and evaluate new techniques. There are several prominent herbicide manufacturers. Additionally, there are commercial entities that manufacture non-pesticide products such as mechanical harvesters, other physical removal equipment, and biologically-based plant control methods.

Outdoor sporting and recreational groups have a vested interest in the management of Wisconsin waterbodies. There are likely thousands of outdoor recreational groups that may have an interest in APM, though there is no centralized register of these organizations and thus the size of this stakeholder group cannot be accurately assessed. In general, the department willingly works with any group that shows an interest in an APM project.

The department collaborates with researchers in academia and at the U.S. Army Corps of Engineers Engineer Research and Development Center to support improved understanding of management efficacy and non-target effects of management. The department may fund research efforts through grants or assist in the development of research projects. Research conducted by these groups is critical to advancing APM in Wisconsin. Applied management research is important for decision-making, but the quality and quantity of APM research is lacking relative to other topics in aquatic science. Historically, academic departments have infrequently conducted this type of research. Thus, collaborations are vital to the continued evolution of APM. Collaborative efforts to ask and answer appropriate APM questions allow the integration of sound science with APM. The University of Wisconsin-Extension and Sea Grant programs also assist in outreach and education efforts to illuminate and explain APM and aquatic invasive species (AIS) issues. They have provided education and outreach on AIS prevention and APM planning, evaluation, and decision-making.

Local governments may have their own ordinances related to APM for waterbodies in their jurisdiction. Individuals interested in conducting APM must meet both local and state requirements. Additionally, there are several county-level AIS coordinators who are supported by state funds. These coordinators are instrumental in that they can assist lake organizations, private APM service providers and other stakeholder groups in management decision-making at a smaller regional level than the department's APM staff, facilitating communication between partners throughout the management process. As described in Chapter 1, all APM activities in Wisconsin must also comply with federal regulations. State and federal agencies also conduct APM activities directly.

Non-profit and non-governmental organizations are also important players that have various roles in APM in Wisconsin. Regional groups such as cooperative invasive species management councils and resource conservation and development councils implement AIS prevention programs, develop county-wide plans, provide environmental education and AIS surveillance, and sometimes finance invasive plant control activities. There are also statewide organizations that influence APM both directly and indirectly. The River Alliance of Wisconsin's Project RED is a citizen-based program for monitoring aquatic invasive plants and other invasive species along riverine corridors; their surveillance efforts help support invasive plant control along stream banks and other wetland environments. Wisconsin Lakes is another example of a statewide organization that influences APM by providing education and technical assistance to lake organizations.

APM also affects tourism, one of Wisconsin's most valuable industries (estimated at $20 billion in 2016). Wisconsin residents, visitors from other states, and international travelers come here for lake recreation, including boating, water skiing, fishing, wildlife viewing, and many other interests. Water quality, access, and healthy wildlife populations are central to these activities. As a result, countless enterprises, such as hotels, resorts, marinas, local restaurants, equipment and bait dealers, and others are dependent on the preservation of Wisconsin's waterbodies.

There are many other entities with interest or involvement in APM activities, depending on the location and nature of the APM work. Sanitary Districts may function similarly to lake organizations in some cases. Other regional organizations, homeowners' associations, and sailing clubs are other examples of groups that have been involved. Individuals proposing APM activities should seek to engage all potential stakeholders to support appropriate management, particularly in public waters.

6. Stakeholder Views on Aquatic Plant Management

6.1. Stakeholder Interview Process

There is a wide range of perspectives on aquatic plants and how they should be managed in Wisconsin. Riparian property owners, recreational boaters, anglers, wildlife enthusiasts, and other stakeholder groups value different aspects of the waterbodies they frequent, and thus their opinions on aquatic plant management (APM) differ. These differences often result in conflicting views on what constitutes a successful management outcome for a waterbody or even the need for management intervention in the first place. Individuals representing various APM stakeholder groups were interviewed as part of this strategic analysis to better understand and consider the varying perspectives. The interview questions were developed to increase awareness of stakeholders' APM goals, how various environmental factors are considered when making management decisions, perspectives on Integrated Pest Management (IPM), suggestions for the Wisconsin Department of Natural Resources' (department's) APM program, and other concerns related to APM.

Three sets of questions were developed: one for stakeholders actively conducting APM activities, one for stakeholders not actively involved in APM, and another for department APM staff. Within the stakeholder groups, interviewees may or may not be actively involved in APM activities. Interviewees were asked at the beginning of the interview whether they are actively involved in APM in order to determine the appropriate set of questions for the interview. The three sets of questions cover similar topics, with some removals and additions where applicable (see Appendix D for specific questions asked during the interview process).

A range of interview candidates were suggested by department APM staff and cross-checked using the department's management record database. Interviewees were selected to explore the wide range of views held, representing variation in lake management histories, geography, and lake physical characteristics. This sampling design is standard for qualitative research and aims to provide a thorough understanding of the range of existing viewpoints, all of which are weighed equally and considered equally important.

In total, 12 department APM staff and 53 individual stakeholders representing 48 organizations from Wisconsin's lake-rich ecoregions were interviewed (Figure 6.1). Interviews were conducted between December 2016 and April 2017. Interviewees included representatives from:

- 19 lake organizations
- 10 private aquatic plant management companies (whose services include chemical or non-chemical aquatic plant control activities)
- Seven APM private consulting companies (whose services are primarily lake management consulting and may or may not include aquatic plant control work)
- Three county government offices
- Three outdoor sporting groups
- Three tribal entities

- One riparian landowner
- One boat rental company
- One sailing club

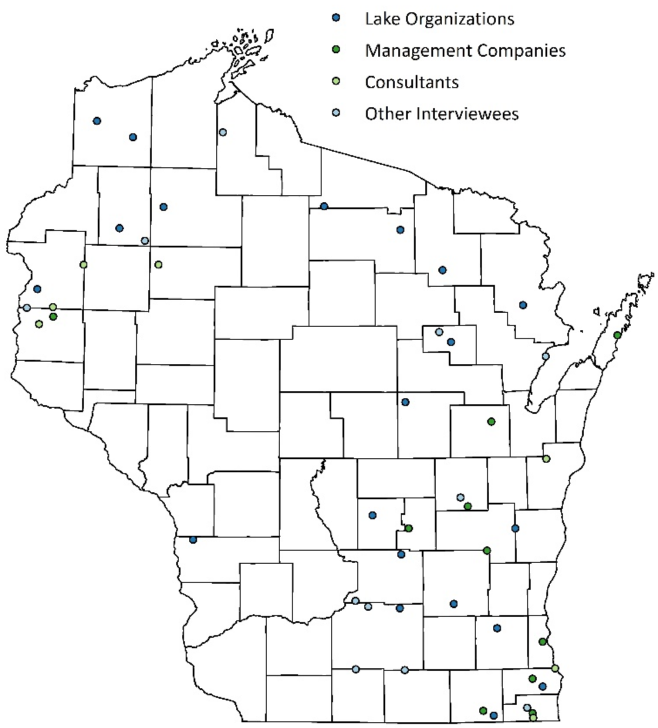

Figure 6.1. Location of various stakeholder categories.

Note: Interviewees from various stakeholder categories were selected from across Wisconsin's three lake-rich ecoregions. The points on this map are staggered somewhat from actual interviewee locations to ensure anonymity. While the locations of department staff interviewees are not shown on this map, all permanent department staff a few limited-term employees that issue APM permits were interviewed.

Upon completion of interviews, dominant themes were identified. The themes are described below, as broken down by stakeholders' APM goals and considerations, as well as suggestions for the department's APM program. Specific quotes supporting these themes can be found in Appendix E and were selected to represent the full range of views expressed in the interviews.

6.2. Interview Findings

6.2.1. Management Goals

APM goals are consistent across stakeholder groups and department APM staff. There is a general desire to "Keep lakes natural and healthy". What this means in detail involves the following major themes (while this list of goals may not be exhaustive, it briefly summarizes the predominant objectives of APM that were described in the stakeholder interviews):

- Reduce aquatic plant abundance when plants are impeding use of a waterbody. This may include controlling overabundant plants that prevent navigation or are aesthetically unpleasing. Some interviewees also noted the importance of APM for preserving the economic climate around lakes.
- Non-native species control. In some cases, this may include attempts to eradicate a non-native plant species, depending on the species to be controlled or the extent of its spread within a waterbody. In other cases, the goal may be to keep the population of a non-native species from becoming overabundant rather than to remove the population completely.
- Ecological protection and restoration. Removal of a population that is negatively impacting a lake ecosystem, preservation of biodiversity and habitat, and lake or ecosystem services protection are also drivers of APM.
- Public education and outreach. Private service providers and department staff as well as lake organization representatives also see APM as an opportunity to educate the public on aquatic ecology and water quality. This goal was described by a subset of interviewees, while the above three goals were well-represented within most interviews.

6.2.2. Management Considerations

Individuals involved in management are generally aware of how seasonal timing, target species, waterbody characteristics, potential development of herbicide resistance, and concentration and exposure times can influence management. Stakeholders are generally more accepting of non-native than native plant management, but perspectives on when management is warranted differ regardless of species origin (whether the target species is native or non-native to Wisconsin). There is also variability in how stakeholders consider negative ecological tradeoffs of management. Regarding IPM, interviewees identified several benefits of, as well as barriers to, its implementation. Below is a summary of interview responses to questions about various factors influencing APM.

- Management Timing. Most interviewees actively involved in APM acknowledged that the life cycle of the target species is important to consider. Several suggested that control efforts for Eurasian watermilfoil (*Myriophyllum spicatum*) and curly-leaf pondweed (*Potamogeton crispus*) should be conducted early in the plant growing season to improve efficacy and minimize non-target impacts to native plant species. Some interviewees also noted exceptions to or challenges associated with early-season management, such as not knowing what plant species will be present or how abundant plants will be when applying for an APM permit before the growing season in a given year, differences in timing of active plant growth concurrent with annual variability in temperature, fish spawning, and if new aquatic invasive species (AIS) will be detected in a waterbody.
- Waterbody Characteristics. Interviewees across stakeholder groups understood that waterbody characteristics (such as size, depth, flow, water clarity, and others) determine what plants are present and what plant control techniques are likely to be most effective. Private, State, and county APM professionals are seen as experts who can advise citizens and lake organizations in considering the influence of waterbody characteristics on various techniques for plant control.

- Herbicide Resistance. Some interviewees, representing various stakeholder groups, had concerns about aquatic plants developing a resistance to herbicides. Some of these individuals said that their concerns led them to change their APM practices. To prevent target plants from becoming resistant, some stakeholders described that they would use less herbicide, avoid using the same herbicide repetitively over time, or use herbicide less frequently. A few stakeholders indicated that in some scenarios regulators were dictating lower herbicide use rates to ensure protection of native plants, and they believed this was leading to repeated under-dosing of invasive populations over time, and thus the development of herbicide resistance. Others felt that more research into this topic was needed before it would influence their APM practices.
- Herbicide Concentration and Exposure Times (CET). Some lake organization representatives were aware of the importance of careful consideration of herbicide CET and most said they look to department staff or private service providers to determine appropriate herbicide products and application rates. Private service providers may or may not recommend using the maximum allowable herbicide application rate, depending on the scale of the herbicide treatment, characteristics of the waterbody, and both the target and non-target plant populations. Preferences for management scale differed among interviewees and pros and cons of both small- and large-scale herbicide treatments were described. These included the challenges of herbicide dissipation and reaching target exposure times in small-scale treatments as well as increased predictability but also severity of ecological impacts of large-scale treatments. Some interviewees also noted that further research is needed in both laboratory and field settings to determine effective CET for different types of herbicides and target species.
- Management of Native vs. Non-Native Plants. Most interviewees felt that management of native plant species should be more conservative than that of non-native plants. However, some noted that management of native plants can be necessary when navigation is impeded. Some APM service providers said they avoid the use of herbicides in native plant control. Non-native plant management was generally considered more acceptable by interviewees, particularly when the plants are aggressively growing. Some interviewees felt that non-native plant populations should not be actively managed if they are not causing ecological harm or impeding recreation.
- Management of Relatively New vs. Well-Established Non-Native Plants. In the case of newly discovered non-native plant populations, many interviewees said early control responses are critical. Others said that new populations should first be monitored to determine whether management is warranted. With respect to management of well-established non-native plant populations, many interviewees emphasized the importance of careful consideration of goals and setting reasonable expectations for management efficacy.
- Integrated Pest Management. The concept of IPM was familiar to department staff and private service providers. Most defined IPM as considering and making use of all available plant control techniques. A subset of APM professionals included waterbody planning and monitoring in their definitions of IPM. IPM was less familiar to lake organizations and stakeholders not actively conducting APM activities but when IPM was described to them, some described ways in which they were already practicing IPM. Interviewees described several benefits of IPM (e.g., the concept recognizes the importance of thoroughly considering all management options, not

favoring any one management technique for all waterbodies, can assist in avoiding repeated use of the same management approach, and can lessen herbicide use and the potential for herbicide resistance) as well as barriers to implementing IPM (e.g., potential increased costs of control efforts, IPM may not always be feasible and can be challenging to implement for companies whose primary services are herbicide treatments).

- Management Tradeoffs. Interviewees generally said they work to minimize negative ecological tradeoffs of management. Many said they aim to do no more ecological harm with their management actions than the target plant population, given that overabundant plants have been shown to be problematic for fish and wildlife resources and can over-compete with desirable plant species. Several discussed the need to find a balance between the potential for negative ecological impacts and management goals. Some felt that impacts to native plants are acceptable in the short-term. On the other hand, a subset of interviewees said they were not willing to accept any tradeoffs of management. A few described that they would be willing to accept negative ecological tradeoffs of management depending on the characteristics or dominant uses of the target waterbody (for example, they may be more willing to accept negative impacts of management in a waterbody with abundant plants which is very heavily used for water-skiing) and suggested classifying lakes for this purpose. A few interviewees also noted that resource availability may determine the degree to which negative management tradeoffs can be minimized. Unpredictability of management outcomes was also identified as a factor making consideration of tradeoffs challenging.

6.2.3. Suggestions for Improving Aquatic Plant Management in Wisconsin

Predominant areas of the department's APM program identified as needing improvement by stakeholders include staff availability, collaboration and communication with private service providers, public outreach, research efforts and implementation, consistency, and grants and fees.

- Relationships and Resources. For the most part, interviewees described having positive relationships with department APM staff. Some stakeholders expressed a need for faster permit approvals or more time working with department staff. A need for more permanent department staff with APM expertise was also discussed. Other approaches for improving relationships and workload included streamlining of grant and permitting processes and increased prioritization of APM work by department staff.
- Collaboration. Several private service providers and lake organization representatives requested a more collaborative approach to APM decision-making. Some lake organization representatives felt that the values of some stakeholder groups are weighted more heavily than others in department decisions and requested a more public decision-making process. These interviewees sometimes wanted department staff to better communicate their rationale for permitting decisions. Interviewees described benefits of collaboration such as increased sharing of information between stakeholders with different backgrounds and experience to help optimize decision-making and ensure all parties are on the same page once a strategy has been determined. Some private APM service providers felt their opinions should be considered more

respectfully, saying it is in everyone's best interest to promote a healthy ecological and recreational resource and noting that APM in Wisconsin relies on the assistance of industry partners.

- Outreach. Various interviewees felt that increased public outreach by department staff on APM issues is needed. Some suggested that department staff are in a good position to conduct outreach because they work on a statewide level and should seek to build a rapport with the public that goes beyond being perceived as a purely regulatory agency. Outreach topics of interest were the ecological importance of aquatic plants, management tradeoffs, research results, navigating the APM permitting process, AIS-spread prevention, updates on new AIS discoveries and emerging AIS, and Citizen Lake Monitoring Network (CLMN) data and how its benefits lake management. Some interviewees stressed that outreach efforts need to engage all APM stakeholders and avoid communicating with any one stakeholder group over another, saying that current efforts reach riparian property owners but may not reach individuals who are frequent visitors of lakes.
- Research. Interviewees across stakeholder groups felt that APM and relevant decisions should be based on scientific research. They highlighted that research is needed to shed light on many unknowns related to the efficacy and non-target ecological effects of herbicides and non-chemical APM methods. They felt that department staff could better and more quickly distribute both the department's research findings and scientific information generated from other states' and organizations' work to APM stakeholders. Some interviewees also explained how they have been able to share the department's research results to help them personally, informing APM decisions for the lakes they live or work on.
- Consistency and Flexibility. Some interviewees, predominantly private service providers and department staff, as well as a few other stakeholder interviewees, noted a need for more consistency in APM permitting and grant funding decisions within and among regions of the state. These individuals expressed that there is often confusion over what decisions are based on administrative code and those that may be influenced by the opinions of department APM staff. They are uncertain of how the APM program will develop and what permits and grants will and will not be approved or funded presently and in the future. However, several interviewees also cautioned that there is a need for some regional and waterbody-specific flexibility to allow localized decision-making. Private management professionals have also requested development of standards or guidelines to assist with APM planning and the bidding process for APM contracts. Several approaches towards consistency were suggested, including increased training and reduced reliance on limited-term employees in permitting, defining nuisance aquatic plant conditions, revising and increasing enforcement of the administrative codes governing APM, development of a decision-making protocol, and compiling relevant APM information into one accessible location.
- Grants and Fees. Stakeholder interviewees, particularly private APM service providers and those in the category of "other stakeholder groups", felt that department grant funding was critical to their operations and lake management in Wisconsin. They suggested that more funding for the grant program is needed to support studies, management planning, and county AIS

coordinators. They suggested increasing taxes or fees to increase funding, though a few other interviewees felt that permit fees can be a barrier to management. Potential changes to the grant program were also suggested, including increasing the amount of time in which grant funding is available once awarded, further dividing grants into different categories to support various types and scales of projects, creating a cap on the amount of funding or number of grants that can be received by an organization for a particular project or management goal and strategy, and increasing support of IPM approaches. One interviewee also suggested the department begin to consider developing an alternative strategy for AIS management over the long-term that does not rely on grant funding.

6.2.4. Other Aquatic Plant Management-Related Concerns

Other topics that came up in the stakeholder interviews include considering how to address emerging issues such as new AIS and climate change, AIS prevention efforts, nutrient reduction, potential policy changes and the general direction and focus of the department's APM program, concerns over current messaging related to Eurasian watermilfoil (*Myriophyllum spicatum*) and common AIS.

- New AIS and Climate Change. A few lake organization representatives were particularly concerned about global climate change and new AIS that have the potential to thrive in Wisconsin. They described that these issues are very difficult to control and are likely to make APM even more complex and difficult in the future.
- AIS Prevention. Lake organization representatives and other interviewees recognized the importance of preventing the spread of AIS, which may help avoid the need for APM. Several approaches towards enhanced AIS prevention were described, including increasing communications about AIS presence statewide and between lakes, enforcement of and penalty for violation of AIS laws, surveillance of commercial entities, and restricting access to waterbodies depending on whether or not they contain AIS.
- The Department's Messaging on Common AIS. Some private service providers and lake organization representatives are concerned about the department's recent messaging on managing AIS that are common in the state, specifically the department advocating a "wait-and-monitor" strategy to determine whether an AIS population will create ecological or recreational impairments before deciding to manage. They suggested the department provide financial assistance for management when ecological or recreational impairments by AIS are realized in cases where a "wait-and-monitor" type of strategy is employed.
- Nutrient Reductions and Watershed Health. A couple of lake organization representatives described a need to work on watershed and non-point source pollution issues to help relieve the need for APM. One interviewee suggested creating a tax to assist with watershed-level issues in waterbodies throughout the state.
- APM Code Revision. Some interviewees, predominantly department staff and private service providers, made specific suggestions for revising Wisconsin's administrative codes related to APM, including combining and updating chs. NR 107 and 109, Wis. Admin. Code requiring

different APM service providers be involved in planning and conducting individual APM projects and incorporating expectations for efficacy and greater ecological protections.

- Balance of Social and Ecological Concerns. Stakeholder opinions differ on the degree of emphasis the department's APM program should give to social and ecological concerns, with some being willing to make ecological or social tradeoffs in their management decisions.

7. Current Practices and Research Implications

7.1. Aquatic Plants and Beneficial Use Impairment

The Wisconsin Department of Natural Resources' (department's) aquatic plant management (APM) Program is charged with balancing social conflicts and ecological concerns. Under the purpose section of ch. NR 107, Wis. Admin. Code, "The department may allow the management of nuisance-causing aquatic plants with chemicals registered and labeled by the U.S. environmental protection agency and labeled and registered by firms licensed as pesticide manufacturers and labelers with the Wisconsin department of agriculture, trade and consumer protection. Chemical management shall be allowed in a manner consistent with sound ecosystem management and shall minimize the loss of ecological values in the water body." Under ch. NR 109, the department recognizes the benefits of aquatic plants, and that social impairments may exist due to excess abundance. Some management of beneficial use impairments, or "nuisance" aquatic plants, whether native or non-native, will likely always be needed and will be the principal component of APM in Wisconsin. However, if aquatic plants are managed only for social reasons, the department's responsibility to protect ecological values may not be met because all management has ecological tradeoffs.

Perceptions of beneficial use impairment are subjective based on an individual's desired lake use. There is currently no standardized definition of nuisance or beneficial use impairment that can accommodate differences in stakeholder perceptions and management goals. This, along with physical differences among waterbodies (see Chapter 7.7), can lead to inconsistent implementation of APM across the state. There are several potential goals of management and it is often difficult for stakeholders to agree on common goals. Even when a common goal is agreed upon, expectations of success in management outcomes also differ. For example, one stakeholder may consider a temporary reduction in plant cover to be successful management while another would only consider multiple years of plant reduction successful. The use of consistent terminology for describing different management outcomes or degrees of success may improve communication and consistency in APM implementation.

Regardless, to fulfill the purpose laid out in chs. NR 107 and 109, Wis. Admin. Code the model for APM in Wisconsin must carefully consider how management goals can be achieved in the context of preserving ecological and social values for each management scenario.

7.2. Management of Non-Native Aquatic Plant Species

Ecological rationale for APM includes native species displacement by non-native species (altering community composition, habitat availability, and ecosystem services), containment of invasive aquatic plants to a given waterbody, and the avoidance of stunted fisheries from overly dense aquatic plant populations. Invasive species are widely cited as one of the top threats to biodiversity globally and invasive plants have the potential to cause shifts in plant communities. The growing concern about aquatic invasive species (AIS) in the late 1990s, and Eurasian watermilfoil (*Myriophyllum spicatum*) in particular, has dramatically altered how APM is conducted in Wisconsin. Non-native and invasive plant management has become a substantial component of APM practice. Stakeholders are generally well-aware of potential AIS impacts, and the majority of APM permits list invasive plants as one or more of the target species. The department has awarded cost-sharing grants for prevention and control of AIS since 2003, which has incentivized management intervention, as a corollary to heightened awareness about AIS.

Scientific understanding of non-native species' impacts across the landscape has greatly evolved in the past 10-15 years. Here, the progression of Wisconsin's response to and research on Eurasian watermilfoil is described as an example to consider in future management of non-native plants. Eurasian watermilfoil is the focus of this section because it is the most commonly targeted species in APM permits and has been widely studied. Other non-native species' potential for ecological impacts and colonization may differ (as a result of species-specific differences, varying waterbody characteristics plant community composition, etc.) past experiences with Eurasian watermilfoil can provide a framework to consider and implement non-native species management depending on the various stages of the invasion process, risks for negative effects of management and the invader itself, and the statewide distribution of the target species.

The department and countless others in government, academia, non-profits, and the private sector have worked to communicate the potential for invasive species to cause ecological harm. In the early 1990s, department staff and other partners described Eurasian watermilfoil in a report to the legislature as a "superweed" that would take over lakes (Bode et al. 1992). The fear of potential impacts associated with Eurasian watermilfoil and other non-native plants, a fear to which messaging from the department and many other natural resources organizations contributed, is a likely driver of the increasing trend in APM permits. Eurasian watermilfoil is the most frequently targeted species in AIS control grants, accounting for $1.45 million in grant awards in 2016. As with other invasive species, Eurasian watermilfoil impacts can be economic, social, and ecological. Eurasian watermilfoil has been shown to be capable of outcompeting other plant species in certain waterbodies and property values on lakes with Eurasian watermilfoil in Wisconsin have been found to be lower by about 13% compared to uninvaded lakes (Horsch and Lewis 2009).

Despite these cases, the severity of invader impacts varies across waterbodies and not every invasion is harmful (Williamson and Fitter 1996; Vander Zanden et al. 2017). A wide variety of AIS, including aquatic plants, fish and invertebrates are "commonly rare and rarely common" (Hansen et al. 2013). Williamson and Fitter (1996) reported that only about one out of every ten invaders that make it to the wild establish self-sustaining populations, while about only one in ten of these are likely to have adverse ecological or economic impacts. [11] In many cases, established populations of Eurasian watermilfoil do

[11] The studies by Hansen et al. (2013) and Williamson and Fitter (1996) evaluated data on invasive animals as well as invasive plants. Hansen et al. included Eurasian watermilfoil and curly-leaf pondweed. Williamson and Fitter included several plant species. Both studies showed similar trends for plants and animals.

not cover large percentages of lake surface (Figure 7.1; Hansen et al. 2013; Nault 2016), suggesting that these populations may remain at levels below what many stakeholders would consider an ecological or recreational impairment. EWM has been shown to competitively exclude native species at the local scale (sites within lakes), but demonstrates positive associations lakewide, suggesting that EWM and native species may occupy slightly different niches and may not be in direct competition (Muthukrishnan et al. 2018; MacDougall and Turkington 2005; Davis and Brinson 1983). Similarly, native plant abundance tends to remain unchanged or increase in association with EWM when examined across lakes (Gräfe 2014; Mikulyuk 2017). At large spatial scales, Eurasian watermilfoil has been shown to coexist with native plant species without reducing native cover or diversity overall (Trebitz and Taylor 2007).

In reality, simply because a plant population is non-native may not necessarily make it a threat. Many factors, including management activities and even native plant populations can also have negative ecological effects. The introduction and spread of aquatic invasive plants over recent decades has led to the desire to preemptively manage in order to avoid potential future beneficial use or ecological impairments. Eurasian watermilfoil management is often conducted aggressively and pro-actively in the early stages of invasion, but in some cases, this aggressive management approach may have had larger non-target impacts on native plant communities than would have resulted from the invader itself (Mikulyuk 2017). Eurasian watermilfoil has also been shown to benefit from disturbance, moving quickly into de-vegetated areas of a lake, so reductions in plant abundance by control activities may unintentionally support Eurasian watermilfoil growth (Galatowitsch et al. 1999). As implied earlier, impairments can be caused by non-native species as well as native species. Native species can have similar abundance and effects on the native plant community as does Eurasian watermilfoil (Mikulyuk 2017). Indeed, under ch. NR 109, even native species can be considered "invasive", if they are causing ecological or social harm.

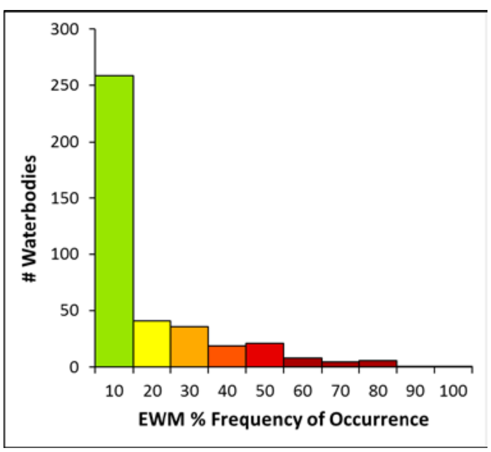

Figure 7.1. Percent of littoral zone (a) with Eurasian watermilfoil.

Note: Data are from Wisconsin waterbodies where Eurasian watermilfoil (*Myriophyllum spicatum*) or hybrid watermilfoil (*M. spicatum* x *sibiricum*) have been detected.

Therefore, careful assessment of detrimental ecological or social impacts of past and present invasions can assist with determining the appropriate management response to future invasions by non-native aquatic plants. Evaluations of scenarios in which non-native plants have had highly detrimental social or environmental effects may allow predictions of which sites are likely to be most vulnerable and for which control may be a high priority.

7.3. Strategies for Managing Non-Native Aquatic Plants

When a new non-native species is detected in a waterbody, early management response often is an attempt to eradicate the new population before it has a chance to spread and establish in the waterbody (Rejmánek and Pitcairn 2002). If successful, eradication can lead to cost savings by removing the need for further management (Simberloff 2003). However, attempts at invasive species eradication are often unsuccessful (Leung et al. 2002). Interestingly, manual removal was employed at some point in the management plan in the majority of the few reported cases of Eurasian watermilfoil (*Myriophyllum spicatum*) eradication. If eradication is not achieved, the ecological benefits of an early response are less clear. An early response strategy with the goal of eradication is warranted for new species to the state or a given region of the state. If successful, this strategy may prevent the species from spreading statewide or regionally. More research is needed on the efficacy of utilizing control as an AIS containment strategy if eradication is not achieved. While logic suggests control efforts that reduce invasive plant abundance within a waterbody would lead to fewer plants being moved from one waterbody to another, there are no studies examining whether control efforts that reduce AIS abundance reduce AIS spread between waterbodies.

Having an adaptive management plan that identifies how management strategies should evolve following multiple unsuccessful eradication attempts can avoid excess spending and employing the same strategy repeatedly without achieving desired outcomes. At this point, shifting management goals to keeping the plant population below a certain threshold density or percentage of lake acreage may be more attainable and cost-effective.

While an adaptive management strategy has been shown to suppress Eurasian watermilfoil populations, some populations will remain low without active control effort (Figure 7.2; Kujawa et al. 2017). A less-active strategy for addressing a new non-native plant population is to conduct regular monitoring to observe trends in abundance and impact. This “wait-and-see” strategy may require a smaller financial investment up front and provide cost savings in the long-term if abundance and impact remains low. However, if the population does spread and form dense stands to a point that warrants management, costs may be higher than if action were taken early following detection. Unmanaged, established Eurasian watermilfoil populations tend to go through cycles, in which population size may grow to a maximum threshold, and then naturally begin to decline (Carpenter 1980a; Sheldon 1994). Stakeholders employing this strategy will need to expect occasional years of high abundance. Continual monitoring of plant populations using a standardized and repeatable methodology can help to determine when management is warranted based on individual lake management goals.

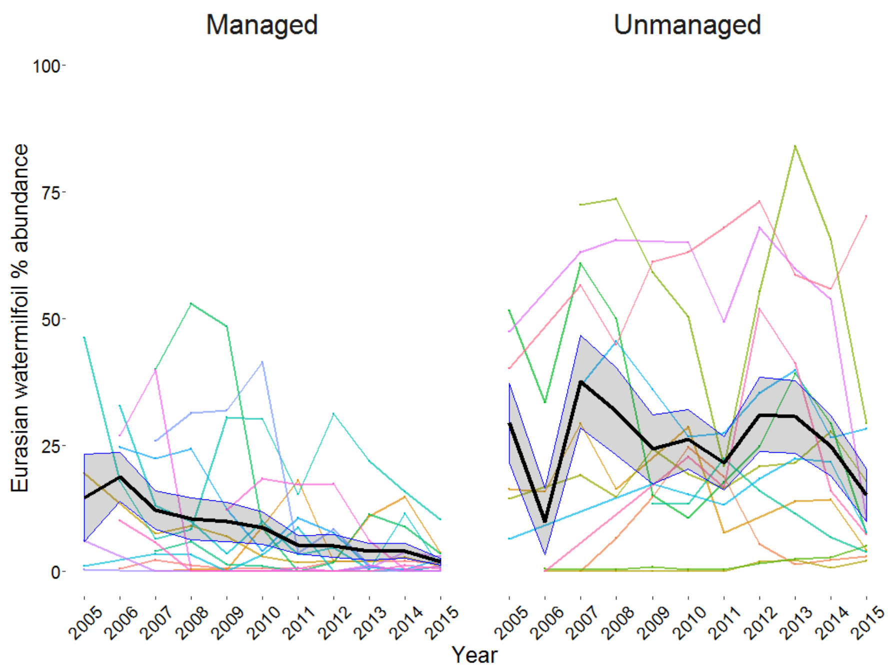

Figure 7.2. Managed versus unmanaged Eurasian watermilfoil populations (Kujawa et al. 2017).

Note: While strategically managed populations tend to have lower abundance than unmanaged populations overall, there are unmanaged populations that naturally maintain low abundance. Each colored line on this figure represents the abundance of an individual lake Eurasian watermilfoil population over time. The black line represents an annual mean abundance of the populations and the shaded region represents the standard error from the mean.

Successful adaptive APM requires collaboration between permit applicants, service providers, department staff and other stakeholders to appropriately address each management scenario. Ecological and social impacts can occur from native plant populations, non-native plant populations, as well as any management approach and plant response to management can be lake-specific. Careful consideration of stakeholder values, resources, ecological setting, and expected efficacy is critical for management goals to be met.

7.4. Implications of Recent Findings on Herbicide Use in Aquatic Environments

Herbicide treatment is the most commonly employed control technique for APM in Wisconsin. The herbicide's effectiveness on the target species as well as potential non-target impacts is dependent on the specific herbicide product used, as well as the concentration (C) and exposure time (ET) at which that herbicide is in contact with the plants. Adequate herbicide CET must be met and maintained for herbicide treatment to be effective in controlling the targeted aquatic plants. However, achieving adequate CET in aquatic scenarios can be quite challenging, as herbicides applied directly to waterbodies are prone to wind and water movements, which are not typically major factors in terrestrial herbicide applications. Recent research on herbicide use in aquatic environments can be used to guide management decisions, with important considerations relating to the target species, non-target species, waterbody type, and treatment scale.

The advent of technologies developed to monitor for herbicide concentrations in water following herbicide application has led to many recent findings on the role of treatment scale in designing effective herbicide management strategies. Section NR 107.04 (3), Wis. Admin. Code identifies small-scale treatments as those less than 10 acres or less than 10% of the littoral zone. From an ecological standpoint, small-scale treatments are those in which the total quantity of applied herbicide is anticipated to impact plants at a localized, not lake-wide, scale. Herbicides applied at a small-scale in aquatic environments dissipate quickly, presenting challenges in meeting target CET values. For example, one recent study tracking 2,4-D for the localized control of Eurasian watermilfoil (*Myriophyllum spicatum*) found that the target CET based on previously conducted laboratory studies was rarely met in small-scale 2,4-D treatments in the field (Nault et al. 2015). Due to this rapid herbicide dissipation, the efficacy of treatments to small areas can be unpredictable and control of the target species can be difficult to achieve and maintain. In addition, efficacy of small-scale treatments may also be hampered by recolonization of the target species from nearby areas of the waterbody which were not treated.

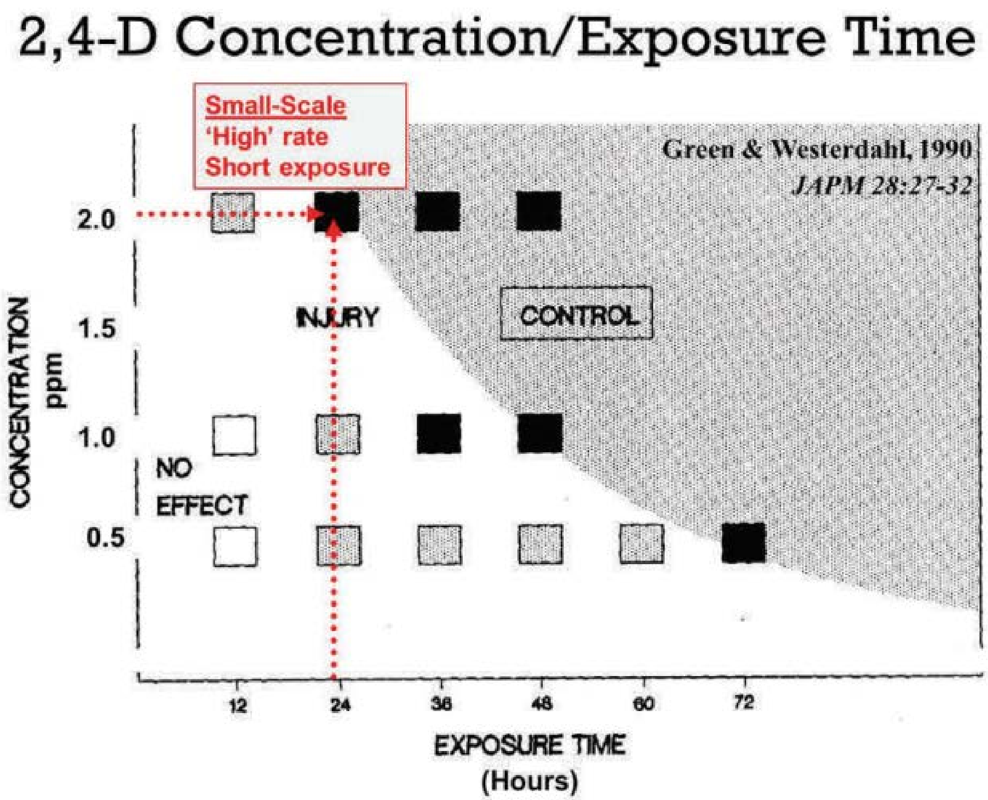

Figure 7.3. Concentration and exposure time graph for 2,4-D.

Note: For small-scale treatments in aquatic environments where herbicide is likely to dissipate off the target site, higher concentrations may be needed to compensate for short exposure. Image source: Green and Westerdahl, 1990.

As described in Chapter 2, localized, small-scale herbicide treatments by individual landowners have traditionally been permitted to address recreational nuisance issues. However, the cumulative ecological impacts of such actions by many individual landowners; multiple small herbicide treatments in a single waterbody can combine and cause an unintended large-scale herbicide treatment, with potentially damaging non-target impacts lake-wide (Nault et al. 2012). If genetic variation in the target population exists, particularly the presence of hybrid watermilfoils, repetitive treatments with the same herbicide may cause a shift towards increased herbicide resistance in the population.

Some scenarios in which small-scale herbicide treatment may be appropriate include 1) attempts to keep newly discovered populations from becoming large enough to impair ecology or recreational uses or 2) following large-scale management to maintain a low population density. When a small-scale herbicide APM strategy is employed, using fast-acting herbicides can increase the likelihood of meeting adequate CET and treatment efficacy overall. Small-scale herbicide treatments are not advised in flowing waterbodies, as they are expected to have severely limited efficacy due to the likelihood of rapid dissipation rates.

Large-scale herbicide treatments (treatments covering more than 10 acres or 10% of a lake's littoral zone) are generally more predictable in terms of anticipated CET and target species efficacy but are also likely to have greater non-target (e.g., plants and animal) impacts lake-wide. At least in the short-term, impacts on non-target plant species are likely unavoidable, so the presence of species of concern (either dominant species providing habitat or rare species) should be considered. Repeated herbicide treatments tend to shift plant communities toward dominance by a few highly tolerant native plant species (Mikulyuk 2017), so employing repeated treatments in lakes with high biodiversity may be inadvisable. Large-scale aquatic plant management, especially in lakes that are eutrophic, can cause increases in algae and reductions in water quality (O'Dell et al. 1995; Crowell et al. 2006; Valley et al. 2006; Wagner et al. 2007). Further research is needed on the long-term impacts of large-scale aquatic herbicide treatments, through comparison of ecological communities in waterbodies with and without a history of repeated chemical applications.

There is no single, accepted threshold at which management of aquatic plants should move from a localized, small-scale approach to a large-scale or whole-lake approach. The level of acceptable impact may depend on the target species. Less selective management strategies with greater non-target impacts may be warranted for species that are newer to the region, relatively isolated in distribution, and which are likely to have large adverse effects on ecosystems or ecosystem services. However, management strategies should take care to protect pristine and/or diverse ecosystems.

Recent research has also revealed the presence and timing of lake stratification is also an important consideration when planning herbicide treatments. In lakes that have stratified, the upper warm layer does not mix with the lower cold regions below the thermocline. Most of the herbicide remains in the relatively warm, upper water layer and doesn't mix to the lower layers (Getsinger et al. 2002; Nault et al. 2014; Netherland and Jones 2015). Thus, volumetric calculations are especially important when planning large-scale treatments. If the lake is stratified but the volume of the whole lake is used to calculate the amount of herbicide to apply, the concentration will be higher than needed and could lead to large non-target impacts to the lake (Nault et al. 2014; Nault et al. 2018). Accurate information on the depth contours of the lake are essential to calculate the amount of herbicide needed to selectively control invasive aquatic plant species in large-scale and whole-lake treatments. For example, in flowages and seepage lakes, volumes may change over time as sedimentation occurs or due to precipitation and evaporation, respectively. Moreover, some older contour maps are not accurate and never referenced water levels to an elevation, potentially creating an incorrect estimate of volume. It may be necessary to update bathymetry data and reference lake elevation to a permanent benchmark in order to achieve accurate lake volume estimates, especially if a waterbody is prone to water level fluctuations. A temperature profile should be collected prior to an herbicide treatment if stratification is expected or if stratification potential is unknown. This information will help to determine the depth of the thermocline and estimate the appropriate volume of lake water to be treated.

Understanding the ecology of aquatic plant communities and life history of target species can also help identify opportunities to increase efficacy and minimize non-target management impacts. For example, phenology data indicates that Eurasian watermilfoil and curly-leaf pondweed can emerge and grow at lower water temperatures than many Wisconsin natives, allowing those invasive species to start growing earlier in the season. Because of this seasonality, managing their populations in early spring may potentially reduce non-target impacts, as certain native plants are still dormant during this time. In addition, managing invasive plants when they are beginning to grow allows for targeting them while they are relatively small and vulnerable, rather than waiting to treat once they are larger and begin to cause ecological or recreational concerns. In the case of curly-leaf pondweed, its life history requires early spring treatment for long-term control. This plant produces vegetative reproductive structures called turions that fall to the lake bottom by early summer, creating a “seedbank” for future population growth. Management of curly-leaf pondweed must take place early in the season in order to limit turion production and long-term population resilience (Netherland et al. 2000; Poovey et al. 2002). If information on the life history of the target species or ecology of the aquatic community in which it exists is lacking, effort should be made to learn more before undertaking management.

Management efficacy can be maximized by using management strategies that have been tested in controlled settings, such as laboratories or mesocosms (controlled outdoor experimental systems), and subsequently evaluated in field trials. Particular attention should be paid to studies that illustrate the relationship between the intensity of a treatment and its effectiveness (Green and Westerdahl 1990; Glomski and Netherland 2010). When managing aquatic plant populations with herbicides, it is important to calculate the applied concentration and estimate a likely exposure time associated with any proposed treatment. The estimation of exposure time should consider treatment size and location, as well as lake-specific information on waterbody type, water movement and herbicide degradation time, and trophic status. In addition, there are many species-herbicide combinations for which an adequate target CET is unknown. In cases where a management strategy is proposed that lacks well-documented intensity-efficacy relationships, implementation should employ a research-based framework that will provide insight into this relationship and inform future management implementation. While not always possible, efforts to understand intensity-efficacy relationships would ideally be developed first in laboratory trials and then tested in the field using a standardized and repeatable monitoring strategy.

7.5. Hybrid Watermilfoil and Herbicide Resistance

Sometimes, two species can genetically combine to produce a new 'hybrid' form. In Wisconsin, pondweeds frequently hybridize, as do cattails, and crosses between native and non-native species are not uncommon. Most attention has been paid recently to hybridization among native and non-native milfoils – and most often we describe the genetic crosses between non-native Eurasian watermilfoil (*Myriophyllum spicatum*) and native northern watermilfoil (*M. sibiricum*). In general, hybrid watermilfoil (*M. spicatum* x *sibiricum*) typically has thicker stems, is a prolific flowerer, and grows much faster than pure-strain EWM (LaRue et al. 2013). These conditions may likely contribute to this plant being particularly less susceptible to chemical control strategies (Glomski and Netherland 2010; Poovey et al. 2007; Nault et al. 2018). An investigation of 28 whole-lake 2,4-D treatments in Wisconsin indicated smaller population reductions and shorter longevity of control on lakes that contained hybrid watermilfoil populations compared to lakes with only pure-strain Eurasian watermilfoil (Nault et al. 2018). Other laboratory and field studies have shown reduced sensitivity to 2,4-D, triclopyr, and fluridone in certain hybrid watermilfoil populations relative to unhybridized Eurasian watermilfoil (Berger et al. 2012; Thum et al. 2012; Berger et al. 2015; Parks et al. 2016). This can present a problem, hybrids have been found more frequently in lakes with a history of 2,4-D use (LaRue 2012).

Considerable molecular genetic diversity has been documented within hybrid watermilfoils, whereas Eurasian watermilfoil diversity has been documented to a lesser degree (Zuellig and Thum 2012). As a group of genetically variable biotypes, investigations have indicated different growth and herbicide response characteristics compared with Eurasian watermilfoil, particularly to auxin-mimic herbicides (Taylor et al. 2017). The heritable genetic variation allows selection pressures, such as herbicide response, to occur following management (Délye et al. 2013). Following implementation of an herbicide treatment, the innate tolerance of some individuals will result in survivorship whereas more sensitive strains will be controlled. Thus, the plants that re-populate the lake (largely through clonal reproduction) will be those that are more tolerant to the specific herbicide. Hybrid watermilfoil has been found more frequently in lakes with a history of 2,4-D use (LaRue 2012), as the pure-strain Eurasian watermilfoil component of the invasive milfoil population is hypothesized to have been selected against. A shift in an invasive milfoil population's ability to be controlled by a specific herbicide through selection is often referred to as herbicide tolerance evolution, whereas others would indicate that herbicide resistance in the population has developed. In some cases, herbicide resistant populations are still susceptible to the herbicide, but oftentimes a higher use rate (concentration and exposure time) may be required to produce the desired level of control. If an invasive milfoil population is comprised completely of pure-strain Eurasian watermilfoil, the limited amount of genetic diversity may not allow for herbicide tolerance selection that would result in shift towards a population with herbicide resistance.

Herbicide resistance is a concern because it threatens the efficacy of current APM practices (see Chapter 6 and Appendix E). While recent studies present evidence for herbicide resistance in hybrid watermilfoil, the potential for herbicide resistance to develop also exists for other species and herbicides. Herbicide resistance has been documented in aquatic plants such as hydrilla (*Hydrilla verticillata*) and dotted duckweed (*Landoltia punctata*) as well as many terrestrial weeds (Michel et al. 2004; Koschnick et al. 2006; Heap 2017). Herbicide resistant weeds are a major issue in agriculture, with glyphosate-resistant weeds alone having been estimated to cost over $1 billion in cotton, corn, and soybean production annually (Frisvold et al. 2017). Unique cases (species-mode of action combinations) of herbicide resistant agricultural weeds in the United States have been increasing steadily since 1975, with 478 unique cases worldwide as of 2016 (Shaw 2016; Heap 2017). While agricultural and aquatic systems are dramatically different in degree of herbicide use (much less in aquatic systems) and plant communities, the current thinking on best management practices to avoid the development of herbicide resistance in agriculture provides a head-start for managing to avoid herbicide resistance in aquatic plants.

Increasing the diversity of plant control strategies, or incorporation of integrated pest management (IPM), is needed to maintain management efficacy in the long-term. Overreliance and repeated use of a single herbicide or mode-of-action is recognized as the cause of herbicide resistance in agriculture (Norsworthy et al. 2012; Shaw 2016). As such, researchers advocate for increasing diversity in weed management strategies and investments into the development of herbicides with new modes of action, noting that implementing agricultural best practices now can lead to substantial cost savings in the future (Davis and Frisvold 2017). The same may apply for managing to prevent herbicide resistance in aquatic plants.

Despite 60 years of demonstrated herbicide resistance in agricultural weeds only limited adoption of agricultural best practices for managing herbicide resistant weeds has occurred (Shaw 2016; Frisvold et al. 2017). The factors influencing incorporation of herbicide resistance management strategies are complex in both agricultural and aquatic systems. Research on different APM techniques and combinations of techniques is needed to support incorporation of IPM into APM practice. The following obstacles to implementing IPM in agriculture have also been identified (Ervin and Jussaume 2014; Hurley and Frisvold 2016), and are also relevant for APM; all of these concerns with incorporating IPM into APM practice also arose in interviews with APM stakeholders:

- Higher costs of non-herbicide plant control strategies
- Time management
- Complexity
- Uncertainty (e.g., about the efficacy of non-herbicide approaches, whether or not resistance is occurring or will occur in the future, whether or not new technologies will be developed that would prevent herbicide resistance from being an issue, etc.)
- Impatience (e.g., the costs of utilizing management practices which may help prevent herbicide resistance are immediate, whereas the benefits may not be immediately apparent)

Encouraging adoption of practices to reduce development of herbicide resistance in aquatic plants may require an approach that engages all APM stakeholders and recognizes situational and stakeholder value differences. The following strategies are possible adapted components of an approach of this kind suggested for agricultural systems that can be applied to aquatic applications (Ervin and Jussaume 2014; Owen et al. 2015; Hurley and Frisvold 2016):

- Increase awareness of herbicide resistance prevention practices as well as economic benefits of those practices through education and outreach to all APM stakeholders
- Develop policies and short-term incentives (through industry or government agency) that support IPM in APM
- Develop monitoring and enforcement procedures that support IPM/APM policies
- Conduct and promote research related to herbicide resistance management (Mortensen et al. 2000)
- Incentivize development of a diverse range of new APM techniques
- Establish localized herbicide resistance monitoring and prevention programs within communities to guide APM efforts for specific threats

Further integration of IPM in APM may reduce the risk of herbicide resistance development in aquatic plants and lead to future cost-savings by ensuring sustained efficacy in all plant control techniques. However, as 60 years of research related to herbicide resistance development in agricultural weeds suggests, significant commitment to implementing strategies to overcome barriers may be required for widespread adoption of these IPM practices.

7.6. Management Planning, Integrated Pest Management, and Adaptive Management

Due to waterbody and stakeholder variability, a comprehensive approach involving planning, IPM, and adaptive management can improve and sustain management outcomes and better meet the objectives outlined in chs. NR 107 and 109, Wis. Admin. Code.

While the goals of stakeholders are diverse, achieving any goal will likely require long-term commitment. Eradication of invasive species has proven very rare unless the species is found very early after introduction and the population is small and isolated. Management of Eurasian watermilfoil and curly-leaf pondweed using large-scale herbicide treatments can sometimes greatly reduce the abundance of a target species for multiple years but also can have substantial effects on non-target species and are unlikely to completely eradicate the target species. Ongoing investment in management is usually necessary to maintain population reductions. Conversely, management conducted on a small scale will likely provide only short-term relief and will necessitate annual input of additional management effort.

Lake organizations and other APM permit applicants should be aware of the long-term commitment and determine if they have the organizational and financial capacity to sustain the annual effort required to achieve a management goal. While small-scale projects appear more affordable at the beginning of management, repeated small-scale herbicide management may end up being costlier over the long-term. When large-scale treatments are used to achieve lakewide reductions, additional small-scale management employing a variety of integrated techniques is typically required following large-scale management to maintain management outcomes. Non-target effects of large-scale treatments can be substantial, and where large-scale herbicide treatments reduce the abundance of both target and non-target species, repeated large-scale treatments may facilitate growth of certain species that are tolerant of disturbance, fundamentally changing the native plant community (Mikulyuk et al. 2017).

Consideration of costs as well as the expected frequency of management is necessary when developing a long-term management plan, and management should seek to achieve the desired outcome while minimizing overall adverse effects to fulfill the objectives of NR 107, NR 109 and WPDES.

The department offers technical assistance and funding for organizations to develop management plans. Incorporation of IPM should be included in the planning process, as it is a condition of WPDES permits. IPM practices can not only help prevent potential development of herbicide resistance but may also increase success in achieving APM goals (Chapters 1.3, 2.2, and 7.5 further describe IPM and its value to APM planning). After plans are approved by the department, organizations become eligible for cost-sharing to implement eligible management strategies. Per [ch. NR 198, Wis. Admin. Code](), grants are available for AIS early detection and response, prevention, established population control, and management evaluation activities.

Below is an example of the elements a lake management plan should identify. A similar approach can be adapted for other surface waters and wetlands as applicable.

a. Concerns of association/district members and/or stakeholders related to the aquatic ecosystem or ecosystem services
b. What is known about the lake now and historically
    i. Status of the aquatic plant community, including a minimum of one year of baseline aquatic plant data
    ii. Lake use (e.g., boating, waterskiing, fishing, drinking water, etc.)
    iii. Inputs of nutrients or other pollutants
    iv. Watershed and shoreline conditions
    v. Water quality
    vi. Fish and wildlife and their habitat requirements
    vii. Lake management history
c. Specific management objectives
d. Target levels of control
e. A review of management options and the associated costs; all management options (including the no management), should be discussed and explained
f. Potential non-target, adverse ecosystem effects of management
g. A management strategy recommendation to achieve the target levels of control
h. A strategy to maintain the outcome following the initial management effort
i. Potential non-target, adverse ecosystem effects of the selected management strategies
j. An implementable invasive species introduction prevention strategy
k. An evaluation strategy to assess the efficacy and impacts of management, including collection of additional data to measure future change
l. An adaptive management timeline (including monitoring, management, and evaluation)
m. A description of the process used to provide the public the opportunity to comment on the plan, including a summary of comments received and documentation of the actions taken in response to the comments

Because most APM goals require long-term commitment, it is critical that there is a plan to evaluate management outcomes. Additional research is needed to better understand management expectations for a variety of species and management techniques. In addition, each system has a specific set of lake users, desired uses, and ecological conditions that will lead to different management strategies and outcomes. Appropriate management evaluation will help managers adapt their strategies to more effectively meet their specific management objectives and facilitate the improvement of best management practices statewide.

Monitoring allows evaluation of management efficacy and non-target effects. It's important that data is collected in a standardized and repeatable way before, during, and after management is conducted. This approach to data collection allows evaluation of management efficacy, longevity, and non-target impacts. Ideally, multiple years of pre- and post-management data should be collected to account for natural variation and document recovery over time. However, the majority of APM projects currently occur on waterbodies without pre- and post-management information because of the added expense for permittees. Grant-funded and research projects provide opportunities to monitor and evaluate APM activities.

The frequency and timing of data collection outlined in a monitoring plan should be designed regarding the specific life history of the target species. For example, curly-leaf pondweed (*Potamogeton crispus*), given its habit to grow to maximum abundance early in the growing season, should be monitored in spring before management is conducted and then again, the following spring to evaluate management. Most other aquatic plant species should be monitored during mid-to-late summer in the year before management and then again either during the year of management, to assess seasonal reductions, or the year after management, to measure year-to-year changes. A monitoring plan should include an assessment of possible non-target effects and monitoring should take place, when most potential non-target species are actively growing. Additionally, the more consistency in monitoring procedures across time and location, the more data can be used to evaluate efficacy and management techniques.

Specific goals of management should also be considered when developing an evaluation plan. For example, if a goal is to disrupt species reproduction and reduce population size over multiple years of management, then the quantification of propagules (e.g., turions, bulbils, etc.) as management progresses over time is important. If the goal is purely for seasonal nuisance relief, then post-management monitoring during the summer of management will best evaluate progress toward that goal. However, if large-scale management is planned for system-wide population control, evaluation should take place in the years following management to verify the longevity of management effects. It is also important to measure the intensity of management. In lakes, this may mean measuring the CET of herbicide in the water following treatment. Quantifying the effort of other management approaches is also appropriate (e.g., the number of hours spent, and area covered using manual removal). It may also be beneficial to monitor and evaluate substrate and water quality along with herbicide concentration. The combination of management intensity and plant data will help to determine if specific management strategies met the management objectives and if changing strategies is warranted.

A good evaluation plan will facilitate adaptive management to better meet desired management goals. Careful planning and assessment at all stages of the management process will improve management outcomes at the individual lake level, facilitate positive collaborations between involved stakeholders through identification of expectations, and contribute to improving APM practices statewide. However, additional costs and time-investment present challenges for the monitoring and evaluation. Strategies to support evaluation in the state's model for APM are needed. These strategies could include revised monitoring methods and/or schedules or statewide prioritization of which APM projects should be monitored.

7.7. Cause for Variation in Management Strategies Statewide

Ecological differences across waterbody types are important to consider when considering a management strategy. As described in Supplemental Chapter S.2.2, the species composition of an aquatic plant community is determined by many natural factors, such as alkalinity, nutrient availability, and water clarity, among others.

Management strategies differ according to environmental factors. In the southern half of the state, watershed development, nutrient loading, and alkalinity are generally higher than in the northern half of the state. These factors contribute to higher invasion rates by non-native plant species and altered, low diversity plant communities made up of more tolerant species. Aquatic plant abundance if oftentimes either much higher or much lower than would be present in the absence of human activity. In the north, where watershed development, nutrient loading, and alkalinity are generally lower and plant communities are more diverse, APM strategies are more frequently protective in nature. However, because non-native species populations are present in fewer waters, stakeholders may choose management strategies to try and eliminate or contain non-native species from further spread. It is important to note that this is not a rule but a generality. Indeed, there are some lakes in the southern part of the state that exhibit qualities of relatively undisturbed conditions, just as there are some lakes in northern part of the state which show higher degrees of anthropogenic impacts.

Socio-economic factors also drive management in various ways across different regions. Many lakes in the south have a long history of APM. A greater number of permit requests are usually received for APM activities in the south. Because plant communities in the south are generally more heavily manipulated, high-quality plant communities are regionally important as habitat refuges and propagule sources for the larger regional plant community. Impaired waters not meeting water quality nutrient standards should be considered as potential candidates for restoration. Impaired waters often also have impaired plant communities; tall-growing, low diversity, disturbance tolerant species that are more likely to cause navigational and use impairments than stable, more diverse native communities. Restoring water quality by reducing incoming nutrients could provide opportunities to "restore" the plant community over time as well.

Each waterbody is unique, and the appropriate management strategy should in turn be uniquely determined, given the characteristics and management goals of that waterbody. Each lake should be afforded careful consideration of the balance between protection and restoration priorities. Ecological differences and disturbance history may influence the decisions made across the state, and these combined with social needs all contribute to differences in management philosophies throughout the state, making consistent statewide implementation of APM policies a challenge. Subjectivity is built into chs. NR 107 and 109 to allow department APM staff to account for the statewide and individual waterbody-level differences described here. In the future, APM policy may benefit from some consistent standards but also recognizing where the uniqueness of individual lakes may require specific management decisions.

7.8. The Importance of Understanding the Relationship between Aquatic Plants and Water Quality

The relationship between water quality and aquatic plants can often be overlooked but should be explicitly considered when developing an APM strategy. Nutrient management can be a key tool in IPM and strategic management. Excessive lake sediment nutrients, particularly nitrogen and phosphorus, go hand-in-hand with excessive plant growth. While high plant biomass is often not thought to be beneficial by stakeholders, lakes that support a healthy population of aquatic plants can better accommodate nutrient additions. Aquatic plants support periphyton (a complex assemblage of tiny freshwater organisms that attach to plants) that take up phosphorus, making that nutrient less available for algae. Furthermore, particulate matter settles out in the slow-moving water of plant beds, and nutrients are then buried when aquatic plant roots stabilize the sediment (Barko and James 1998; Brenner et al. 2006).

While abundant nutrients may contribute to excessive aquatic plant growth, reducing nutrient loading is not a short-term solution. For most stakeholders, a temporary solution to reduce seasonal nuisance levels of vegetative aquatic plants is much more tangible and preferred. Aquatic plant control efforts will always be a temporary solution to improving access for waterbody uses (e.g., navigation, recreation). Nutrient-rich lakes tend to favor tall-growing plants species that are most likely to interfere with beneficial waterbody uses. While it is understandable that management actions intended to reduce the abundance of aquatic plants are often requested in high-nutrient eutrophic lakes, management should always be conducted with care because large-scale aquatic plant management actions can potentially “flip” a heavily vegetated lake to a turbid lake, dominated by blue-green algae with few aquatic plants. This algae-dominated condition can persist for a long time (Wagner et al. 2007; Hilt et al. 2013).

On the other side of the nutrient gradient, protective measures are particularly important for oligotrophic and mesotrophic lakes. These lakes have fewer nutrients and fewer aquatic plants than eutrophic lakes, so protection of fish and wildlife habitat is important to consider when aquatic plant control is considered. Herbicides have been shown to persist longer and can result in greater aquatic plant damage in these types of lake (Frater et al. 2016; Nault et al. 2018). This, combined with the tendency for these lakes to have less aquatic plant habitat than other lake types, may lead to greater potential for negative effects of management on invertebrate, fish, and wildlife populations if plant cover is reduced. The addition of sediment and nutrient runoff to these lakes can change the plant community from short-statured to larger, taller aquatic plant species that are more likely to impair beneficial uses in the future (Borman 2007). Creating and maintaining healthy, natural shorelines and implementing watershed protection plans to prevent additional sediment and nutrient runoff from reaching the lake should be part of a plant management strategy.

Decreasing nutrient loads to freshwaters and/or removing or inactivating the nutrients already present may addresses the root cause of nuisance plant growth in the long-term. When external nutrient loading is the primary cause of high nutrient content in a waterbody, approaches to reduce agricultural and stormwater runoff can be beneficial. Reducing external nutrient loading can be challenging, as it requires collaboration with and behavioral changes from watershed residents. The department's Surface Water Grants, Total Maximum Daily Load (TMDL), and Nine Key Element Planning efforts attempt to set targets and make progress towards reductions in nutrient loading. Despite the challenges, nutrient management may provide long-term relief from or prevent overabundant aquatic plant growth, reducing the need for chemical or physical control.

It is important to note that nutrient reductions alone will not be enough to reduce aquatic plant coverage to socially-desired levels in most lakes, especially in a time-frame acceptable to most stakeholders. In high-nutrient lakes, reducing nutrient loading to the extent that it could reduce aquatic plant growth is expected to be a very long, multi-generational process. Efforts would first be needed to dramatically reduce external loading, followed by in-lake methods to reduce the internal nutrient load. Additionally, in very shallow lakes, where increased light availability throughout the waterbody make it particularly easy for aquatic plants to grow, nutrient reduction is not likely to reduce plant cover. In eutrophic and hypereutrophic lakes, nutrient management may improve water clarity and reduce algal abundance to the point it increases aquatic plant cover (Helsel and Zagar 2003). In this way, water quality restoration efforts may come with some added recreational or navigational impairments.

Regardless of waterbody type, considering the nutrient content of the target ecosystem can benefit aquatic plant management (APM) efforts. Reducing nutrient loading may help reduce the need for APM and can improve water quality. Consideration of a lake's nutrient content when conducting APM can also prevent serious, unintended ecological consequences. Therefore, nutrient management should be integrated in and regarded as a key component of planning APM activities.

8. Management Alternatives

This chapter presents a set of potential management alternatives to the status quo in aquatic plant management (APM) as practiced by the Wisconsin Department of Natural Resources (department), its partners, and APM stakeholders. These alternatives are based on suggestions made by stakeholder interviewees (see Chapter 6 and Appendix E), reviews of the scientific literature, and additional discussions with APM stakeholders and department staff. Every alternative suggested by stakeholder interviewees is included here, although it is possible that additional ideas and alternatives could still be identified.

As is the case with all strategic analyses, the department is neither prioritizing nor advocating for any alternative. [12] Each alternative presented here constitutes a potential course of action that the department, its partners, and/or APM stakeholders may consider as a means of improving some aspect of APM in Wisconsin. For the most part, individual alternatives are not mutually exclusive. That is, pursuing one alternative would not rule out pursuing others.

As presented in the eight sections that follow, individual alternatives are grouped into broad categories, beginning with "Collaboration" (section 8.1). These were identified by stakeholder interviewees as aspects of APM in Wisconsin needing improvement (see Chapter 6). Some alternatives address more than one aspect of APM. For example, the alternative *Collect additional data on APM activities* is listed under "Program Tracking and Evaluation" (section 8.4), although it also relates to "Integrating New Information" (section 8.5).

Each of the eight sections begins with a summary of how the aspect of APM in question (e.g., collaboration) might fare should the status quo be left unchanged. Individual alternatives are then described. At the end of each section, a summary table lists all the alternatives, including whether they would require changes to Wisconsin administrative code and/or statute, along with linked references to other chapters and appendices containing relevant background and supporting information.

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[12] Per the requirements of s. NR 150.10 (3) (b), a strategic analysis "shall consider the alternatives and environmental effects in a dispassionate manner and may not advocate a particular position about alternatives."

8.1. Collaboration

Stakeholders identified that the department should increase staff commitment and collaboration with partners to continue to ensure permitting decisions consider all relevant ecological and socio-economic information, pursue sound science, and maintain positive and fruitful partnerships.

If the *status quo* is maintained:

APM staff and permittees may continue to experience friction related to permitting decisions. Partners may continue to feel left out of lake and aquatic plant management processes.

Alternatives:

Collaboration - Alternative 1. Create an APM Study Group for communication and collaboration with stakeholders on the direction of APM policy in the state.

> Under this alternative, an APM Study Group consisting of department staff and predominantly non-department APM stakeholders and partners could be formed to discuss the future direction of APM. The Study Group could provide input on how APM can be more collaborative, updates and feedback on current APM practice. The department currently plans to form an APM Study Group to assist in finalizing this strategic analysis between 2018-2019. This alternative could make that group a standing study group.

Collaboration - Alternative 2. Establish a mentorship program for individuals new to the APM permitting process.

> A mentorship program for APM permit applicants could aid in navigating the permitting process and increase sharing of perspectives, information regarding management experience and efficacy, as well as ecological tradeoffs of management. The department and/or partner groups could develop a list of trained citizen volunteers with up-to-date experience conducting APM who would be willing to provide advice to new applicants. Individuals new to APM could then contact a volunteer in their area of the state with questions about the process, allowing them to learn from the experience of someone who has previously been in their position. One approach would be to partner with UW-Extension's Lake Leaders, individuals who have taken courses on lake management and community organization. This alternative may lead APM permit applicants to rely less on department APM staff or private consultants in management planning.

Collaboration - Alternative 3. Establish a more public and open process around APM activities and decision-making during the APM permitting process.

> Many APM actions are initiated by lake property owners or lake associations while others involve county and city water resources staff. There are many ways APM actions may be initiated but, regardless of the entity pursuing management, that entity typically works directly through the APM permitting process with department staff. Despite the fact that APM permits and applications can be viewed by the public online (see Appendix F for instructions), stakeholders who are not directly

involved in the permitting process may be unaware of the proposed action. Having a more public and open process particularly around large-scale APM activities, with increased notification requirements and potential for public meetings, could better inform and involve stakeholders not actively conducting APM activities, and some department staff and partners currently initiate this type of enhanced stakeholder engagement. This would also likely lengthen the permitting process and increase workload for department staff, APM permittees, and private APM professionals.

Collaboration - Alternative 4. Extend the maximum amount of time allowed for processing APM permits when collaboration with Native American tribes or the Great Lakes Indian Fish and Wildlife Commission (GLIFWC) are required.

Increasing the time allowed to process permits involving the tribes and/or GLIFWC could help to ensure that tribal organizations have adequate time to review and consider proposed APM activities when they occur within the Ceded Territory or within tribal lands. It could also set better expectations for permit applicants regarding permit processing times. Department staff could notify applicants when permits are likely to be processed if they're expected to require more than 15 business days. This may also lengthen the permitting process.

Collaboration - Alternative 5. Require all department APM coordinators to obtain and maintain Department of Agriculture, Trade, and Consumer Protection (DATCP) certification in aquatic pesticide use.

This would require department APM staff to have a similar understanding of aquatic pesticide use as the private management professionals whose activities they regulate. Requiring DATCP certification for department APM coordinators may further improve consistency among department staff and ensure department and industry APM professionals have similar knowledge of how chemical management activities are to be conducted as well as the ecological effects of those activities. This is currently the policy of the department's APM program but has been difficult to carry out due to the many staff involved in issuing APM permits.

Collaboration - Alternative 6. Require DATCP pesticide applicator certification or other training certificate for consultants who do not conduct chemical treatments but define treatment areas and choose products and application rates.

This alternative would require that private APM consultants, who sometimes specify herbicide products and application rates in APM plans, have the same level of training as chemical applicators who conduct the herbicide treatments. Full certification or proof of similar training or understanding without annual certification (e.g., an exam or participation in a workshop or class) could be required. This may improve proposed treatment plans but would increase workload for private consultants. Additionally, this alternative would require collaboration between the department and DATCP.

Collaboration - Alternative 7. Implement strategies to support further adoption of Integrated Pest Management (IPM) in APM practice.

Adopting strategies to better support IPM implementation in APM will assure compliance with the Wisconsin Pollution Discharge Elimination System (WPDES) directive to utilize an IPM approach and help improve management outcomes and prevent the potential development of herbicide resistance in aquatic plants. Strategies may include further development and enforcement of IPM/APM policy, incentivizing the use and development of a diverse range of APM approaches by industry or government, or establishing localized plans to drive IPM and herbicide resistance management in APM. Education and outreach on the benefits of these IPM practices may be required to align all APM stakeholders (see Chapter 7.5 and Outreach and Education Alternative 5). Effective monitoring for compliance with rules may also be needed to support enforcement. Additionally, a plan for the longevity of the incentive program may help prevent unprecedented costs over the long-term. This alternative may require changes in APM policies.

Collaboration - Alternative 8. Develop a separate APM permit and grant application form for APM activities in wetland and shoreline sites.

This alternative could ease the permitting process for applicants interested in controlling aquatic plants in wetland and shoreline settings. Department staff across programs have expressed concern that wetland invasive plant management can be difficult through the APM program. Revision of grant and permit application forms could make the program more inclusive of wetland plant management and improve relations and collaboration with public applicants and DNR staff involved in terrestrial plant management. This alternative could improve the wetland plant management process in the state, especially if combined with Alternative 9 above.

Collaboration - Alternative 9. Revoke public notice and mapping requirements for APM permits for treating of individual or patches of non-native plants with herbicides in wetland areas larger than 10 acres.

Currently, if an individual intends to treat individual or patches of non-native plants with herbicides in areas larger than 10 acres, they may opt to apply for a permit to treat the entire wetland area to avoid having to map specific locations and allow the flexibility to treat non-native plants as they are encountered in the area. If an applicant decides to apply with a proposed treatment larger than 10 acres in waters of the state, there are additional mapping and public notice requirements under ch. NR 107. This can also result in additional expenses and fees. This alternative would allow individuals to apply and specify if they intend to only treat individual or patches of non-native plants within a site, saving time and effort for the applicant. Additionally, this would reduce workload for applicants which may support additional control of non-native species. This alternative could propose revised public notice requirements for herbicide treatments of this kind to appropriately allow the public to comment on the treatment activities.

Collaboration - Alternative 10. Reduce APM permitting fees to make APM more affordable for permittees.

With reduced permitting fees, APM would be more affordable, allowing a larger number of interested individuals to conduct APM, and potentially reducing the frequency of illegal APM activities. An increasing number of permit applications would increase department staff workload. The department would not be able to support as many APM staff, further increasing workload for remaining staff and exacerbating issues related to collaboration, communications, and integration of new APM information.

Collaboration – Alternative 11. Reduce department reliance on limited-term employees (LTE) for implementation of the APM program or designate specific scenarios in which permanent staff should take on the work.

This alternative could help ensure that the APM program or various aspects of the APM program are executed by department staff with enough experience in APM permitting and planning. While the LTEs conducting this work often have ample experience, turnover can be an issue for department staff workload and be concerning to some APM stakeholders. Increased reliance on permanent department staff could also improve consistency in permitting decisions and facilitate longer-term collaboration between stakeholders and department staff. This alternative would increase the already high workload for permanent department staff and may therefore be best implemented in combination with Resources and Workload - Alternative 1 or some other strategy.

Collaboration – Alternative 12. Request input from APM stakeholders at annual meetings on research questions of interest.

At regularly scheduled annual meetings, the department could request ideas from APM stakeholders on research studies that would benefit their work. This could help steer the direction of research efforts funded by state grants or efforts the state collaborates on with other parties to ensure that those efforts will further APM practice statewide.

Collaboration – Alternative 13. Create a new permanent position within the department to facilitate collaboration between the department and APM service providers.

This alternative would allow a full-time individual within the department to work with APM service providers. This person could keep APM service providers informed of projects occurring within the department and involve them in those projects when appropriate. This person could also bring an increased awareness of APM stakeholder concerns to the department and work toward addressing those concerns. This alternative may be best implemented along with Resources and Workload Alternative 1 or some other strategy to avoid losses to other aspects of the APM program.

Table 8-1. Alternatives related to collaboration between DNR staff and APM partners, stakeholders

Alternative (√ = Planned or in Progress)	**Requires changes to Rules or Statutes?**	**Possible Outcomes / Consequences**	**Additional Information:**
1. Form APM Study Group √	No	• Improved communication and collaboration • Temporarily increased workload for study group participants	Ch. 5.2 Appendix D
2. Establish mentorship program	No	• Improved communication and collaboration	Ch. 5.2 Appendix D
3. Increase public involvement in the permitting process	Yes (Chapters NR 107 and NR 109)	• Improved communication, particularly with stakeholders not actively involved in APM activities • Increased permit processing time and workload	Ch. 5.2 Appendix D
4. Extend maximum processing time for permits involving tribes/GLIFWC	Yes: Chapters NR 107 and NR 109	• Improved collaboration with Native American tribes • Increased permit processing time	Ch. 4 Appendix B
5. Require all department APM coordinators to obtain and maintain Department of Agriculture, Trade, and Consumer Protection (DATCP) certification in aquatic pesticide use	No	• Improved collaboration by requiring similar training of department staff and APM service providers • Improved consistency by requiring similar training among department staff	Ch. 2 Ch. 5 Appendix D
6. Require DATCP pesticide applicator certification of APM service providers who advise on APM activities	Unknown	• Improved communication and collaboration • Improved herbicide treatment planning • Increased workload for some APM service providers	Ch. 5 Appendix D
7. Implement strategies to support implementation of IPM	Unknown	• Improved communication and collaboration • Increased implementation of IPM • Reduced potential for development of herbicide resistance • Increased or re-allocated costs for the state • Collaboration between department staff and policymakers	Ch. 1.3 Ch. 2.2 Ch. 5.2 Ch. 6.3 Ch. 6.6 Appendix D
8. Develop separate APM permit and grant application forms for APM in wetland sites	No	• Improved collaboration between DNR staff and applicants • Improved data management • Improved permit and grant review processes • Decreased workload for DNR staff and permit applicants	Ch. 3
9. For APM in wetland sites, revise requirements specific to large-scale chemical treatments	Yes (Chapter NR 107)	• Reduced workload and costs for APM service providers • Revised public notice requirements for some wetland APM	Ch. 3

(Continued)

Alternative (√ = Planned or in Progress)	**Requires changes to Rules or Statutes?**	**Possible Outcomes / Consequences**	**Additional Information:**
10. Reduce APM permitting fees	Yes (Chapters NR 107 and NR 109)	• Increased APM activities throughout the state • Increased compliance with APM policy • Increased APM staff workload, which may decrease collaboration and communication	Ch. 5 Appendix D
11. Reduce reliance on LTEs for APM program implementation	No	• Improved consistency in APM permitting decisions • Improved collaboration • Improved permit and grant review processes • Increased APM staff workload	Ch. 2 Ch. 5 Appendix D
12. Request stakeholder input on APM research of interest	No	• Encourage the initiation of research projects of interest to APM stakeholders • Increase likelihood of APM research being implemented in APM practice	Ch. 2.4 Ch. 5.2 Ch. 6.6 Appendix D
13. Create a department position for facilitating collaboration between staff and APM service providers	No	• Improved collaboration with APM service providers • Increase department awareness of APM stakeholder concerns	

8.2. Department Resources and Workload

Based on stakeholder interviews, individuals' relationships with department APM staff are generally positive. However, some have expressed a need for more one-on-one interaction, check-ins, shorter permit review times, and stability for department staff. Department APM staff feel overwhelmed with their workloads, which involve balancing their APM duties with many other responsibilities related to other programs.

If the *status quo* is maintained:

Stakeholders may continue to feel that department APM staff do not have enough time to consider their concerns and provide guidance. Permit review times may increase if the number of permit applications received annually continues to increase.

Alternatives:

Resources and Workload - Alternative 1. Increase the number of department APM staff.

> Increasing the number of department APM coordinators would likely allow better communication and collaboration with stakeholders and enhanced review of APM permits and management evaluation. More permanent APM staff, with a greater understanding of organizational knowledge and practice than LTEs, would likely improve permitting decisions and maintain consistency in those decisions. Additional APM staff duties could focus on specific needs such as APM research, AIS education, or other topics.

Resources and Workload - Alternative 2. Create new DNR positions specializing in APM and AIS for each region of the state.

> Currently, APM work is the responsibility of regional department lake biologists who are also responsible for assisting with many other aspects of lake management. This enhanced specialization could not only reduce workload for the current lake biologists, it could also improve consistency in APM decision-making, particularly if these were permanent positions. Customer service may also improve as both classifications have more time to dedicate to various projects and working with citizens.

Resources and Workload - Alternative 3. Reduce regulation of APM in private ponds.

> APM in private ponds is of lower interest to the public than APM in public waters, yet APM in public and private waterbodies is similarly regulated. Creation of a general permit, allowing multi-year permits, exempting lined artificial private ponds, or exempting permits for APM in all private ponds could benefit permit applicants through reduced permit processing times or reduced frequency in going through the permitting process. Fees and reporting requirements would need to be adjusted accordingly. This alternative would reduce the workload of the department's APM Central Permit Intake Coordinator but would not reduce workload for department APM field staff. Reduced regulation of APM activities in private ponds could reduce funding for department's APM program

and may have detrimental effects on fish and wildlife populations, endangered or at-risk species, groundwater infiltration, as well as waterbody and human health. Moreover, if record-keeping requirements change along with permitting requirements, department staff and service providers may not maintain records of management history, which are important for devising management strategies. Record-keeping requirements and a process for adjusting permit conditions from one year to another (for multi-year permits) may help to reduce potential negative effects associated with this alternative.

Resources and Workload - Alternative 4. Allow issuance of multi-year permits for chemical APM projects in public waterbodies, following the approval of an APM plan.

Multi-year ch. NR 109 permits can already be approved for mechanical control activities when they align with a DNR-approved APM plan. Allowing multi-year ch. NR 107 permits for chemical APM activities could reduce workload for department APM staff, as well as consultants, and permitees. Fees and reporting requirements would need to be adjusted accordingly. Given natural annual variation in aquatic plant communities, chemical APM activities may be conducted unnecessarily in the absence of regulatory oversight which may result in unnecessary costs and adverse ecological impacts.

Resources and Workload - Alternative 5. Increase permit exemptions and/or develop general permits when the purpose of management agrees with the purpose of NR 107.

Implementing this alternative could streamline invasive species control efforts initiated by the department and its partners, aiding in preventing invasive species' spread and potentially increasing collaboration among department programs. This change would require revision of ch. NR 107, and ch. NR 109 has a similar exemption. This may result in some losses of permit fee revenue for the department.

Resources and Workload - Alternative 6. Increase APM permitting fees to support additional staff, efficiency, and collaboration.

Increasing APM permit fees could help to support more APM staff, which could improve the program's responsiveness and communication with stakeholders as well as the quality of management recommendations and actions. Of course, this would also result in greater costs for the permittee. Increasing the baseline permitting fee, rather than cost per acre managed, may help prevent excessive cost increases.

Resources and Workload - Alternative 7. Create a department assurance process for private aquatic plant managers and consultants like that used in wetland delineation.

Development of a DNR assurance process for private aquatic plant managers and consultants could assist in streamlining the permitting process and set high professional standards. The department could require applicators to have this assurance to conduct APM on public waters. APM professionals who are assured could receive lighter permit review and use the assurance in marketing their services. At minimum, an assurance program would likely require definition of objective criteria and a minimum level of education, training, and experience for assurance. Assurance training could involve aquatic plant species identification, best management practices for APM, and other topics. However, an assurance program of this kind would need to carefully consider how assurance would differ from DATCP pesticide licensing, what value the assurance would provide in terms of building trust and reducing workloads for department staff and APM professionals. Careful consideration of quality assurance approaches, consequences of non-compliance, potential partnerships and acceptance by other agencies regulating APM, and whether individuals or organizations would be certified would also be needed. At this time, the department is implementing an aquatic plant identification training program which could be built into the assurance process.

Resources and Workload - Alternative 8. Partner with DATCP to develop a certification program specifically for APM in public waters.

This could allow integration of best practices for APM in public waters into DATCP's pesticide applicator certification program and could allow appointment of a new applicator class, helping to streamlining the APM permitting process and setting high professional standards. The department could require applicators to have this certification to conduct APM on public waters. APM professionals who are certified could receive lighter permit review and use the certification in marketing their services. At minimum, a certification program would likely require definition of objective criteria and a minimum level of education, training, and experience for certification. Certification training could involve aquatic plant species identification, best management practices for APM, and other topics. However, a certification program of this kind would need to carefully consider how certification would differ from DATCP pesticide licensing, what value the certification would provide in terms of building trust and reducing workloads for department staff and APM professionals. Careful consideration of quality assurance approaches, consequences of non-compliance, potential partnerships and acceptance by other agencies regulating APM, and whether individuals or organizations would be certified would also be needed.

Resources and Workload - Alternative 9. Develop online templates for use in APM planning.

Online planning templates could help streamline APM planning efforts. Several of the components of a lake management plan (identified in Chapter 7.6) could be populated in a template that interfaces with the department's Surface Water Integrated Monitoring System (SWIMS) database. The template could possibly be used to model outcomes and timelines of various management strategies and their costs to assist individuals interested in conducting APM activities with determining the appropriate strategy for meeting their goals. This could reduce the amount of effort invested in APM planning for consultants and department staff. It could also reduce the amount of grant funding dedicated to APM planning and free up resources for use in other efforts. The utility of this template would be dependent on the accuracy and organization of SWIMS data. It would also require extensive effort up front for development.

Resources and Workload – Alternative 10. Designate a specific annual time-window in which APM permits can be submitted and processed.

This alternative would create a set period of the year in which APM permits could be received and processed by the department. APM staff could prioritize APM work during this time period, reducing their APM workload for the remainder of the year. This could also come with a deadline by which all applicants should have received their approved permits, which may better allow the department to meet their expectations. However, this may prevent management of problematic plant populations that arise unexpectedly, thereby frustrating APM stakeholders who find it convenient to be able to apply for an APM permit throughout the calendar year.

Table 8-2. Alternatives related to department resources and workload.

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
1. Increase the number of DNR APM staff	Unknown	• Reduced DNR APM staff workload • Improved communication and collaboration • Improved APM permit review	Ch. 2 Ch. 5 Appendix D
2. Create new regional DNR positions specializing in APM and AIS	No	• Reduced DNR APM staff workload • Improved communication and collaboration • Improved consistency in APM permitting decisions	Ch. 5 Appendix D
3. Reduce regulation of APM in private ponds	Yes (Chapter NR 107, or new general permit)	• Reduced workload for APM permit applicants • Reduced permit processing times • Reduced DNR Central Office APM staff workload • Adjusted fees and reporting requirements • Reduced DNR staff evaluation prior to APM activities • Potential for reduced compliance/ negative ecological effects	Ch. 2.3, 2.5 Ch. 5 Appendix B Appendix D
4. With plan, allow multi-year NR 107 permits in public waterbodies	Yes (Chapter NR 107)	• Reduced workload for APM permit applicants • Reduced permit processing times • Reduced DNR APM staff workload • Reduced DNR staff evaluation prior to APM activities • Adjusted fees, reporting, and posting requirements • Potential for increased overall costs, frequency, and detrimental ecological effects of APM	Ch. 2.2 Appendix B
5. Increase permit exemptions and/or develop general permits when the purpose of management agrees with the purpose of NR 107	Yes (Chapter NR 107)	• Reduced DNR staff workload • Small reduction in DNR permit fee revenue	Ch. 3
6. Increase APM permitting fees	Yes (Chapters NR 107 and NR 109)	• Increased costs for APM permit applicants • Potential to support additional DNR APM staff and activities (see "Expected Outcomes" in this table for Resources and Workload Alternative 1) • Potential to reduced DNR APM staff workload	Ch. 5 Appendix B

(Continued)

Alternative (√ = Planned or in Progress)	**Requires changes to Rules or Statutes?**	**Possible Outcomes / Consequences**	**Additional Information:**
7. Create a DNR certification process for private APM professionals	Unknown	• Small increase in workload for private APM professionals • Designation for private APM professionals to utilize in marketing their services • Implement standards for private APM professionals • Potential for lighter permit review of certified individuals • Potential to require certification for APM conducted on public waterbodies • Potential for reduced DNR APM staff workload • Potential for overlap with DATCP pesticide licensing	Ch. 2.3
8. Partner with DATCP to develop a certification program for APM in public waters	Yes (Chapter NR 107)	• Small increase in workload for private APM professionals • Designation for private APM professionals to utilize in marketing their services • Implement standards for private APM professionals • Potential for lighter permit review of certified individuals • Potential to require certification for APM conducted on public waterbodies • Potential for reduced DNR APM staff workload • Potential for overlap with DATCP pesticide licensing	Ch. 2.3
9. Develop online templates for use in APM planning	No	• Reduced DNR APM staff workload in the long-term • Reduced DNR funding spent on APM planning • Need for continued maintenance of the template by DNR staff to ensure appropriate recommendations • Potential for improved APM permit review • Potential for improved management plan recommendations by DNR staff and private APM professionals	Ch. 2.3 Appendix D3
10. Designate an annual time-window for submission and processing of APM permits	Unknown	• Reduce workload for APM staff for part of the year • Improve collaboration by providing APM permit applicants with specific expectations • Cause frustration for APM stakeholders facing unexpected problematic plant populations	Ch. 2 Ch. 5 Appendix D

8.3. Public Outreach and Communications

While additional resources and staff time may be needed to support improvements, dedicated public outreach and communications about APM in Wisconsin is needed. Stakeholders have expressed the need for the department to improve its rapport with the public, better distribute information on the ecological tradeoffs of management and AIS prevention, provide better description of how to navigate the APM process, and reach out to stakeholder groups not directly involved in APM permitting.

If the *status quo* is maintained:

The public may continue to feel that information relating to APM issues is not accessible and improvements to management techniques may be under-utilized. Individuals and groups interested in conducting APM activities may continue to find the permitting process difficult to navigate. Stakeholders not directly conducting APM activities may continue to have limited input into program practice.

Alternatives:

Outreach and Communication - Alternative 1. Develop an APM listserv and newsletter for sharing information between department APM staff, partners, and members of the public with an interest in APM.

> A moderated APM discussion listserv could allow individuals involved in APM from across the state to develop a network for sharing their experiences with navigating the APM permitting process, differing APM perspectives, and successes and failures with various management techniques. A formal, quarterly newsletter from the department's APM program may improve transparency and connections between department APM staff and partners. The newsletter could highlight: recent program activities, successful management efforts, new information on management techniques and emerging AIS, and individuals exhibiting excellent APM practice and leadership. The listserv would also invite participants to request features for future newsletters. A web-based record of the conversations hosted by the listserv could also reduce the need for department staff to answer the same questions repeatedly and provide a resource for APM stakeholders and permit applicants.

Outreach and Communication - Alternative 2. Host an annual meeting for sharing new APM-related information with the public.

> Department staff annually could host a series of presentations on navigating the APM permitting process and new information related to APM in Wisconsin. Presentations could be given by various APM stakeholders. This alternative could engage individuals interested in conducting APM activities and encourage sharing of successes and failures with various management techniques. The department currently hosts an annual meeting similar to this for private APM practitioners but could be extended to the general public through an additional collaboration with the Wisconsin Lakes Partnership Convention or another forum.

Outreach and Communication - Alternative 3. Dedicate DNR APM staff to periodically revising informational factsheets and outreach materials with the latest information to keep messaging current.

As new information related to APM is generated, department APM staff could continue to share it with the public and partners. Designation of this responsibility could be dedicated to a single individual in the department's APM program so staff and partners have a contact to inform as they become aware of new findings.

Outreach and Communication - Alternative 4. Increase engagement of stakeholder groups and staff not directly involved in APM activities.

There are several APM stakeholder groups of which some representatives are not involved with APM activities directly, but still value or influence aquatic resources, including: outdoor sporting groups, recreational users who do not own lakeside property, farmers, building or development firms, and others. Including members of these groups in the outreach efforts described above, such as the email list and periodic, in-person meetings, could help to serve all groups affected by APM.

Outreach and Communication - Alternative 5. Develop and conduct education and outreach related to herbicide resistance management and IPM in APM.

Education and outreach on IPM could support adoption of IPM principles as part of APM. This alternative may help reduce the risk of herbicide resistance in aquatic plants. If permit applicants become interested in non-chemical APM approaches as a result of this alternative, it may present challenges for contractors whose primary services currently rely on a particular aquatic plant control technique. As a result, educational efforts may be supported by other approaches supporting adoption of IPM practices (as described in Collaboration Alternative 7).

Outreach and Communication - Alternative 6. Develop and conduct education and outreach related to different lake types and their expected respective aquatic plant communities.

Educational outreach about aquatic plants and lake ecology could support the setting of appropriate expectations and realistic management goals. This may lead to greater acceptance of high-abundance or high-density plant communities in some waterbodies. Concurrently, permit requests and department staff workload associated with APM permits may decrease, potentially along with workload and income for private APM professionals. However, this alternative may instead lead to incorporation of different management strategies that seek more realistic outcomes or reduced non-target impacts without altogether reducing implementation of APM activities.

Outreach and Communication - Alternative 7. Develop and adopt consistent terminology for referring to different management goals and desired management outcomes.

Careful use of consistent terminology could reduce confusion when communicating about specific APM projects. This may make it easier to agree upon a given management strategy as well as standard strategies for common management scenarios. For example, further defining "effective management" or "long-term control" could benefit discussions of expected management outcomes. In the future, APM practitioners would have to be conscious of emerging ideas to define and incorporate them to continue consistent language use (Reference Ch. 6.1, paragraph 2).

Outreach and Communication - Alternative 8. Following release of APM-related publications, develop and distribute specific suggestions for how findings should relate to management.

Development and distribution of specific management implications shortly following the publication of popular and peer-reviewed APM-related articles could continue to support sound management and help stakeholders remain informed with the most current knowledge on APM. The department's APM web page could serve as a clearing house of updated information for stakeholders. Publications from department staff and other sources could be included. Quarterly or "as needed" research updates, with a description of how findings might influence management, could help to ensure that partners feel engaged and have increased awareness and expectations of what APM staff consider in permitting decisions. These updates could also facilitate much-needed discussion about how new information might influence management strategies and policies.

Table 8-3. Alternatives related to public outreach and communications.

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
1. Develop an APM email list for use by APM stakeholders	No	• Improved communication between members of the public interested and involved in APM • Increased communication and transparency between DNR staff and the public • A web-based record of conversations, questions, and answers related to APM • Need for continued maintenance of the record by DNR staff • Reduced DNR APM staff workload in the long-term • Potential to facilitate consensus and understanding of APM policy and effective management strategies	Ch. 5.2 Appendix D3
2. Host an annual meeting for sharing new APM-related information with the public	No	• Improved communication between members of the public interested and involved in APM • Increased communication and transparency between DNR staff and the public • Improved collective understanding of the varying APM perspectives among different stakeholder groups • Potential to facilitate consensus and understanding of APM policy and effective management strategies	Ch. 5.2 Appendix D3
3. Dedicate DNR staff to periodically revising APM outreach materials	No	• Assurance that informational materials distributed by DNR are accurate and up-to-date	Ch. 5.2 Appendix D3
4. Increase engagement of stakeholder groups and staff not directly involved in APM activities	No	• Increased communication and transparency between DNR staff and the public • Improved collective understanding of the varying APM perspectives among different stakeholder groups • Assurance that all stakeholder groups affected by APM are considered in policy and permit decision-making	Ch. 5.2 Appendix D3

(Continued)

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
5. Develop and conduct education and outreach related to herbicide resistance management and IPM	No	• Increased implementation of IPM in APM practice • Reduced potential for development of herbicide resistance in frequently treated aquatic plants • Potential challenges for APM businesses that do not provide a range of techniques in their plant control services, unless accompanied by implementation of the approaches described in Collaboration Alternative 9	Ch. 1.3 Ch. 2.2 Ch. 5.2 Ch. 6.3, 6.5, 6.6 Appendix D
6. Develop and conduct education and outreach related to different lake types and their plant communities	No	• Potential to set stakeholder expectations of natural aquatic plant cover in different types of lakes • Potential to lead to greater acceptance of aquatic plant presence, thereby reducing or modifying APM permit requests	Ch. 5.2 Ch. 6.2, 6.7, 6.8 Ch. 9.2
7. Develop consistent terminology	No	• Improved communication and collaboration	Ch. 6.1., paragraph 2
8. Develop and distribute publications on APM program guidance developed in response to new studies	No	• Improved communication and collaboration • Intermittently Increased workload for department staff	Ch. 5 Appendix D

8.4. Program Tracking and Evaluation

Self-evaluation and self-assessment are integral to organizational success. Without basic knowledge of how the department's APM program is currently operating, it will be difficult to assess how well the program meets its goals in the future. Some examples of program operations that should be accounted for include the number of permits issued and received, treatment details for each permit (acreage, species controlled, effort expended in hours, etc.), and money spent by permittees on APM activities.

If the *status quo* is maintained:

Technical review of overall program goals and individual permit applications would likely continue to be difficult for staff without data integration. The same would likely be true for stakeholders that are creating APM plans. At best, substantial amounts of time may be spent finding disparate pieces of information to help evaluate plant management decisions, and at worst the reported outcomes of management would be anecdotal rather than data driven. This would likely stall the process of adaptively managing aquatic plants over time and evaluating the department's progress in meeting objectives.

Alternatives:

Program Evaluation - Alternative 1. Collect additional data on APM activities and incorporate those data into the DNR APM database, including (but not limited to) records of non-chemical methods, how much funding and time was spent, which species were targeted, and herbicide concentrations used when applicable.

> This would provide more complete records of APM actions statewide. Having readily available details relating to the APM history of a given waterbody could assist groups investigating new management strategies and improve management decisions. It would also allow better estimates of the costs of APM activities in the state. This would require collecting further information on treatment records than is currently required. The department is already working to integrate APM data into its Surface Water Integrated Monitoring System (SWIMS) database and treatment record data could eventually be uploaded directly to the database.

Program Evaluation - Alternative 2. Conduct a full economic analysis of APM in Wisconsin.

> A thorough economic analysis of APM in Wisconsin could allow for a more comprehensive and detailed comparison of costs and benefits than what is covered in Chapter 4. This alternative would require collecting further cost information on treatment records and permits (as described in Alternative 1 above). Non-market benefits, such as cultural and recreational ecosystem services, could potentially be estimated through survey methods.

Table 8-4. Alternatives related to program tracking and evaluation.

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
1. Collect additional data on APM records to incorporate into the APM database	• No	• Improved understanding of the scale and costs of APM activities statewide • Improved APM permit review and management recommendations • Small increase in workload for private APM professionals	Ch. 2.4, 2.5 Ch. 6.6
2. Conduct a full economic analysis of APM in Wisconsin	• No	• Improved understanding of the scale and costs of APM activities statewide as well as the beneficiaries of APM	Ch. 2.5 Ch. 4 Ch. 5.2 Appendix D

8.5. Integrating New Information

Recent work has led to a better understanding of the efficacy and limitations associated with various APM techniques, potentially leading to substantial cost savings and improved outcomes for Wisconsin's natural resources and APM stakeholders. However, the capacity to support continued evaluation of management efforts has markedly decreased. Stakeholders have expressed concerns about an uninformed APM program, including the department's ability to respond to emerging issues such as new aquatic invasive species (AIS), changing climate, and others.

If the *status quo* is maintained:

APM is not often considered in academic settings and is less often directed at questions related to during management activities. The quality of management decisions in the future may be hampered by the lack of information along with the ability of APM professionals and stakeholders to respond to emerging problems presented by novel invasive species and new management techniques.

Alternatives:

Information Integration - Alternative 1. Increase funding and staff for evaluation of APM projects.

> Additional staff time directed toward evaluating APM projects and aquatic plant communities in lakes statewide could allow the department to continue to improve understanding of management options in the interest of efficiency and better management outcomes. Because management evaluation and response to emerging issues such as new AIS and management techniques are ongoing needs, creation of permanent positions dedicated to evaluating projects could also support quick communication of findings related to management efficacy and their eventual inclusion in policy as needed.

Information Integration - Alternative 2. Increase contract-based evaluation of APM projects.

> Relying on contractors supported by funding from department or academic partners could support improved understanding of management options and efficiency, ultimately leading to better outcomes. This could be accomplished through increased funding for project evaluation.

Information Integration - Alternative 3. Build a team-based approach to evaluating management efficacy and non-target effects.

> A collaborative approach to monitoring aquatic plant communities and evaluating management actions could strengthen APM partnerships, increase collective understanding of effective management, and help fill gaps in understanding of management tradeoffs. Many private aquatic plant managers, consultants and individuals involved in Citizen Lake Monitoring already conduct aquatic plant surveys. Further organization of these efforts with industry and academic partners in unmanaged lakes and before and after management could increase understanding of and confidence in findings, support for implementation of these findings, and reduce department staff workload.

Information Integration - Alternative 4. Develop a future-forward strategy for evaluating impacts of and management options for approaching AIS and other emerging issues.

Development of a plan to address emerging issues would allow Wisconsin to best prepare for future challenges. This alternative could involve a variety of APM stakeholder groups and involve prioritization and allocation of projects and funding to guide management in the face of emerging challenges such as new AIS and changes in plant communities in response to a changing climate.

Information Integration - Alternative 5. Require monitoring of aquatic plant communities on all waterbodies where APM is conducted.

Required monitoring could allow heightened tracking of APM results and allow all parties involved to make better adaptive management decisions. Currently, projects funded through department grants require pre- and post-management monitoring of the aquatic plant community. Expanding this to all projects could increase workload for private managers responsible for conducting the monitoring work as well as costs for individuals pursuing APM action. This would require rule changes to chs. NR 107 and 109.

Information Integration - Alternative 6. Require herbicide concentration monitoring for aquatic herbicide treatments supported by department grant funding.

Implementing a condition that aquatic herbicide treatments funded by department grants must be accompanied by herbicide concentration monitoring may improve understanding of herbicide movement in aquatic environments, supporting further evaluation of treatment efficacy and suggestions for appropriate herbicide use. In order for this alternative to benefit understanding of effective herbicide use, department staff time would be needed to analyze, interpret, and communicate findings related to the potentially large concentration monitoring dataset that would result. If the added expense of concentration monitoring is not accounted for in grants, this alternative may lead to unexpected expenses and workload for grantees.

Information Integration - Alternative 7. Conduct further evaluation of APM projects that utilize non-chemical control techniques, combinations of non-chemical techniques, combinations of chemical and non-chemical techniques, combinations of chemical control techniques, and chemical control techniques with new modes of action and formulations.

This alternative would improve understanding of the efficacy, selectivity, and longevity of a wide range of APM techniques and combinations of techniques and may support incorporation of IPM in APM practice. Demonstrating efficacy in a diverse range of approaches may support APM professionals in providing those services for aquatic plant control. If employed, effective approaches could help reduce the potential for herbicide resistance development in aquatic plants. This alternative would also support Collaboration Alternative 8 (see Chapter 8.1) and Outreach and Communication Alternative 5 (see Section 8.3).

Information Integration - Alternative 8. Continue long-term monitoring of aquatic plant communities in lakes not being actively managed.

For the past ten years, the department has conducted annual aquatic plant surveys on the same set of managed and unmanaged lakes. Continued monitoring of various types of unmanaged lakes can provide a reference for evaluating differences in plant communities from those in managed lakes, which may allow better assessment of non-target impacts of management and strategies for minimizing those non-target impacts. Unmanaged lakes also provide a reference from which the success of management activities in managed lakes can be evaluated, informing more effective management in the future. Without information on unmanaged systems, there is no way to know how natural variation in aquatic plant populations may be contributing to changes in those populations before and after management.

Table 8-5. Alternatives related to integrating new APM-related information into APM practice.

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
1. Increase funding and staff for evaluation of APM projects	Unknown	• Improved understanding of plant management options • Improved communication of assessment findings • Improved recommendations for APM practice	Ch. 2.4 Ch. 5.2 Ch. 6.6 Appendix D
2. Increase contract-based commitments to evaluating APM projects	Unknown	• Improved understanding of plant management options • Improved communication of assessment findings • Improved recommendations for APM practice	Ch. 2.4 Ch. 5.2 Ch. 6.6 Appendix D
3. Build a team-based approach to evaluating management efficacy and non-target effects	Unknown	• Improved understanding of plant management options • Improved communication of assessment findings • Improved recommendations for APM practice • Increased coordination and collaboration with private APM professionals and individuals involved in Citizen Lake Monitoring • Reduced DNR APM staff workload	Ch. 2.4 Ch. 5.2 Ch. 6.6 Appendix D
4. Develop a long-term strategy for managing approaching AIS and other emerging issues	No	• Improved recommendations for APM practice • Identification of emerging issues related to APM • Increased capacity to respond to emerging APM issues • Development of a system for prioritizing resources when new populations of aquatic invasive plants are discovered or when facing other emerging challenges	Ch. 2.4 Ch. 5.2 Appendix D4
5. Require monitoring of aquatic plant communities on all waterbodies where APM is conducted	Yes (Chapters NR 107 and NR 109)	• Increased workload for private APM professionals • Increased costs of APM • Need for dedicated DNR staff to evaluate and synthesize the monitoring data collected • Improved understanding of plant management options • Improved recommendations for APM practice	Ch. 2.4 Ch. 6.6

(Continued)

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
6. Require herbicide concentration monitoring for aquatic herbicide treatments supported by DNR grant funding	Yes (Chapter NR 198)	• Improved understanding of chemical APM approaches • Improved recommendations for chemical APM practice • Need for dedicated DNR staff to collect, evaluate, and synthesize the monitoring data collected • Potential for reduced APM costs in the long-term as a result of more effective herbicide treatments • Potential for increased cost of each DNR-funded grant involving chemical APM	Ch. 2.4 Ch. 5 Ch. 6
7. Conduct further evaluation of projects utilizing different control methods	No	• Improved understanding of plant management options • Improved recommendations for implementing IPM in APM practice • Reduced potential for development of herbicide resistance in frequently treated aquatic plants • Need for dedicated DNR staff to collect, evaluate, and synthesize the monitoring data collected	Ch. 1.3 Ch. 2.2 Ch. 5.2 Ch. 6.3, 6.5, 6.6 Appendix D
8. Continue monitoring aquatic plant communities in unmanaged lakes	No	• Improved understanding of natural aquatic plant communities • Need for dedicated DNR staff to collect, evaluate, and synthesize the monitoring data collected • Potential for improved recommendations for APM practice • Potential to set stakeholder expectations of natural aquatic plant cover in different types of lakes	Ch. 2.4 Ch. 6.3, 6.6

8.6. Consistency in Evaluating Permit Applications

APM permits are currently evaluated by regional and central office department staff. Staff understand that some aspects of review are the same regardless of the project. Aspects such as processing permits within allotted time, requiring notification, permit completeness and other code required items needed for a permit are the same. This is “process consistency.” Staff also understand that not all lakes are the same, so permit conditions may be added that address a lake’s physical, chemical or biological components. This is “project consistency.” Staff also consider the system’s treatment history, stakeholder goals, and any relevant information on ecological tradeoffs. This section is primarily focused on the process APM staff use to consider a permit and which aspects they weigh, to improve consistency in how permits are evaluated statewide. There is no explicitly-defined permit review process. The relative weight of each aspect assessed by an APM coordinator may vary depending on stakeholder goals and values (for example, whether a species is native or non-native to the state may have greater weight in influencing management outcomes depending on ecological quality).

If the *status quo* is maintained:

The steps of evaluating a permit may continue to vary across department staff. This may lead to regional inconsistency in how permits are considered, as well as the decisions that result. The status quo would allow for maximum flexibility in decision-making and is minimally-prescriptive. This may lead to unequal consideration of various points in the process across regions.

Alternatives:

Consistency - Alternative 1. Define a strategic philosophy and direction for the department’s APM program.

> The department’s APM coordinators have the responsibility of protecting and preserving the surface waters of the state while at the same time permitting management activities with some degree of environmental impacts. A strategic philosophy of the APM program could incorporate these responsibilities with recommendations for how management should be conducted, similar (but not limited) to what is described in Chapter 6 of this strategic analysis. A unified approach could provide permittees, private management professionals, and other stakeholders with a set of expectations for what APM activities are permissible. It could also be used in training of department APM staff for consistency and in guiding future direction and policies around APM in the long-term. This philosophy could outline what aspects of the APM program and permit process should be implemented consistently statewide, as well as those for which some regional flexibility is appropriate.

Consistency - Alternative 2. Standardize the specific aspects considered in the permit review process and the methods by which they are evaluated.

> This could provide guidance to assist APM staff in considering and evaluating the same aspects when processing permit requests, improving consistency in the permitting process and decision-

making. This philosophy could outline what aspects of the APM program and permit process should be implemented consistently statewide, as well as those for which some regional flexibility is appropriate.

Consistency - Alternative 3. Use the points of consideration in Consistency Alternative 2 to create a decision-making flowchart to support best management practices.

Development of a flowchart to aid staff in APM permit review could further support cross-region consistency. A flowchart would make the review criteria explicit and consolidate all the above aspects toward recommended decision points. The flowchart could allow for the flexibility necessary to weigh each decision point per regional differences in lake ecological quality and stakeholder goals. It could also allow department APM coordinators to utilize new information to make decisions based on expectations for efficacy and non-target ecological impacts.

Consistency - Alternative 4. Increase training for department APM staff.

Department APM coordinators may meet as needed to discuss various topics related to permitting and program practices. Development of a more formalized and mandatory training program could give all coordinators the same knowledge base from which to operate, improving consistency statewide. This could involve: development of a department APM handbook consisting of guidance documents, description of work done by other agencies such as DATCP and WPDES, the department's philosophy for APM (Consistency Alternative 1), considerations for chemical use and permit processing (possibly including the flowchart developed in Consistency Alternative 3), field supervision procedures, reporting requirements, safety protocols, and other pertinent information. Regular meetings to review the handbook and discuss unusual permits or issues could further increase consistency among department APM staff. Department staff issuing permits could also be required to go through training or pass an exam related to the material in the handbook before working independently.

Consistency - Alternative 5. Increase training for county and regional AIS coordinators funded by DNR grants.

County AIS coordinators are an important part of Wisconsin's AIS Partnership and because they often assist lake organizations, further training could improve consistency in messaging between them and DNR APM staff.

Consistency - Alternative 6. Develop a working definition for the social and environmental conditions that warrant APM.

Setting a threshold or definition of the conditions that must be met before APM can be conducted could improve consistency in the APM actions permitted statewide and set clearer expectations for potential permit applicants and private management professionals. Some conditions to be considered could include: extent of navigational impairment, aquatic plant density or abundance, whether the species is native or non-native to Wisconsin, impairments to recreation such as swimming or fishing, aesthetics, and others.

Consistency - Alternative 7. Revise Wisconsin's APM administrative codes.

Eliminating overlap in the administrative codes described in Chapter 1 could simplify many aspects of APM permitting and planning as well as AIS regulations. Code revision could make the permitting process simpler for both APM staff and permittees and integrate new information on effective use of various APM techniques. Code revision could set different policies for non-native and native plant management, management of AIS in irrigation canals, allow consideration of plant biodiversity, waterbody characteristics, and treatment scale in permitting decisions, set guidelines for when monitoring and implementation of IPM should be conducted, require APM plans or set guidelines for management of native plants for navigation and established-AIS populations, and/or incorporate other aspects that would improve APM permitting. Changes to administrative codes could change APM practice dramatically and should consider all stakeholders' views and effects on their involvement. Revised codes could benefit from a built-in process that allows some changes in the implementation of the APM program without requiring full rewriting of the code, to allow adaptations in response to new knowledge regarding effective and appropriate APM practice. Additionally, full review of other states' APM programs beyond what is described in Chapter S.1 for comparison could benefit the code revision process.

Table 8-6. Alternatives related to consistency in evaluating APM permit requests.

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
1. Define a strategic philosophy and direction for DNR's APM program	No	• Guidance for DNR staff regarding how to interpret ambiguous sections in administrative codes • Improved consistency in evaluating APM permit requests • Development of best management practices for DNR staff and stakeholders to strive to implement • Potential to set stakeholder expectations for what APM activities are permissible	Ch. 1.5 Ch. 2.4 Ch. 5.2 Ch. 6 Appendix D
2. Standardize APM permit considerations and the process for evaluating those considerations	No	• Guidance for DNR staff regarding how to interpret ambiguous sections in administrative codes • Improved consistency in evaluating APM permit requests • Improved transparency in APM permit review	Ch. 5.2 Ch. 6.7 Ch. 9.2 Appendix D
3. Create a decision-making flowchart to support the standardized process described in alternative Consistency Alternative 2.	No	• Potential to improve the "Expected Outcomes" in Consistency Alternative 2 in this table • Potential to reduced DNR APM staff workload	Ch. 5.2 Ch. 6.7 Ch. 9.2 Appendix D
4. Increase training for DNR APM staff	No	• Improved APM permit review and management recommendations • Improved consistency in evaluating APM permit requests • Development of a permitting handbook for DNR APM staff • Need for dedicated DNR staff to continuously update the handbook as needed	Ch. 5.2 Ch. 6.7 Ch. 9.2 Appendix D
5. Increase training for county and regional AIS coordinators funded by DNR grants	No	• Improved consistency in messaging regarding APM practice • Potential to set stakeholder expectations for what APM activities are permissible	Ch. 5.2 Ch. 6.7 Ch. 9.2 Appendix D

(Continued)

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
6. Develop a working definition for the social and environmental conditions that warrant APM	Yes (Chapters NR 107 and NR 109; s. 287.17 (2), Wis. Stats.)	• Guidance for DNR staff regarding how to interpret ambiguous sections in administrative codes • Improved consistency in messaging regarding APM practice • Improved transparency in APM permit review • Potential to set stakeholder expectations for what APM activities are permissible and encouraged	Ch. 5.2 Ch. 6.1, 6.7 Ch. 9.2 Appendix D
7. Revise Wisconsin's APM Administrative Codes	Yes (Chapters NR 107 and NR 109)	• Eliminate overlap between APM-related Admin. Codes • Potential to reduce DNR APM staff workload • Potential to improve consistency and transparency in APM permit review • Potential to integrate recent information supporting APM best practices • Potential for all "Possible Outcomes" in tables 8-1 through 8-8 requiring changes in Admin. Codes	Ch. 1-6 Appendix D

8.7. Grants

The department's Surface Water Grants program is critical to stakeholders actively involved in conducting APM activities. Administrative code revision for the grant program is currently underway. While planning for and educating about all aquatic plants is an eligible activity for all surface water grants, only invasive species are eligible for control grants. There are several ways in which stakeholders have suggested the grants program could be improved or revised.

If the *status quo* is maintained:

The current amount of grant funding available would be maintained. Individuals who fit in with current grant criteria would continue to get support while others would need to fund their APM activities through other sources or cope with their aquatic plant concerns without state-funded management. DNR funding would not be able to support all APM activities and may not support best management practices. APM in Wisconsin would continue to be heavily supported by department grant funding.

Alternatives

Grants - Alternative 1. Increase the amount of department grant funding available for supporting APM projects statewide as well as county and regional APM and AIS staff and other members of Wisconsin's AIS partnership.

> Increased funding could support a larger number of APM projects statewide, increasing the number of APM permits along with department staff workload. Funding of APM activities and personnel could be increased through further taxing of lake users, increased permitting fees, or other approaches. This could also help provide stability for county and regional AIS coordinators, allowing them to have continuous working relationships with citizens conducting APM activities. It could also support a larger number of county staff to facilitate projects between the department and the public. This alternative would best be implemented along with further training for county and regional AIS coordinators from department staff and revised surface water grant codes. The department is currently testing a contract-based, rather than grant-based, model for supporting county and regional AIS staff.

Grants - Alternative 2. Divide department grant funding into different categories to support different types of APM projects.

> Partitioning of department grant funding into several additional categories, each with different ranking criteria, could support a variety of different types of APM projects and a greater range of applicants, as well as different management goals and techniques. Further categories could support different scales of APM projects and degrees of public access. This would likely reduce the available funding for groups who routinely receive grants based on the current grant ranking criteria.

Grants - Alternative 3. Set clearer and more open criteria for ranking department grant applications.

Some stakeholders have expressed frustration in applying for grants because they are not aware of what department staff consider in ranking applications. The department could strive to make the applicants more aware that ranking criteria are publicly available. Involving stakeholders more in creating grant ranking criteria and periodically revising them based on new information and best management practices could ease the grant writing process for applicants, support sound management, and increase fairness in distribution of grant funding. If criteria are too rigid, this alternative may lead to the grant program supporting only a few types of APM projects, potentially presenting a stopping block for innovative management approaches.

Grants - Alternative 4. Direct department grant funding to support a wider range of IPM approaches.

State funding of a wider variety of APM techniques, such as mechanical harvesting, and others, could support the implementation of IPM statewide. It could support private APM professionals providing these techniques as services and provide options to permit applicants interested in conducting APM without the use of herbicides. It could also reduce the potential for development of herbicide resistance in aquatic plants and lead to changes in costs and efficacy of management activities that are grant funded, affecting plant abundance. If the state were to fund management techniques that are costlier per acre than others, it may not be able to fund as many APM projects. This may also reduce the funding available to support APM using herbicides and impact private APM professionals for whom herbicide application is their primary service.

Grants - Alternative 5. Increase the amount of time funding remains available for APM projects, once granted.

Some former grant recipients have expressed challenges associated with time limits on when department grant funding must be expended, explaining that some projects may be difficult to complete within a 1- or 2-year period. Lengthening the time in which funding must be spent could increase the efficacy of APM projects and longevity of results. It could also tie up funds in long-term projects which could otherwise be used to support additional efforts through other applicants.

Grants - Alternative 6. Limit the amount of department funding that can be awarded to any one sponsor or the number of grants that any one sponsor can receive to conduct herbicide treatments over a certain time period.

A limit on the amount of funding allotted to any given applicant could be a set figure or scaled figure based on waterbody characteristics, recreational use of the waterbody to be managed, fiscal capacity of the applying entity, or other factors. This could reduce capacity for repetitive large-scale herbicide treatments or prevent continuous funding to any one applicant, while making more funds available to others. It could also reduce repeated herbicide treatment and the potential for herbicide resistance and encourage the use of alternative non-chemical management strategies. Once a given entity has reached the funding limit, it could become eligible for funding again after a certain number of years or for different management goals.

Grants - Alternative 7. Reduce or eliminate department grant funding for herbicide treatments for aquatic invasive plant populations that have become well-established in a given waterbody.

This could require applicants to either rely more heavily on other APM techniques or their own sources of funding for herbicide treatments of well-established aquatic invasive plant species. This alternative may increase the average cost per grant-funded APM project, resulting in funding fewer projects overall. It could also likely reduce the number of APM permits for herbicide treatments, potentially increasing the abundance of aquatic nuisances in waterbodies statewide, and present challenges or reduce revenue for private APM professionals. It could also reduce the potential for development of herbicide resistance in aquatic plants, encourage or discourage the use of long-term management strategies, and satisfy individuals who do not support the use of herbicides. On the other hand, this alternative may also result in permitees relying more heavily on self-funded and less comprehensive herbicide treatments, which may contribute to herbicide resistance development.

Grants - Alternative 8. Reduce or eliminate department grant funding for APM herbicide treatments.

This could require applicants to either rely more heavily on other APM techniques or their own sources of funding for herbicide treatments. It could also reduce the number of APM permits for herbicide treatments, potentially increasing the abundance of aquatic nuisances in waterbodies statewide, and present challenges or reduce revenue for private APM professionals. If fewer herbicide treatments are conducted as a result of this alternative, this may also reduce the potential for development of herbicide resistance in aquatic plants and satisfy individuals who do not support the use of herbicides. On the other hand, this alternative may also result in permitees relying more heavily on self-funded and less comprehensive herbicide treatments, which may contribute to herbicide resistance development in aquatic plants.

Grants - Alternative 9. Develop a strategy for APM and AIS management in Wisconsin that does not rely on department grant funding.

Some stakeholders have suggested the department develop a plan for supporting APM and AIS management without the use of State grant funding, to provide resilience for the program in the face of budget cuts or other changes to the program's funding source. Shifting to a model not funded by the state would greatly alter the way aquatic plants are managed in Wisconsin. It is unclear how a model like this would function, given that state law requires the protection of aquatic plant communities and preserving waterbody access.

Grants – Alternative 10. When assessing grant applications, prioritize projects that take a watershed-level approach and those that leverage the power of regional and local partnerships.

This alternative could support effective partnerships and additional work at the watershed scale using the Surface Water Grants Program. This may improve invasive species prevention efforts by encouraging groups to consider the connections the between waterbodies. It may also engage additional stakeholders and assist in addressing issues such as nutrient loading that sometimes contribute to overabundant plant growth in lakes.

Table 8-7. Alternatives related to the department's Surface Water Grants program.

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
1. Increase the amount of DNR grant funding available for supporting APM projects statewide and partner organizations' APM/AIS staff	No	• Increased stability for county and regional AIS staff • Potential for increased taxes on lake users or permitting fees • Potential for increased APM permit applications and workload for DNR APM staff • Potential for reduced workload for DNR APM staff through further assistance from partner organizations	Ch. 2.6 Ch. 5.2 Appendix D
2. Further divide DNR grant funding into categories to support different types of APM projects	Yes (Chapter NR 198)	• Increased support for a wider range of different types of APM projects • Potential for reduced funding for some existing grant categories	Ch. 2.6 Ch. 5.2 Appendix D
3. Set clearer and more open criteria for ranking DNR grant applications	No	• Increased awareness of DNR grant ranking criteria • Increased transparency in DNR grant application review • If criteria are too strict, the grant program may not be able to support a variety of types of APM projects	Ch. 2.6 Ch. 5.2 Appendix D
4. Direct DNR grant funding to support a wider range of IPM approaches	Yes (Chapter NR 198)	• Increased implementation of IPM statewide • Differences in costs and efficacy of grant-funded APM • Provide options to individuals interested in conducting APM without the use of herbicides • Reduced potential for development of herbicide resistance in frequently treated aquatic plants • Potential to reduce grant funding available to support chemical APM activities • Potential challenges for APM businesses that do not provide a range of techniques in their plant control services	Ch. 1.3 Ch. 2.2, 2.6 Ch. 5.2 Ch. 6.3, 6.5, 6.6 Appendix D
5. Increase the amount of time funding remains available for APM projects, once it has been granted	• Yes (Chapter NR 198)	• Increased support of long-term projects • Reduced availability of funding to support new projects	Ch. 2.6 Ch. 5.2 Appendix D

(Continued)

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
6. Limit the amount of DNR funding or grants that any one applying entity can be allocated to conduct herbicide treatments	Yes (Chapter NR 198)	• Increased distribution of grant funding to a wider variety of applicants • Reduced capacity for repetitive large-scale management actions • Prevent continuous funding to any one applicant • Reduced potential for development of herbicide resistance in frequently treated aquatic plants • Potential to encourage or discourage long-term management strategies	Ch. 2.6 Ch. 5.2 Ch. 6.3, 6.5, 6.6 Appendix D
7. Reduce or eliminate DNR funding for herbicide treatments for well-established invasive plant control	Yes (Chapter NR 198)	• Increased chemical APM activities that are self-funded • Potential to encourage or discourage long-term management strategies • Potential to increase implementation of IPM statewide • Potential challenges for APM businesses that do not provide a range of techniques in their plant control services • Potential to reduce or increase the number of chemical APM permits • Reduced or increased potential for development of herbicide resistance in frequently treated aquatic plants • Potential to increase abundance of nuisance-causing aquatic plant populations	Ch. 2.6 Ch. 5.2 Ch. 6.3, 6.5, 6.6 Appendix D

(Continued)

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
8. Reduce or eliminate DNR funding for APM herbicide treatments	Yes (Chapter NR 198)	• Increased chemical APM activities that are self-funded • Potential to increase implementation of IPM statewide • Potential challenges for APM businesses that do not provide a range of techniques in their plant control services • Potential to reduce or increase the number of chemical APM permits • Reduced or increased potential for development of herbicide resistance in frequently treated aquatic plants • Potential to increase abundance of nuisance-causing aquatic plant populations	Ch. 2.6 Ch. 5.2 Ch. 6.3, 6.5, 6.6 Appendix D
9. Develop a strategy for APM and AIS management in Wisconsin that does not rely on DNR grant funding	Unknown	• Provide a plan for the continued implementation of aquatic invasive plant management if AIS funding were to be reduced	Ch. 2.6 Ch. 5.2 Appendix D
10. Prioritize projects with a watershed-level approach and those with effective partnerships	Unknown	• Improve invasive species prevention efforts • Encourage a more holistic approach for APM • Support projects that address other water quality issues in addition to APM	

8.8. Watershed Health, AIS Prevention, Enforcement, Overall Emphasis, and Other Topics

Several stakeholders have suggested APM in Wisconsin shift toward approaches which address some of the causes of excessive plant growth.

If the *status quo* is maintained:

> The focus of APM in Wisconsin would continue to be centered on addressing excessive plant growth in waterbodies, as opposed to the potential causes of that excessive growth. Currently the department asks whether nutrient controls have been employed on the permit application. However, the complexity of this leads to ambiguity and often is not addressed. The department's APM program would continue to seek balance between addressing social and environmental concerns.

Other Topics - Alternative 1. Heighten emphasis on runoff issues and ecological stewardship in the department's APM program.

> The department's APM program could increase and redirect their efforts toward reducing nutrient loading and promoting healthy shorelines. This could involve partnership with DNR's Wastewater, Watershed, Healthy Lakes, and Directed Lakes programs, as well as farmers' and builders' associations and others. As one approach, the department could develop a statewide watershed protection program or put further emphasis on Lake Management Implementation grants to support implementation of plans that address nutrient loading and improving or protecting near-shore conditions. The department could also support more research evaluating the sociological challenges associated with implementing these plans to develop recommendations for removing those barriers. Department grants could incentivize native shoreline plantings and other approaches, which could in turn support private providers of these services. This would likely require reassessment of the roles of department APM staff and re-allocation of current resources away from traditional, reactive management activities and the private entities providing those services.

Other Topics - Alternative 2. Develop a classification system for Wisconsin waterbodies to support management decision-making.

> Some APM stakeholders have suggested developing a classification system for waterbodies to set guidelines on the management activities that can be permitted. Classification criteria could include: waterbody condition, degree of recreational use, prominent types of recreational activities, ecological value, and other factors. This could likely result in waterbodies in poor environmental condition with high recreational use to steadily decline in condition, if plant destruction and removal increased for recreational purposes rather than ecological ones. In turn, it may also protect those waterbodies that are currently in good ecological condition and preserve that condition for the long-

term. This is one approach that could help set expectations for involved stakeholders and provide a framework for decision-making and consistency.

Other Topics - Alternative 3. Increase enforcement of movement of aquatic invasive plants between waterbodies by citizens.

This alternative could require boat and gear disinfection upon leaving a waterbody, restricting access to waterbodies with high-priority AIS, and/or increasing issuance of vehicle citations to improve efforts to prevent the spread of invasive plants, and other invasive organisms, to new waterbodies. However, this alternative could potentially have negative effects on tourism if employed statewide, as lake users may avoid using public landings or take less time to enjoy water-related recreational activities as a result. On the other hand, AIS can also negatively affect tourism. This alternative would likely help reduce the spread of AIS from lake-to-lake, increase awareness of AIS issues, and reduce the need for APM. If employed on a waterbody in which a prohibited species has been detected (one that is new to the state and has not been found in any other, or only a few, waterbodies) this strategy could be especially effective for limiting movement of that species to other waterbodies and the associated social concerns would remain localized to that waterbody. Some of these options may require changes in WI State Statutes and increase DNR staff workload or reassessment of DNR staff responsibilities.

Other Topics - Alternative 4. Allocate more resources toward preventing introduction of non-native plants to waterbodies with higher chances of negative ecological consequences of those non-native plant species.

Prioritizing AIS prevention efforts for waterbodies that are more likely to be adversely affected by AIS could help to reduce non-native species' spread and the need for conducting APM activities. Various forms of further resource allocation could include installation of watercraft decontamination, mandatory decontamination, watercraft entry restrictions, and enhanced AIS outreach for those waterbodies. Some of these approaches would require legislative action. This would require extensive research into the environmental suitability of different lake characteristics for many plant species. It could also make resources less available to waterbodies which are not predicted to experience adverse ecological impacts, leaving them vulnerable. Because predictions are likely to have at least some uncertainty associated with them, those vulnerable waterbodies may experience impacts that were unexpected. There would likely be logistical challenges related to finding the staff to focus on waterbodies expected to be at risk of negative ecological consequences of non-native plant invasions.

Other Topics - Alternative 5. Increase collaboration with and/or enforcement of industries which provide pathways for the spread of aquatic invasive plants.

This could heighten efforts to partner with or enforce regulations on shipping, plant nurseries, and other industries to prevent the spread of invasive plants, reducing the demand for plant management if successful. This alternative could increase industry representatives' knowledge of

AIS issues, potentially leading to increased ch. NR 40, Wis. Admin. Code, understanding and compliance. This would require reassessment of the roles of DNR APM staff and could present challenges for the industries involved. This alternative is also a deliverable of DNR's grant from the Great Lakes Restoration Initiative. Additional taxing of these industries or fees for non-compliance have also been suggested as a source of revenue to support APM efforts.

Other Topics - Alternative 6. Repeal permit and certified applicator requirement for chemical control of non-native plants below the Ordinary High-Water Mark (OHWM) on exposed lakebeds.

This alternative may make it easier for property owners to control wetland invasive plants on the exposed lakebed because they would not have to go through the permitting process or hire a certified applicator. While plant control on the exposed lake bed is a common winter activity, many individuals may not be aware of the current permit and certification requirements, making legal requirements difficult to enforce. This alternative may relieve enforcement officers from the challenge of enforcing these activities. However, in the absence of permits and legal requirements for this activity, tracking its frequency and the types of plants controlled is likely to become more difficult.

Other Topics - Alternative 7. Repeal permit requirement for non-native plant removal at wetland or shoreline sites below a given water depth where the site is likely to dry out by the time control work is conducted.

Currently, if a target site is wet at the time a permit is applied for, a permit is still needed for plant control at sites that are likely to dry out. This alternative may relieve individuals seeking to control non-native plants in wetland and shoreline settings from having to go through the APM permitting process and paying permitting fees at sites that are likely to dry out in the warmer months. However, this may encourage individuals to use herbicides which are not approved for aquatic use, potentially harming amphibians and other sensitive organisms. It can also be difficult to predict whether or not a site will dry out and may encourage noncompliance at sites which remain saturated.

Other Topics - Alternative 8. Develop a set of guidelines for the bidding process for individual APM projects.

Private APM professionals have expressed frustration about the bidding process for individual APM projects, with concerns over their companies not being selected for jobs when their services were less expensive than others'. Development of a set of guidelines for the bidding process for APM projects could help alleviate these concerns and support optimal management decisions by full consideration of costs, equipment, safety, efficacy, and other concerns.

Other Topics – Alternative 9. Increase regulation of APM in private ponds.

Central Office department staff, instead of field staff, began processing permits for APM in private ponds in 2014. Reverting to increased supervision or regulation of these activities may benefit fish and wildlife populations, endangered or at-risk species, waterbody and human health, and reduce groundwater infiltration. This alternative could increase workload for department staff and permit applicants.

Other Topics – Alternative 10. Require DASH equipment modification to prevent suction of bottom sediment.

This alternative would reduce some of the unintended ecological effects of DASH of aquatic plants. It would likely result in some additional expense or workload for DASH operators. This alternative could be implemented as part of Consistency Alternative 7.

Table 8-8. Alternatives related to other aspects of APM.

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
1. Heighten DNR's emphasis on runoff issues and ecological stewardship	Unknown	• Potential to reduce nutrient runoff, promote healthy shorelines, and other practices to protect water quality • A larger network of partners involved in APM • Reassessment of the roles of DNR APM staff • Some re-allocation of resources away from traditional APM activities and the entities providing those services	Ch. 5.2 Ch. 6.8 Appendix D
2. Develop a classification system for Wisconsin waterbodies to support management decision-making	Unknown	• Changes in the APM strategies utilized in differently classified waterbodies • Potential to set stakeholder expectations for what APM activities are permissible • Improved consistency in APM permit review • Potential the condition of high-use waterbodies to decline and preserved conditions of lower-use waterbodies	Ch. 5.2 Ch. 6.2, 6.3, 6.7 Ch. 9.2 Appendix D
3. Increase enforcement of movement of AIS between waterbodies by citizens	Unknown	• Potential for mandatory boat and gear disinfection, restricting access to waterbodies with high-profile AIS, and increased issuance of AIS-related citations • Potential to assist in reducing the spread of AIS • Reduced demand for APM activities and permits • Reassessment of the roles of DNR staff • Potential to reduce or increase DNR staff workload	Ch. 1.3 Ch. 5.2 Ch. 6.6 Appendix D
4. Allocate more resources toward invasive plant prevention around waterbodies with greater risk of negative ecological consequences by invasive plants	No	• Potential to assist in reducing the spread of AIS • For waterbodies with high risk of experiencing negative ecological consequences from plant invasions: o Potential for enhanced outreach, mandatory boat and gear disinfection, restricting access, and increased issuance of AIS-related citations • Potential to leave waterbodies vulnerable if predicted to have low risk of experiencing negative ecological consequences from plant invasions • Challenges in finding staff to focus on high-risk waterbodies • Reduced demand for APM activities and permits, resulting in reductions in DNR APM staff workload	Ch. 1.3 Ch. 5.2 Ch. 6.6 Appendix D

(Continued)

Alternative	Requires changes to Rules or Statutes?	Possible Outcomes / Consequences	Additional Information:
5. Increase collaboration with and/or enforcement of industries which provide pathways for AIS spread	No	• Increased awareness of industries' role in preventing the spread of AIS • Potential to assist in reducing the spread of AIS • Reduced demand for APM activities and permits, resulting in reductions in DNR APM staff workload • Reassessment of the roles of DNR staff	Ch. 1.3 Appendix D
6. Repeal permit and certified applicator requirement for non-native plant removal below the OHWM on exposed lakebeds	Yes (Chapter NR 107)	• Reduce workload and increase compliance by individuals chemically treating invasive aquatic plants on exposed lakebeds • Reduce workload for DNR Law Enforcement staff • Decreased understanding the frequency and extent of this APM activity statewide ability • Decreased ability to ensure compliance with this APM activity	Ch. 2.3 Ch. 3 Appendix B
7. Repeal permit requirement for invasive plant removal at wetland or shoreline sites that are likely to dry out by the time of control work	Yes (Chapter NR 107)	• Reduced workload for DNR APM staff and private APM professionals • Reduced costs for private APM professionals and fee revenue for DNR's APM program • Decreased ability to ensure compliance with this APM activity	Ch. 1.5 Appendix B
8. Develop a set of guidelines for the bidding process for individual APM projects	No	• Set standards for private APM services	Ch. 5.2 Appendix B Appendix D
9. Increase regulation of APM in private ponds.	Unknown	• Benefits to fish and wildlife populations, endangered or at-risk species, waterbody and human health, and reduced groundwater infiltration. • Increased workload for department staff • Increased workload for APM permit applicants	Ch. 2.3, 2.5 Ch. 5 Appendix B Appendix D
10. Require DASH equipment to prevent sediment suction	Yes (Chapter NR 109)	• Reduce unintended ecological effects of DASH • Increase expense or workload for DASH operators	Ch. S. 3.4.1

Supplemental Chapters

S.1. Aquatic Plant Management in Other States

For consideration in future development of aquatic plant management (APM) in Wisconsin, APM programs in seven other U.S. states were investigated to provide context for and comparison to Wisconsin's program. Information on state APM programs was collected through interviews with agency staff, a multi-state meeting on APM, and review of online program materials. Each state has different guidance and issues of concern related to aquatic plants. States were generally chosen due to their abundance of water resources and proximity to Wisconsin while others provide contrast to Wisconsin's APM program. All states reviewed have permitting processes for APM activities. Information about the APM programs in these states is summarized in Table S.1-1.

Program Details

Connecticut - The Connecticut Department of Energy and Environmental Protection (DEEP) requires permits for herbicide and phosphate removal treatments (phosphate removal requires a permit if the purpose of the treatment is to control algae; if the purpose of the treatment is to improve water quality, it does not). The permit application fee is $200 per year. Special conditions may be written into a permit if species of special conservation status may be impacted by the treatment. If flumioxazin or triclopyr are proposed to be applied within a public water supply watershed, or if any chemical is proposed to be used within 200 feet of a public water supply well, the application must also be approved by the state's Department of Public Health. All aquatic pesticide treatments fall under the National Pollutant Discharge Elimination System (NPDES) general permit (GP), and obtaining an individual pesticide permit automatically satisfies the requirements of the GP. If more than 80 acres or 25 linear miles of shoreline will be treated, the applicant must also file a registration under the GP which includes a Pesticide Discharge Management Plan and obtain written authorization from the Water Permitting and Enforcement Division. Water utilities are not required to obtain an individual permit for treatment of public water supply reservoirs, however, they are still subject to the GP. Connecticut DEEP also has a triploid grass carp (*Ctenopharyngodon idella*) permitting program which allows the usage of these fish under selected conditions. No fees are collected for triploid grass carp permits. Mechanical harvesting, benthic barriers, dredging, drawdowns, barley straw, and other physical removal methods are not regulated by the state. However, local municipalities may have their own approval processes for APM activities. Primary species of concern include non-native phragmites, Brazilian waterweed (*Egeria densa*), variable-leaf watermilfoil (*Myriophyllum heterophyllum*), Eurasian watermilfoil (*M. spicatum*), fanwort (*Cabomba caroliniana*), curly-leaf pondweed (*Potamogeton crispus*), and hydrilla (*Hydrilla verticillata*).

Indiana - The Indiana Department of Natural Resources has a permitting process for all chemical, physical, and biological APM techniques, except for privately owned waters or when the area to be managed along the landowner's shoreline area does not exceed 25 feet or a total of 624 square feet. The permit application fee is $5. If the treatment is in or near a public water supply, review and approval from the Indiana Department of Environmental Management is needed. Eurasian watermilfoil, curly-leaf pondweed, and starry stonewort (*Nitellopsis obtusa*) are the primary non-native species managed while species of concern, such as hydrilla and Brazilian waterweed, warrant more intensive management efforts.

Maine - Physical and chemical APM activities require a permit from the state's Department of Environmental Protection (DEP). Application fees are $75 for two-year physical control permits and $185 for annual herbicide permits. Herbicide control of invasive aquatic plants may be conducted only by the DEP's Invasive Aquatic Species Program, or an agent appointed by the Program. The most commonly employed APM techniques are Diver Assisted Suction Harvesting (DASH) and benthic barriers. Eleven species are eligible for herbicide control but treatment has only occurred on three occasions to control hydrilla and Eurasian watermilfoil. The goal of each of the three herbicide treatments was ecosystem restoration. Biological control is not permitted. Primary species of concern are variable-leaf milfoil and hydrilla, and more recently brittle naiad (*Najas minor*). Few populations of Eurasian watermilfoil are present in Maine waterbodies and a milfoil summit is held each year as a form of public outreach.

Michigan - The Michigan Department of Environmental Quality (DEQ) issues permits for APM using pesticides. Special permit conditions are implemented when chemical treatment may negatively impact threatened or endangered species or result in a public health hazard. Permit application fees vary between $75-$1500 depending on the acreage proposed for treatment. Michigan DEQ staff may limit the size of treatments for native control projects. A permit is generally not required for mechanical harvesting or manual cutting. Other physical APM activities such as hand-pulling, DASH, benthic mats, weed rollers, and dredging require a permit from Michigan DEQ. Eurasian watermilfoil, curly-leaf pondweed, invasive phragmites, and starry stonewort are the primary aquatic invasive species (AIS) targeted. Non-native purple loosestrife (*Lythrum salicaria*), fanwort, flowering rush (*Butomus umbellatus*), European water-clover (*Marsilea quadrifolia*), parrot feather (*Myriophyllum aquaticum*), water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), and European frog-bit (*Hydrocharis morsus-ranae*) have also been found and are being managed in Michigan.

Minnesota - Management actions that require permits from the Minnesota Department of Natural Resources include herbicide and algaecide treatments, destruction of emergent plant species, movement of plants between waterbodies, and the use of automated aquatic plant control devices (e.g., weed rollers). Physical removal of submerged vegetation from a continuous area less than 2500 square feet or physical removal of floating-leafed vegetation to create navigational channels is allowed without a permit. APM permits are issued for nearshore nuisance plant control whereas Invasive Aquatic Plant Management (IAPM) permits are issued for selective control intended to reduce the population of an invasive plant species. Most APM permits are $35. Generally, a first-time permit requires site inspection to allow the Minnesota DNR agent to determine if management is warranted. Subsequent permits do not require a site visit. Roughly 4000-5000 APM permits are issued annually compared to 250-300 IAPM permits. Management techniques that are not allowed in Minnesota include the use of hydraulic jets, bottom barriers, and plant removal in posted fish-spawning areas, undeveloped shorelines, or when the plants are not interfering with recreation. Excavating the lake bottom requires a separate dredging permit. Primary non-native aquatic plant species of concern include Eurasian watermilfoil, curly-leaf pondweed, starry stonewort, and flowering rush.

New York – New York State has multiple AIS priorities dictated by its AIS Management Plan (July 2015), document that emphasizes prevention. The highest priority for the AIS Management Plan implementation is the expansion of watercraft inspection steward programs. The New York Department of Environmental Conservation (DEC) has a permitting process for benthic barriers, drawdown, dredging, chemical, and biological (grass carp and herbivorous insects) APM techniques. The pesticide permit fee is $100. Harvesting requires a General Permit for invasive species removal which is regulated at the regional level. Grass carp stocking requires a special permit. As per the aquatic pesticide permit and various wetlands permits, restrictions may be placed on activities based on conditions such as proximity to valuable habitat or drinking water intakes. The state also has an Invasive Species Coordination Section (Bureau of Invasive Species and Ecosystem Health) which is responsible for outreach efforts and assists lake groups with decision-making and permitting processes. This section also oversees or participates in several control projects and long-term monitoring of AIS, especially plants, on major waterways. Eurasian watermilfoil is the most commonly managed aquatic plant species, while hydrilla is the primary aquatic plant species of concern. In general, management of invasive species (those identified under 6 NYCRR Part 575) are prioritized over management of nuisance or native species.

Washington - Washington Department of Ecology (DOE) has an Aquatic Plant and Algae Management general permit for chemical treatment of aquatic plants, algae, and phosphorus sequestration with a current annual fee of $618 (fees are usually adjusted every other year based on the state fiscal growth factor). For native nuisance plants, the area permitted for treatment may not exceed more than a certain percentage (which varies depending on the overall acreage of the waterbody) of the littoral zone of the waterbody. Restrictions are different for aquatic plants designated as noxious weeds by the State Noxious Weed Control Board (https://www.nwcb.wa.gov/). The entire population of noxious weeds may be treated regardless of the area it occupies within a waterbody. Herbicide applications may be allowed near irrigation channels, but treatment of the irrigation canals requires a different permit. Chemicals used for phosphorus sequestration (e.g., alum) are also allowed under this permit. All or part of a waterbody may be treated at one time. There is also a separate permit for emergent and shoreline aquatic noxious weed control that does not involve a direct discharge of herbicide to the waterbody. All herbicide permits are subject to a phenology review prior to approval. Washington Department of Fish and Wildlife (WDFW) and DOE have developed waterbody-specific herbicide treatment timing windows based on wildlife phenology or seasonal habits. Treatment must take place during the treatment window if it will affect a sensitive species or life stage (e.g., smolting salmonids).

Physical APM actions require a WDFW hydraulic project approval (HPA) with an associated $150 fee. This permit is required for any form of physical control as described in their Aquatic Plants and Fish Manual, including benthic barriers, hand pulling, DASH, mechanical methods, and others. In many cases, such as homeowner physical plant removal, WDFW has created a shortcut HPA in the form of the Aquatic Plants and Fish pamphlet. As long as the user has a copy of the pamphlet and follows its conditions, a full HPA is not necessary. WDFW also allows stocking of grass carp with a permit and a $94 fee. Harmful algae blooms (HAB), noxious weeds, and phosphorus are the major concerns for APM in Washington.

Monitoring, Management Evaluation, and Reporting

The state of Connecticut's Agricultural Experiment Station surveys aquatic plants in approximately 250 waterbodies each year for the purposes of management evaluation and baseline monitoring. Non-native plant species are present in about 2/3 of the surveyed waterbodies.

Indiana DNR uses a random point sampling approach for pre- and post-management evaluation on lakes with state-funded management activities, where sampling effort is determined by lake size and trophic status. These surveys are conducted on approximately 30-40 lakes per year. Otherwise routine baseline monitoring is limited to qualitative assessment.

Maine DEP has a grant-funded aquatic plant identification program that trains and supports volunteers to conduct baseline plant surveys. Maine DEP staff also conduct plant surveys in areas where management is expected to occur. They also conduct baseline littoral habitat surveys that include assessment of aquatic plant richness and density in lakes selected annually.

Michigan DEQ typically does not conduct pre- and post-management evaluations as part of the Aquatic Nuisance Control permitting program. Commercial pesticide applicators or consulting companies conduct the evaluative surveys and summarize the data. Michigan DEQ staff may conduct surveys associated with management on a case-by-case basis when critical habitat or some other unusual circumstance is involved, or as part of a U.S. Fish and Wildlife Service Great Lakes Restoration Initiative funded early detection and response program for aquatic invasive plants that are on Michigan's watch list. End-of-season treatment reports are required from each permittee describing the target species, location and extent of the area treated, as well as herbicide brand name, amount, and rate of application. Because funds are limited, Michigan DEQ monitoring efforts are often selective and reactive. Surveys are conducted in response to management issues such as algal blooms, fish kills, recreational impediments, and others. The Michigan Water Resources Division conducts a limited number of targeted AIS surveys on approximately ten inland lakes each year. Additionally, they have integrated AIS monitoring into other routine stream, river, and inland lake surveys to capture incidental AIS observations.

In Minnesota, APM permittees are asked to develop maps of the proposed management area and, following management, report the size of the managed area along with the amount of any herbicide applied. Much of the APM pesticide treatment work and reporting is done by commercial aquatic plant control companies. Many IAPM permitted projects have pre- and post-treatment monitoring, often required as part of a Lake Vegetation Management Plan. IAPM treatment monitoring is conducted by Minnesota DNR staff, consultants, or volunteers. Across the state, aquatic plant communities are annually monitored using point-intercept surveys by the Minnesota Biological Survey and the Minnesota DNR's Shallow Lakes and Lake Habitat Programs.

New York DEC inspects waterbodies where chemical treatments are planned to make sure there are no environmental or drinking water impacts. They historically required monitoring of aquatic plant communities for management activities subject to enhanced permit review, but now monitoring is left up to local communities to support their treatments. The Adirondack Park Agency, which manages lands and waters within the boundary of the Park, also has a permitting process for APM and requires plant surveys in conjunction with any large-scale plant management operations and all aquatic pesticide treatments. New York maintains a list of waterbodies with documented aquatic invasive species through the iMapInvasives database (http://www.nyimapinvasives.org/) derived from confirmed AIS identifications from state agency, trained volunteer, and other monitoring programs. Several of these programs are funded by the NYSDEC.

Washington DOE has conducted APM research to evaluate various management techniques in the past. They conduct routine monitoring of aquatic plant communities on a set of waterbodies selected based on the likelihood of non-native plant presence, degree of public concern about aquatic plants, and level of recreational use. State, grant-funded noxious weed and HAB control projects receive qualitative oversight.

Grant Programs

In Maine and Indiana, state funding is available to support APM by lake organizations and other groups. Washington DOE also has a grant program for HAB-treatment and aquatic plant removal. Minnesota DNR formerly had a grant program for the control of curly-leaf pondweed, Eurasian watermilfoil, purple loosestrife, and flowering rush but the grant program now provides those funds to applicants for a wide variety of aquatic invasive species management activities. Michigan DEQ grant funding is focused on advancing the understanding and evaluation of AIS management techniques. Grant funding is also available in Michigan to Cooperative Invasive Species Management Areas (CISMAs), which are jurisdictions that facilitate collaboration across stakeholder groups in a given area of the state. These grants address regional priorities in Michigan, which may include management of aquatic invasive plants. New York DEC previously had an Invasive Species Eradication Fund through which groups could apply for cost-shared funding for APM projects but there is no longer dedicated funding for APM. Funding for invasive species management through state Water Quality Improvement Program grants are limited to aquatic habitat restoration projects. Similarly, Connecticut DEEP had a grant program in 2015 and 2016 to help fund herbicide treatments, physical control methods, research studies, and other APM activities but those funds are no longer available.

Applicators

Only certified applicators may conduct herbicide treatment of aquatic plants in Connecticut, Maine and Washington. In Washington, applicators are required to have an additional aquatic endorsement. In Minnesota, only a certified applicator can conduct an herbicide treatment if the herbicide is on the state’s restricted use pesticide (RUP) list. Individuals without certification may only apply non-restricted pesticides in private ponds that have no outlet. In Michigan, more than 90% of permitted treatments are conducted by licensed and certified pesticide applicators. Non-licensed individuals may conduct treatments with products that are not restricted. In Indiana, anyone who receives a permit can apply herbicides or manage aquatic vegetation. Though not required to get a permit from the state, hiring a certified chemical applicator is a condition on most permits proposing treatments covering areas larger than the landowner's exempted 625 square feet. In New York, landowners can apply herbicides on ponds less than one acre in size with no outlet and a single landowner; other treatments require a pesticide permit and licensed applicators.

Herbicide Treatment Scale

In Michigan, chemical treatments are permitted on a partial and whole-lake basis. Typical treatments are limited to near-shore control of nuisance aquatic plants along developed sections of the waterbody, and selective control of non-native aquatic plants across the lake. A small number of permits are issued annually for whole-lake fluridone treatments targeting non-native milfoil; Michigan state law limits fluridone concentrations such that they may not exceed 6 ppb. Minnesota and Connecticut have limits on the percentage of lake surface areas or littoral zones that can be treated with herbicides. Minnesota limits the amount of the littoral zone that can be treated with herbicides to 15% unless a variance is issued as part of a Lake Vegetation Management Plan. In general, Connecticut requests that herbicide treatments in public lakes (or those which they have a fisheries management interest in) will not result in aquatic plant coverage dropping below 20 to 40 % of the littoral zone to ensure that the waterbody maintains sufficient aquatic habitat value for fish. Whole-lake chemical treatments are not allowed in these states. In Washington, there are only limits on the scale of herbicide treatments for native plant species. Indiana DNR is currently developing guidance on the maximum percentage of a waterbody which can be treated. In New York, there are limits for copper sulfate treatment (whole-lake treatments using copper sulfate may not be conducted all at one time via a single application), and there is a wide range in the scale of herbicide treatments.

Chemical Treatment Notification

Michigan DEQ requires pre-treatment notification in writing to each impacted property owner, and through signs which must be posted along the shoreline of impacted areas of the waterbody. Written permissions are required from each impacted owner of waterbody bottomland, unless the permittee is a member of a special assessment district or statutory lake board. Additional notifications, such as newspaper postings and public service announcements, may be required on a case-by-case basis. In Connecticut, a newspaper posting and installation of signs at the treatment site must precede any herbicide treatment, while Indiana and Minnesota require signs but do not require a newspaper posting as notification of herbicide treatment. Minnesota DNR requires landowner signatures for treatments, but a signature waiver may be requested for IAPM permits due to an undue burden placed on the applicant to obtain all signatures. The signature waiver requires an alternate form of landowner notification. A newspaper posting can be substituted for the required signatures. New York DEC requires that signs be posted at lake access sites and riparian landowners be notified. Notifications must be given to anyone with access to the waterbody and anyone a certain distance downstream based on dilution models developed by permit applicants. Additionally, in New York, the permittee must supply drinking water if there is any discharge from the waterbody into drinking water sources that would result in impacts to drinking water. In Maine, a public meeting must be held before a Notice of Intent to apply aquatic herbicides is submitted to the Maine DEC. Signage, press, and mail notifications are also required.

In Washington, notice is required at the time a permit is applied for in the form of two newspaper notifications (published one week apart). The notice must also be delivered to all shoreline parties in the proposed treatment area and all those along the shoreline within one quarter mile of the edge of the proposed treatment area. Application for a permit also requires a 30-day public comment period. Washington DOE also requires pre-treatment notification in the form of a notice at least 10 days (at most 42 days) before the first treatment of the season to all those whose shoreline property is in the treatment area or within one quarter mile of the edge of the treatment area. The notification also provides the option for parties to request additional notification prior to treatment or to request an alternative water supply if the shoreline property owner drinks the water or holds a legal water right for irrigation. Treatment notification signs are posted at most 48 hours prior to treatment and must remain in place until any water use restrictions are concluded. To be able to better answer questions from the public, DOE requires permittees to submit pre- and post-treatment notices which state what the treatment plans are, and then what actually occurred.

Table S.1-1. Comparison between eighth states' aquatic plant management (APM)

State	Chemical Control Permit Required	Physical Control Permit Required	Has Grant Program	Quantitative Baseline Monitoring by State Agency	Quantitative Management Evaluation by State Agency	Allow Large-Scale Chemical Treatments	Chemical Treatment Notification	Other Points of Note
Connecticut	Y	N	N	S	S	N	Press notification and sign posting	• Chemical APM activities may require approval by Department of Public Health • Municipalities may have rules for APM
Indiana	Y for areas >25 ft^2	Y for areas >25 ft^2	Y	N	Y, for state-funded APM	Y	Sign posting	• Chemical APM may require approval from State Department of Environmental Management
Maine	Y	Y	Y	S	S	U	Public meeting, mail, press, and sign notification	• The most common APM activities used are physical approaches; biological control is not permitted
Michigan	Y	S	Y	S	S	Y	Sign posting and written notification	• Limits lakewide fluridone concentrations to ≤6 ppb
Minnesota	Y	S	Y	S	S	S	Sign posting	• Different permits for 1) individuals and organizations, 2) APM and IAPM
New York	Y	S	N	S	S	Y	Sign posting and personal notification	• Permittee may need to supply drinking water for some APM activities
Washington	Y	Y	Y	N	S	Y, for non-native species	Multiple press and written notifications, public comment period, and sign posting	• Specific timing windows for chemical APM based phenology • Permittee may need to supply drinking water • Allow HAB management
Wisconsin	Y	S	Y	S	S	Y	Press notification and sign posting	• Large-scale treatment permits require additional information

Note: 'Y' = yes, 'N' = no, 'S' = some, 'U' = unknown.

S.2. Ecology and Ecosystem Services of Aquatic Plants

S.2.1. Aquatic Ecosystems and the Value of Aquatic Plants

Freshwaters are some of the most imperiled ecosystems on the planet (Vitousek et al. 1997; Vörösmarty and Sahagian 2000; Vörösmarty et al. 2010). While freshwaters make up just a small fraction of the total amount of water on earth, they are extremely important and valuable. Life on earth requires freshwater for survival and people use freshwaters in many ways, including recreation, irrigation, sanitation and transportation (Postel and Carpenter 1997). In the modern age, freshwaters experience stressors ranging from pollution and nutrient enrichment to changes in natural flow patterns. As a result, many waterbodies show signs of degradation (Danz et al. 2007; Williamson et al. 2008; Stendera et al. 2012).

The ecology of aquatic ecosystems must be understood in order to support and protect healthy freshwaters. In general, healthy waters have biological communities that are in a natural condition with water that is unpolluted and where human disturbance is low. These waterbodies are often resilient to natural events that affect them and are capable of performing ecological functions like nutrient cycling, oxygen production, and decomposition that are so important to humans and other organisms. This chapter is primarily focused on the general ecology of lakes and how it is influenced by aquatic plants. While this chapter does not cover wetland and river systems comprehensively, an effort has been made to describe how the ecology of aquatic plants in these systems differs from that of lake systems. Reference to other resources may be warranted for readers interested in aquatic plant ecology and management beyond lakes.

Waterbodies can be very different from one another. The physical, chemical, and biological environment in a given aquatic ecosystem depends on natural patterns in geology, topography, climate, vegetation, and history (Domisch et al. 2015). For example, nutrients are important sources of food for plants and algae. When soil nutrient levels are low in lakes, the water is often extremely clear with very few plants and animals. When nutrient levels are naturally higher, lakes can support lots of plants, fish and waterfowl. The amount of nutrients available is one of the most important factors that leads to differences in aquatic ecosystems. A waterbody may have low nutrient levels at first, but over time, human activity may cause nutrients levels to increase. The increase in the amount of nutrients entering the waterbody (nutrient loading) will help feed populations of submersed aquatic plants. As more nutrients are added, algae and periphyton (a complex assemblage of tiny freshwater organisms) attached to the plants and other surfaces increase which can shade out some of the underwater plants. Finally, emergent and floating plants increase, followed by free-floating algae called phytoplankton (Figure S.2.1). These changes have major impacts on the rest of the biota, mainly because plants are key members of the aquatic food web and many other lake organisms depend on them. There is a large amount of variation among lakes, so it follows that they cannot all be managed in the same way. Some lakes may be inherently more or less capable of performing certain ecological functions, and some may have inherently different kinds of recreational or socio-economic value.

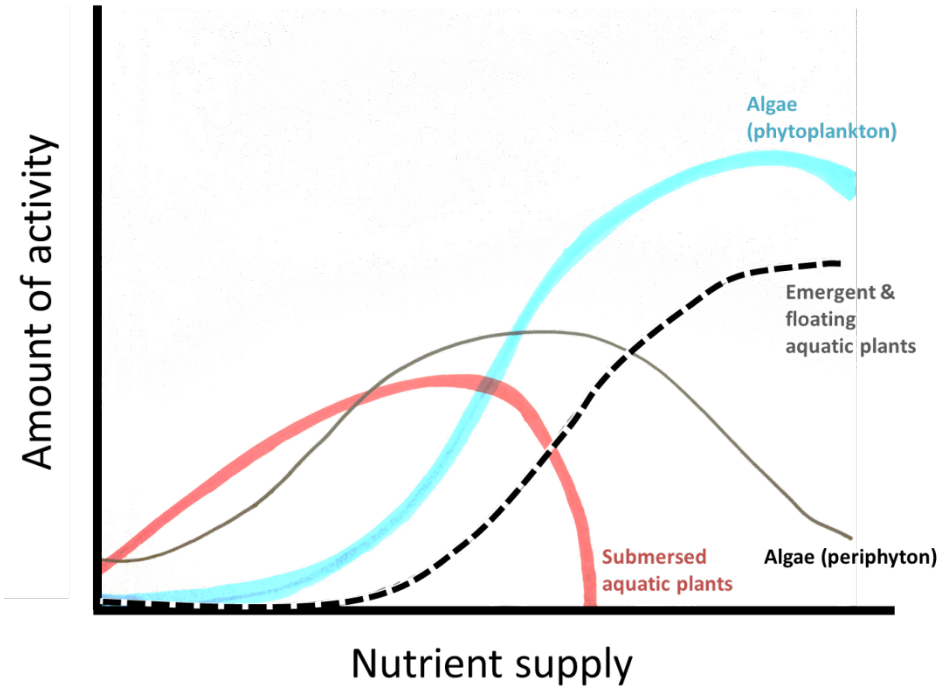

Figure S.2.1. Change in plant and algae population as a function of nutrient levels.
Note: As indicated in this conceptual diagram, plant and algae populations change as nutrient levels increase in lakes.

Nutrients are very important to the biology of aquatic systems. As lakes experience an increase in nutrient loading, significant changes can be conceptually separated into distinct trophic states. The concept of trophic states is useful even though the changes actually happen gradually along a continuum. When nutrient levels are low, the lake trophic state is called oligotrophic. Oligotrophic lakes have few nutrients, very clear water and can support only small (if any) populations of plants and animals. When nutrient levels increase a bit, biological populations increase and more plants and animals may be found. In these mesotrophic lakes, water clarity may start to decrease, but can still be quite high (especially when there are abundant underwater plants). Continuing along the nutrient spectrum, eutrophic lakes have high nutrient levels. They are extremely productive, but water clarity is generally low due to large amounts of free floating (planktonic) algae. Finally, at the extreme end of the nutrient spectrum, hypereutrophic lakes are super-productive but have extremely low water clarity. These lakes have very large phytoplankton populations and only free-floating and emergent plants are able to survive the low light conditions (Figure S.2.2). Fish, insect, and other members of the biological community usually cannot survive under hypereutrophic conditions.

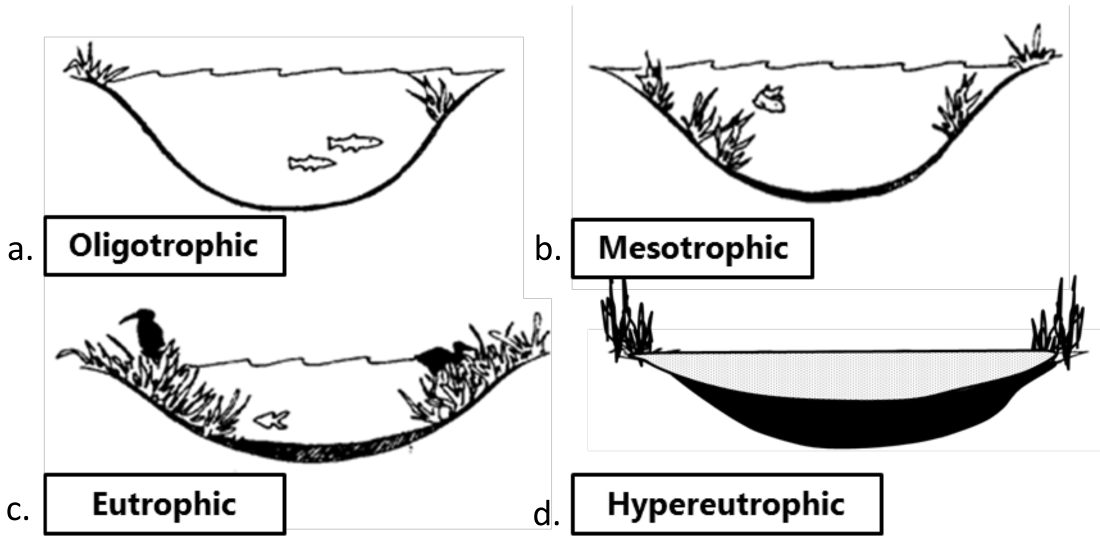

Figure S.2.2. Diagram of various lake trophic states.

Note: A lake's trophic state is dependent on nutrient levels. These diagrams represent lakes along the nutrient enrichment gradient, ranging from those with low (a) to high (d) nutrient content. Image source: Hamilton Lake Improvement Board.

The process of increasing nutrients in a lake along with the resulting effects of these increases is called eutrophication. Eutrophication can happen naturally over time. A lake may start out as oligotrophic, but as rainwater carries in nutrients that support plant growth from the surrounding watershed, the lake slowly becomes enriched. This natural process occurs very slowly, typically over centuries or millennia. As eutrophication progresses, life goes through natural cycles of growth, death and decay. Dead plant and animal material settles to the bottom of the lake and starts decomposing, producing additional nutrients and organic substrate (often referred to in common terms as "muck" or "ooze"). Organic substrate accumulates, lakes get shallower, and nutrient levels continue to increase. Thus, through this natural process, and usually over millennia, even a once-oligotrophic lake can become shallower and more productive.

Human activities can also result in eutrophication, but when human-related or "cultural" eutrophication happens, it often occurs much more rapidly. While natural eutrophication may progress over centuries or millennia, cultural eutrophication can occur as nutrient loading increases on the scale of decades. Agricultural activities and urbanization cause increases in nutrient-rich runoff and sewage discharge which contributes to nutrient loading and cultural eutrophication. In fact, human-caused eutrophication is one of the primary threats to freshwater ecosystems in the US and worldwide (Parry 1998; Dudgeon et al. 2006). Extremely dense populations of aquatic plants and algae are often a sign of cultural eutrophication. The resulting overgrowth of plants and algae often leads to a desire to manage aquatic plant and algae populations directly, using techniques like harvesting or herbicide applications, even though the ultimate cause of overgrowth is often related to nutrient loading. Often, if excess nutrients are the ultimate cause of nuisance populations, managing aquatic plant communities directly will provide only a temporary solution. While wetlands are often referred to as filters or "nature's kidneys" that protect water quality, they can also become oversaturated with nutrients, leading to alteration of plant communities which can be very difficult to reverse (Zedler 2003).

In addition to nutrients, physical characteristics of waterbodies are important to consider when making management decisions. For example, the rate at which water moves through a particular system can affect management actions, especially those that involve adding herbicides that require a certain concentration and exposure time in order to achieve control. Water that flows quickly through rivers will quickly move herbicides downstream, making them unable to provide control on the targeted site. Flowages and impoundments can have a similar problem. Often described as 'wide spots in the river' when compared to most lakes, the movement of water through these systems is still rapid (ranging from hours to days), which is often quick enough to interfere with the action of certain herbicides. Water moves more slowly through larger drainage lakes, which can often act as settling pools because water stays on-site for a longer period of time. On the other end of the spectrum, lakes that lack inlets or outlets and are unconnected to the surface water drainage network (e.g., seepage lakes) do not experience quick turnover of their water volume and can have extremely long water retention times. Wetlands also often have long water retention times due to both biotic and abiotic factors; the micro-topography of small hills and pools formed by the varied plant growth forms in diverse wetland plant communities represent a biotic mechanism that can increase water retention time (Werner and Zedler 2002; Bruland and Richardson 2006), whereas wetlands formed on the landscape with only seasonal or very-limited connection to other surface waters are more like lakes which lack surface inlets or outlets.

Even in unconnected lakes, however, it is important to consider water movement. During summer, the sun warms the upper layer of the lake but the sun's warmth fails to reach the deeper areas. Because the temperature of water affects its density, water in a deep lake has a strong vertical temperature difference created by the sun will "stratify" into layers. Water in a stratified lake doesn't easily mix; the deeper waters are much colder than the surface. Many people often experience this temperature difference when they dive into deep waters during the summer. The colder region is separated from the warmer areas by a thermocline, where the temperature changes rapidly. During summer, the thermocline separates the upper, warmer layers that are heated by the sun's energy and the lower, colder layers that remain down below. In the winter the pattern is reversed, with the slightly warmer water on the bottom and ice and colder water on top. Due to a unique property of water, water in solid form (ice) has a relatively spacious molecular configuration that is less dense than liquid water which explains why ice floats. During winter, the dense water at the bottom is in fact warmer than top layers just under colder but less-dense ice. Year round, though photosynthesis, aquatic plants and phytoplankton produce food upon which other organisms in the larger lake food web rely. This "primary production" decreases beginning in the fall and reaches a low point in the winter months with plant decay. In spring, the temperature differential switches again as the sun's energy re-warms the top of the lake. For a brief period, as the temperature throughout the lake equalizes, the lake water mixes easily, just a bit of wind can start the water turning over (Figure S.2.3). Because these water movements can affect the way substances move and where they are located within a waterbody, stratification and the timing of mixing events is important to consider when planning management actions. For example, in deeper waterbodies an applied herbicide can potentially become "trapped" in the upper stratified layer and not mix into the cooler bottom layer, changing the way concentration calculations should be performed. Stratification often does not occur in shallow lakes (generally <18 feet maximum depth) where the sun can penetrate most of the water and where wind mixes the water easily.

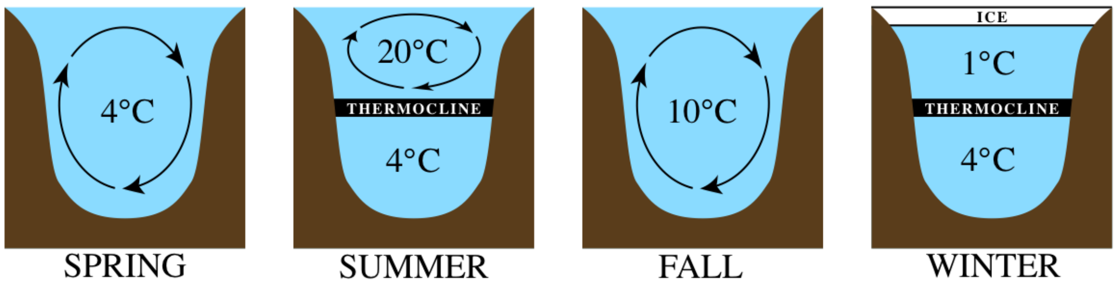

Figure S.2.3. Seasonal periods of mixing and stratification in a temperate lake.

The field of wetland ecology and management is comparatively young (Anderson and Davis 2013) with various political and ecological definitions of what constitutes a wetland. There is no universal classification system for wetlands like that described for lakes above. Some of the more common classifications used by resource managers include the U.S. Fish and Wildlife Service "Cowardin" classification and the hydrogeomorphic classification, among others (Cowardin et al. 1979; Brinson 1993; Lillie et al. 2002). While the lake types described above are based heavily on water chemistry and geologic influences, soil type is also critical to consider in classifying wetlands. Being situated at the interface between fully aquatic and terrestrial environments, wetlands may have characteristics of both; supporting algae, aquatic invertebrates and vertebrates as well as vascular plants found in both aquatic and terrestrial systems. Wetland structure varies with hydrology, geomorphic setting, and nutrient content (Cherry 2011). In Wisconsin, wetlands are typically classified by natural plant community types and generally are managed and assessed based on their plant communities as well. Nearly 40 different wetland community types are present in the state.

Similar to lakes, wetlands also experience extreme seasonal changes. Primary production decreases in the winter as plants and phytoplankton senesce (i.e., die back), though production in wetlands is likely to drop to an even lower level because plants are not able to continue to grow beneath the ice as in lakes. Depending on the dominant water source(s) to a wetland (e.g., ground water, surface water, precipitation, etc.), hydrology often undergoes extreme seasonal changes to the point where the soil may not be wetted or ponded at all during a majority of the year. Also, because wetland soils are often rich in organic matter that can retain heat, the growing season in wetlands often begins earlier and ends later.

Beyond increased nutrient inputs, alterations in natural hydrology and salinity as a result of human activities are also serious threats to wetland ecosystems (Keddy and Fraser 2000; Wilcox et al. 2002). Any sort of damming, ditching, or decreases in groundwater inputs may make the environment more suitable to colonization by invasive species, in addition to altering nutrient cycling and overall wetland structure. Invasive plants such as reed canary grass, non-native cattails (*Typha* spp.), phragmites (*Phragmites australis* subsp. *australis*), and purple loosestrife (*Lythrum salicaria*) may also benefit from road salt inputs leading to changes in system salinity (Farnsworth and Meyerson 2003).

Aquatic Plant Ecology

Light travels through water less easily than it does through air, so deep parts of a lake are often very dark and do not support abundant life. On the other hand, light is abundant in shallow areas, generally ranging from 0 to 20 feet deep. These light-rich shallow areas are referred to as the lake's "littoral zone". Littoral zones teem with life; this is where most of the biological activity in a lake occurs. Aquatic plants are key components of lake littoral zones. The availability of sunlight and presence of aquatic plants are one of the main reasons littoral zones are so rich and productive. The open water area beyond the littoral zone where light cannot penetrate to the bottom is referred to as the lake's pelagic zone (Figure S.2.4). While wetlands often do not have zones analogous to lakes in terms of depth and light availability, complexes of different wetland types may still result in different areas of a complex contributing varying degrees of primary productivity (Cherry 2011). See Eggers and Reed 2015 (p. 23-24) for visual representations of how wetland environments integrate with the zones depicted in Figure S.2.4.

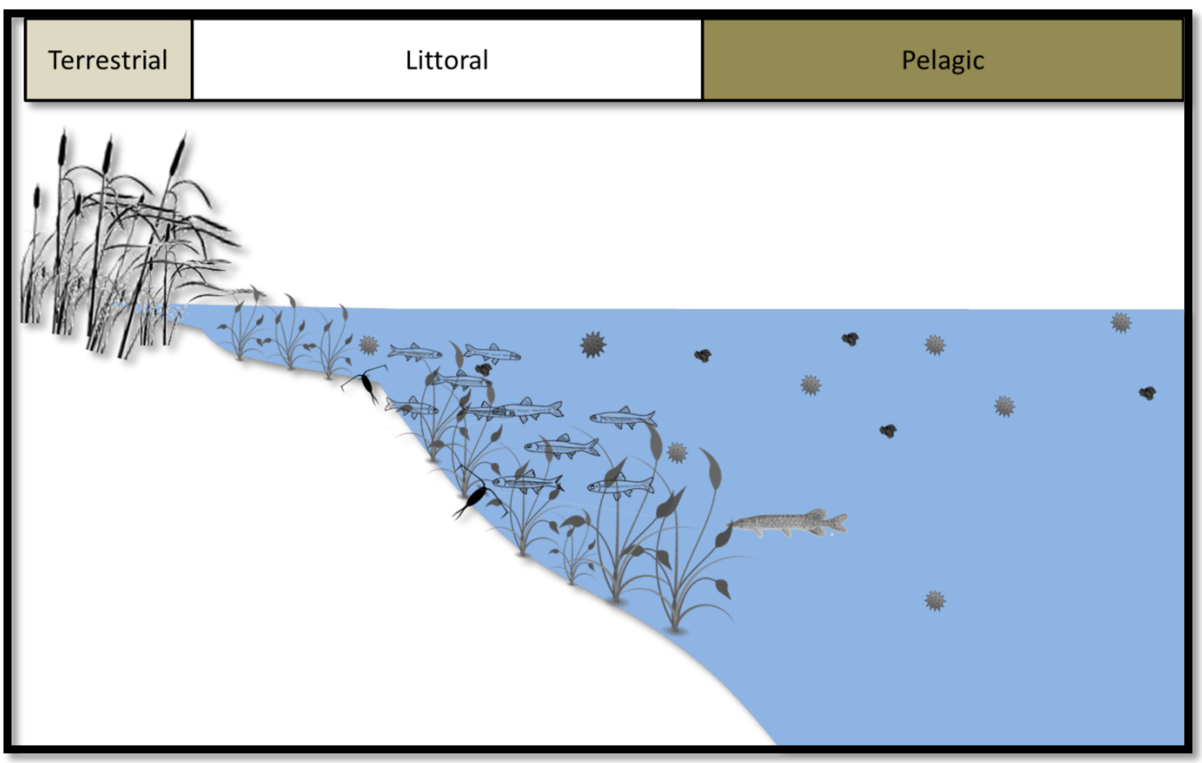

Figure S.2.4. Visualization of the habitat zones of a waterbody.

Aquatic plants are vitally important to lakes: they provide food and habitat for animals like fish and waterfowl, they influence nutrient dynamics, help support clear water, and prevent sediment uplift and erosion (Jeppesen et al. 1998). Aquatic plants are affected by anthropogenic (i.e., human-influenced) disturbance, including unnatural nutrient increases, shoreline modification, and alterations to hydrological regimes (Roberts et al. 1995; Radomski and Goeman 2001; Egertson et al. 2004; Alahuhta et al. 2011). Healthy aquatic plant communities are critical to support and maintain healthy aquatic environments. Over the past several decades, scientific research has helped define the critical role aquatic plants play in biochemical, physical, and biotic interactions in lakes (Anderson and Kalff 1986; Carpenter and Lodge 1986; Chilton 1990; Nielsen and Sand-Jensen 1991; Scheffer 1998; Bornette and Puijalon 2010). One of the most obvious and valued service they provide is that of supporting and maintaining conditions of clear water with biologically diverse communities. Lakes that lack aquatic plants can be turbid, devoid of life and dominated by free-floating phytoplankton, (see Figure S.2.5).

One can think of clear water and turbid water as two possible alternate realities for a given lake. Whether a lake is in one category or the other depends largely on the availability of nutrients. Lakes that support a healthy population of aquatic plants can better withstand the stress of cultural eutrophication. Aquatic plants sequester nutrients, making them less available for phytoplankton that would otherwise shade them out. Furthermore, particulate organic matter settles out in the slow-moving water surrounding plant beds, and nutrients are buried when aquatic plant roots stabilize the sediment (Barko and James 1998; Brenner et al. 2006). Additionally, populations of water-clearing zooplankton that eat phytoplankton find refuge in aquatic plant beds and help keep the amount of phytoplankton in check (Stansfield et al. 1997).

Figure S.2.5. Phosphorus-enriched versus unenriched water. Note: Enriched water (below the curtain) is highly turbid. Canadian Experimental Lake Area. Source: http://saveela.org.

Figure S.2.6. Examples of lakes with clear (a) and turbid water (b)
Source: Public Domain (a), Mary Gansberg (b).

Although nutrient enrichment can sometimes create dense stands of plants that may interfere with recreation, the ecosystem services aquatic plants provide in supporting ecological health and maintaining clear water conditions may outweigh the drawbacks (Figure S.2.6). In situations where there are few aquatic plants or when nutrient levels are so high that the stabilizing function of aquatic plants is overwhelmed, phytoplankton populations can grow so dense that they begin to block light from passing through water. Too much shade can then kill any remaining aquatic plants, and few other organisms can survive the harsh conditions this creates. Enriched lakes without plants have green, turbid water and low recreational and conservation value. Unfortunately, the condition of phytoplankton domination is difficult to reverse. Even when nutrients are reduced, phytoplankton populations can persist, as aquatic plants find it difficult to gain a foothold in extremely turbid conditions. These phytoplankton populations can grow to nuisance levels that are more difficult to manage than nuisance aquatic plant populations and can also potentially be hazardous to public health when blue-green algae toxins are present.

The many contributions of aquatic plants to lake ecology are apparent when you consider all the functions that combine to support clear water and lake biodiversity. The next section explores in more depth why aquatic plants are important via their effects on lake biogeochemistry, physical environment, and biology.

Biogeochemistry

Phosphorus, nitrogen, and carbon are three nutrients that are crucial for the growth of aquatic plants, algae, and other organisms, and are known as the building blocks of organic life. Aquatic plants influence how and where nutrients are stored and how nutrients move within lakes, rivers, and wetlands. Nutrient dynamics have large effects on the waterbody's biotic and abiotic environment and are often modified or mediated by aquatic plants. In wetlands, due to a very high ratio of soil surface area to water volume, the sediment-water interface leads to even tighter nutrient cycling and greater primary production in some cases than in lakes (McClain et al. 2003). In lakes, a large proportion of primary production occurs in the littoral zone, and productivity is significantly higher in lakes with abundant submerged aquatic plants (Brothers et al. 2013).

Nitrogen, Phosphorus, and Other Trace Nutrients

Just like on land, most of the nutrients in aquatic environments are found in the ground, or substrate. Aquatic plants and microbes connect the waterbody substrate with the overlying water by incorporating substrate nutrients into their tissues (Carpenter 1980b; Smith and Adams 1986; Barko and James 1998). Once nutrients have been incorporated, small amounts leak slowly from living tissues back into the water. Aquatic plant tissue can also release large amounts of nutrients into the water during periods of aging and decay at the end of the growing season or in response to large-scale management actions. This release of nutrients from plant material has a strong seasonal component and must be considered in situations where aquatic plant die-off is a potential outcome of plant management activities.

Oxygen

Aquatic plants both consume oxygen (at night) and produce it (during the day). This leads to marked daily and seasonal fluctuations in the oxygen environment (Ondok et al. 1984). Aquatic plants' role as oxygen suppliers in waterbodies is vitally important for other aquatic organisms, but different species will affect the oxygen environment differently (Wetzel and Søndergaard 1998; Caraco et al. 2006). Submersed plants release the oxygen they generate into the water column, while floating-leaf plants release a lot of the oxygen they produce into the air. Thus, the level of dissolved oxygen in the water in a floating-leaf plant bed is often much lower than the level of oxygen the water of a submersed plant stand (Caraco et al. 2006). In addition, the decay of dead plant material consumes oxygen, so as aquatic plants grow and die, oxygen fluctuations can occur that can impact other organisms. For instance, research has shown that large aquatic plant die-offs and the resulting oxygen consumption due to decay can lead to oxygen deficits that can threaten fish communities (Battle and Mihuc 2000; Misra 2010).

Finally, aquatic plants' influence on oxygen levels in aquatic environments can indirectly affect other organisms via changes in the lake chemical environment. One way this occurs is when daily and seasonal patterns in oxygen production create hot spots of biogeochemical activity. For example, some plant species have roots that release oxygen into the sediment, changing the oxygen environment for bottom-dwelling organisms that are important to the ecosystem. These oxygen-rich microzones are critical for regulating chemical reactions (Caraco et al. 2006), as oxygenated sediments are more likely to hold phosphorus out of the water column. This can work to reduce the movement of phosphorus from the sediment to the water and have cascading effects on water clarity (Sand-Jensen et al. 1982; Jaynes and Carpenter 1986).

Carbon

Carbon is necessary for all organic life forms: it fuels metabolism in plants and animals and is the main source of energy for living things. Plants are important to the biosphere because they can use carbon and then make it available to other organisms. In addition, carbon leaches from living and dying aquatic plants and is released during the night. These carbon fluxes have important effects on fish and other organisms in the freshwater food web (Wetzel and Søndergaard 1998). Additionally, some aquatic plant species can utilize diverse forms of inorganic carbon which are not directly usable by other aquatic organisms (Maberly and Madsen 1998). Many specialized plants can remove carbon dioxide from the water, shifting the pH to an alkaline environment which causes calcium carbonate to fall out of solution. This causes the subsequent deposition of calcium carbonate as marl in lake sediments.

Physical Environment

Aquatic plants play an important role in the physical environment of lake littoral zones. Just as on land, aquatic plants create shade by intercepting incoming light. In lakes with aquatic plants that have floating leaves or form surface mats, the amount of light that penetrates to deeper areas of the lake is drastically reduced (Titus and Adams 1979). In addition, because aquatic plants provide habitat for zooplankton and other organisms that eat algae, they can also indirectly help clear the water (Timms and Moss 1984; Schriver et al. 1995). Aquatic plants' influence on the light availability in lakes is particularly important for sight-based predators like fish that eat other fish and zooplankton. Furthermore, aquatic plants can have substantial effects on lake temperature. For example, productive lakes generally support fish that are tolerant of warm water temperatures; thick aquatic plant mats can increase water temperatures up to 10°F relative to open-water areas (Dale and Gillespie 1977).

Aquatic plants structure the physical environment as they decay and deposit particulate organic material in lake littoral zones, which is one of the primary ways sediment is created. Sediment accumulation in lakes naturally creates more habitat for aquatic plants and is a natural part of eutrophication (Carpenter and Lodge 1986). Furthermore, the organic content in lake sediments is an important food source for benthic (bottom-dwelling) organisms. In addition to creating sediment, aquatic plant roots function to stabilize sediment, reducing uplift and related nutrient recycling, and clearing the water.

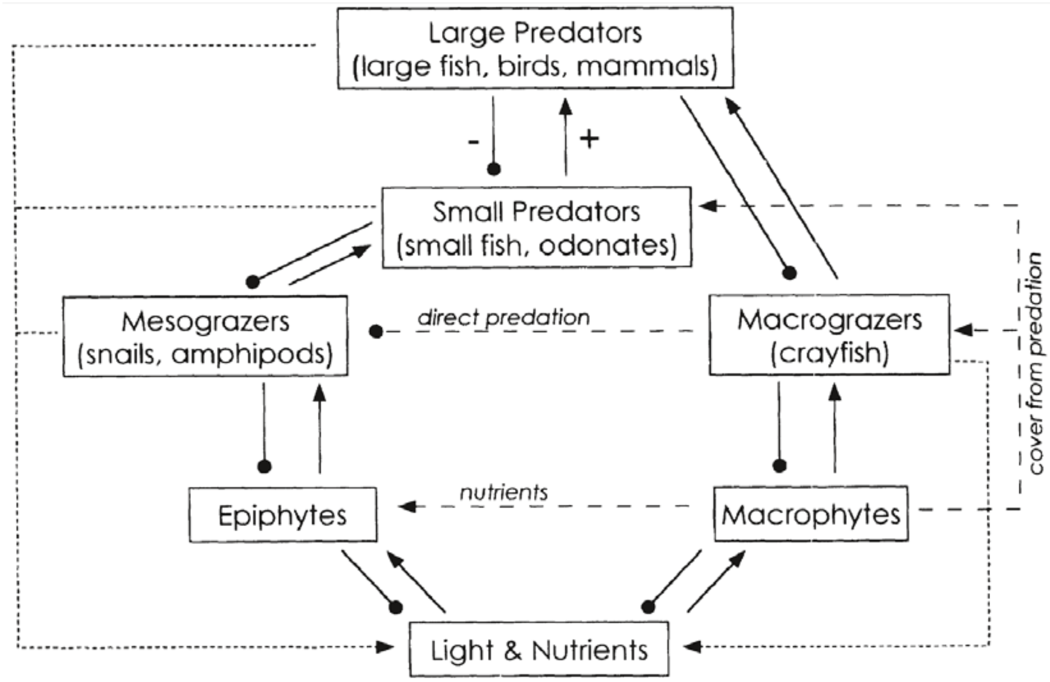

Figure S.2.7. Generalized lake food web for submerged aquatic plant systems.

Note: Lines ending in arrows represent positive effects, circles indicate negative effects. Dashed lines indicate possible interactions. Dotted lines indicate possible nutrient recycling routes. (Reproduced with permission, Crowder, McCollum and Martin in Jeppesen et al. 1998.)

Finally, aquatic plants have major impacts on the movement of water. Dense aquatic plant beds can slow water movement and reduce water turbulence. Slower water movement is associated with increased settling rates and more stable sediments (Barko et al. 1991). In fact, sedimentation rates in littoral zones with aquatic plants can be twice as high (James and Barko 1990). The beneficial effects of aquatic plants on sediment stability should be kept in mind when considering management actions designed to reduce aquatic plant abundance for recreational use.

Biotic Interactions

Aquatic plants are critical components of aquatic food webs and are important to biological communities living in and near lakes (Figure S.2.7). As discussed above, plants are primary producers that assimilate carbon which is later used by other organisms. Aquatic plants support diverse and abundant algal and animal communities by providing habitat, hiding places, and food. Below are more details regarding some of the most common biological interactions related to aquatic plant communities.

Invertebrates

Aquatic plants provide habitat for numerous other organisms. For instance, within dense aquatic plant beds, zooplankton can exist in large numbers despite high predation pressure (Timms and Moss 1984;

Lauridsen and Lodge 1996; Stansfield et al. 1997). The ability of aquatic plants to provide zooplankton hiding places and habitat likely helps zooplankton to eat more phytoplankton, which in turn produces clear water that can be important to visual fish predators (Jeppesen et al. 1997).

Aquatic plants also provide food and cover for aquatic insects and snails (Timms and Moss 1984; Engel 1985; Beckett et al. 1992; Lauridsen and Lodge 1996). As such, invertebrates are positively associated with the presence of aquatic plants (Wiley et al. 1984; Cronin et al. 2006; Ali et al. 2007). Furthermore, a very palatable form of algae grows on aquatic plant surfaces which is an excellent food source for invertebrates (Cattaneo and Kalff 1980).

Fish

Freshwater fish rely on food originating in aquatic plant beds (Vander Zanden et al. 2011). Aquatic plants play a major role in creating food and providing refuge for other organisms and are consequently important for fish survival (Devries and Stein 1992; Chipps et al. 2009). Aquatic plants support diverse and abundant macroinvertebrate communities which are important for the fish forage base (Holland and Huston 1985; Rozas and Odum 1988).

In addition to providing food and habitat for prey items, structurally complex aquatic plant habitat supports high growth rates and abundance for many fishes (Trebitz et al. 1997; Olson et al. 1998; Cross and McInerny 2006). Aquatic plants provide refuge from predators and cover for sport fish species during spawning (Janecek 1988). Other fish species tend to demonstrate a preference for having aquatic plants nearby, likely because open areas with no nearby cover present higher risk of predation (Colle and Shireman 1980; Killgore and Dibble 1993).

Aquatic plant beds in freshwater environments may help increase larval fish survival by acting similarly to estuaries in marine systems, which often provide nurseries for larval fish (Beck et al. 2001). Aquatic plant beds, like estuaries, have slow-moving water, provide protection from predation, and supply abundant food (Barko and James 1998). For example, larval darters, pumpkinseed, and perch prefer shallow areas with dense aquatic plants (Gregory and Powles 1985). In a study on the Upper Mississippi, areas with submerged vegetation had more than double the density of young-of-the-year sport fish relative to areas without vegetation (Holland and Huston 1985).

As far as aquatic plant density and abundance goes, there is evidence that fish prefer “intermediate” levels. A moderate amount of plants provides food as well as cover to hide from predators, and fish had a more varied diet in moderately dense aquatic plant beds, translating to more prey of higher quality (Crowder and Cooper 1982). Beyond simple density, certain fish species prefer certain aquatic plant growth forms, and lakes with aquatic plants of multiple growth forms (e.g., floating, submerged, emergent plants) were associated with fish like northern pike and pumpkinseed (Cross and McInerny 2006). Lakes with sparse cover, on the other hand, were associated with bottom-dwelling fish like common carp (*Cyprinus carpio*) and bullheads (*Ameiurus* spp.). Species belonging to the perch, minnow, killifish, carp, and sunfish families have been shown to prefer complex aquatic plant environments with lots of species (Poe et al. 1986). Field observations show that largemouth bass (*Micropterus salmoides*) and bluegill (*Lepomis macrochirus*) are most abundant in complex versus simple environments, apparently displaying preference for complex plant growth (Janecek 1988). Fish that eat other fish often cruise the edges of plant beds while looking for food, and often move perpendicularly to shore along aquatic plant bed edges (Savitz et al. 1983). In fact, artificial creation of edge habitat has been explored as a way to manage aquatic plant populations to support game fish populations. Some studies have shown increased bluegill growth and more bass by harvesting narrow channels in the littoral zone of a lake with dense with aquatic plant cover, removing less than half but more than 30% of the plant biomass (Cross et al. 1992; Trebitz et al. 1997; Olson et al. 1998).

Terrestrial Links

Aquatic plants may contribute to terrestrial food webs in a variety of ways. Many species break into fragments as a form of vegetative reproduction. Other species can spontaneously uproot, and water turbulence can mechanically fragment aquatic plants. The air-filled spaces in stems and leaves of many aquatic plant species make them float, and fragments can thus drift and spread, and also accumulate on shore (Spencer and Lekić 1974). The accumulation of aquatic plant biomass on shore can act as a source of nutrients and habitat for land-dwelling creatures.

Another way that aquatic plants contribute to terrestrial systems is by providing habitat for terrestrial insects that live in the water as larvae. For example, benthic macroinvertebrates and larval forms of terrestrial insects are much more numerous under beds of aquatic plants than in open water areas (Keast 1984; Strayer 2007). A limited amount of work has also found that aquatic plants are used in the short-term by terrestrial invertebrates.

Finally, aquatic plants support populations of larger semi-aquatic and terrestrial animals such as waterfowl and other wading birds. For instance, the population and brood density of blue-winged teal (*Anas discors*) populations corresponds to changes in aquatic plant biomass (Mitchell and Perrow 1998). Some waterfowl use aquatic plants as an important source of food. Additionally, large herbivores also interact with aquatic plants. Moose, for example, are often found to be active at lake and river edges, where they feed extensively on plant material. Moose thereby represent an important link between aquatic and terrestrial systems (Bump et al. 2009). In general, biotic interactions among terrestrial animals and aquatic plants have been demonstrated, though additional work is necessary to quantify and more completely describe additional interactions.

Invasion Potential

It seems logical that aquatic ecosystems already teeming with plant life will be more difficult to inhabit by invading, non-native species. However, while observations that communities with a greater diversity of species are less likely to be invaded have been made in small-scale studies (Wardle 2001; Kennedy et al. 2002; Fargione and Tilman 2005), the opposite pattern has been observed at regional scales (i.e., with greater diversity comes greater numbers of invasive species; Stohlgren et al. 1999; Levine and D'Antonio 1999; Muthukrishnan et al. 2018). Many of these studies suggest that the observed relationships between diversity and invasibility are being driven by ecological characteristics (e.g., water quality, land use, etc.) rather than actual interactions among species. Additionally, in Wisconsin lakes, the most diverse native plant communities often are not dominated by those species likely to pose a competitive match against some of the most common invasives.

S.2.2. Ecology of Aquatic Plants in Wisconsin

There is a strong gradient in natural environmental conditions when moving from south to north across the state of Wisconsin, and this natural gradient helps determine what kinds of plants grow in the littoral vegetative community. Species composition varies primarily along a strong gradient in alkalinity and secondarily according to water clarity and factors associated with nutrient enrichment (Mikulyuk et al. 2011). Alkalinity controls the form of carbon that is available to plants and has been observed time and again to be one of the most important factors that determines the distribution and abundance of aquatic plants (Vestergaard and Sand-Jensen 2000). In the northern regions, aquatic plant communities more often include low-growing rosette species (oftentimes called 'isoetids') that use carbon extracted from the sediments along with some taller species associated with low alkalinity (like certain pondweeds and stonewort species). In the south, species typical of high alkalinity systems which can use bicarbonate carbon sources include species like coontail (*Ceratophyllum demersum*) and muskgrasses (*Chara* spp.), as well as species adapted to enriched, turbid water like free-floating duckweeds (Mikulyuk et al. 2011). Wetlands types also vary to some degree according to a north-south gradient based on geology and disturbance, though some kinds of wetlands, such as emergent marshes, can be found throughout the state.

In addition to natural factors, human-related factors are also important in determining what kind of plants grow in a given lake. The northern region of Wisconsin is largely forested and less impacted by human activity relative to the southern region of the state, and as a result, the aquatic plant communities in the north are more typical of those one would find in pristine conditions (Nichols 1999). Watershed development has been associated with increased incidence of species introductions, as well as decreased species diversity and a decline in disturbance-sensitive plants, including pondweeds, isoetids, and floating leaf plants (Borman et al. 2009; Sass et al. 2010).

S.2.3. Ecosystem Services of Aquatic Plants

Ecosystems are complex: they include all interconnected biological communities and supporting nonliving elements in an area. Some ecosystems are terrestrial. For example, a temperate forest ecosystem may contain deciduous and coniferous trees, understory vegetation, insects, mammals, birds, reptiles, leaf litter, air, water, and soil. Other ecosystems, like coral reefs, streams, and lakes are aquatic. Aquatic ecosystems may include insects, fish, plants, and algae, as well as the water the organisms live in, sediment, calcium carbonate, nitrogen, phosphorus, and oxygen dissolved in the water. Aquatic ecosystems may also include shoreline trees that drop leaves into the water or marginal emergent plants that reduce erosion and stabilize shorelines. Ecosystems, both aquatic and terrestrial, provide goods, services, and values that people depend on, especially the provision of clean air to breathe and clean water to drink. Wetlands filter pollutants and trap sediments and nutrients, recharging our groundwater supply; without them, our water would be undrinkable. Plants in the global ecosystem produce oxygen. If all the plants were removed our planet would be almost immediately uninhabitable. It is vitally important to recognize the immeasurable value of these and other ecosystem services provided by the natural world, and that action is taken to protect them to support a better quality of life.

The goods and services provided by ecosystems are numerous and varied but can be divided into four conceptual groups (Figure S.2.8). For example, the cycles and movement of nutrients are critical for agricultural food production. "Provisioning" services describe ecosystems' supply of directly extractable goods, such as lumber, fresh water, food and oxygen. "Regulating" services include functions that help regulate natural processes such as controls on flooding, climate, and water purification. Finally, "cultural" ecosystem services include those aspects that increase quality of life and enjoyment via their cultural value. For example, some people enjoy the aesthetics of nature, find spiritual meaning in natural places, enjoy recreating in natural environments, or appreciate ecosystems because they help us understand how the world works (Millennium Ecosystem Assessment 2005).

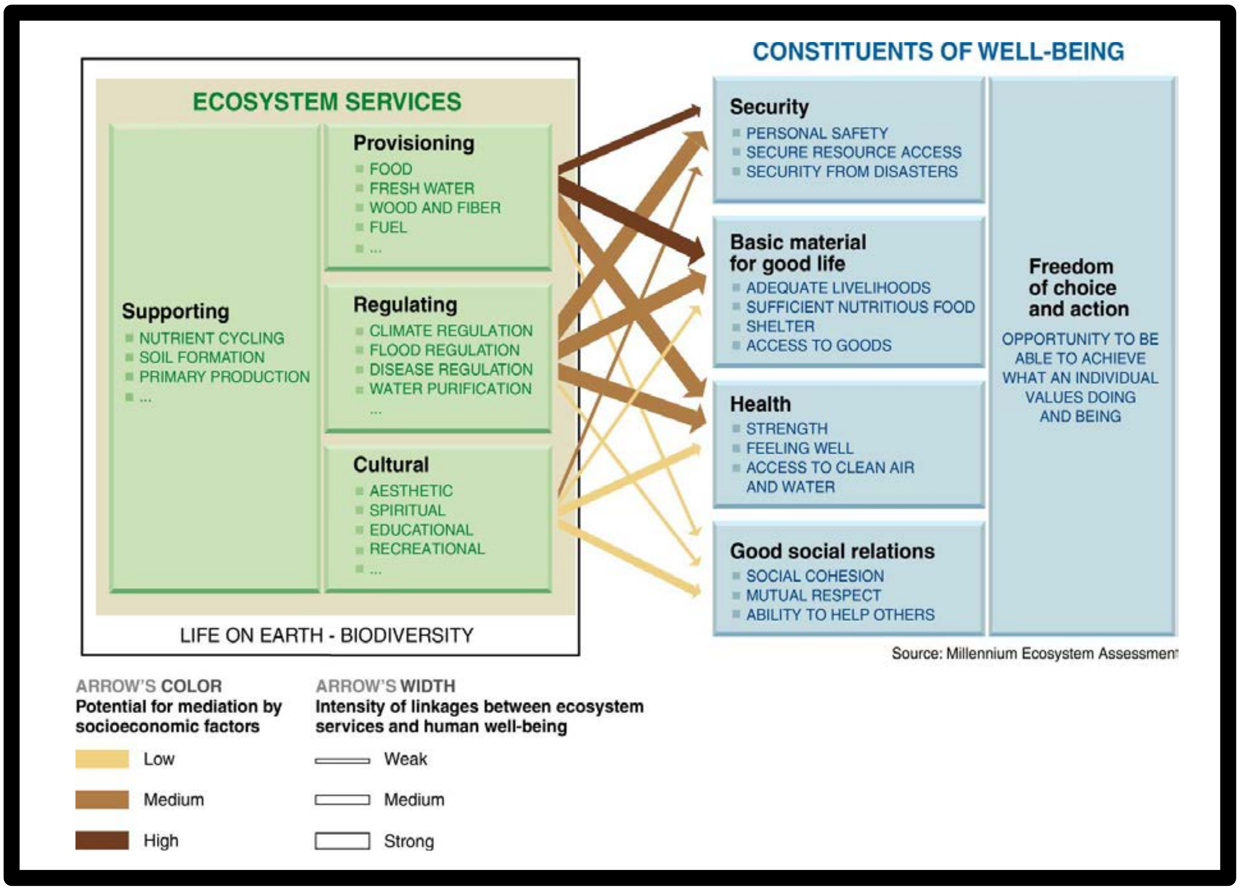

Figure S.2.8. Links between ecosystem services and human well-being.
Source: Millennium Ecosystem Assessment (2005).

Freshwater Ecosystem Services

Freshwater ecosystems make up a small fraction of all of the water on earth, but they provide an incredible number of services that are necessary for human life and well-being (Aylward et al. 2005). One of the most important services of freshwater ecosystems is the provision of fresh water that is directly used by people for irrigation, sanitation, consumption, and transportation. Freshwater ecosystems also provide habitat for aquatic organisms that are harvested for use as food and medicine. Regulatory services provided include the support of high water quality via filtration and purification, the regulation of water flow and floods, as well as erosion prevention. Supporting services include freshwaters' role in nutrient cycling, climate, and primary productivity. In addition, freshwater ecosystems provide numerous cultural services like paddling, boating, sport fishing, and tourism, as well as aesthetic and spiritual values that contribute to human quality of life.

Ecosystem Services Provided by Aquatic Plants

Just as freshwater systems provide numerous ecosystem services, the aquatic plants supported by aquatic environments also provide ecosystem services. Aquatic plants, especially emergent species, are used as food, medicine, and in cultural practices (Meena and Rout 2016). Provisioning services by aquatic plants have great economic value and contribute to human well-being. For instance, some aquatic plant species are used directly as food; in northern Wisconsin, wild rice (*Zizania palustris*) is typically harvested in late summer for personal and commercial use. It has high nutritional value and is a large part of the regional diet and is also of immense cultural importance for Great Lakes Native Americans. Less heavily utilized, but still valuable, are arrowhead tubers (*Sagittaria* spp.), cattail stalks (*Typha* spp.), and American lotus (*Nelumbo lutea*) seeds and roots. Cattail down is an incredibly effective thermal insulator, while the main body of the plant may also have potential for use as a biofuel (Ciria et al. 2005).

Aquatic plants also offer several important regulating ecosystem services. They trap sediments, nutrients and pollutants, and produce oxygen that is crucially important to life in aquatic systems (Millennium Ecosystem Assessment 2005). In fact, the ability of aquatic plants to remove pollutants like heavy metals from the water has been harnessed commercially. Highly productive species like water hyacinth (*Eichhornia crassipes*) and duckweed (*Lemna* spp.) have been used to remove pollutants from municipal wastewater (Ciria et al. 2005). Aquatic plants are widely used in constructed treatment beds (often referred to as "constructed treatment wetlands"), which attempt to re-create the nutrient cycling and other water quality functions natural wetlands can perform. These man-made systems can provide effective means of nutrient retention, with observed decreases in phosphorus of up to 92% and retention of pesticides measured as high as 96% in experimental systems, though research is ongoing (Mitsch et al. 1995; Arts et al. 2012). Aquatic plant assemblages of high biodiversity are especially effective at water purification (Engelhardt and Ritchie 2001).

Supporting services necessary for other services are also performed by aquatic plants. As primary producers, their ability to photosynthesize makes aquatic plants important as a source of energy for other organisms that live in the ecosystem. Aquatic plants support biodiversity of other trophic levels such as fish and waterfowl, and are also incredibly important for the movement and cycling of nutrients (Millennium Ecosystem Assessment 2005). Aquatic plants are also important in sediment accumulation and contribute a large quantity of organic material to the lake bottom (Barko and James 1998).

Finally, aquatic plants are culturally valuable. Whether it is from an aesthetic or spiritual perspective, many find the image of natural wetlands, rivers, or lake aquatic plant communities beautiful or inspiring. Indeed, the beauty of aquatic plants has inspired many works of art. People often place value on a feeling of wildness, and aquatic plants often lend that sense of wildness to freshwater systems. Furthermore, plants are important in their support of fish and wildlife populations that are culturally and aesthetically valuable. Finally, aquatic plants also support recreation, both indirectly by their maintenance of clear water, as well as directly in their provisioning of habitat for fishing, trapping, wildlife watching, and hunting. Important cultural practices (e.g., wild rice harvesting, sowing and harvesting lotus seeds) are also centered on aquatic plant communities.

Despite the many ecosystem services they provide, aquatic plants can sometimes cause great controversy (van Nes et al. 2002). Shallow lakes with abundant aquatic plant communities are common across Wisconsin but are not universally valued because the plants can oftentimes interfere with recreational enjoyment of the lake (WDNR 2014). Unfortunately, anthropogenic (i.e., human-influenced) nutrient enrichment stimulates plant growth, which often makes this problem worse (Duarte 1995).

It is understandable that management actions intended to reduce the abundance of aquatic plants are often requested. However, some management actions such as large-scale herbicide treatments can lead to massive aquatic plant die-offs that can create a turbid-water system dominated by phytoplankton and blue-green algae (Wagner et al. 2007; Hilt et al. 2013). Despite the potential for these adverse effects, the number of permit requests for controlling aquatic plants continues to increase. To support informed decisions and prioritize management actions, managers must rely on science-based tools. By utilizing the best available science to make decisions, aquatic plant communities can be managed in ways that balance risks and benefits while meeting local needs. Work situated at the interface of ecology and management for aquatic plants is critically needed to produce better outcomes for freshwater ecosystems.

S.2.4. Climate Change and Aquatic Ecosystems

The effects of climate change on Wisconsin's ecosystems are also likely to be a factor in successfully implementing aquatic plant management in the future. During interviews conducted to support the Strategic Analysis (Chapter 6 and Appendix E), several stakeholders expressed concern about the potential impacts of climate change on aquatic ecosystems and future management decisions.

While precise impacts may be uncertain, climate change is expected to affect aquatic ecosystems by altering conditions like water temperature, duration of ice cover, precipitation patterns, and water quality (Rahel and Olden 2008). As a result, there is potential for invasive species that are already present to expand their geographic ranges, or for more frequent occurrence of conditions that support plant growth at a level that some may consider a nuisance (Hellmann et al 2008).

In addition, these conditions may support the establishment of new invasive species better adapted to warming waters and changes in water quality. Changing temperatures may also affect existing pathways and vectors for the introduction and spread of invasives or result in new pathways. For example, there could be shifts in the length or timing of recreational seasons, potentially impacting the risk of spread of aquatic invasive species by recreational users (EPA 2008). The ways in which both native and non-native plants respond to these types of ecological changes has the potential to significantly impact APM decision-making and the efficacy of various management strategies in the future.

S.3. Wisconsin's Toolbox for Aquatic Plant Management

Human-caused nutrient addition is the largest threat to water quality in the United States and is a major cause of freshwater impairment worldwide (Parry 1998; Dudgeon et al. 2006). In a watershed, everything flows downstream; fertilizer added to the land moves with runoff water to join the larger surface water drainage network. Wastewater discharged directly into streams also becomes part of the hydrological system. These non-point (runoff) and point (end-of-pipe discharge) pollution sources contribute to increased nutrient levels in freshwater ecosystems. The enrichment of our freshwaters has numerous consequences.

Of relevance for APM is that added nutrients stimulate the growth of aquatic plants and phytoplankton, and in some cases can cause them to grow to high abundance. Decreasing nutrient loads to waterbodies would address the root cause of nuisance algae and plant growth. However, when addressing the ultimate cause of impairment (nutrient loading) is not deemed to be possible (at least in the short-term), it becomes necessary to explore local solutions to temporarily decrease nuisance levels of aquatic plants and phytoplankton.

There are many strategies and tools available to manage aquatic plant communities. Some methods can be selectively applied to a species, while others are non-selectively applied to the larger plant community. The clear majority of aquatic plant and algae management techniques will have effects on non-target elements of the ecosystem. When weighing the decision of whether and how to manage aquatic plant communities, caution is key. It is important to balance the benefit of management with any possible ecological, economic, or social costs. To support informed utilization of the numerous aquatic plant management techniques that are currently available, reviews of the most common techniques and suggestions for appropriate and effective use are included in this Chapter. Lists of susceptible and tolerant plant species are given for many of the management techniques; only species for which control efficacy has been evaluated (in field, mesocosm, or laboratory studies) using each technique are listed. Other species are likely to be tolerant or susceptible to each management technique, for which the effects of each technique have not yet been evaluated. Generally, only plants native to Wisconsin, plants found in states adjacent to Wisconsin, or non-native plants included in ch. NR 40, Wis. Admin. Code, are included in the discussions of species susceptibility and tolerance in this Chapter.

While not discussed in detail in this strategic analysis, other management techniques include:

- Mowing, weed whipping, and scraping (removing sediment or soil along with seeds and rhizomes) in semi-aquatic environments such as some wetlands, along stream banks, and right-of-ways.
- Raking to remove floating or submersed aquatic vegetation.
- Ditch plugs (structures built in drainage ditches to maintain a pre-determined water level in a waterbody for restoration activities).

- Chemical curtains, which are barriers made of semi-impermeable material that may be placed around a targeted treatment area for several days to contain herbicide activity to a specific area (some additional regulatory approvals may be required for deployment of chemical curtains depending on the scenario).

S.3.1. Management Techniques Not Allowed in Wisconsin

Grass carp, triploid grass carp

The use of grass carp (*Ctenopharyngodon idella*) for APM is prohibited in Wisconsin. For more detail, see Supplemental Chapter S.3.5 (Biological Control).

Cutting without Removal

Like mowing a lawn, excess aquatic plant growth can be removed by mechanical harvesting (cutting). Just as some lawn mowers leave cuttings on the grass while others have bagging systems to remove them, aquatic harvesters can be similarly engineered. However, cutting aquatic plants without removing the resulting biomass can cause major impacts on lake biota and water quality (James et al. 2002). As such, cutting plants and leaving the fragments to drift and decay, which releases nutrients, is not permitted in the state of Wisconsin.

S.3.2. Management Techniques for which Permits are Not Issued by Wisconsin DNR's Aquatic Plant Management Program

Sodium Arsenite

Sodium arsenite was used historically for aquatic nuisance plant control, predominantly from the 1920s to the late 1960s. In waterbodies where it was utilized, arsenic can still be detected in the sediment today. Because the compound persists in the environment without breaking down into non-toxic components, the sodium arsenite is no longer used for APM in Wisconsin.

Liming

The application of lime (as $Ca(OH)_2$ or $CaCO_3$) has been used in lake management as a means of addressing acidification in waterbodies, as well as eutrophication to a lesser degree. Like alum treatments (described below), lime can be used to sequester phosphorus, making it less available for uptake by algae and plants. If lime is being used for this purpose, it is regulated under ch. NR 109, Wis. Admin. Code, as a plant inhibitor and a permit is required. Several studies have shown the effects of liming on phosphorus sequestration tend not to persist without repeated treatment, suggesting this approach should not be used as a long-term restoration tool (Reedyk et al. 2001). Laboratory studies have also shown liming to be less effective at reducing phosphorus concentrations than alum (Prepas et al. 2001).

There is little scientific literature related to the use of lime for aquatic plant management. Over-application of lime can be toxic to aquatic life through alteration of pH, so careful calculation is needed to maintain pH values within the waterbody's natural range. Studies have shown varying reductions in aquatic plant biomass depending on waterbody characteristics, reductions in chlorophyll *a*, changes in phytoplankton community composition, and increases in turbidity (Prepas et al. 2001; Angeler and Goedkoop 2010). In some Swedish lakes, liming has also been associated with altered food web relationships and decreased fish growth and catch per unit effort (Angeler and Goedkoop 2010; Lau et al. 2017).

"Muck" Removal Products

These products are often bacterial or enzymatic pellets intended to reduce soft sediment or decomposing organic matter on the lake bed. Some sellers suggest they can be used to manage aquatic algae or plants through nutrient digestion by the pellets. There has been little to no reported evaluation of the efficacy and ecological impacts of these products for aquatic plant and algae control, or even the reduction of organic sediments in lakes. If muck removal products are being used as a means of aquatic plant or algae control, or if it is applied as a point-source (i.e., using a pipe or nozzle), a permit is required under ch. NR 107, Wis. Admin. Code and may need U.S. EPA registration.

Weed Rollers

A weed roller is an automated device which uses aluminum or PVC tubes continuously rolling and rotating on a central pivot point to eliminate aquatic vegetation. Because weed rollers rest on the bottom of a waterbody, they are regulated and require a permit from the DNR Waterways and Wetlands Section under s. 30.12 Stats. DNR APM coordinators may review and provide input on applications but are not responsible for approving or denying permits for these types of automated plant removal systems.

Weed rollers have several potential impacts to waterbodies and recreation. They must be placed at an adequate depth so as not to interfere with navigation by passing boats and according to manufacturers, should not be working or plugged in when swimmers are present. Evaluations of weed rollers have found adverse impacts to water quality, macroinvertebrates, fisheries, and potential for erosion by sediment resuspension and removal of plants in the lake littoral zone (Montz 2001; James et al. 2004, 2006). Agitation of plants may also cause fragmentation which can increase plant spread throughout the lake (Smith and Barko 1990).

S.3.3. Herbicide Treatment

Herbicides are the most commonly employed method for controlling aquatic plants in Wisconsin. They are extremely useful tools for accomplishing aquatic plant management (APM) goals, like controlling invasive species, providing waterbody access, and ecosystem restoration. This Chapter includes basic information about herbicides and herbicide formulations, how herbicides are assessed for ecological and human health risks and registered for use, and some important considerations for the use of herbicides in aquatic environments.

A pesticide is a substance used to either directly kill pests or to prevent or reduce pest damage; herbicides are pesticides that are used to kill plants. Only a certain component of a pesticide product is intended to have pesticidal effects and this is called the active ingredient. The active ingredient is listed near the top of the first page on an herbicide product label. Any product claiming to have pesticidal properties must be registered with the U.S. EPA and regulated as a pesticide.

Inert ingredients often make up most of a pesticide formulation and are not intended to have pesticidal activity, although they may enhance the pesticidal activity of the active ingredient. These ingredients, such as carriers and solvents, are often added to the active ingredient by manufacturers, or by an herbicide applicator during use, to allow mixing of the active ingredient into water, make it more chemically stable, or aid in storage and transport. Manufacturers are not required to identify the specific inert ingredients on the pesticide label. In addition to inert ingredients included in manufactured pesticide formulations, adjuvants are inert ingredient products that may be added to pesticide formulations before they are applied to modify the properties or enhance pesticide performance. Adjuvants are typically not intended to have pesticidal properties and are not regulated as pesticides under the Federal Insecticide, Fungicide and Rodenticide Act. However, research has shown that inert ingredients can increase the efficacy and toxicity of pesticides especially if the appropriate label uses aren't followed (Mesnage et al. 2013; Defarge et al. 2016).

The combination of active ingredients and inert ingredients is what makes up a pesticide formulation. There are often many formulations of each active ingredient and pesticide manufacturers typically give a unique product or trade name to each specific formulation of an active ingredient. For instance, "Sculpin G" is a solid, granular 2,4-D amine product, while "DMA IV" is a liquid amine 2,4-D product, and the inert ingredients in these formulations are different, but both have the same active ingredient. Care should always be taken to read the herbicide product label as this will give information about which pests and ecosystems the product is allowed to be used for. Some formulations (i.e., non-aquatic formulations of glyphosate such as "Roundup") are not allowed for aquatic use and could lead to environmental degradation even if used on shorelines near the water. There are some studies which indicate that the combination of two chemicals (e.g., 2,4-D and endothall) applied together produces synergistic efficacy results that are greater than if each product was applied alone (Skogerboe et al. 2012). Conversely, there are studies which indicate that the combination of two chemicals (i.e., diquat and penoxsulam) will result in an antagonistic response between the herbicides, and result in reduced efficacy than when applying penoxsulam alone (Wersal and Madsen 2010b).

The U.S. EPA is responsible for registering pesticide products before they may be sold. To have their product registered, pesticide manufacturers must submit toxicity test data to the EPA that shows that the intended pesticide use(s) will not create unreasonable risks. "Unreasonable" in this context means that the risks of use outweigh the potential benefits. Once registered, the EPA must re-evaluate each pesticide and new information related to its use every 15 years. The current cycle of registration review will end in 2022, with a new cycle and review schedule starting then. In addition, EPA may decide to only register certain uses of any given pesticide product and can also require that only trained personnel can apply a pesticide before the risks outweigh the benefits. Products requiring training before application are called Restricted Use Pesticides.

As part of their risk assessments, EPA reviews information related to pesticide toxicity. Following laboratory testing, ecotoxicity rankings are given for different organismal groups based on the dosage that would cause harmful ecological effects (e.g., death, reduction in growth, reproductive impairment, and others). For example, the ecotoxicity ranking for 2,4-D ranges from "practically non-toxic" to "slightly toxic" for freshwater invertebrates, meaning tests have shown that doses of >100 ppm and 10-100 ppm are needed to cause 50% mortality or immobilization in the test population, respectively. Different dose ranges and indicators of "harm" are used to assess toxicity depending on the organisms being tested. More information can be found on the EPA's website.

Beyond selecting herbicide formulations approved for use in aquatic environments, there are additional factors to consider supporting appropriate and effective herbicide use in those environments. Herbicide treatments are often used in terrestrial restorations, so they are also often requested in the management and restoration of aquatic plant communities. However, unlike applications in a terrestrial environment, the fluid environment of freshwater systems presents a set of unique challenges. Some general best practices for addressing challenges associated with herbicide dilution, migration, persistence, and non-target impacts are described in Chapter 7.4. More detailed documentation of these challenges is described below and in discussions on individual herbicides in Supplemental Chapter S.3.3 (Herbicide Treatment).

As described in Chapter 7.4, when herbicide is applied to waters, it can quickly migrate offsite and dilute to below the target concentrations needed to provide control (Hoeppel and Westerdal 1983; Madsen et al. 2015; Nault et al. 2015). Successful plant control with herbicide is dependent on concentration exposure time (CET) relationships. In order to examine actual observed CET relationships following herbicide applications in Wisconsin lakes, a study of herbicide CET and Eurasian watermilfoil (*Myriophyllum spicatum*) control efficacy was conducted on 98 small-scale (0.1-10 acres) 2,4-D treatment areas across 22 lakes. In the vast majority of cases, initial observed 2,4-D concentrations within treatment areas were far below the applied target concentration, and then dropped below detectable limits within a few hours after treatment (Nault et al. 2015). These results indicate the rapid dissipation of herbicide off the small treatment areas resulted in water column concentrations which were much lower than those recommended by previous laboratory CET studies for effective Eurasian watermilfoil control. Concentrations in protected treatment areas (e.g., bays, channels) were initially higher than those in areas more exposed to wind and waves, although concentrations quickly dissipated to below detectable limits within hours after treatment regardless of spatial location. Beyond confining small-scale treatments to protected areas, utilizing or integrating faster-acting herbicides with shorter CET requirements may also help to compensate for reductions in plant control due to dissipation (Madsen et al. 2015). The use of chemical curtains or adjuvants (weighting or sticking agents) may also help to maintain adequate CET, however more research is needed in this area.

This rapid dissipation of herbicide off of treatment areas is important for resource managers to consider in planning, as treating numerous targeted areas at a 'localized' scale may actually result in low-concentrations capable of having lakewide impacts as the herbicide dissipates off of the individual treatment sites. In general, if the percentage of treated areas to overall lake surface area is >5% and targeted areas are treated at relatively high 2,4-D concentrations (e.g., 2.0-4.0 ppm), then anticipated lakewide concentrations after dissipation should be calculated to determine the likelihood of lakewide effects (Nault et al. 2018).

Aquatic-use herbicides are commercially available in both liquid and granular forms. Successful target species control has been reported with both granular and liquid formulations. While there has been a commonly held belief that granular products are able to 'hold' the herbicide on site for longer periods of time, actual field comparisons between granular and liquid 2,4-D forms revealed that they dissipated similarly when applied at small-scale sites (Nault et al. 2015). In fact, liquid 2,4-D had higher initial observed water column concentrations than the granular form, but in the majority of cases concentrations of both forms decreased rapidly to below detection limits within several hours after treatment Nault et al. 2015). Likewise, according to United Phosphorus, Inc. (UPI), the sole manufacturer of endothall, the granular formulation of endothall does not hold the product in a specific area significantly longer than the liquid form (Jacob Meganck [UPI], *personal communication*).

In addition, the stratification of water and the formation of a thermal density gradient can confine most applied herbicides in the upper, warmer water layer of deep lakes. In some instances, the entire lake water volume is used to calculate how much active ingredient should be applied to achieve a specific lakewide target concentration. However, if the volume of the entire lake is used to calculate application rates for stratified lakes, but the chemical only readily mixes into the upper water layer, the achieved lakewide concentration is likely to be much higher than the target concentration, potentially resulting in unanticipated adverse ecological impacts.

Because herbicides cannot be applied directly to specific submersed target plants, the dissipation of herbicide over the treatment area can lead to direct contact with non-target plants and animals. No herbicide is completely selective (i.e., effective specifically on only a single target species). Some plant species may be more susceptible to a given herbicide than others, highlighting the importance of choosing the appropriate herbicide, or other non-chemical management approach, to minimize potential non-target effects of treatment. There are many herbicides and plant species for which the CET relationship that would negatively affect the plant is unknown. This is particularly important in the case of rare, special concern, or threatened and endangered species. Additionally, loss of habitat following any herbicide treatment or other management technique may cause indirect reductions in populations of invertebrates or other organisms. Some organisms will only recolonize the managed areas as aquatic plants become re-established.

Below are reviews for the most commonly used herbicides for APM in Wisconsin. Much of the information here was pulled directly from DNR's APM factsheets (http://dnr.wi.gov/lakes/plants/factsheets/), which were compiled in 2012 using U.S. EPA herbicide product labels, U.S. Army Corps of Engineers reports, and communications with natural resource agencies in other northern, lake-rich states. These have been supplemented with more recent information from primary research publications.

Each pesticide has at least one mode of action which is the specific mechanism by which the active ingredient exerts a toxic effect. For example, some herbicides inhibit production of the pigments needed for photosynthesis while others mimic plant growth hormones and cause uncontrolled and unsustainable growth. Herbicides are often classified as either systemic or contact in mode of action, although some herbicides are able to function under various modes of action depending on environmental variables such as water temperature. Systemic pesticides are those that are absorbed by organisms and can be moved or translocated within the organism. Contact pesticides are those that exert toxic effects on the part(s) of an organism that they come in contact with. The amount of exposure time needed to kill an organism is based on the specific mode of action and the concentration of any given pesticide. In the descriptions below herbicides are generally categorized into which environment (above or below water) they are primarily used and a relative assessment of how quickly they impact plants.

Herbicides can be applied in many ways. In lakes, they are usually applied to the water's surface (or below the water's surface) through controlled release by equipment including spreaders, sprayers, and underwater hoses. In wetland environments, spraying by helicopter, backpack sprayer, or application by cut-stem dabbing, wicking, injection, or basal bark application are also used.

S.3.3.1. Submersed or Floating, Relatively Fast-Acting Herbicides

Diquat

Registration and Formulations

Diquat (or diquat dibromide) initially received Federal registration for control of submersed and floating aquatic plants in 1962. It was initially registered with the U.S. EPA in 1986, evaluated for reregistration in 1995, and is currently under registration review. A registration review decision was expected in 2015 but has not been released (EPA Diquat Plan 2011). The active ingredient is 6,7-dihydrodipyrido[1,2-α:2',1'-c] pyrazinediium dibromide, and is commercially sold as liquid formulations for aquatic use.

Mode of Action and Degradation

Diquat is a fast-acting herbicide that works through contact with plant foliage by disrupting electron flow in photosystem I of the photosynthetic reaction, ultimately causing the destruction of cell membranes (Hess 2000; WSSA 2007). Plant tissues in contact with diquat become impacted within several hours after application, and within one to three days the plant tissue will become necrotic. Diquat is considered a non-selective herbicide and will rapidly kill a wide variety of plants on contact. Because diquat is a fast-acting herbicide, it is oftentimes used for managing plants growing in areas where water exchange is anticipated to limit herbicide exposure times, such as small-scale treatments. Due to rapid vegetation decomposition after treatment, only partial treatments of a waterbody should be conducted to minimize dissolved oxygen depletion and associated negative impacts on fish and other aquatic organisms. Untreated areas can be treated with diquat 14 days after the first application.

Diquat is strongly attracted to silt and clay particles in the water and may not be very effective under highly turbid water conditions or where plants are covered with silt (Clayton and Matheson 2010).

The half-life of diquat in water generally ranges from a few hours to two days depending on water quality and other environmental conditions. Diquat has been detected in the water column from less than a day up towards 38 DAT, and remains in the water column longer when treating waterbodies with sandy sediments with lower organic matter and clay content (Coats et al. 1964; Grzenda et al. 1966; Yeo 1967; Sewell et al. 1970; Langeland and Warner 1986; Langeland et al. 1994; Poovey and Getsinger 2002; Parsons et al. 2007; Gorzerino et al. 2009; Robb et al. 2014). One study reported that diquat is chemically stable within a pH range of 3 to 8 (Florêncio et al. 2004). Due to the tendency of diquat to be rapidly adsorbed to suspended clays and particulates, long exposure periods are oftentimes not possible to achieve in the field. Studies conducted by Wersal et al. (2010a) did not observe differences in target species efficacy between daytime versus night-time applications of diquat. While large-scale diquat treatments are typically not implemented, a study by Parsons et al. (2007), observed declines in both dissolved oxygen and water clarity following the herbicide treatment.

Diquat binds indefinitely to organic matter, allowing it to accumulate and persist in the sediments over time (Frank and Comes 1967; Simsiman and Chesters 1976). It has been reported to have a very long-lived half-life (1000 days) in sediment because of extremely tight soil sorption, as well as an extremely low rate of degradation after association with sediment (Wauchope et al. 1992; Peterson et al. 1994). Both photolysis and microbial degradation are thought to play minor roles in degradation (Smith and Grove 1969; Emmett 2002). Diquat is not known to leach into groundwater due to its very high affinity to bind to soils.

One study reported that combinations of diquat and penoxsulam resulted in an antagonistic response between the herbicides when applied to water hyacinth (*Eichhornia crassipes*) and resulted in reduced efficacy than when applying penoxsulam alone. The antagonistic response is likely due to the rapid cell destruction by diquat that limits the translocation and efficacy of the slower acting enzyme inhibiting herbicides (Wersal and Madsen 2010b).

Toxicology

There are no restrictions on swimming or eating fish from waterbodies treated with diquat. Depending on the concentration applied, there is a 1-3 day waiting period after treatment for drinking water. However, in one study, diquat persisted in the water at levels above the EPA drinking water standard for at least 3 DAT, suggesting that the current 3-day drinking water restriction may not be sufficient under all application scenarios (Parsons et al. 2007). Water treated with diquat should not be used for pet or livestock drinking water for one day following treatment. The irrigation restriction for food crops is five days, and for ornamental plants or lawn/turf, it varies from one to three days depending on the concentration used. A study by Mudge et al. (2007) on the effects of diquat on five popular ornamental plant species (begonia, dianthus, impatiens, petunia, and snapdragon) found minimal risks associated with irrigating these species with water treated with diquat up to the maximum use rate of 0.37 ppm.

Ethylene dibromide (EDB) is a trace contaminant in diquat products which originates from the manufacturing process. EDB is a documented carcinogen, and the EPA has evaluated the health risk of its presence in formulated diquat products. The maximum level of EDB in diquat dibromide is 0.01 ppm (10 ppb). EBD degrades over time, and it does not persist as an impurity.

Diquat does not have any apparent short-term effects on most aquatic organisms that have been tested at label application rates (EPA Diquat RED 1995). Diquat is not known to bioconcentrate in fish tissues. A study using field scenarios and well as computer modelling to examine the potential ecological risks posed by diquat determined that diquat poses a minimal ecological impact to benthic invertebrates and fish (Campbell et al. 2000). Laboratory studies indicate that walleye (*Sander vitreus*) are more sensitive to diquat than some other fish species, such as smallmouth bass (*Micropterus dolomieu),* largemouth bass (*Micropterus salmoides*), and bluegills (*Lepomis macrochirus*), with individuals becoming less sensitive with age (Gilderhus 1967; Paul et al. 1994; Shaw and Hamer 1995). Maximum application rates were lowered in response to these studies, such that applying diquat at recommended label rates is not expected to result in toxic effects on fish (EPA Diquat RED 1995). Sublethal effects such as respiratory stress or reduced swimming capacity have been observed in studies where certain fish species (e.g., yellow perch (*Perca flavescens*), rainbow trout (*Oncorhynchus mykiss*), and fathead minnows (*Pimephales promelas*)) have been exposed to diquat concentrations (Bimber et al. 1976; Dodson and Mayfield 1979; de Peyster and Long 1993). Another study showed no observable effects on eastern spiny softshell turtles (*Apalone spinifera*; Paul and Simonin 2007). Reduced size and pigmentation or increased mortality have been shown in some amphibians but at above recommended label rates (Anderson and Prahlad 1976; Bimber and Mitchell 1978; Dial and Bauer-Dial 1987). Toxicity data on invertebrates are scarce and diquat is considered not toxic to most of them. While diquat is not highly toxic to most invertebrates, significant mortality has been observed in some species at concentrations below the maximum label use rate for diquat, such as the amphipod *Hyalella azteca* (Wilson and Bond 1969; Williams et al. 1984), water fleas (*Daphnia* spp.). Reductions in habitat following treatment may also contribute to reductions of *Hyalella azteca*. For more information, a thorough risk assessment for diquat was compiled by the Washington State Department of Ecology Water Quality Program (WSDE 2002). Available toxicity data for fish, invertebrates, and aquatic plants is summarized in tabular format by Campbell et al. (2000).

Species Susceptibility

Diquat has been shown to control a variety of invasive submerged and floating aquatic plants, including Eurasian watermilfoil (*Myriophyllum spicatum*), curly-leaf pondweed (*Potamogeton crispus*), parrot feather (*Myriophyllum aquaticum*), Brazilian waterweed (*Egeria densa*), water hyacinth, water lettuce (*Pistia stratiotes*), flowering rush (*Butomus umbellatus*), and giant salvinia (*Salvinia molesta*; Netherland et al. 2000; Nelson et al. 2001; Poovey et al. 2002; Langeland et al. 2002; Skogerboe et al. 2006; Martins et al. 2007, 2008; Wersal et al. 2010a; Wersal and Madsen 2010a; Wersal and Madsen 2012; Poovey et al. 2012; Madsen et al. 2016). Studies conducted on the use of diquat for hydrilla (*Hydrilla verticillata*) and fanwort (*Cabomba caroliniana*) control have resulted in mixed reports of efficacy (Van et al. 1987; Langeland et al. 2002; Glomski et al. 2005; Skogerboe et al. 2006; Bultemeier et al. 2009; Turnage et al. 2015). Non-native phragmites (*Phragmites australis* subsp. *australis*) has been shown to not be significantly reduced by diquat (Cheshier et al. 2012).

Skogerboe et al. 2006 reported on the efficacy of diquat (0.185 and 0.37 ppm) under flow-through conditions (observed half-lives of 2.5 and 4.5 hours, respectively). All diquat treatments reduced Eurasian watermilfoil biomass by 97 to 100% compared to the untreated reference, indicating that this species is highly susceptible to diquat. Netherland et al. (2000) examined the role of various water temperatures (10, 12.5, 15, 20, and 25°C) on the efficacy of diquat applications for controlling curly-leaf pondweed. Diquat was applied at rates of 0.16-0.50 ppm, with exposure times of 9-12 hours. Diquat efficacy on curly-leaf pondweed was inhibited as water temperature decreased, although treatments at all temperatures were observed to significantly reduce biomass and turion formation. While the most efficacious curly-leaf pondweed treatments were conducted at 25°C, waiting until water warms to this temperature limits the potential for reducing turion production. Diquat applied at 0.37 ppm (with a 6 to 12-hour exposure time) or at 0.19 ppm (with a 72-hour exposure time) was effective at reducing biomass of flowering rush (Poovey et al. 2012; Madsen et al. 2016).

Native species that have been shown to be affected by diquat include: American lotus (*Nelumbo lutea*), common bladderwort (*Utricularia vulgaris*), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), needle spikerush (*Eleocharis acicularis*), Illinois pondweed (*Potamogeton illinoensis*), leafy pondweed (*P. foliosus*), clasping-leaf pondweed (*P. richardsonii*), fern pondweed (*P. robbinsii*), sago pondweed (*Stuckenia pectinata*), and slender naiad (*Najas flexilis*) (Hofstra et al. 2001; Glomski et al. 2005; Skogerboe et al. 2006; Mudge 2013; Bugbee et al. 2015; Turnage et al. 2015). Diquat is particularly toxic to duckweeds (*Landoltia punctata* and *Lemna* spp.), although certain populations of dotted duckweed (*Landoltia punctata*) have developed resistance of diquat in waterbodies with a long history (20-30 years) of repeated diquat treatments (Peterson et al. 1997; Koschnick et al. 2006). Variable effects have been observed for water celery (*Vallisneria americana*), long-leaf pondweed (*Potamogeton nodosus*), and variable-leaf watermilfoil (*Myriophyllum heterophyllum*; Skogerboe et al. 2006; Glomski and Netherland 2007; Mudge 2013).

Flumioxazin

Registration and Formulations

Flumioxazin (2-[7-fluoro-3,4-dihydro-3-oxo-4-(2-propynyl)-2H-1,4-benzoxazin-6-yl]-4,5,6,7-tetrahydro-1H-isoindole-1,3(2H)-dione) was registered with the U.S. EPA for agricultural use in 2001 and registered for aquatic use in 2010. The first registration review of flumioxazin is expected to be completed in 2017 (EPA Flumioxazin Plan 2011). Granular and liquid formulations are available for aquatic use.

Mode of Action and Degradation

The mode of action of flumioxazin is through disruption of the cell membrane by inhibiting protoporphyrinogen oxidase which blocks production of heme and chlorophyll. The efficacy of this mode of action is dependent on both light intensity and water pH (Mudge et al. 2012a; Mudge and Haller 2010; Mudge et al. 2010), with herbicide degradation increasing with pH and efficacy decreasing as light intensity declines.

Flumioxazin is broken down by water (hydrolysis), light (photolysis) and microbes. The half-life ranges from approximately 4 days at pH 5 to 18 minutes at pH 9 (EPA Flumioxazin 2003). In the majority of Wisconsin lakes half-life should be less than 1 day.

Flumioxazin degrades into APF (6-amino-7-fluro-4-(2-propynyl)-1,4,-benzoxazin-3(2H)-one) and THPA (3,4,5,6-tetrahydrophthalic acid). Flumioxazin has a low potential to leach into groundwater due to the very quick hydrolysis and photolysis. APF and THPA have a high potential to leach through soil and could be persistent.

Toxicology

Tests on warm and cold-water fishes indicate that flumioxazin is "slightly to moderately toxic" to fish on an acute basis, with possible effects on larval growth below the maximum label rate of 0.4 ppm (400 ppb). Flumioxazin is moderately to highly toxic to aquatic invertebrates, with possible impacts below the maximum label rate. The potential for bioaccumulation is low since degradation in water is so rapid. The metabolites APF and THPA have not been assessed for toxicity or bioaccumulation.

The risk of acute exposure is primarily to chemical applicators. Concentrated flumioxazin doesn't pose an inhalation risk but can cause skin and eye irritation. Recreational water users would not be exposed to concentrated flumioxazin.

Acute exposure studies show that flumioxazin is "practically non-toxic" to birds and small mammals. Chronic exposure studies indicate that flumioxazin is non-carcinogenic. However, flumioxazin may be an endocrine disrupting compound in mammals (EPA Flumioxazin 2003), as some studies on small mammals did show effects on reproduction and larval development, including reduced offspring viability, cardiac and skeletal malformations, and anemia. It does not bioaccumulate in mammals, with the majority excreted in a week.

Species Susceptibility

The maximum target concentration of flumioxazin is 0.4 ppm (400 ppb). At least one study has shown that flumioxazin (at or below the maximum label rate) will control the invasive species fanwort (*Cabomba caroliniana*), hydrilla (*Hydrilla verticillata*), Japanese stiltgrass (*Microstegium vimineum*), Eurasian watermilfoil (*Myriophyllum spicatum*), water lettuce (*Pistia stratiotes*), curly-leaf pondweed (*Potamogeton crispus*), and giant salvinia (*Salvinia molesta*), while water hyacinth (*Eichhornia crassipes*) and water pennyworts (*Hydrocotyle* spp.) do not show significant impacts (Bultemeier et al. 2009;

Glomski and Netherland 2013a; Glomski and Netherland 2013b; Mudge 2013; Mudge and Netherland 2014; Mudge and Haller 2012; Mudge and Haller 2010). Flowering rush (*Butomus umbellatus*; submersed form) showed mixed success in herbicide trials (Poovey et al. 2012; Poovey et al. 2013). Native species that were significantly impacted (in at least one study) include coontail (*Ceratophyllum demersum*), water stargrass (*Heteranthera dubia*), variable-leaf watermilfoil (*Myriophyllum heterophyllum*), America lotus (*Nelumbo lutea*), pond-lilies (*Nuphar* spp.), white waterlily (*Nymphaea odorata*), white water crowfoot (*Ranunculus aquatilis*), and broadleaf cattail (*Typha latifolia*), while common waterweed (*Elodea canadensis*), squarestem spikerush (*Eleocharis quadrangulate*), horsetail (*Equisetum hyemale*), southern naiad (*Najas guadalupensis*), pickerelweed (*Pontederia cordata*), Illinois pondweed (*Potamogeton illinoensis*), long-leaf pondweed (*P. nodosus*), broadleaf arrowhead (*Sagittaria latifolia*), hardstem bulrush (*Schoenoplectus acutus*), common three-square bulrush (*S. pungens*), softstem bulrush (*S. tabernaemontani*), sago pondweed (*Stuckenia pectinata*), and water celery (*Vallisneria americana*) were not impacted relative to controls. Other species are likely to be susceptible, for which the effects of flumioxazin have not yet been evaluated.

Carfentrazone-ethyl

Registration and Formulations

Carfentrazone-ethyl is a contact herbicide that was registered with the EPA in 1998. The active ingredient is ethyl 2-chloro-3-[2-chloro-4-fluoro-5-[4-(difluoromethyl)-4,5-diydro-3-methyl-5-oxo-1H-1,2,4-trizol-1-yl)phenyl]propanoate. A liquid formulation of carfentrazone-ethyl is commercially sold for aquatic use.

Mode of Action and Degradation

Carfentrazone-ethyl controls plants through the process of membrane disruption which is initiated by the inhibition of the enzyme protoporphyrinogen oxidase, which interferes with the chlorophyll biosynthetic pathway. The herbicide is absorbed through the foliage of plants, with injury symptoms viable within a few hours after application, and necrosis and death observed in subsequent weeks.

Carfentrazone-ethyl breaks down rapidly in the environment, while its degradates are persistent in aquatic and terrestrial environments. The herbicide primarily degrades via chemical hydrolysis to carfentrazone-chloropropionic acid, which is then further degraded to carfentrazone -cinnamic, -propionic, -benzoic and 3-(hydroxymethyl)-carfentrazone-benzoic acids. Studies have shown that degradation of carfentrazone-ethyl applied to water (pH = 7-9) has a half-life range of 3.4-131 hours, with longer half-lives (>830 hours) documented in waters with lower pH (pH = 5). Extremes in environmental conditions such as temperature and pH may affect the activity of the herbicide, with herbicide symptoms being accelerated under warm conditions.

While low levels of chemical residue may occur in surface and groundwater, risk concerns to non-target organisms are not expected. If applied into water, carfentrazone-ethyl is expected to adsorb to suspended solids and sediment.

Toxicology

There is no restriction on the use of treated water for recreation (e.g., fishing and swimming). Carfentrazone-ethyl should not be applied directly to water within ¼ mile of an active potable water intake. If applied around or within potable water intakes, intakes must be turned off prior to application and remain turned off for a minimum of 24 hours following application; the intake may be turned on prior to 24 hours only if the carfentrazone-ethyl and major degradate level is determined by laboratory analysis to be below 200 ppb. Do not use water treated with carfentrazone-ethyl for irrigation in commercial nurseries or greenhouses. In scenarios where the herbicide is applied to 20% or more of the surface area, treated water should not be used for irrigation of crops until 14 days after treatment, or until the carfentrazone-ethyl and major degradate level is determined by analysis to be below 5 ppb.

In scenarios where the herbicide is applied as a spot treatment to less than 20% of the waterbody surface area, treated water may be used for irrigation by commercial turf farms and on residential turf and ornamentals without restriction. If more than 20% of the waterbody surface area is treated, water should not be used for irrigation of turf or ornamentals until 14 days after treatment, or until the carfentrazone-ethyl and major degradate level is determined by analysis to be below 5 ppb.

Carfentrazone-ethyl is listed as very toxic to certain species of algae and listed as moderately toxic to fish and aquatic animals. Treatment of dense plants beds may result in dissolved oxygen declines from plant decomposition which may lead to fish suffocation or death. To minimize impacts, applications of this herbicide should treat up to a maximum of half of the waterbody at a time and wait a minimum of 14 days before retreatment or treatment of the remaining half of the waterbody. Carfentrazone-ethyl is considered to be practically non-toxic to birds on an acute and sub-acute basis.

Carfentrazone-ethyl is harmful if swallowed and can be absorbed through the skin or inhaled. Those who mix or apply the herbicide need to protect their skin and eyes from contact with the herbicide to minimize irritation and avoid breathing the spray mist. Carfentrazone-ethyl is not carcinogenic, neurotoxic, or mutagenic and is not a developmental or reproductive toxicant.

Species Susceptibility

Carfentrazone-ethyl is used for the control of floating and emergent aquatic plants such as duckweeds (*Lemna* spp.), watermeals (*Wolffia* spp.), water lettuce (*Pistia stratiotes*), water hyacinth (*Eichhornia crassipes*), and salvinia (*Salvinia* spp.). Carfentrazone-ethyl can also be used to control submersed plants such as Eurasian watermilfoil (*Myriophyllum spicatum*).

S.3.3.2. Submersed, Relatively Slow-Acting Herbicides

2,4-D

Registration and Formulations

2,4-D is an herbicide that is widely used as a household weed-killer, agricultural herbicide, and aquatic herbicide. It has been in use since 1946 and was registered with the U.S. EPA in 1986 and evaluated and reregistered in 2005. It is currently being evaluated for reregistration, and the estimated registration review decision date was in 2017 (EPA 2,4-D Plan 2013). The active ingredient is 2,4-dichloro-phenoxyacetic acid. There are two types of 2,4-D used as aquatic herbicides: dimethyl amine salt (DMA) and butoxyethyl ester (BEE). The ester formulations are toxic to fish and some important invertebrates such as water fleas (*Daphnia* spp.) and midges at application rates. 2,4-D is commercially sold as a liquid amine as well as ester and amine granular products for control of submerged, emergent, and floating-leaf vegetation. Only 2,4-D products labeled for use in aquatic environments may be used to control aquatic plants.

Mode of Action and Degradation

Although the exact mode of action of 2,4-D is not fully understood, the herbicide is traditionally believed to target broad-leaf dicotyledon species with minimal effects generally observed on numerous monocotyledon species, especially in terrestrial applications (WSSA 2007). 2,4-D is a systemic herbicide which affects plant cell growth and division. Upon application, it mimics the natural plant hormone auxin, resulting in bending and twisting of stems and petioles followed by growth inhibition, chlorosis (reduced coloration) at growing points, and necrosis or death of sensitive species (WSSA 2007). Following treatment, 2,4-D is taken up by the plant and translocated through the roots, stems and leaves, and plants begin to die within one to two weeks after application, but can take several weeks to decompose. The total length of target plant roots can be an important in determining the response of an aquatic plant to 2,4-D (Belgers et al. 2007). Treatments should be made when plants are growing. After treatment, the 2,4-D concentration in the water is reduced primarily through microbial activity, off-site movement by water, or adsorption to small particles in silty water.

Previous studies have indicated that 2,4-D degradation in water is highly variable depending on numerous factors such as microbial presence, temperature, nutrients, light, oxygen, organic content of substrate, pH, and whether or not the water has been previously exposed to 2,4-D or other phenoxyacetic acids (Howard et al. 1991). Once in contact with water, both the ester and amine formulations dissociate to the acid form of 2,4-D, with a faster dissociation to the acid form under more alkaline conditions. 2,4-D degradation products include 1,2,4-benzenetriol, 2,4-dichlorophenol, 2,4-dichloroanisole, chlorohydroquinone (CHQ), 4-chlorophenol, and volatile organics.

The half-life of 2,4-D has a wide range depending on water conditions. Half-lives have been reported to range from 12.9 to 40 days, while in anaerobic lab conditions the half-life has been measured at 333 days (EPA RED 2,4-D 2005). In large-scale low-concentration 2,4-D treatments monitored across numerous Wisconsin lakes, estimated half-lives ranged from 4-76 days, and the rate of herbicide degradation was generally observed to be slower in oligotrophic seepage lakes. Of these large-scale 2,4-D treatments, the threshold for irrigation of plants which are not labeled for direct treatment with 2,4-D (<0.1 ppm (100 ppb) by 21 DAT) was exceeded the majority of the treatments (Nault et al. 2018). Previous historical use of 2,4-D may also be an important variable to consider, as microbial communities which are responsible for the breakdown of 2,4-D may potentially exhibit changes in community composition over time with repeated use (de Lipthay et al. 2003; Macur et al. 2007). Additional detailed information on the environmental fate of 2,4-D is compiled by Walters 1999.

There have been some preliminary investigations into the concentration of primarily granular 2,4-D in water-saturated sediments, or pore-water. Initial results suggest the concentration of 2,4-D in the pore-water varies widely from site to site following a chemical treatment, although in some locations the concentration in the pore-water was observed to be 2-3 times greater than the application rate (Jim Kreitlow [DNR], *personal communication*). Further research and additional studies are needed to assess the implications of this finding for target species control and non-target impacts on a variety of organisms.

Toxicology

There are no restrictions on eating fish from treated waterbodies, human drinking water, or pet/livestock drinking water. Based upon 2,4-D ester (BEE) product labels, there is a 24-hour waiting period after treatment for swimming. Before treated water can be used for irrigation, the concentration must be below 0.1 ppm (100 ppb), or at least 21 days must pass. Adverse health effects can be produced by acute and chronic exposure to 2,4-D. Those who mix or apply 2,4-D need to protect their skin and eyes from contact with 2,4-D products to minimize irritation and avoid inhaling the spray. In its consideration of exposure risks, the EPA believes no significant risks will occur to recreational users of water treated with 2,4-D.

There are differences in toxicity of 2,4-D depending on whether the formulation is an amine (DMA) or ester (BEE), with the BEE formulation shown to be more toxic in aquatic environments. BEE formulations are considered toxic to fish and invertebrates such as water fleas and midges at operational application rates. DMA formulations are not considered toxic to fish or invertebrates at operational application rates. Available data indicate 2,4-D does not accumulate at significant levels in the tissues of fish. Although fish exposed to 2,4-D may take up very small amounts of its breakdown products to then be metabolized, the vast majority of these products are rapidly excreted in urine (Ghassemi et al. 1981).

On an acute basis, EPA assessment considers 2,4-D to be “practically non-toxic” to honeybees and tadpoles. Dietary tests (substance administered in the diet for five consecutive days) have shown 2,4-D to be “practically non-toxic” to birds, with some species being more sensitive than others (when 2,4-D was orally and directly administered to birds by capsule or gavage, the substance was “moderately toxic” to some species). For freshwater invertebrates, EPA considers 2,4-D amine to be “practically non-toxic” to “slightly toxic” (EPA RED 2,4-D 2005). Field studies on the potential impact of 2,4-D on benthic macroinvertebrate communities have generally not observed significant changes, although at least one study conducted in Wisconsin observed negative correlations in macroinvertebrate richness and abundance following treatment, and further studies are likely warranted (Stephenson and Mackie 1986; Siemering et al. 2008; Harrahy et al. 2014). Additionally, sublethal effects such as mouthpart deformities and change in sex ratio have been observed in the midge *Chironomus riparius* (Park et al. 2010).

While there is some published literature available looking at short-term acute exposure of various aquatic organisms to 2,4-D, there is limited literature is available on the effects of low-concentration chronic exposure to commercially available 2,4-D formulations (EPA RED 2,4-D 2005). The department recently funded several projects related to increasing our understanding of the potential impacts of chronic exposure to low-concentrations of 2,4-D through AIS research and development grants. One of these studies observed that fathead minnows (*Pimephales promelas*) exposed under laboratory conditions for 28 days to 0.05 ppm (50 ppb) of two different commercial formulations of 2,4-D (DMA® 4 IVM and Weedestroy® AM40) had decreases in larval survival and tubercle presence in males, suggesting that these formulations may exert some degree of chronic toxicity or endocrine-disruption which has not been previously observed when testing pure compound 2,4-D (DeQuattro and Karasov 2016). However, another follow-up study determined that fathead minnow larval survival (30 days post hatch) was decreased following exposure of eggs and larvae to pure 2,4-D, as well as to the two commercial formulations (DMA® 4 IVM and Weedestroy® AM40), and also identified a critical window of exposure for effects on survival to the period between fertilization and 14 days post hatch (Dehnert et al. 2018).

Another related follow-up laboratory study is currently being conducted to examine the effects of 2,4-D exposure on embryos and larvae of several Wisconsin native fish species. Preliminary results indicate that negative impacts of embryo survival were observed for 4 of the 9 native species tested (e.g., walleye, northern pike, white crappie, and largemouth bass), and negative impacts of larval survival were observed for 4 of 7 natives species tested (e.g., walleye, yellow perch, fathead minnows, and white suckers; Dehnert and Karasov, *in progress*).

A controlled field study was conducted on six northern Wisconsin lakes to understand the potential impacts of early season large-scale, low-dose 2,4-D on fish and zooplankton (Rydell et al. 2018). Three lakes were treated with early season low-dose liquid 2,4-D (lakewide epilimnetic target rate: 0.3 ppm (300 ppb)), while the other three lakes served as reference without treatment. Zooplankton densities were similar within lakes during the pre-treatment year and year of treatment, but different trends in several zooplankton species were observed in treatment lakes during the year following treatment. Peak abundance of larval yellow perch (*Perca flavescens*) was lower in the year following treatment, and while this finding was not statistically significant, decreased larval yellow perch abundance was not observed in reference lakes. The observed declines in larval yellow perch abundance and changes in zooplankton trends within treatment lakes in the year after treatment may be a result of changes in aquatic plant communities and not a direct effect of treatment. No significant effect was observed on peak abundance of larval largemouth bass (*Micropterus salmoides*), minnows, black crappie (*Pomoxis nigromaculatus*), bluegill (*Lepomis macrochirus*), or juvenile yellow perch. Larval black crappie showed no detectable response in growth or feeding success. Net pen trials for juvenile bluegill indicated no significant difference in survival between treatment and reference trials, indicating that no direct mortality was associated with the herbicide treatments. Detection of the level of larval fish mortality found in the lab studies would not have been possible in the field study given large variability in larval fish abundance among lakes and over time.

Concerns have been raised about exposure to 2,4-D and elevated cancer risk. Some epidemiological studies have found associations between 2,4-D and increased risk of non-Hodgkin lymphoma in high exposure populations, while other studies have shown that increased cancer risk may be caused by other factors (Hoar et al. 1986; Hardell and Eriksson 1999; Goodman et al. 2015). The EPA determined in 2005 that there is not sufficient evidence to classify 2,4-D as a human carcinogen (EPA RED 2,4-D 2005).

Another chronic health concern with 2,4-D is the potential for endocrine disruption. There is some evidence that 2,4-D may have effects on reproductive development, though other studies suggest the findings may have had other causes (Garry et al. 1996; Coady et al. 2013; Goldner et al. 2013; Neal et al. 2017). The extent and implications of this are not clear and it is an area of ongoing research.

Detailed literature reviews of 2,4-D toxicology have been compiled by Garabrant and Philbert (2002), Jervais et al. (2008), and Burns and Swaen (2012).

Species Susceptibility

With appropriate concentration and exposure, 2,4-D is capable of reducing abundance of the invasive plant species Eurasian watermilfoil (*Myriophyllum spicatum*), parrot feather (*M. aquaticum*), water chestnut (*Trapa natans*), water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*; Elliston and Steward 1972; Westerdahl et al. 1983; Green and Westerdahl 1990; Helsel et al. 1996, Poovey and Getsinger 2007; Wersal et al. 2010b; Cason and Roost 2011; Robles et al. 2011; Mudge and Netherland 2014). Perennial pepperweed (*Lepidium latifolium)* and fanwort (*Cabomba caroliniana*) have been shown to be somewhat tolerant of 2,4-D (Bultemeier et al. 2009; Whitcraft and Grewell 2012).

Efficacy and selectivity of 2,4-D is a function of concentration and exposure time (CET) relationships, and rates of 0.5-2.0 ppm coupled with exposure times ranging from 12 to 72 hours have been effective at achieving Eurasian watermilfoil control under laboratory settings (Green and Westerdahl 1990). In addition, long exposure times (>14 days) to low-concentrations of 2,4-D (0.1-0.25 ppm) have also been documented to achieve milfoil control (Hall et al. 1982; Glomski and Netherland 2010).

According to product labels, desirable native species that may be affected include native milfoils (*Myriophyllum* spp.), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), naiads (*Najas* spp.), waterlilies (*Nymphaea* spp. and *Nuphar* spp.), bladderworts (*Utricularia* spp.), and duckweeds (*Lemna* spp.). While it may affect softstem bulrush (*Schoenoplectus tabernaemontani*), other species such as American bulrush (*Schoenoplectus americanus*) and muskgrasses (*Chara* spp.) have been shown to be somewhat tolerant of 2,4-D (Miller and Trout 1985; Glomski et al. 2009; Nault et al. 2014;

Nault et al. 2018). Wild rice (*Zizania palustris*) is sensitive to 2,4-D when applied to young, actively growing plants (Nelson et al. 2003).

In large-scale, low-dose (0.073-0.5 ppm) 2,4-D treatments evaluated by Nault et al. (2018), milfoil exhibited statistically significant lakewide decreases in posttreatment frequency across 23 of the 28 (82%) of the treatments monitored. In lakes where year of treatment milfoil control was achieved, the longevity of control ranged from 2–8 years. However, it is important to note that milfoil was not 'eradicated' from any of these lakes and is still present even in those lakes which have sustained very low frequencies over time. While good year of treatment control was achieved in all lakes with pure Eurasian watermilfoil populations, significantly reduced control was observed in most lakes with hybrid watermilfoil (*Myriophyllum spicatum* x *sibiricum*) populations. Eurasian watermilfoil control was correlated with the mean concentration of 2,4-D measured during the first two weeks of treatment, with increasing lakewide concentrations resulting in increased Eurasian watermilfoil control. In contrast, there was no significant relationship observed between Eurasian watermilfoil control and mean concentration of 2,4-D. In lakes where good (>60%) year of treatment control of hybrid watermilfoil was achieved, 2,4-D degradation was slow, and measured lakewide concentrations were sustained at >0.1 ppm (>100 ppb) for longer than 31 days. In addition to reduced year of treatment efficacy, the longevity of control was generally shorter in lakes that contained hybrid watermilfoil versus Eurasian watermilfoil, suggesting that hybrid watermilfoil may have the ability to rebound quicker after large-scale treatments than pure Eurasian watermilfoil populations. However, it is important to keep in mind that hybrid watermilfoil is broad term for multiple different strains, and variation in herbicide response and growth between specific genotypes of hybrid watermilfoil has been documented (Taylor et al. 2017).

In addition, the study by Nault et al. (2018) documented several native monocotyledon and dicotyledon species that exhibited significant declines posttreatment. Specifically, northern watermilfoil (*Myriophyllum sibiricum*), slender naiad (*Najas flexilis*), water marigold (*Bidens beckii*), and several thin-leaved pondweeds (*Potamogeton pusillus*, *P. strictifolius*, *P. friesii* and *P. foliosus*) showed highly significant declines in the majority of the lakes monitored. In addition, variable/Illinois pondweed (*P. gramineus*/*P. illinoensis*), flat-stem pondweed (*P. zosteriformis*), fern pondweed (*P. robbinsii*), and sago pondweed (*Stuckenia pectinata*) also declined in many lakes. Ribbon-leaf pondweed (*P. epihydrus*) and water stargrass (*Heteranthera dubia*) declined in the lakes where they were found. Mixed effects of treatment were observed with water celery (*Vallisneria americana*) and southern naiad (*Najas guadalupensis*), with some lakes showing significant declines posttreatment and other lakes showing increases.

Since milfoil hybridity is a relatively new documented phenomenon (Moody and Les 2002), many of the early lab studies examining CET for milfoil control did not determine if they were examining pure Eurasian watermilfoil or hybrid watermilfoil (*M. spicatum* x *sibiricum*) strains. More recent laboratory and mesocosm studies have shown that certain strains of hybrid watermilfoil exhibit more aggressive growth and are less affected by 2,4-D (Glomski and Netherland 2010; LaRue et al. 2013; Netherland and Willey 2017; Taylor et al. 2017), while other studies have not seen differences in overall growth patterns or treatment efficacy when compared to pure Eurasian watermilfoil (Poovey et al. 2007). Differences between Eurasian and hybrid watermilfoil control following 2,4-D applications have also been documented in the field, with lower efficacy and shorter longevity of hybrid watermilfoil control when compared to pure Eurasian watermilfoil populations (Nault et al. 2018). Field studies conducted in the Menominee River Drainage in northeastern Wisconsin and upper peninsula of Michigan observed hybrid milfoil genotypes more frequently in lakes that had previous 2,4-D treatments, suggesting possible selection of more tolerant hybrid strains over time (LaRue 2012).

Fluridone

Registration and Formulations

Fluridone is an aquatic herbicide that was initially registered with the U.S. EPA in 1986. It is currently being evaluated for reregistration. The estimated registration review decision date was in 2014 (EPA Fluridone Plan 2010). The active ingredient is (1-methyl-3-phenyl-5-[3-(trifluoromethyl) phenyl]-4(1H)-pyridinone). Fluridone is available in both liquid and slow-release granular formulations.

Mode of Action and Degradation

Fluridone's mode of action is to reduce a plant's ability to protect itself from sun damage. The herbicide prevents the plant from making a protective pigment and as a result, sunlight causes the plant's chlorophyll to break down. Treated plants will turn white or pink at the growing tips a week after exposure and will begin to die one to two months after treatment (Madsen et al. 2002). Therefore, fluridone is only effective if plants are actively growing at the time of treatment. Effective use of fluridone requires low, sustained concentrations and a relatively long contact time (e.g., 45-90 days). Due to this requirement, fluridone is usually applied to an entire waterbody or basin. Some success has been demonstrated when additional follow-up 'bump' treatments are used to maintain the low concentrations over a long enough period of time to produce control. Fluridone has also been applied to riverine systems using a drip system to maintain adequate CET.

Following treatment, the amount of fluridone in the water is reduced through dilution and water movement, uptake by plants, adsorption to the sediments, and via breakdown caused by light and microbes. Fluridone is primarily degraded through photolysis (Saunders and Mosier 1983), while depth, water clarity and light penetration can influence degradation rates (Mossler et al. 1989; West et al. 1983). There are two major degradation products from fluridone: n-methyl formamide (NMF) and 3-trifluoromethyl benzoic acid.

The half-life of fluridone can be as short as several hours, or hundreds of days, depending on conditions (West et al. 1979; West et al. 1983; Langeland and Warner 1986; Fox et al. 1991, 1996; Jacob et al. 2016). Preliminary work on a seepage lake in Waushara County, WI detected fluridone in the water nearly 400 days following an initial application that was then augmented to maintain concentrations via a 'bump' treatment at 60 and 100 days later (Onterra 2017a). Light exposure is influential in controlling degradation rate, with a half-life ranging from 15 to 36 hours when exposed to the full spectrum of natural sunlight (Mossler et al. 1989). As light wavelength increases, the half-life increases too, indicating that season and timing may affect fluridone persistence. Fluridone half-life has been shown to be only slightly dependent on fluridone concentration, oxygen concentration, and pH (Saunders and Mosier 1983). One study found that the half-life of fluridone in water was slightly lower when the herbicide was applied to the surface of the water as opposed to a sub-surface application, suggesting that degradation may also be affected by mode of application (West and Parka 1981).

The persistence of herbicide in the sediment has been reported to be much longer than in the overlying water column, with studies showing persistence ranges from 3 months to a year in sediments (Muir et al. 1980; Muir and Grift 1982; West et al. 1983). Persistence in soil is influenced by soil chemistry (Shea and Weber 1983; Mossler et al. 1993). Fluridone concentrations measured in sediments reach a maximum in one to four weeks after treatment and decline in four months to a year depending on environmental conditions. Fluridone adsorbs to clay and soils with high organic matter, especially in pellet form, and can reduce the concentration of fluridone in the water. Adsorption to the sediments is reversible; fluridone gradually dissipates back into the water where it is subject to chemical breakdown.

Some studies have shown variable release time of the herbicide among different granular fluridone products (Mossler et al. 1993; Koschnick et al. 2003; Bultemeier and Haller 2015). In addition, pelletized formulations may be more effective in sandy hydrosoils, while aqueous suspension formulations may be more appropriate for areas with high amounts of clay or organic matter (Mossler et al. 1993)

Toxicology

Fluridone does not appear to have short-term or long-term effects on fish at approved application rates, but fish exposed to water treated with fluridone do absorb fluridone into their tissues. However, fluridone has demonstrated a very low potential for bioconcentration in fish, zooplankton, and aquatic plants (McCowen et al. 1979; West et al. 1979; Muir et al. 1980; Paul et al. 1994). Fluridone concentrations in fish decrease as the herbicide disappears from the water. Studies on the effects of fluridone on aquatic invertebrates (e.g., midge and water flea) have shown increased mortality at label application rates (Hamelink et al. 1986; Yi et al. 2011). Studies on birds indicate that fluridone would not pose an acute or chronic risk to birds. In addition, no treatment related effects were noted in mice, rats, and dogs exposed to dietary doses. No studies have been published on amphibians or reptiles. There are no restrictions on swimming, eating fish from treated waterbodies, human drinking water or pet/livestock drinking water. Depending on the type of waterbody treated and the type of plant being watered, irrigation restrictions may apply for up to 30 days. There is some evidence that the fluridone degradation product NMF causes birth defects, though NMF has only been detected in the lab and not following actual fluridone treatments in the field, including those at maximum label rate (Osborne et al. 1989; West et al. 1990).

Species Susceptibility

Because fluridone treatments are often applied at a lakewide scale and many plant species are susceptible to fluridone, careful consideration should be given to potential non-target impacts and changes in water quality in response to treatment. Sustained native plant species declines and reductions in water clarity have been observed following fluridone treatments in field applications (O'Dell et al. 1995; Valley et al. 2006; Wagner et al. 2007; Parsons et al. 2009). However, reductions in water clarity are not always observed and can be avoided (Crowell et al. 2006). Additionally, the selective activity of fluridone is primarily rate-dependent based on analysis of pigments in nine aquatic plant species (Sprecher et al. 1998b).

Fluridone is most often used for control of invasive species such as Eurasian and hybrid watermilfoil (*Myriophyllum spicatum* x *sibiricum*), Brazilian waterweed (*Egeria densa*), and hydrilla (*Hydrilla verticillata*; Schmitz et al. 1987; MacDonald et al. 1993; Netherland et al. 1993; Netherland and Getsinger 1995a, 1995b; Cockreham and Netherland 2000; Hofstra and Clayton 2001; Madsen et al. 2002; Netherland 2015). However, fluridone tolerance has been observed in some hydrilla and hybrid watermilfoil populations (Michel et al. 2004; Arias et al. 2005; Puri et al. 2006; Slade et al. 2007; Berger et al. 2012, 2015; Thum et al. 2012; Benoit and Les 2013; Netherland and Jones 2015). Fluridone has also been shown to affect flowering rush (*Butomus umbellatus*), fanwort (*Cabomba caroliniana*), buttercups (*Ranunculus* spp.), long-leaf pondweed (*Potamogeton nodosus*), Illinois pondweed (*P. illinoensis*), leafy pondweed (*P. foliosus*), flat-stem pondweed (*P. zosteriformis*), sago pondweed (*Stuckenia pectinata*), oxygen-weed (*Lagarosiphon major*), northern watermilfoil (*Myriophyllum sibiricum*), variable-leaf watermilfoil (*M. heterophyllum*), curly-leaf pondweed (*Potamogeton crispus*), coontail (*Ceratophyllum demersum*), common waterweed (*Elodea canadensis*), southern naiad (*Najas guadalupensis*), slender naiad (*N. flexilis*), white waterlily (*Nymphaea odorata*), water marigold (*Bidens beckii*), duckweed (*Lemna* spp.), and watermeal (*Wolffia columbiana*) (Wells et al. 1986; Kay 1991; Farone and McNabb 1993; Netherland et al. 1997; Koschnick et al. 2003; Crowell et al. 2006; Wagner et al. 2007; Parsons et al. 2009; Cheshier et al. 2011; Madsen et al. 2016). Muskgrasses (*Chara* spp.), water celery (*Vallisneria americana*), cattails (*Typha* spp.), and willows (*Salix* spp.) have been shown to be somewhat tolerant of fluridone (Farone and McNabb 1993; Poovey et al. 2004; Crowell et al. 2006).

Large-scale fluridone treatments that targeted Eurasian and hybrid watermilfoils have been conducted in several Wisconsin lakes. Recently, five of these waterbodies treated with low-dose fluridone (2-4 ppb) have been tracked over time to understand herbicide dissipation and degradation patterns, as well as the efficacy, selectivity, and longevity of these treatments. These field trials resulted in a pre- vs. post-treatment decrease in the number of vegetated littoral zone sampling sites, with a 9-26% decrease observed following treatment (an average decrease in vegetated littoral zone sites of 17.4% across waterbodies). In four of the five waterbodies, substantial decreases in plant biomass (≥10% reductions in average total rake fullness) was documented at sites where plants occurred in both the year of and year after treatment. Good milfoil control was achieved, and long-term monitoring is ongoing to understand the longevity of target species control over time. However, non-target native plant populations were also observed to be negatively impacted in conjunction with these treatments, and long-term monitoring is ongoing to understand their recovery over time. Exposure times in the five waterbodies monitored were found to range from 320 to 539 days before falling below detectable limits. Data from these recent projects is currently being compiled and a compressive analysis and report is anticipated in the near future.

Endothall

Registration and Formulations

Endothall was registered with the U.S. EPA for aquatic use in 1960 and reregistered in 2005 (Menninger 2012). Endothall is the common name of the active ingredient endothal acid (7-oxabicyclo[2,2,1] heptane-2,3-dicarboxylic acid). Granular and liquid formulations are currently registered by EPA and DATCP. Endothall products are used to control a wide range of terrestrial and aquatic plants. Two types of endothall are available: dipotassium salt and dimethylalkylamine salt ("mono-N,N-dimethylalkylamine salt" or "monoamine salt"). The dimethylalkylamine salt form is toxic to fish and other aquatic organisms and is faster-acting than the dipotassium salt form.

Mode of Action and Degradation

Endothall is considered a contact herbicide that inhibits respiration, prevents the production of proteins and lipids, and disrupts the cellular membrane in plants (MacDonald et al. 1993; MacDonald et al. 2001; EPA RED Endothall 2005; Bajsa et al. 2012). Although typical rates of endothall application inhibit plant respiration, higher concentrations have been shown to increase respiration (MacDonald et al. 2001). The mode of action of endothall is unlike any other commercial herbicide. For effective control, endothall should be applied when plants are actively growing, and plants begin to weaken and die within a few days after application.

Uptake of endothall is increased at higher water temperatures and higher amounts of light (Haller and Sutton 1973). Netherland et al. (2000) found that while biomass reduction of curly-leaf pondweed (*Potamogeton crispus*) was greater at higher water temperature, reductions of turion production were much greater when curly-leaf pondweed was treated a lower water temperature (18 °C vs 25 °C).

Degradation of endothall is primarily microbial (Sikka and Saxena 1973) and half-life of the dipotassium salt formulations is between 4 to 10 days (Reinert and Rodgers 1987; Reynolds 1992), although dissipation due to water movement may significantly shorten the effective half-life in some treatment scenarios. Half of the active ingredient from granular endothall formulations has been shown to be released within 1-5 hours under conditions that included water movement (Reinert et al. 1985; Bultemeier and Haller 2015). Endothall is highly water soluble and does not readily adsorb to sediments or lipids (Sprecher et al. 2002; Reinert and Rodgers 1984). Degradation from sunlight or hydrolysis is very low (Sprecher et al. 2002). The degradation rate of endothall has been shown to increase with increasing water temperature (UPI, *unpublished data*). The degradation rate is also highly variable across aquatic systems and is much slower under anaerobic conditions (Simsiman and Chesters 1975). Relative to other herbicides, endothall is unique in that is comprised of carbon, hydrogen, and oxygen with the addition of potassium and nitrogen in the dipotassium and dimethylalkylamine formulations, respectively. This allows for complete breakdown of the herbicide without additional intermediate breakdown products (Sprecher et al. 2002).

Toxicology

All endothall products have a drinking water standard of 0.1 ppm and cannot be applied within 600 feet of a potable water intake. Use restrictions for dimethylalkylamine salt formulations have additional irrigation and aquatic life restrictions.

Dipotassium salt formulations

At recommended rates, the dipotassium salt formulations appear to have few short-term behavioral or reproductive effects on bluegill (*Lepomis macrochirus*) or largemouth bass (*Micropterus salmoides;* Serns 1977; Bettolli and Clark 1992; Maceina et al. 2008). Bioaccumulation of dipotassium salt formulations by fish from water treated with the herbicide is unlikely, with studies showing less than 1% of endothall being taken up by bluegill (Sikka et al. 1975; Serns 1977). In addition, studies have shown the dipotassium salt formulation induces no significant adverse effects on aquatic invertebrates when used at label application rates (Serns 1975; Williams et al. 1984). A freshwater mussel species was found to be more sensitive to dipotassium salt endothall than other invertebrate species tested, but significant acute toxicity was still only found at concentrations well above the maximum label rate. However, as with other plant control approaches, some aquatic plant-dwelling populations of aquatic organisms may be adversely affected by application of endothall formulations due to habitat loss.

During EPA reregistration of endothall in 2005, it was required that product labels state that lower rates of endothall should be used when treating large areas, “such as coves where reduced water movement will not result in rapid dilution of the herbicide from the target treatment area or when treating entire lakes or ponds.”

Dimethylalkylamine salt formulations

In contrast to the respective low to slight toxicity of the dipotassium salt formulations to fish and aquatic invertebrates, laboratory studies have shown the dimethylalkylamine formulations are toxic to fish and macroinvertebrates at concentrations above 0.3 ppm. In particular, the liquid formulation will readily kill fish present in a treatment site. Product labels for the dimethylalkylamine salt formulations recommend no treatment where fish are an important resource.

The dimethylalkylamine formulations are more active on aquatic plants than the dipotassium formulations, but also are 2-3 orders of magnitude more toxic to non-target aquatic organisms (EPA RED Endothall 2005; Keckemet 1969). The 2005 reregistration decision document limits aquatic use of the dimethylalkylamine formulations to algae, Indian swampweed (*Hygrophila polysperma*), water celery (*Vallisneria americana*), hydrilla (*Hydrilla verticillata*), fanwort (*Cabomba caroliniana*), bur reed (*Sparganium* sp.), common waterweed (*Elodea canadensis*)*,* and Brazilian waterweed (*Egeria densa*). Coontail (*Ceratophyllum demersum*), watermilfoils (*Myriophyllum* spp.), naiads (*Najas* spp.), pondweeds (*Potamogeton* spp.), water stargrass (*Heteranthera dubia*), and horned pondweed (*Zannichellia palustris*) were to be removed from product labels (EPA RED Endothall 2005).

Species Susceptibility

According to the herbicide label, the maximum target concentration of endothall is 5000 ppb (5.0 ppm) acid equivalent (ae). Endothall is used to control a wide range of submersed species, including non-native species such as curly-leaf pondweed and Eurasian watermilfoil (*Myriophyllum spicatum*). The effects of the different formulations of endothall on various species of aquatic plants are discussed below.

Dipotassium salt formulations

At least one mesocosm or lab study has shown that endothall (at or below the maximum label rate) will control the invasive species hydrilla (Netherland et al. 1991; Wells and Clayton 1993; Hofstra and Clayton 2001; Pennington et al. 2001; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Netherland and Haller 2006; Poovey and Getsinger 2010), oxygen-weed (*Lagarosiphon major*; Wells and Clayton 1993; Hofstra and Clayton 2001), Eurasian watermilfoil (Netherland et al. 1991; Skogerboe and Getsinger 2002; Mudge and Theel 2011), water lettuce (*Pistia stratiotes*; Conant et al. 1998), curly-leaf pondweed (Yeo 1970), and giant salvinia (*Salvinia molesta*; Nelson et al. 2001). Wersal and Madsen (2010a) found that parrot feather (*Myriophyllum aquaticum*) control with endothall was less than 40% even with two days of exposure time at the maximum label rate. Endothall was shown to control the shoots of flowering rush (*Butomus umbellatus*), but control of the roots was variable (Poovey et al. 2012; Poovey et al. 2013). One study found that endothall did not significantly affect photosynthesis in fanwort with 6 days of exposure at 2.12 ppm ae (2120 ppb ae; Bultemeier et al. 2009). Large-scale, low-dose endothall treatments were found to reduce curly-leaf pondweed frequency, biomass, and turion production substantially in Minnesota lakes, particularly in the first 2-3 years of treatments (Johnson et al. 2012).

Native species that were significantly impacted (at or below the maximum endothall label rate in at least one mesocosm or lab study) include coontail (Yeo 1970; Hofstra and Clayton 2001; Hofstra et al. 2001; Skogerboe and Getsinger 2002; Wells and Clayton 1993; Mudge 2013), southern naiad (*Najas guadalupensis*; Yeo 1970; Skogerboe and Getsinger 2001), white waterlily (*Nymphaea odorata*; Skogerboe and Getsinger 2001), leafy pondweed (*Potamogeton foliosus*; Yeo 1970), Illinois pondweed (*Potamogeton illinoensis*; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Skogerboe and Getsinger 2002; Mudge 2013), long-leaf pondweed (*Potamogeton nodosus*; Yeo 1970; Skogerboe and Getsinger 2001; Shearer and Nelson 2002; Mudge 2013), small pondweed (*P. pusillus*; Yeo 1970), broadleaf arrowhead (*Sagittaria latifolia*; Skogerboe and Getsinger 2001), sago pondweed (*Stuckenia pectinata*; Yeo 1970; Sprecher et al. 1998a; Skogerboe and Getsinger 2002; Slade et al. 2008), water celery (*Vallisneria americana*; Skogerboe and Getsinger 2001; Skogerboe and Getsinger 2002; Shearer and Nelson 2002; Mudge 2013), and horned pondweed (Yeo 1970; Gyselinck and Courter 2015).

Species which were not significantly impacted or which recovered quickly include watershield (*Brasenia schreberi*; Skogerboe and Getsinger 2001), muskgrasses (*Chara* spp.; Yeo 1970; Wells and Clayton 1993; Hofstra and Clayton 2001), common waterweed (Yeo 1970; Wells and Clayton 1993; Skogerboe and

Getsinger 2002), water stargrass (Skogerboe and Getsinger 2001), water net (*Hydrodictyon reticulatum*; Wells and Clayton 1993), the freshwater macroalgae *Nitella clavata* (Yeo 1970), yellow pond-lily (*Nuphar advena*; Skogerboe and Getsinger 2002), swamp smartweed (*Polygonum hydropiperoides*; Skogerboe and Getsinger 2002), pickerelweed (*Pontederia cordata*; Skogerboe and Getsinger 2001), softstem bulrush (*Schoenoplectus tabernaemontani*; Skogerboe and Getsinger 2001), and broadleaf cattail (*Typha latifolia*; Skogerboe and Getsinger 2002).

Field trials mirror the species susceptibility above and in addition show that endothall also can impact several high-value pondweed species (*Potamogeton* spp.), including large-leaf pondweed (*P. amplifolius*; Parsons et al. 2004), fern pondweed (*P. robbinsii*; Onterra 2015; Onterra 2018), white-stem pondweed (*P. praelongus*; Onterra 2018), small pondweed (Big Chetac Chain Lake Association 2016; Onterra 2018), clasping-leaf pondweed (*P. richardsonii*; Onterra 2018), and flat-stem pondweed (*P. zosteriformis*; Onterra 2017b).

Dimethylalkylamine salt formulations

The dimethylalkylamine formulations are more active on aquatic plants than the dipotassium formulations (EPA RED Endothall 2005; Keckemet 1969). At least one mesocosm study has shown that dimethylalkylamine formulation of endothall (at or below the maximum label rate) will control the invasive species fanwort (Hunt et al. 2015) and the native species common waterweed (Mudge et al. 2015), while others have shown that the dipotassium formulation does not control these species well.

Imazamox

Registration and Formulations

Imazamox is the common name of the active ingredient ammonium salt of imazamox (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-5-(methoxymethl)-3-pyridinecarboxylic acid. It was registered with U.S. EPA in 2008 and is currently under registration review with an estimated registration decision between 2019 and 2020 (EPA Imazamox Plan 2014). In aquatic environments, a liquid formulation is typically applied to submerged vegetation by broadcast spray or underwater hose application and to emergent or floating leaf vegetation by broadcast spray or foliar application. There is also a granular formulation.

Mode of Action and Degradation

Imazamox is a systemic herbicide that moves throughout the plant tissue and prevents plants from producing a necessary enzyme, acetolactate synthase (ALS), which is not found in animals. Susceptible plants will stop growing soon after treatment, but plant death and decomposition will occur over several weeks (Mudge and Netherland 2014). If used as a post-emergence herbicide, imazamox should be applied to plants that are actively growing. Resistance to ALS-inhibiting herbicides has appeared in weeds at a higher rate than other herbicide types in terrestrial environments (Tranel and Wright 2002).

Dissipation studies in lakes indicate a half-life ranging from 4 to 49 days with an average of 17 days. Herbicide breakdown does not occur readily in deep, poorly-oxygenated water where there is no light. In this part of a lake, imazamox will tend to bind to sediments rather than breaking down, with a half-life of approximately 2 years. Once in soil, leaching to groundwater is believed to be very limited. The breakdown products of imazamox are nicotinic acid and di- and tricarboxylic acids. It has been suggested that photolytic break down of imazamox is faster than other herbicides, reducing exposure times. However, short-term imazamox exposures have also been associated with extended regrowth times relative to other herbicides (Netherland 2011).

Toxicology

Treated water may be used immediately following application for fishing, swimming, cooking, bathing, and watering livestock. If water is to be used as potable water or for irrigation, the tolerance is 0.05 ppm (50 ppb), and a 24-hour irrigation restriction may apply depending on the waterbody. None of the breakdown products are herbicidal nor suggest concerns for aquatic organisms or human health.

Most concerns about adverse effects on human health involve applicator exposure. Concentrated imazamox can cause eye and skin irritation and is harmful if inhaled. Applicators should minimize exposure by wearing long-sleeved shirts and pants, rubber gloves, and shoes and socks.

Honeybees are affected at application rates so drift should be minimized during application. Lab tests using rainbow trout (*Oncorhynchus mykiss*), bluegill (*Lepomis macrochirus*), and water fleas (*Daphnia magna*) indicate that imazamox is not toxic to these species at label application rates. Imazamox is rated “practically non-toxic” to fish and aquatic invertebrates and does not bioaccumulate in fish. Additional studies on birds indicate toxicity only at dosages that exceed approved application rates.

In chronic tests, imazamox was not shown to cause tumors, birth defects or reproductive toxicity in test animals. Most studies show no evidence of mutagenicity. Imazamox is not metabolized and was excreted by mammals tested. Based on its low acute toxicity to mammals, and its rapid disappearance from the water column due to light and microbial degradation and binding to soil, imazamox is not considered to pose a risk to recreational water users.

Species Susceptibility

In Wisconsin, imazamox is used for treating non-native emergent vegetation such as non-native phragmites (*Phragmites australis* subsp. *australis*) and flowering rush (*Butomus umbellatus*). Imazamox may also be used to treat the invasive curly-leaf pondweed (*Potamogeton crispus*). Desirable native species that may be affected could include other pondweed species (long-leaf pondweed (*P. nodosus*), flat-stem pondweed (*P. zosteriformis*), leafy pondweed (*P. foliosus*), Illinois pondweed (*P. illinoensis*), small pondweed (*P. pusillus*), variable-leaf pondweed (*P. gramineus*), water-thread pondweed (*P. diversifolius*), perfoliate pondweed (*P. perfoliatus*), large-leaf pondweed (*P. amplifolius*), watershield (*Brasenia schreberi*), and some bladderworts (*Utricularia* spp.). Higher rates of imazamox will control Eurasian watermilfoil (*Myriophyllum spicatum*) but would also have greater non-target impacts on native plants. Imazamox can also be used during a drawdown to prevent plant regrowth and on emergent vegetation.

At low concentrations, imazamox can cause growth regulation rather than mortality in some plant species. This has been shown for non-native phragmites and hydrilla (*Hydrilla verticillata*; Netherland 2011; Cheshier et al. 2012; Theel et al. 2012). In the case of hydrilla, some have suggested that this effect could be used to maintain habitat complexity while providing some target species control (Theel et al. 2012). Imazamox can reduce biomass of non-native phragmites though some studies found regrowth to occur, suggesting a combination of imazapyr and glyphosate to be more effective (Cheshier et al. 2012; Knezevic et al. 2013).

Some level of control of imazamox has also been reported for water hyacinth (*Eichhornia crassipes*), parrot feather (*Myriophyllum aquaticum*), Japanese stiltgrass (*Microstegium vimineum*), water lettuce (*Pistia stratiotes*), and southern cattail (*Typha domingensis*; Emerine et al. 2010; de Campos et al. 2012; Rodgers and Black 2012; Hall et al. 2014; Mudge and Netherland 2014). Imazamox was observed to have greater efficacy in controlling floating plants than emergents in a study of six aquatic plant species, including water hyacinth, water lettuce, parrot feather, and giant salvinia (*Salvinia molesta*; Emerine et al. 2010). Non-target effects have been observed for softstem bulrush (*Schoenoplectus tabernaemontani*), pickerelweed (*Pontederia cordata*), and the native pondweeds long-leaf pondweed, Illinois pondweed, and coontail (*Ceratophyllum demersum*; Koschnick et al. 2007; Mudge 2013).

Giant salvinia, white waterlily (*Nymphaea odorata*), bog smartweed (*Polygonum setaceum*), giant bulrush (*Schoenoplectus californicus*), water celery (*Vallisneria americana*; though the root biomass of wide-leaf *Vallisneria* may be reduced), and several algal species have been found by multiple studies to be unaffected by imazamox (Netherland et al. 2009; Emerine et al. 2010; Rodgers and Black 2012; Mudge 2013; Mudge and Netherland 2014). Other species are likely to be susceptible, for which the effects of imazamox have not yet been evaluated.

Florpyrauxifen-benzyl

Registration and Formulations

Florpyrauxifen-benzyl is a relatively new herbicide, which was first registered with the U.S. EPA in September 2017. The active ingredient is 4-amino-3-chloro-6-(4-chloro-2-fluoro-3-methoxyphenyl)-5-fluoro-pyridine-2-benzyl ester, also identified as florpyrauxifen-benzyl. Florpyrauxifen-benzyl is used for submerged, floating, and emergent aquatic plant control (e.g., ProcellaCOR™) in slow-moving and quiescent waters, as well as for broad spectrum weed control in rice (*Oryza sativa*) culture systems and other crops (e.g., Rinskor™).

Mode of Action and Degradation

Florpyrauxifen-benzyl is a member of a new class of synthetic auxins, the arylpicolinates, that differ in binding affinity compared to other currently registered synthetic auxins such as 2,4-D and triclopyr (Bell et al. 2015). Florpyrauxifen-benzyl is a systemic herbicide (Heilman et al. 2017).

Laboratory studies and preliminary field dissipation studies indicate that florpyrauxifen-benzyl in water is subject to rapid photolysis (Heilman et al. 2017). In addition, the herbicide can also convert partially via hydrolysis to an acid form at high pH (>9) and higher water temperatures (>25°C), and microbial activity in the water and sediment can also enhance degradation (Heilman et al. 2017). The acid form is noted to have reduced herbicidal activity (Netherland and Richardson 2016; Richardson et al. 2016). Under growth chamber conditions, water samples at 1 DAT found that 44-59% of the applied herbicide had converted to acid form, while sampling at 7 and 14 DAT indicated that all the herbicide had converted to acid form (Netherland and Richardson 2016). The herbicide is short-lived, with half-lives ranging from 4 to 6 days in aerobic aquatic environments, and 2 days in anaerobic aquatic environments (WSDE 2017). Degradation in surface water is accelerated when exposed to sunlight, with a reported photolytic half- life in laboratory testing of 0.07 days (WSDE 2017).

There is some anecdotal evidence that initial water temperature and/or pH may impact the efficacy of florpyrauxifen-benzyl (Beets and Netherland 2018). Florpyrauxifen-benzyl has a high soil adsorption coefficient (KOC) and low volatility, which allows for rapid plant uptake resulting in short exposure time requirements (Heilman et al. 2017). Florpyrauxifen-benzyl degrades quickly (2-15 days) in soil and sediment (Netherland et al. 2016). Few studies have yet been completed for groundwater, but based on known environmental properties, florpyrauxifen-benzyl is not expected to be associated with potential environmental impacts in groundwater (WSDE 2017).

Toxicology

No adverse human health effects were observed in toxicological studies submitted for EPA herbicide registration, regardless of the route of exposure (Heilman et al. 2017). There are no drinking water or recreational use restrictions, including swimming and fishing, and no restrictions on irrigating turf. There is a short waiting period (dependent on application rate) for other non-agricultural irrigation purposes.

Florpyrauxifen-benzyl showed a good environmental profile for use in water, and is "practically non-toxic" to birds, bees, reptiles, amphibians, and mammals (Heilman et al. 2017). No ecotoxicological effects were observed on freshwater mussel or juvenile chinook salmon (Heilman et al. 2017). Florpyrauxifen-benzyl will temporarily bioaccumulate in freshwater organisms but is rapidly depurated and/or metabolized within 1 to 3 days after exposure to high (>150 ppb) concentrations (WSDE 2017).

An LC_{50} value indicates the concentration of a chemical required to kill 50% of a test population of organisms. LC_{50} values are commonly used to describe the toxicity of a substance. Label recommendations for milfoils do not exceed 9.65 ppb and the maximum label rate for an acre-foot of water is 48.25 ppb. Acute toxicity results using rainbow trout (*Oncorhynchus mykiss*), fathead minnow (*Pimephales promelas*), and sheepshead minnows (*Cyprinodon variegatus variegatus*) indicated LC_{50} values of greater than 49 ppb, 41 ppb, and 40 ppb, respectively when exposed to the technical grade active ingredient (WSDE 2017). An LC_{50} value of greater than 1,900 ppb was reported for common carp (*Cyprinus carpio*) exposed to the ProcellaCOR end-use formulation (WSDE 2017).

Acute toxicity results for the technical grade active ingredient using water flea (*Daphnia magna*) and midge (*Chironomus* sp.) indicated LC_{50} values of greater than 62 ppb and 60 ppb, respectively (WSDE 2017). Comparable acute ecotoxicity testing performed on *D. magna* using the ProcellaCOR end-use formulation indicated an LC_{50} value of greater than 8 ppm (80,000 ppb; WSDE 2017).

The ecotoxicological no observed effect concentration for various organisms as reported by Netherland et al. (2016) are: fish (>515 ppb ai), water flea (*Daphnia* spp.; >21440 ppb ai), freshwater mussels (>1023 ppb ai), saltwater mysid (>362 ppb ai), saltwater oyster (>289 ppb ai), and green algae (>480 ppb ai). Additional details on currently available ecotoxicological information is compiled by WSDE (2017).

Species Susceptibility

Florpyrauxifen-benzyl is a labeled for control of invasive watermilfoils (e.g., Eurasian watermilfoil (*Myriophyllum spicatum*), hybrid watermilfoil (*M. spicatum* x *sibiricum*), parrot feather (*M. aquaticum*)), hydrilla (*Hydrilla verticillata*), and other non-native floating plants such as floating hearts (*Nymphoides* spp.), water hyacinth (*Eichhornia crassipes*), and water chestnut (*Trapa natans*; Netherland and Richardson 2016; Richardson et al. 2016). Natives species listed on the product label as susceptible to florpyrauxifen-benzyl include coontail (*Ceratophyllum demersum*; Heilman et al. 2017), watershield (*Brasenia schreberi*), and American lotus (*Nelumbo lutea*). In laboratory settings, pickerelweed (*Pontederia cordata*) vegetation has also been shown to be affected (Beets and Netherland 2018).

Based on available data, florpyrauxifen-benzyl appears to show few impacts to native aquatic plants such as aquatic grasses, bulrush (*Schoenoplectus* spp.), cattail (*Typha* spp.), pondweeds (*Potamogeton* spp.), naiads (*Najas* spp.), and water celery (*Vallisneria americana*; WSDE 2017). Laboratory and mesocosm studies also found water marigold (*Bidens beckii*), white waterlily (*Nymphaea odorata*), common waterweed (*Elodea canadensis*), water stargrass (*Heteranthera dubia*), long-leaf pondweed (*Potamogeton nodosus*), and Illinois pondweed (*P. illinoensis*) to be relatively less sensitive to florpyrauxifen-benzyl than labeled species (Netherland et al. 2016; Netherland and Richardson 2016). Non-native fanwort (*Cabomba caroliniana*) was also found to be tolerant in laboratory study (Richardson et al. 2016).

Since florpyrauxifen-benzyl is a relatively new approved herbicide, detailed information on field applications is very limited. Trials in small waterbodies have shown control of parrot feather (*Myriophyllum aquaticum*), variable-leaf watermilfoil (*M. heterophyllum*), and yellow floating heart (*Nymphoides peltata*; Heilman et al. 2017).

S.3.3.3. Emergent and Wetland Herbicides

Glyphosate

Registration and Formulations

Glyphosate is a commonly used herbicide that is utilized in both aquatic and terrestrial sites. It was first registered for use in 1974. EPA is currently re-evaluating glyphosate and the registration decision was expected in 2014 (EPA Glyphosate Plan 2009). The use of glyphosate-based herbicides in aquatic environments that are not approved for aquatic use is very unsafe and is a violation of federal and state pesticide laws. Different formulations of glyphosate are available, including isopropylamine salt of glyphosate and potassium glyphosate.

Glyphosate is effective only on plants that grow above the water and needs to be applied to plants that are actively growing. It will not be effective on plants that are submerged or have most of their foliage underwater, nor will it control regrowth from seed.

Mode of Action and Degradation

Glyphosate is a systemic herbicide that moves throughout the plant tissue and works by inhibiting an important enzyme needed for multiple plant processes, including growth. Following treatment, plants will gradually wilt, appear yellow, and will die in approximately 2 to 7 days. It may take up to 30 days for these effects to become apparent for woody species.

Application should be avoided when heavy rain is predicted within 6 hours. To avoid drift, application is not recommended when winds exceed 5 mph. In addition, excessive speed or pressure during application may allow spray to drift and must be avoided. Effectiveness of glyphosate treatments may be reduced if applied when plants are growing poorly, such as due to drought stress, disease, or insect damage. A surfactant approved for aquatic sites must be mixed with glyphosate before application.

In water, the concentration of glyphosate is reduced through dispersal by water movement, binding to the sediments, and break-down by microorganisms. The half-life of glyphosate is between 3 and 133 days, depending on water conditions. Glyphosate disperses rapidly in water, so dilution occurs quickly, thus moving water will decrease concentration, but not half-life. The primary breakdown product of glyphosate is aminomethylphosphonic acid (AMPA), which is also degraded by microbes in water and soil.

Toxicology

Most aquatic forms of glyphosate have no restrictions on swimming or eating fish from treated waterbodies. However, potable water intakes within ½ mile of application must be turned off for 48 hours after treatment. Different formulations and products containing glyphosate may vary in post-treatment water use restrictions.

Most glyphosate-related health concerns for humans involve applicator exposure, exposure through drift, and the surfactant exposure. Some adverse effects from direct contact with the herbicide include temporary symptoms of dermatitis, eye ailments, headaches, dizziness, and nausea. Protective clothing (goggles, a face shield, chemical resistant gloves, aprons, and footwear) should be worn by applicators to reduce exposure. Recently it has been demonstrated that terrestrial formulations of glyphosate can have toxic effects to human embryonic cells and linked to endocrine disruption (Benachour et al. 2007; Gasnier et al. 2009).

Laboratory testing indicates that glyphosate is toxic to carp (*Cyprinus* spp.), bluegills (*Lepomis macrochirus*), rainbow trout (*Oncorhynchus mykiss*), and water fleas (*Daphnia* spp.) only at dosages well above the label application rates. Similarly, it is rated "practically non-toxic" to other aquatic species tested. Studies by other researchers examining the effects of glyphosate on important food chain organisms such as midge larvae, mayfly nymphs, and scuds have demonstrated a wide margin of safety between application rates.

EPA data suggest that toxicological effects of the AMPA compound are similar to that of glyphosate itself. Glyphosate also contains a nitrosamine (n-nitroso-glyphosate) as a contaminant at levels of 0.1 ppm or less. Tests to determine the potential health risks of nitrosamines are not required by the EPA unless the level exceeds 1.0 ppm.

Species Susceptibility

Glyphosate is only effective on actively growing plants that grow above the water's surface. It can be used to control reed canary grass (*Phalaris arundinacea*), cattails (*Typha* spp.; Linz et al. 1992; Messersmith et al. 1992), purple loosestrife (*Lythrum salicaria*), phragmites (*Phragmites australis* subsp. *australis*; Back and Holomuzki 2008; True et al. 2010; Back et al. 2012; Cheshier et al. 2012), water hyacinth (*Eichhornia crassipes*; Lopez 1993; Jadhav et al. 2008), water lettuce (*Pistia stratiotes*; Mudge and Netherland 2014), water chestnut (*Trapa natans*; Rector et al. 2015), Japanese stiltgrass (*Microstegium vimineum*; Hall et al. 2014), giant reed (*Arundo donax*; Spencer 2014), and perennial pepperweed (*Lepidium latifolium*; Boyer and Burdick 2010). Glyphosate will also reduce abundance of white waterlily (*Nymphaea odorata*) and pond-lilies (*Nuphar* spp.; Riemer and Welker 1974). Purple loosestrife biocontrol beetle (*Galerucella calmariensis*) oviposition and survival have been shown not to be affected by integrated management with glyphosate. Studies have found pickerelweed (*Pontederia cordata*) and floating marsh pennywort (*Hydrocotyle ranunculoides*) to be somewhat tolerant to glyphosate (Newman and Dawson 1999; Gettys and Sutton 2004).

Imazapyr

Registration and Formulations

Imazapyr was registered with the U.S. EPA for aquatic use in 2003 and is currently under registration review. It was estimated to have a registration review decision in 2017 (EPA Imazapyr Plan 2014). The active ingredient is isopropylamine salt of imazapyr (2-[4,5-dihydro-4-methyl-4-(1-methylethyl)-5-oxo-1H-imidazol-2-yl]-3-pyridinecarboxylic acid). Imazapyr is used for control of emergent and floating-leaf vegetation. It is not recommended for control of submersed vegetation.

Mode of Action and Degradation

Imazapyr is a systemic herbicide that moves throughout the plant tissue and prevents plants from producing a necessary enzyme, acetolactate synthase (ALS), which is not found in animals. Susceptible plants will stop growing soon after treatment and become reddish at the tips of the plant. Plant death and decomposition will occur gradually over several weeks to months. Imazapyr should be applied to plants that are actively growing. If applied to mature plants, a higher concentration of herbicide and a longer contact time will be required.

Imazapyr is broken down in the water by light and has a half-life ranging from three to five days. Three degradation products are created as imazapyr breaks down: pyridine hydroxy-dicarboxylic acid, pyridine dicarboxylic acid (quinolinic acid), and nicotinic acid. These degradates persist in water for approximately the same amount of time as imazapyr (half-lives of three to eight days). In soils imazapyr is broken down by microbes, rather than light, and persists with a half-life of one to five months (Boyer and Burdick 2010). Imazapyr does not bind to sediments, so leaching through into groundwater is likely.

Toxicology

There are no restrictions on recreational use of treated water, including swimming and eating fish from treated waterbodies. If application occurs within a ½ mile of a drinking water intake, then the intake must be shut off for 48 hours following treatment. There is a 120-day irrigation restriction for treated water, but irrigation can begin sooner if the concentration falls below 0.001 ppm (1 ppb). Imazapyr degradates are no more toxic than imazapyr itself and are excreted faster than imazapyr when ingested.

Concentrated imazapyr has low acute toxicity on the skin or if ingested but is harmful if inhaled and may cause irreversible damage if it gets in the eyes. Applicators should wear chemical-resistant gloves while handling, and persons not involved in application should avoid the treatment area during treatment. Chronic toxicity tests for imazapyr indicate that it is not carcinogenic, mutagenic, or neurotoxic. It also does not cause reproductive or developmental toxicity and is not a suspected endocrine disrupter.

Imazapyr is "practically non-toxic" to fish, invertebrates, birds and mammals. Studies have also shown imazapyr to be "practically non-toxic" to "slightly toxic" to tadpoles and juvenile frogs (Trumbo and Waligora 2009; Yahnke et al. 2013). Toxicity tests have not been published on reptiles. Imazapyr does not bioaccumulate in animal tissues.

Species Susceptibility

The imazapyr herbicide label is listed to control the invasive plants phragmites (*Phragmites australis* subsp. *australis*), purple loosestrife (*Lythrum salicaria*), reed canary grass (*Phalaris arundinacea*), non-native cattails (*Typha* spp.) and Japanese knotweed (*Fallopia japonica*) in Wisconsin. Native species that are also controlled include cattails (*Typha* spp.), waterlilies (*Nymphaea* sp.), pickerelweed (*Pontederia cordata*), duckweeds (*Lemna* spp.), and arrowhead (*Sagittaria* spp.).

Studies have shown imazapyr to effectively control giant reed (*Arundo donax*), water hyacinth (*Eichhornia crassipes*), manyflower marsh-pennywort (*Hydrocotyle umbellata*); yellow iris (*Iris pseudacorus*), water lettuce (*Pistia stratiotes*), perennial pepperweed (*Lepidium latifolium*), Japanese stiltgrass (*Microstegium vimineum*), parrot feather (*Myriophyllum aquaticum*), and cattails (Boyer and Burdick 2010; True et al. 2010; Back et al. 2012; Cheshier et al. 2012; Whitcraft and Grewell 2012; Hall et al. 2014; Spencer 2014; Cruz et al. 2015; DiTomaso and Kyser 2016). Giant salvinia (*Salvinia molesta*) was found to be imazapyr-tolerant (Nelson et al. 2001).

S.3.3.4. Herbicides Used for Submersed and Emergent Plants

Triclopyr

Registration and Formulations

Triclopyr was initially registered with the U.S. EPA in 1979, reregistered in 1997, and is currently under review with an estimated registration review decision in 2019 (EPA Triclopyr Plan 2014). There are two forms of triclopyr used commercially as herbicides: the triethylamine salt (TEA) and the butoxyethyl ester (BEE). BEE formulations are considered highly toxic to aquatic organisms, with observed lethal effects on fish (Kreutzweiser et al. 1994) as well as avoidance behavior and growth impairment in amphibians (Wojtaszek et al. 2005). The active ingredient triethylamine salt (3,5,6-trichloro-2-pyridinyloxyacetic acid) is the formulation registered for use in aquatic systems. It is sold both in liquid and granular forms for control of submerged, emergent, and floating-leaf vegetation. There is also a liquid premixed formulation that contains triclopyr and 2,4-D, which when combined together are reported to have synergistic impacts. Only triclopyr products labeled for use in aquatic environments may be used to control aquatic plants.

Mode of Action and Degradation

Triclopyr is a systemic plant growth regulator that is believed to selectively act on broadleaf (dicot) and woody plants. Following treatment, triclopyr is taken up through the roots, stems and leaf tissues, plant growth becomes abnormal and twisted, and plants die within one to two weeks after application (Getsinger et al. 2000). Triclopyr is somewhat persistent and can move through soil, although only mobile enough to permeate top soil layers and likely not mobile enough to potentially contaminate groundwater (Lee et al. 1986; Morris et al. 1987; Stephenson et al. 1990).

Triclopyr is broken down rapidly by light (photolysis) and microbes, while hydrolysis is not a significant route of degradation. Triclopyr photodegrades and is further metabolized to carbon dioxide, water, and various organic acids by aquatic organisms (McCall and Gavit 1986). It has been hypothesized that the major mechanism for the removal of triclopyr from the aquatic environment is microbial degradation, though the role of photolysis likely remains important in near-surface and shallow waters (Petty et al. 2001). Degradation of triclopyr by microbial action is slowed in the absence of light (Petty et al. 2003). Triclopyr is very slowly degraded under anaerobic conditions, with a reported half-life (the time it takes for half of the active ingredient to degrade) of about 3.5 years (Laskowski and Bidlack 1984). Another study of triclopyr under aerobic aquatic conditions yielded a half-life of 4.7 months (Woodburn and Cranor 1987). The initial breakdown products of triclopyr are TCP (3,5,6-trichloro-2-pyridinol) and TMP (3,5,6-trichloro-2-methoxypridine).

Several studies reported triclopyr half-lives between 0.5-7.5 days (Woodburn et al. 1993; Getsinger et al. 2000; Petty et al. 2001; Petty et al. 2003). Two large-scale, low-dose treatments were reported to have longer triclopyr half-lives from 3.7-12.1 days (Netherland and Jones 2015). Triclopyr half-lives have been shown to range from 3.4 days in plants, 2.8-5.8 days in sediment, up to 11 days in fish tissue, and 11.5 days in crayfish (Woodburn et al. 1993; Getsinger et al. 2000; Petty et al. 2003). TMP and TCP may have longer half-lives than triclopyr, with higher levels in bottom-feeding fish and the inedible parts of fish (Getsinger et al. 2000).

Toxicology

Based upon the triclopyr herbicide label, there are no restrictions on swimming, eating fish from treated waterbodies, or pet/livestock drinking water use. Before treated water can be used for irrigation, the concentration must be below 0.001 ppm (1 ppb), or at least 120 days must pass. Treated water should not be used for drinking water until concentrations of triclopyr are less than 0.4 ppm (400 ppb). There is a least one case of direct human ingestion of triclopyr TEA which resulted in metabolic acidosis and coma with cardiovascular impairment (Kyong et al. 2010).

There are substantial differences in toxicity of BEE and TEA, with the BEE shown to be more toxic in aquatic settings. BEE formulations are considered highly toxic to aquatic organisms, with observed lethal effects on fish (Kreutzweiser et al. 1994) as well as avoidance behavior and growth impairment in amphibians (Wojtaszek et al. 2005). Triclopyr TEA is "practically non-toxic" to freshwater fish and invertebrates (Mayes et al. 1984; Gersich et al. 1984). It ranges from "practically non-toxic" to "slightly toxic" to birds (EPA Triclopyr RED 1998). TCP and TMP appear to be slightly more toxic to aquatic organisms than triclopyr; however, the peak concentration of these degradates is low following treatment and depurates from organisms readily, so that they are not believed to pose a concern to aquatic organisms.

Species susceptibility

Triclopyr has been used to control Eurasian watermilfoil (*Myriophyllum spicatum*) and hybrid watermilfoil (*M. spicatum* x *sibiricum*) at both small- and large-scales (Netherland and Getsinger 1992; Getsinger et al. 1997; Poovey et al. 2004; Poovey et al. 2007; Nelson and Shearer 2008; Heilman et al. 2009; Glomski and Netherland 2010; Netherland and Glomski 2014; Netherland and Jones 2015). Getsinger et al. (2000) found that peak triclopyr accumulation was higher in Eurasian watermilfoil than flat-stem pondweed (*Potamogeton zosteriformis*), indicating triclopyr's affinity for Eurasian watermilfoil as a target species.

According to product labels, triclopyr is capable of controlling or affecting many emergent woody plant species, purple loosestrife (*Lythrum salicaria*), phragmites (*Phragmites australis* subsp. *australis*), American lotus (*Nelumbo lutea*), milfoils (*Myriophyllum* spp.), and many others. Triclopyr application has resulted in reduced frequency of occurrence, reduced biomass, or growth regulation for the following species: common waterweed (*Elodea canadensis*), water stargrass (*Heteranthera dubia*), white waterlily (*Nymphaea odorata*), purple loosestrife, Eurasian watermilfoil, parrot feather (*Myriophyllum aquaticum*), variable-leaf watermilfoil (*M. heterophyllum*), watercress (*Nasturtium officinale*), phragmites, flat-stem pondweed (*Potamogeton zosteriformis*), clasping-leaf pondweed (*P. richardsonii*), stiff pondweed (*P. strictifolius*), variable-leaf pondweed (*P. gramineus*), white water crowfoot (*Ranunculus aquatilis*), sago pondweed (*Stuckenia pectinata*), softstem bulrush (*Schoenoplectus tabernaemontani*), hardstem bulrush (*S. acutus*), water chestnut (*Trapa natans*), duckweeds (*Lemna* spp.), and submerged flowering rush (*Butomus umbellatus*; Cowgill et al. 1989; Gabor et al. 1995; Sprecher and Stewart 1995; Getsinger et al. 2003; Poovey et al. 2004; Hofstra et al. 2006; Poovey and Getsinger 2007; Champion et al. 2008; Derr 2008; Glomski and Nelson 2008; Glomski et al. 2009; True et al. 2010; Cheshier et al. 2012; Netherland and Jones 2015; Madsen et al. 2015; Madsen et al. 2016). Wild rice (*Zizania palustris*) biomass and height has been shown to decrease significantly following triclopyr application at 2.5 mg/L. Declines were not significant at lower concentrations (0.75 mg/L), though seedlings were more sensitive than young or mature plants (Madsen et al. 2008). American bulrush (*Schoenoplectus americanus*), spatterdock (*Nuphar variegata*), fern pondweed (*Potamogeton robbinsii*), large-leaf pondweed (*P. amplifolius*), leafy pondweed (*P. foliosus*), white-stem pondweed (*P. praelongus*), long-leaf pondweed (*P. nodosus*), Illinois pondweed (*P. illinoensis*), and water celery (*Vallisneria americana*) can be somewhat tolerant of triclopyr applications depending on waterbody characteristics and application rates (Sprecher and Stewart 1995; Glomski et al. 2009; Wersal et al. 2010b; Netherland and Glomski 2014).

Netherland and Jones (2015) evaluated the impact of large-scale, low-dose (~0.1-0.3 ppm) granular triclopyr) applications for control of non-native watermilfoil on several bays of Lake Minnetonka, Minnesota. Near complete loss of milfoil in the treated bays was observed the year of treatment, with increased milfoil frequency reported the following season. However, despite the observed increase in frequency, milfoil biomass remained a minor component of bay-wide biomass (<2%). The number of points with native plants, mean native species per point, and native species richness in the bays were not reduced following treatment. However, reductions in frequency were seen amongst individual species, including northern watermilfoil (*Myriophyllum sibiricum*), water stargrass, common waterweed, and flat-stem pondweed.

Penoxsulam

Registration and Formulations

Penoxsulam (2-(2,2-difluoroethoxy)--6-(trifluoromethyl-N-(5,8-dimethoxy[1,2,4] triazolo[1,5-c]pyrimidin-2-yl))benzenesulfonamide), also referred to as DE-638, XDE-638, XR-638 is a post-emergence, acetolactate synthase (ALS) inhibiting herbicide. It was first registered for use by the U.S. EPA in 2009. It is liquid in formulation and used for large-scale control of submerged, emergent, and floating-leaf vegetation. Information presented here can be found in the EPA pesticide fact sheet (EPA Penoxsulam 2004).

Mode of Action and Degradation

Penoxsulam is a slow-acting herbicide that is absorbed by above- and below-ground plant tissue and translocated throughout the plant. Penoxsulam interferes with plant growth by inhibiting the AHAS/ALS enzyme which in turn inhibits the production of important amino acids (Tranel and Wright 2002). Plant injury or death usually occurs between 2 and 4 weeks following application.

Penoxsulam is highly mobile but not persistent in either aquatic or terrestrial settings. However, the degradation process is complex. Two degradation pathways have been identified that result in at least 13 degradation products that persist for far longer than the original chemical. Both microbial- and photo-degradation are likely important means by which the herbicide is removed from the environment (Monika et al. 2017). It is relatively stable in water alone without sunlight, which means it may persist in light-limited areas.

The half-life for penoxsulam is between 12 and 38 days. Penoxsulam must remain in contact with plants for around 60 days. Thus, supplemental applications following initial treatment may be required to maintain adequate concentration exposure time (CET). Due to the long CET requirement, penoxsulam is likely best suited to large-scale or whole-lake applications.

Toxicology

Penoxsulam is unlikely to be toxic to animals but may be "slightly toxic" to birds that consume it. Human health studies have not revealed evidence of acute or chronic toxicity, though some indication of endocrine disruption deserves further study. However, screening-level assessments of risk have not been conducted on the major degradates which may have unknown non-target effects. Penoxsulam itself is unlikely to bioaccumulate in fish.

Species Susceptibility

Penoxsulam is used to control monocot and dicot plant species in aquatic and terrestrial environments. The herbicide is often applied at low concentrations of 0.002-0.02 ppm (2-20 ppb), but as a result long exposure times are usually required for effective target species control (Cheshier et al. 2011; Mudge et al. 2012b). For aquatic plant management applications, penoxsulam is most commonly utilized for control of hydrilla (*Hydrilla verticillata*). It has also been used for control of giant salvinia (*Salvinia molesta*), water hyacinth (*Eichhornia crassipes*), and water lettuce (*Pistia stratiotes*; Richardson and Gardner 2007; Mudge and Netherland 2014). However, the herbicide is only semi-selective; it has been implicated in injury to non-target emergent native species, including arrowheads (*Sagittaria* spp.) and spikerushes (*Eleocharis* spp.) and free-floating species like duckweed (Mudge and Netherland 2014; Cheshier et al. 2011). Penoxsulam can also be used to control milfoils such as Eurasian watermilfoil (*Myriophyllum spicatum*) and variable-leaf watermilfoil (*M. heterophyllum*; Glomski and Netherland 2008). Seedling emergence as well as vegetative vigor is impaired by penoxsulam in both dicots and monocots, so buffer zone and dissipation reduction strategies may be necessary to avoid non-target impacts (EPA Penoxsulam 2004).

When used to treat salvinia, the herbicide was found to have effects lasting 10 weeks following treatment (Mudge et al. 2012b). The herbicide is effective at low doses and while low-concentration applications of slow-acting herbicides often result in temporary growth regulation and stunting, plants are likely to recover following treatment. Thus, complementary management strategies should be employed to discourage early regrowth (Mudge et al. 2012b). In particular, joint biological and herbicidal control with penoxsulam has shown good control of water hyacinth (Moran 2012). Alternately, a low concentration may be maintained over time by repeated low-dose applications. Studies show that maintaining a low concentration for at least 8-12 weeks provided excellent control of salvinia, and that a low dose followed by a high-dose application was even more efficacious (Mudge et al. 2012b).

S.3.4. Physical Removal Techniques

There are several management options which involve physical removal of aquatic plants, either by manual or mechanical means. Some of these include manual and mechanical cutting and hand-pulling or Diver-Assisted Suction Harvesting (DASH).

S.3.4.1. Manual and Mechanical Cutting

Manual and mechanical cutting involve slicing off a portion of the target plants and removing the cut portion from the waterbody. In addition to actively removing parts of the target plants, destruction of vegetative material may help prevent further plant growth by decreasing photosynthetic uptake, and preventing the formation of rhizomes, tubers, and other growth types (Dall Armellina et al. 1996a, 1996b; Fox et al. 2002). These approaches can be quick to allow recreational use of a waterbody but because the plant is still established and will continue to grow from where it was cut, it often serves to provide short-term relief (Bickel and Closs 2009; Crowell et al. 1994). A synthesis of numerous historical mechanical harvesting studies is compiled by Breck et al. 1979.

The amount of time for macrophytes to return to pre-cutting levels can vary between waterbodies and with the dominant plant species present (Kaenel et al. 1998). Some studies have suggested that annual or biannual cutting of Eurasian watermilfoil (*Myriophyllum spicatum*) may be needed, while others have shown biomass can remain low the year after cutting (Kimbel and Carpenter 1981; Painter 1988; Barton et al. 2013). Hydrilla (*Hydrilla verticillata*) has been shown to recover beyond pre-harvest levels within weeks in some cases (Serafy et al. 1994). In deeper waters, greater cutting depth may lead to increased persistence of vegetative control (Unmuth et al. 1998; Barton et al. 2013). Higher frequency of cutting, rather than the amount of plant that is cut, can result in larger reductions to propagules such as turions (Fox et al. 2002).

The timing of cutting operations, as for other management approaches, is important. For species dependent on vegetative propagules, control methods should be taken before the propagules are formed. However, for species with rhizomes, cutting too early in the season merely postpones growth while later-season cutting can better reduce plant abundance (Dall Armellina et al. 1996a, 1996b). Eurasian watermilfoil regrowth may be slower if cutting is conducted later in the summer (June or later). Cutting in the fall, rather than spring or summer, may result in the lowest amount of Eurasian watermilfoil regrowth the year after management (Kimbel and Carpenter 1981). However, managing early in the growing season may reduce non-target impacts to native plant populations when early-growing non-native plants are the dominant targets (Nichols and Shaw 1986). Depending on regrowth rate and management goals, multiple harvests per growing season may be necessary (Rawls 1975).

Vegetative fragments which are not collected after cutting can produce new localized populations, potentially leading to higher plant densities (Dall Armellina et al. 1996a). Eurasian watermilfoil and common waterweed (*Elodea canadensis*) biomass can be reduced by cutting (Abernethy et al. 1996), though Eurasian watermilfoil can maintain its growth rate following cutting by developing a more-densely branched form (Rawls 1975; Mony et al. 2011). Cutting and physical removal tend to be less expensive but require more effort than benthic barriers, so these approaches may be best used for small infestations or where non-native and native species inhabit the same stand (Bailey and Calhoun 2008).

Ecological Impacts of Manual and Mechanical Cutting

Plants accrue nutrients into their tissues, and thus plant removal may also remove nutrients from waterbodies (Boyd 1970), though this nutrient removal may not be significant among all lake types. Cutting and harvesting of aquatic plants can lead to declines in fish as well as beneficial zooplankton, macroinvertebrate, and native plant and mussel populations (Garner et al. 1996; Aldridge 2000; Torn et al. 2010; Barton et al. 2013). Many studies suggest leaving some vegetated areas undisturbed to reduce negative effects of cutting on fish and other aquatic organisms (Swales 1982; Garner et al. 1996; Unmuth et al. 1998; Aldridge 2000; Greer et al. 2012). Recovery of these populations to cutting in the long-term is understudied and poorly understood (Barton et al. 2013). Effects on water quality can be minimal but nutrient cycling may be affected in wetland systems (Dall Armellina et al. 1996a; Martin et al. 2003). Cutting can also increase algal production, and turbidity temporarily if sediments are disturbed (Wile 1978; Bailey and Calhoun 2008).

Some changes to macroinvertebrate community composition can occur as a result of cutting (Monahan and Caffrey 1996; Bickel and Closs 2009). Studies have also shown 12-85% reductions in macroinvertebrates following cutting operations in flowing systems (Dawson et al. 1991; Kaenel et al. 1998). Macroinvertebrate communities may not rebound to pre-management levels for 4-6 months and species dependent on aquatic plants as habitat (such as simuliids and chironomids) are likely to be most affected. Reserving cutting operations for summer, rather than spring, may reduce impacts to macroinvertebrate communities (Kaenel et al. 1998).

Mechanical harvesting can also incidentally remove fish and turtles inhabiting the vegetation and lead to shifts in aquatic plant community composition (Engel 1990; Booms 1999). Studies have shown mechanical harvesting can remove between 2%-32% of the fish community by fish number, with juvenile game fish and smaller species being the primary species removed (Haller et al. 1980; Mikol 1985). Haller et al. (1980) estimated a 32% reduction in the fish community at a value of $6000/hectare. However, fish numbers rebounded to similar levels as an unmanaged area within 43 days after harvesting in the Potomac River in Maryland (Serafy et al. 1994). In addition to direct impacts to fish populations, reductions in fish growth rates may correspond with declines in zooplankton populations in response to cutting (Garner et al. 1996).

S.3.4.2. Hand Pulling and Diver-Assisted Suction Harvesting (DASH)

Hand-pulling and DASH involve removing rooted plants from the bottom sediment of the water body. The entire plant is removed and disposed of elsewhere. Hand-pulling can be done at shallower depths whereas DASH, in which SCUBA divers do the pulling, may be better suited for deeper aquatic plant beds. As a permit condition, DASH and hand-pulling may not result in lifting or removal of bottom sediment (i.e., dredging). Efforts should be made to preserve water clarity because turbid conditions reduce visibility for divers, slowing the removal process and making species identification difficult. When operated with the intent to distinguish between species and minimize disturbance to desirable vegetation, DASH can be selective and provide multi-year control (Boylen et al. 1996). One study found reduced cover of Eurasian watermilfoil both in the year of harvest and the following year, along with increased native plant diversity and reduced overall plant cover the year following DASH implementation (Eichler et al. 1993). However, hand harvesting or DASH may require a large time or economic investment for Eurasian watermilfoil and other aquatic vegetation control on a large-scale (Madsen et al. 1989; Kelting and Laxson 2010). Lake type, water clarity, sediment composition, underwater obstacles and presences of dense native plants, may slow DASH efforts or even prohibit the ability to utilized DASH. Costs of DASH per acre have been reported to typically range from approximately $5,060-8,100 (Cooke et al. 1993; Mattson et al. 2004). Additionally, physical removal of turions from sediments, when applicable, has been shown to greatly reduce plant abundance for multiple subsequent growing seasons (Caffrey and Monahan 2006), though this has not been implemented in Wisconsin due to the significant effort it requires.

Ecological Impacts of Hand-Pulling and DASH

Because divers are physically uprooting plants from the lake bed, hand removal may disturb benthic organisms. Additionally, DASH may also result in some accidental capture of fish and invertebrates, small amounts of sediment removal, or increased turbidity. It is possible that equipment modifications could help minimize some of these unintended effects. Because DASH is a relatively new management approach, less information is available about potential impacts than for some more established techniques like large-scale mechanical harvesting.

S.3.4.3. Benthic Barriers

Benthic barriers can be used to kill existing plants or prevent their growth from the outset. They are sometimes referred to as benthic mats, or screens, and involve placing some sort of covering over a plant bed, which provides a physical obstruction to plant growth and reduces light availability. They may be best used for dense, confined infestations or along shore or for providing boat lanes (Engel 1983; Payne et al. 1993; Bailey and Calhoun 2008). Reductions in abundance of live aquatic plants beneath the barrier may be seen within weeks (Payne et al. 1993; Carter et al. 1994). The target plant species, light availability, and sediment accumulation have been shown to influence the efficacy of benthic barriers for aquatic plant control. Effects on the target plants may be more rapid in finer sediments because anoxic conditions are reached more quickly due to higher sediment organic content and oxidization by bacteria (Carter et al. 1994). Benthic barriers may be more expensive but less time intensive than some of the physical removal approaches described above (Carter et al. 1994; Bailey and Calhoun 2008). Engel (1983) suggests that benthic barriers may be useful in situations where plants are growing too deep for other physical removal approaches or effective herbicide application. They may also improve plant control when used in combination with herbicide treatments to hold most of the herbicide to a given treatment area (Helsel et al. 1996).

There is some necessary upkeep associated with the use of benthic barriers. Some barriers can be difficult to re-use because of algae and plants that can grow on top of the barrier. Periodically removing sediment that accumulates on the barrier can help offset this (Engel 1983; Carter et al. 1994; Laitala et al. 2012). Some materials are made to be removed after the growing season, which may make cleaning and re-use easier (Engel 1983). Additionally, gases often accumulate beneath benthic barriers as a result of plant decay, which can cause them to rise off the bottom of the waterbody, requiring further maintenance (Engel 1983; Ussery et al. 1997; Bailey and Calhoun 2008). Eurasian watermilfoil (*Myriophyllum spicatum*) and other plant species have been shown to recolonize the managed area quickly following barrier removal (Eichler et al. 1995; Boylen et al. 1996), so this approach may require hand-pulling or other integrated approaches once the barrier is removed (Carter et al. 1994; Eichler et al. 1995; Bailey and Calhoun 2008). Some studies have observed low abundance of plants maintained for 1-2 months after barriers were removed (Engel 1983). Others found that combining 2,4-D treatments with benthic barriers could reduce Eurasian watermilfoil to a degree that helped native plants recolonize the target site (Helsel et al. 1996).

The material used to create benthic barriers can vary and include biodegradable jute matting, fiberglass screens, and woven polypropylene fibers (Mayer 1978; Perkins et al. 1980; Lewis et al. 1983; Hoffman et al. 2013). Some plants such as Eurasian watermilfoil and common waterweed (*Elodea canadensis*; Eichler et al. 1995) are able to growth through the mesh in woven barriers but this material can be effective in reducing growth on certain target plant species (Payne et al. 1993; Caffrey et al. 2010; Hoffman et al. 2013). Hofstra and Clayton (2012) suggested that less dense materials barriers may provide selective control of some species while allowing more tolerant species, such as some charophytes (*Chara* spp. and *Nitella* spp.), to grow through. More dense materials may prevent growth of a wider range of aquatic plants (Hofstra and Clayton 2012). Most materials must be well anchored to the bottom of the waterbody, which can be accomplished early in the growing season or by placing the barriers on ice before thawing of the waterbody (Engel 1983). Gas accumulation can occur in using both fibrous mesh and screen-type barriers (Engel 1983).

Eurasian watermilfoil and common waterweed have been found to be somewhat resistant to control by benthic barriers (Perkins et al. 1980; Engel 1983) while affected species include hydrilla (*Hydrilla verticillata*), curly-leaf pondweed (*Potamogeton crispus*), and coontails (*Ceratophyllum* spp.; Engel 1983; Payne et al. 1993; Carter et al. 1994). One study found that an 8-week barrier placement removed Eurasian watermilfoil while allowing native plant regrowth after the barrier was retrieved; while shorter durations were less effective in reducing Eurasian watermilfoil abundance and longer durations negatively impacted native plant regrowth (Laitala et al. 2012).

Ecological Impacts of Benthic Barriers

Macroinvertebrates will be negatively affected by benthic barriers while they are in place (Engel 1983) but have been shown to rebound to pre-management conditions shortly after removal of the barrier (Payne et al. 1993; Ussery et al. 1997). Benthic barriers may also affect spawning of some warm water fish species through direct disruption of spawning habitat (NYSFOLA 2009). Additionally, increased ammonium and decreased dissolved oxygen contents are often observed beneath benthic barriers (Carter et al. 1994; Ussery et al. 1997). These water chemistry considerations may partially explain decreases in macroinvertebrate populations (Engel 1983; Payne et al. 1993) and ammonium content is likely to increase with sediment organic content (Eakin 1992). Toxic methane gas has also been found to accumulate beneath benthic barriers (Gunnison and Barko 1992).

There may be some positive ecological aspects of benthic barriers. Barriers may reduce turbidity and nutrient release from sediments (Engel 1983). They may also provide channels that improve ease of fish foraging when other aquatic plant cover is present near the managed area. Fish may feed on the benthic organisms colonizing any sediment accumulating on top of the barrier (Payne et al. 1993). Payne et al. (1993) also suggest that, despite negative impacts in the managed area, the overall impact of benthic barriers is negligible since they typically are only utilized in small areas of the littoral zone. However, further research is needed on the effects of benthic barriers on fish and wildlife populations and their ability to rebound following barrier removal (Eichler et al. 1995).

S.3.4.4. Dredging

Dredging is a method that involves the removal of top layers of sediment and associated rooted plants, sediment-dwelling organisms, and sediment-bound nutrients. This approach is “non-selective” (USACE 2012), meaning that it offers limited control over what material is removed. In addition to being employed as an APM technique, dredging is often used to manage water flow, provide navigation channels, and reduce the chance of flooding (USACE 2012). Due to the expense of this method, APM via dredging is often an auxiliary effect of dredging performed for other purposes (Gettys et al. 2014). However, reduced sediment nutrient load and decreased light penetration due to greater depth post-dredging may result in multi-season reductions in plant biomass and density (Gettys et al. 2014).

Several studies discuss the utility of dredging for APM. Dredging may be effective in controlling species that propagate by rhizomes, by removing the rhizomes from the sediment before they have a chance to grow (Dall Armellina et al. 1996b). Additionally, invasive phragmites has been controlled in areas where dredging increases water depth to ≥ 5-6 feet; though movement of the equipment used in dredging activities has been implicated in expanding the range of invasive phragmites (Gettys et al. 2014). In streams, dredging resulted in a significant reduction in plant biomass (≥ 90%). However, recovery of plant populations reflected the timing of management actions relative to flowering: removal prior to flowering allowed for plant population recovery within the same growing season, while removal after flowering meant populations did not rebound until the next spring (Kaenel and Uehlinger 1999). Sediment testing for chemical residue levels high enough to be considered hazardous waste (from historically used sodium arsenite, copper, chromium, and other inorganic compounds) should be conducted before dredging, to avoid stirring of toxic material into the water column. The department routinely requires sediment analysis before dredging begins and destination approval of spoils to prevent impacts from sediment leachate outside of the disposal area. Planning and testing can be an extensive component to a dredging project.

Ecological effects of Dredging

Repeated dredging may result in plant communities consisting of populations of fast-growing species that are capable of rebounding quickly (Sand-Jensen et al. 2000). In experimental studies, faster growing invasive plant species with a higher tolerance for disturbance were able to better recover from simulated dredging than slower growing native plant species, suggesting that post-dredging plant communities may be comprised of undesirable invasives (Stiers et al. 2011).

Macroinvertebrate biomass has been shown to decrease up to 65% following dredging, particularly among species which use plants as habitat. Species that live deeper in sediments, or those that are highly mobile, were less affected. As macroinvertebrates are valuable components of aquatic ecosystems, it is recommended that plant removal activities consider impacts on macroinvertebrates (Kaenel and Uehlinger 1999). Dredging can also result in declines to native mussel populations (Aldridge 2000).

Impacts to fish and water quality parameters have also been observed. Dredging to remove aquatic plants significantly increased both dissolved oxygen levels and the number of fish species found inhabiting farm ponds (Mitsuo et al. 2014). This increase in fish abundance may have been due to extremely high pre-dredging density of aquatic plants, which can negatively influence fish foraging success. In another study, aquatic plant removal decreased the amplitude of daily oxygen fluctuations in streams. However, post-dredging changes in metabolism were short-lived, suggesting that algae may have taken over primary productivity (Kaenel et al. 2000). Finally, several studies have also documented or suggested a reduction in sediment phosphorous levels after dredging, which may in turn reduce nutrient availability for aquatic plant growth (Van der Does et al. 1992; Kleeberg and Kohl 1999; Meijer et al. 1999; Søndergaard et al. 2001; Zuccarini et al. 2011). However, consideration must be given to factors affecting whether goals are obtainable via dredging (e.g., internal or external phosphorus inputs, water retention time, sediment characteristics, etc.).

S.3.4.5. Drawdown

Water-level drawdown is another approach for aquatic plant control as well as aquatic plant restoration. Exposure of aquatic plant vegetation, seeds, and other reproductive structures may reduce plant abundance by freezing, drying, or consolidation of sediments. This management technique is not effective for control of all aquatic plant species. Due to potential ecological impacts, it is necessary to consider other factors such as: waterfowl habitat, fisheries enhancement, release of nutrients and solids downstream, and refill and sediment consolidation potential. Often drawdowns for aquatic plant control and/or restoration can be coordinated to time with dam repair or repair of shoreline structures. A review by Cooke (1980), suggests drawdown can provide at least short-term aquatic plant control (1-2 years) when the target species is vulnerable to drawdown and where sediment can be dewatered under rigorous heat or cold for 1-2 months. Costs can be relatively low when a structure for manipulating water level is in place (otherwise high capacity pumps must be used). Conversely, costs can be high to reimburse an owner for lost power generation if the water control structure produces hydro-electric power. The aesthetic and recreational value of a waterbody may be reduced during a drawdown, as large areas of sediment are exposed prior to revegetation. Bathymetry is also important to consider, as small decreases in water level may lead to drop-offs if a basin does not have a gradual slope (Cooke 1980). The downcutting of the stream to form a new channel can also release high amounts of solids and organic matter that can impair water quality downstream. For example, in July 2005, the Waupaca Millpond, Waupaca Co. had to conduct an emergency drawdown that resulted in the river downcutting a new channel. High suspended solid concentrations and BOD resulted in decreased water clarity, sedimentation and depressed dissolved oxygen levels. A similar case occurred in 2015 with the Amherst Mill Pond, Portage Co. during a drawdown at a rate of six inches per day (Scott Provost [WDNR], *personal communication*).

Because extreme heat or cold provide optimal conditions for aquatic plant control, drawdowns are typically conducted in the summer or winter. Because of Wisconsin's cold winters, winter drawdown is likely to have several advantages when used for aquatic plant management, including avoiding many conflicts with recreational use, potential for cyanobacterial blooms, and terrestrial and emergent plant growth in sediments exposed by reduced water levels (ter Heerdt and Drost 1994; Bakker and Hilt 2016).

A synthesis of the abiotic and biotic responses to annual and novel winter water level drawdowns in littoral zones of lakes and reservoirs is summarized by Carmignani and Roy 2017. Climatic conditions also determine the capacity of a waterbody to support drawdown (Coops et al. 2003). Resources managers pursuing drawdown must carefully calculate the waterbody's water budget and the potential for increased cyanobacterial blooms in the future may reduce the number of suitable waterbodies (Callieri et al. 2014). Additionally, mild winters and groundwater seepage in some waterbodies may prevent dewatering, leading to reduced aquatic plant control (Cooke 1980). Complete freezing of sediment is more likely to control aquatic plants. Sediment exposure during warmer temperatures (>5° C) can also result in the additional benefit of oxidizing and compacting organic sediments (Scott Provost and Ted Johnson [DNR], *personal communication*). When drawdowns are conducted to improve migratory bird habitat, summer drawdowns prove to be more beneficial for species of shorebirds, as mudflats and shallow water are exposed to promote the production of and accessibility to invertebrates during late summer months that coincide with southward migration (Herwig and Gelvin-Innvaer 2015). Drawdowns conducted during mid-late summer can result in conditions that are favorable for cattails (*Typha* spp.) germination and expansion. However, cattails can be controlled if certain stressors are implemented in conjunction with a drawdown, such as cutting, burning or herbicide treatment during the peak of the growing season. The ideal situation is to cut cattail during a drawdown and flood over cut leaves when water is raised. However, this option is not always feasible due to soil conditions and equipment limitations.

Ecological Impacts of Water-level Drawdown

Artificial manipulation of water level is a major disturbance which can affect many ecological aspects of a waterbody. Because drawdown provides species-selective aquatic plant control, it can alter aquatic plant community composition and relative abundance and distribution of species (Boschilia et al. 2012; Keddy 2000). Sometimes this is the intent of the drawdown, which creates plant community characteristics that are desired for wildlife or fish habitat. Consecutive annual drawdowns may prevent the re-establishment of native aquatic plants or lead to reduced control of aquatic plant abundance as drawdown-tolerant species begin to dominate the community (Nichols 1975). Sediment exposure can also lead to colonization of emergent vegetation in the drawdown zone. In one study, four years of consecutive marsh drawdown led to dominance of invasive phragmites (*Phragmites australis* subsp. *australis*; ter Heerdt and Drost 1994). However, when drawdowns are conducted properly, it can provide a favorable response to native emergent plants for providing food and cover for migrating waterfowl in the fall. Population increases in emergent plant species such as bulrush (*Schoenoplectus* spp.), bur-reeds (*Sparganium* spp.), and wild rice (*Zizania palustris*) is often a goal of drawdowns, which provides a great food source for fish and wildlife, and provides important spawning and nesting habitat. Full or partial drawdowns that are conducted after wild rice production in the fall tend to favor early successional emergent germination such as wild rice and bulrush the following spring. Spring drawdowns are also possible for producing wild rice but must be done during a tight window following ice-out and slowly raised prior to the wild rice floating leaf stage.

Drawdown can also have various effects on ecosystem fauna. Drawdowns can influence the mortality, movement and behavior of native freshwater mussels (Newton et al. 2014). Although mussels can move with lowering water levels, they can be stranded and die if they are unable to move fast enough or get trapped behind logs or other obstacles (WDNR et al. 2006). Some mussels will burrow down into the mud or sand to find water but can desiccate if the water levels continue to lower (Watters et al. 2001). Maintaining a slow drawdown rate can allow mussels to respond and stranded individuals can be relocated to deeper water during the drawdown period to reduce mussel death (WDNR et al. 2006). Macroinvertebrate communities may experience reduced species diversity and abundance from changes to their environment due to drawdown and loss of habitat provided by aquatic plants (Wilcox and Meeker 1992; McEwen and Butler 2008). These effects may be reduced by considering benthic invertebrate phenology in determining optimal timing for drawdown release. Adequate moisture is required to support the emergence of many macroinvertebrate species and complete drawdown may also result in hardening of sediments which can trap some species (Coops et al. 2003). Reduced macroinvertebrate availability can have negative effects on waterfowl and game fish species which rely on macroinvertebrate food sources (Wilcox and Meeker 1992). Depending on the time of year, drawdown may also lead to decreased reproductive success of some waterfowl through nest loss, including common loon (*Gavia immer*) and red-necked grebe (*Podiceps grisegena*; Reiser 1998). However, drawdown may lead to increased production of annual plants and seed production, thereby increasing food availability for brooding and migrating waterfowl. Semi-aquatic mammals such as muskrats and beavers may also be adversely affected by water level drawdown (Thurber et al. 1991;

Smith and Peterson 1988, 1991). DNR Wildlife Management staff follow guidance to ensure drawdowns are timed with the seasons or temperature to minimize negative impacts to wildlife. Negative impacts to reptiles are possible during the spring if water is raised following a drawdown, as nests may be flooded. In the fall, negative impacts to reptiles and amphibians are possible if water is lowered when species are attempting to settle into sediments for hibernation. The impact may be reduced dissolved oxygen if they are below the water or freezing if the water is dropped below the point of hibernation (Herwig and Smith 2016a, 2016b). Surveying and relocation of stranded organisms may help to mitigate some of these impacts. In Wisconsin there are general provisions for conducting drawdowns for APM that are designed to mitigate or even eliminate potential negative impacts.

Water chemistry can also be affected by water level fluctuation. Beard (1973) describes a substantial algal bloom occurring the summer following a winter drawdown which provided successful aquatic plant control. Other studies reported reduced dissolved oxygen, severe cyanobacterial blooms with summer drawdown, or increased nutrient concentrations and reduced water clarity during summer drawdown for urban water supply (Cooke 1980; Geraldes and Boavida 2005; Bakker and Hilt 2016). Water clarity and trophic state may be improved when drawdown level is similar to a waterbody's natural water level regime (Christensen and Maki 2015).

Species Susceptibility to Water-level Drawdown

Not all plant species are susceptible to management by water level drawdown and some dry- or cold-tolerant species may benefit from it (Cooke 1980). Generally, plants and charophytes which reproduce primarily by seed benefit from drawdowns while those that reproduce vegetatively tend to be more negatively affected. Marsh vegetation can be dependent on water level fluctuation (Keddy and Reznicek 1986). Cooke (1980) provides a summary table of drawdown responses for 63 aquatic plant species. Watershield (*Brasenia schreberi*), fern pondweed (*Potamogeton robbinsii*), pond-lilies (*Nuphar* spp.) and watermilfoils (*Myriophyllum* spp.) tend to be controlled by drawdown. Increases in abundance associated with drawdown have often been seen for duckweed (*Lemna minor*), rice cutgrass (*Leersia oryzoides*) and slender naiad (*Najas flexilis*; Cooke 1980). One study showed drawdown reduced Eurasian watermilfoil (*Myriophyllum spicatum*) at shallow depths while another cautioned that Eurasian watermilfoil vegetative fragments may be able to grow even after complete desiccation (Siver et al. 1986; Evans et al. 2011). Similarly, a tank-simulated drawdown experiment suggested short-term summer drawdown may be effective in controlling monoecious hydrilla (*Hydrilla verticillata*; Poovey and Kay 1998). However, other studies have shown hydrilla fragments to be resistant to drying following drawdown (Doyle and Smart 2001; Silveira et al. 2009). A study on Brazilian waterweed (*Egeria densa*) showed that stems were no longer viable after 22 days of exposure due to drawdown (Dugdale et al. 2012).

Two examples of recent drawdowns in Wisconsin that were evaluated for their efficacy in controlling invasive aquatic plants occurred in Lac Sault Dore and Musser Lake, both in Price County, which were conducted in 2010 and 2013, respectively. Dam maintenance was the initial reason for these drawdowns, with the anticipated control of nuisance causing aquatic invasive species as a secondary benefit. Aquatic plant surveys showed that the drawdown in Lac Sault Dore resulted in a 99% relative reduction in the littoral cover of Eurasian watermilfoil when comparing pre- vs. post-drawdown frequencies. Native plant cover expanded following the drawdown and Eurasian watermilfoil cover has continued to remain low (82% relative reduction compared to pre-drawdown) as of 2017 (Onterra 2013). Lake-wide cover of curly-leaf pondweed in Musser Lake decreased following drawdown (63% relative reduction compared to pre-drawdown), and turion viability was also reduced. Reductions in native plant populations were observed, though population recovery could be seen in the second year following the drawdown (Onterra 2016). These examples of water-level drawdowns in Wisconsin show that they can be valuable approaches for aquatic invasive species control in some waterbodies. Water level reduction must be conducted such that a sufficient proportion of the area occupied by the target species is exposed. Numerous other single season winter drawdowns monitored in central Wisconsin by department staff show similar results (Scott Provost [DNR], *personal communication*). Careful timing and proper duration is needed to maximize control of target species and growth of favorable species.

S.3.5. Biological Control

Biological control refers to any method involving the use of one organism to control another. This method can be applied to both invasive and native plant populations, since all organisms experience growth limitation through various mechanisms (e.g., competition, parasitism, disease, predation) in their native communities. As such, when control of aquatic plants is desired it is possible that a growth limiting organism, such as a predator, exists and is suitable for this purpose.

Care must be taken to ensure that the chosen biological control method will effectively limit the target population and will not cause unintended negative effects on the ecosystem. The world is full of examples of biological control attempts gone wrong: for example, Asian lady beetles (*Harmonia axyridis*) have been introduced to control agricultural aphid pests. While the beetles have been successful in controlling aphid populations in some areas, they can also outcompete native lady beetles and be a nuisance to humans by amassing on buildings (Koch 2003). Additionally, a method of control that works in some Wisconsin lakes may not work in other parts of the state where differing water chemistry and/or biological communities may affect the success of the organism. The department recognizes the variation in control efficacy and well as potential unintentional effects of some organisms and is very cautious in allowing their use for control of aquatic plants.

Purple loosestrife beetles

The use of herbivorous insects to reduce populations of aquatic plants is another method of biocontrol. Several beetle species native to Eurasia (*Galerucella calmariensis*, *G. pusilla*, *Hylobius transversovittatus*, and *Nanophyes marmoratus*) have been well-studied and intentionally released in North America for their ability to suppress populations of the invasive wetland plant, purple loosestrife (*Lythrum salicaria*). These beetles only feed on loosestrife plants and therefore are not a threat to other wetland plant species (Kok et al. 1992; Blossey et al. 1994a, 1994b; Blossey and Schroeder 1995). The department implements a purple loosestrife biocontrol program, in which citizens rear and release beetles on purple loosestrife stands to reduce the plants' ability to overtake wetlands, lakeshores, and other riparian areas.

Beetle biocontrol can provide successful long-term control of purple loosestrife. The beetles feed on purple loosestrife foliage which in turn can reduce seed production (Katovich et al. 2001). This approach typically does not eradicate purple loosestrife but stresses loosestrife populations such that other plants are able to compete and coexist with them (Katovich et al. 1999). Depending on the composition of the plant community invaded by purple loosestrife and the presence of other non-native invasive species, further restoration efforts may be needed following biocontrol efforts to support the regrowth of beneficial native plants (McAvoy et al. 2016).

Several factors have been identified that may influence the efficacy of beetle biocontrol of purple loosestrife. Purple loosestrife beetles have for the most part been shown to be capable of successfully surviving and establishing in a variety of locations (Hight et al. 1995; McAvoy et al. 2002; Landis et al. 2003). The different species have different preferred temperatures for feeding and reproduction (McAvoy and Kok 1999; McAvoy and Kok 2004). In addition, one study suggests that the number of beetles introduced does not necessarily correlate with greater beetle colonization (Yeates et al. 2012). Disturbance, such as flooding and predation by other animals on the beetles, can also reduce desired effects on loosestrife populations (Nechols et al. 1996; Dech and Nosko 2002; Denoth and Myers 2005). Finally, one study suggests that the use of triclopyr amine for purple loosestrife control may be compatible with beetle biocontrol, although there may be negative effects on beetle egg-batch size or indirect effects if the beetle's food source is too greatly depleted (Lindgren et al. 1998). Some mosquito larvicides may harm purple loosestrife beetles (Lowe and Hershberger 2004).

Milfoil weevils

Similar to the use of beetles for biological control of purple loosestrife, the use of milfoil weevils (*Euhrychiopsis lecontei*) has been investigated in North America to control populations of non-native Eurasian and hybrid watermilfoils (*Myriophyllum spicatum* x *sibiricum*). This weevil species is native to North America and is often naturally present in waterbodies that contain native watermilfoils, such as northern watermilfoil (*M. sibiricum*). The weevils have the potential to damage Eurasian watermilfoil (*M. spicatum*) by feeding on stems and leaves and/or burrowing into stems. Weevils may reduce milfoil plant biomass, inhibit growth, and compromise buoyancy (Creed and Sheldon 1993; Creed and Sheldon 1995; Havel et al. 2017a). Damage caused to the milfoil tissue may then indirectly increase susceptibility to pathogens (Sheldon and Creed 1995).

In experiments, weevils have been shown to negatively impact Eurasian watermilfoil populations to varying degrees. Experiments by Creed and Sheldon (1994) found that plant weight was negatively affected when weevils were at densities of 1 and 2 larvae/tank, and Eurasian watermilfoil in untreated control tanks added more root biomass than those in tanks with weevils, suggesting that weevil larvae may interfere with the plant's ability to move nutrients. Similarly, experiments by Newman et al. (1996)

found that weevils at densities of 6, 12, and 24 adults/tank caused significant decreases in Eurasian watermilfoil stem and root biomass, and that higher weevil densities generally produced more damage.

In natural communities, effects of weevils have been mixed, likely because waterbody characteristics may play a role in determining weevil effects on Eurasian watermilfoil populations in natural lakes. In a 56 ha (138 acre) pond in Vermont, weevil density was negatively associated with Eurasian watermilfoil biomass and distribution; Eurasian watermilfoil beds were reduced from 2.5 (6.2 acres) to 1 ha (2.5 acres) in one year, and biomass decreased by 4 to 30 times (Creed and Sheldon 1995). A survey of Wisconsin waterbodies conducted by Jester et al. (2000) revealed that most lakes containing Eurasian watermilfoil also contained weevils. Weevil abundance varied from functionally non-detectable to 2.5 weevils/stem and was positively associated with the presence of large, shallow Eurasian watermilfoil beds (compared to deep, completely submerged beds). There was no relationship between natural weevil abundance and Eurasian watermilfoil density between lakes. However, when the authors augmented natural weevil populations in plots in an attempt to achieve target densities of 1, 2, or 4/stem, they found that augmentation was associated with significant decreases in Eurasian watermilfoil biomass, stem density and length, and tips/stem (Jester et al. 2000). However, another more recent study conducted in several northern Wisconsin lakes found no effect of weevil stocking on Eurasian watermilfoil or native plant biomass (Havel et al. 2017a).

There are several factors to consider when determining whether weevils are an appropriate method of biocontrol. First, previous research has suggested that densities of at least 1.5 weevils per stem are required for control (Newman and Biesboer 2000). Adequate densities may not be achievable due to factors including natural population fluctuations, the amount of available milfoil biomass within a waterbody, the presence of insectivorous predators, such as bluegills (*Lepomis macrochirus*), and the availability of nearshore overwintering habitat (Thorstenson et al. 2013; Havel et al. 2017a). In addition, weevils fed and reproduce on native milfoil species and biocontrol efforts could potentially impact these species, although experiments conducted by Sheldon and Creed (2003) found that native milfoil weevil density was lower and weevils caused less damage than when they were found on Eurasian watermilfoil. Adult weevils spend their winters on land, so available habitat for adults must be present for a waterbody to sustain weevil populations (Reeves and Lorch 2011; Newman et al. 2001). Additionally, one study found that lakes with no Eurasian watermilfoil (despite the presence of other milfoil species) and lakes that had a recent history of herbicide treatment had lower weevil densities than similar, untreated lakes or lakes with Eurasian watermilfoil (Havel et al. 2017b).

Grass carp – not allowed in Wisconsin

The use of grass carp (*Ctenopharyngodon idella*) to control aquatic plants is not allowed in Wisconsin; they are a prohibited invasive species under ch. NR 40, Wis. Admin. Code, which makes it illegal to possess, transport, transfer, or introduce grass carp in Wisconsin.

Sterile (also known as triploid) grass carp have been used to control populations of aquatic plants with varying success (Pípalová 2002; Hanlon et al. 2000). Whether this method is effective depends on several factors. For instance, each individual fish must be tested to ensure sterility before stocking, which can be a time- and resource-consuming process. Since the sterile fish do not reproduce, it can be difficult to achieve the desired density in a given waterbody. In addition, grass carp, like many fish species, have dietary preferences for different plant species which must be considered (Pine and Anderson 1991). Further information summarizing the effects of stocking triploid grass carp can be found in Pípalová (2006), Dibble and Kovalenko (2009), and Bain (1993).

S.3.6. Cyanobacteria and Algae Management

"Algae" in Wisconsin waterbodies are a generalized taxonomic grouping that includes both true algae such as filamentous green algae, and cyanobacteria, commonly known as blue-green algae, which are true photosynthetic bacteria. "Algae" and "algal blooms" hereafter refers to both true algae and cyanobacteria.

When algae populations reproduce and grow rapidly to noticeable or nuisance levels, they are referred to as algal blooms. Filamentous green algae may produce floating mats, microscopic dinoflagellates (single-celled organisms) may discolor water, and cyanobacteria may accumulate in floating scums. Some species of cyanobacteria produce neurotoxins, hepatotoxins, or cytotoxins that if ingested or inhaled can harm humans and other animals. Blooms of these potentially toxin-producing cyanobacterial species are often referred to as cyanobacterial harmful algal blooms (cHABs). cHABs and other algal blooms have been increasing in occurrence and intensity over recent decades in response to increases in nitrogen and phosphorus in water bodies due to human activities in watersheds, to climate-related changes such as decreased ice cover and increased severe precipitation events, and to biological changes such as the impacts of filter-feeding AIS like zebra mussels (*Dreissena polymorpha*; Auer et al. 2010; Watson et al. 2015). It is often difficult to predict exactly when algal blooms may be formed, how long they will persist in waterbodies, and in the case of cHABs, whether they will produce toxins.

Managing the underlying causes of algal blooms should be the first management action. Reduction of nutrients in lakes and ponds will reduce the likelihood and/or severity of algal blooms. Developing a management plan to reduce the amount of nutrients that move from land to water is a critical step in reducing algal blooms over the long-term.

Once nutrient runoff has been reduced as much as possible, there may still be enough nutrients within a lake or pond to continue to fuel algal blooms. These internal nutrients in a waterbody can be managed with whole lake manipulations used to settle out or chemically bind phosphorus. Phosphorus can be settled out or bound with the use of several chemicals (e.g., alum, calcium, iron, or lanthanum). This nutrient sequestration is intended to make nutrients unavailable for algae.

In addition, aeration, oxygenation, or circulation of portions of a lake or pond can in some cases be used to increase dissolved oxygen levels throughout the waterbody, allowing dissolved nutrients to be chemically bound and less available to algae. These techniques to sequester internal lake nutrients have been shown to be effective for months to decades. Finding the appropriate tool for the specific waterbody based on physical, chemical, and biological characteristics of that waterbody is important. Aeration has not been shown to be effective for the control of aquatic plants.

Algaecides (with endothall, copper, or peroxide) may control temporarily algae and cyanobacteria but do not fix the underlying cause of algal blooms. Algaecides also have short half-lives and are likely to offer only short-term relief as algae may quickly repopulate a nutrient-enriched waterbody in the absence of the previous bloom. This is accompanied with the possible complication of less desirable cyanobacteria, which are optimally adapted for higher temperatures, becoming prevalent in the summer. In addition, there are documented non-target effects of certain algaecides, such as copper sulfate. The predominant toxin-producing cyanobacteria in Wisconsin form visible blooms and scums, which can alert the public that there is a potentially hazardous condition. There are concerns that treating a potentially toxin-producing cHAB could induce toxin release from dying cells, while the dying bloom may not be visually apparent to recreational users. Furthermore, releasing toxins in a single large dose could cause more harm to lake organisms than if toxins were bound up in cyanobacterial cells. Because of the risk of toxin release to public and environmental health and the short duration of algaecide efficacy in nutrient-enriched water bodies, the department issues permits for algaecides sparingly and primarily for private ponds.

S.3.6.1. Alum Treatment

Alum treatment can be used to reduce internal phosphorus loading in lakes, through chemical binding of aluminum sulfate with phosphorus in lake sediments. It can improve water quality in lakes where internal nutrient loading is the primary driver of excess primary production (Brattebo et al. 2015). Elimination of annually or repeatedly occurring toxic cyanobacterial blooms often prompts the use of this approach. In cases of high external loading, maintenance alum treatments may be needed to preserve improvements in water quality, so employing strategies to minimize external loading is beneficial. Alum treatments in several waterbodies have resulted in water quality improvements or shifts from high algal abundance to a clearer state with more abundant aquatic plants (Moore and Christensen 2009; Brattebo et al. 2017; Wagner et al. 2017). Alum can either be applied at the water's surface or injected into sediments, though the injection method may be more expensive and miss phosphorus held in epilimnetic and metalimnetic sediments (Brattebo et al. 2015; Schütz et al. 2017). While there are several substances which can be used for phosphorus sequestration, alum has been employed most often in Wisconsin and other substances may be better suited to waterbody types which are not present in the state.

A multitude of factors can hamper the efficacy of alum treatments. The relative contributions of internal and external phosphorus loading, the use of appropriate equipment and safety protocols, water and wind movement, sediment resuspension, waterbody characteristics such as alkalinity, pH, organic carbon content, residence time, and bathymetry, the dosages of both alum and sodium aluminate (which is used as a buffer for maintaining neutral pH values in some systems), and mixing rate are critical considerations (de Vicente et al. 2008a; Egemose et al. 2009; Brattebo et al. 2015). Steep bathymetry may lead to accumulation of aluminum in some parts of the lake and none in others, reducing binding of phosphorus (Huser et al. 2016). The binding efficiency of aluminum also decreases over time if it does not sequester phosphorus within the first few weeks after treatment (de Vicente et al. 2008b).

Longevity of the effects of alum treatments has been shown to be greater in deep, stratified lakes (as opposed to shallow, polymictic (thermally mixed) lakes). In shallow lakes, the presence of aquatic plants and bottom-dwelling invertebrates and fish may also reduce the duration or efficacy of results (Welch and Kelly 1990; Nogaro et al. 2006; Huser et al. 2016).

Ecological Impacts of Alum Treatment

Careful consideration of lake alkalinity in an alum treatment planning is important to prevent changes in waterbody pH which can be toxic to fish and other aquatic life. Changes in community composition and reductions in macroinvertebrate density have been observed following alum treatment, particularly for chaoborids (midges) and oligochaetes (worms; Steinman and Ogdahl 2008, 2012). Zooplankton populations may also experience declines but have been found to recover in the years following treatment. Aquatic plant populations are typically not adversely affected and increases in water clarity may in turn increase the abundance of aquatic plants following treatment (Brattebo et al. 2017; Wagner et al. 2017). Studies have also shown reductions in waterbody silicate and dissolved organic carbon as well as sediment oxygen uptake and ammonium release following treatment (Egemose et al. 2011).

S.3.6.2. Barley Straw

Barley straw is a by-product of barley production and consists of dry barley stalks after fruits have been removed. It was traditionally used as large animal bedding, but in the 1970s an accidental addition of barley straw to a pond revealed a possible application to aquatic ecosystem management. Multiple follow-up studies have shown that decomposing barley straw inhibits algae and cyanobacteria growth in water, although in field applications results can take up to a year to manifest. Degradation of the barley straw is necessary for control and is enhanced by loosely packing it in highly permeable netting. The mode of action is likely related to the release of humic substances (e.g., colored dissolved organic matter, or CDOM) which reacts with UV light to produce reactive oxygen compounds like hydrogen peroxide (Haggard et al. 2013). This mode of action is not unique to barley straw. Similar effects have been observed following treatment with dried wetland plants (e.g., hardstem bulrush (*Schoenoplectus acutus*), broadleaf cattail (*Typha latifolia*)) in place of barley straw, which indicates an important function of fringing wetlands in increasing CDOM and possibly regulating algae populations.

Barley straw has been studied as a method to reduce populations of phytoplankton, filamentous green algae, and cyanobacteria. One large-scale study conducted in a water supply reservoir showed a 6-year suppression of diatoms and cyanobacteria, and algal densities dropped quickly to one quarter the original amount and remained low for the duration of the study (Barrett et al. 1999). In that study, applications were conducted using barley straw applied in quantities averaging 0.04 $g/d/m^3$ over the course of the study. Enhanced degradation was attained by using 10m x 5m diameter net ‘sausages’ with mesh size of 10-12 mm that permitted water flow. Species controlled consisted of primarily

Asterionella (diatoms) and *Anabaena* (cyanobacteria). Other controlled species included *Melosira, Stephanodiscus, Synedra,* and *Tabellaria* (diatoms), and *Golenkenia, Pediastrum, Staurastrum* and *Chlorella* (green algae). A different reservoir study applied 50g/m^3 barley straw loosely wrapped in mesh and resulted in significant decreases in chlorophyll *a* and cyanobacteria (Everall and Lees 1996).

Lab studies and smaller-scale field treatments generally show greater reductions than do large-scale field applications. In one instance, filamentous green algal growth was reduced by 90% for three years starting with the growing season following an initial barley straw application in a canal. Similar reductions were observed for *Cladophora glomerata* grown in chambers *in situ* in a stream (Welch et al. 1990). A tank study used 2.57g/m^3 barley straw to inhibit the cyanobacterium *Microcystis aeruginosa* by 95% (Newman and Barrett 1993). Mesocosm additions of barley straw extract at 5 g/L resulted in a biomass reduction (to 7.8% of untreated control values) of the cyanobacterium *Aphanizomenon flos-aquae* (Haggard et al. 2013). Additions of 1% weight by volume were also effective, and the use of even very dilute concentration of barley straw extract (0.005%) inhibited the growth of *Microcystis* sp. in flasks (Ball et al. 2001).

Degradation rate is important to consider, and straw bales which are too tightly compacted will be slow to degrade and have limited efficacy on reducing algal populations. Innovative application methods such as using wide mesh and a tree-wrapping machine likely enhance degradation and control (Lembi 2002).

Efficacy may vary by species and across waterbodies. Reports of success across treatments are highly variable, with some studies showing success and others demonstrating failure. Some studies report barley straw treatment reduced populations of filamentous green algae while others report only a decrease in phytoplankton with a concomitant increase in mat-forming filamentous green algae (Lembi 2002). A University of Nebraska study applied barley straw to a lake impaired by cyanobacterial blooms but observed no increase in water quality, leading them to abandon further research (Lembi 2002). Additionally, barley straw is not currently regulated as a pesticide by the U.S. EPA, which means it has not been subjected to the extensive study typically required for pesticide regulation, and thus is associated with a degree of risk and uncertainty with respect to efficacy, implementation and non-target impacts.

Ecological Impacts of Barley Straw

Barley straw decomposition may place oxidative stress on an ecosystem that could have other negative effects that outweigh the potential for algal control. In one case study, dissolved oxygen levels dropped almost to zero in the absence of aeration (Haggard et al. 2013). However, another study showed that barley straw suppresses new algal growth but does not kill algae that is already present which suggests a different cause of the decreases in dissolved oxygen, possibly related to straw decomposition (Lembi 2002). Additionally, barley straw releases phosphorus which would subsequently be available to fuel algal growth. Furthermore, it is unknown whether barley straw treatments applied to cyanobacterial blooms would place cells under oxidative stress and possibly exacerbate the problem by inducing toxin production (Dziallas and Grossart 2011).

S.3.7. Attempted Starry Stonewort Control using Copper-based Herbicides

Several copper formulations (e.g., Komeen crystal, chelated copper) and combinations of copper and other registered aquatic herbicides (copper + hydrothol, copper + diquat, copper + flumioxazin) have been utilized in attempts to control the non-native macroalgae starry stonewort (*Nitellopsis obtusa*). Copper applications in Wisconsin for starry stonewort control have been applied at rates of 0.5-0.83 ppm. Monitoring of copper herbicide concentrations in the water following treatment indicate that the algaecide appears to dissipate quickly (within hours) off small treatment sites, similar to what has been previously documented with other aquatic herbicides applied at a localized scale. Pre- and post-treatment monitoring of SSW control efficacy indicates that copper treatments may temporarily reduce starry stonewort biomass under some management scenarios, but it does not kill the entire vegetative plant nor the reproductive bulbils. In dense starry stonewort populations, it appears that the active ingredients are sequestered in the upper portions of the starry stonewort mats and the lower portions of the mats are not injured (Pullman and Crawford 2010). While the entire starry stonewort plant is not killed, plant height may be able to be reduced in order to minimize recreational impacts, which is sometimes referred to as a 'hair cut treatment' (Pullman and Crawford 2010).

One recently published study examined the effects of mechanical harvesting and chelated copper algaecide treatments on starry stonewort biomass, bulbil density, and bulbil viability in Lake Koronis, MN (Glisson et al. 2018). Chelated copper algaecide applications alone and in combination with mechanical harvesting significantly reduced starry stonewort biomass but algaecide treatment alone failed to reduce the capacity of starry stonewort to regenerate via bulbils. A secondary application of a granular algaecide following the initial treatment with liquid algaecide did not further reduce biomass in any treated area. Another study reported that following multiple chelated copper applications in a Michigan lake, there were no significant differences in starry stonewort biomass or height between treated and untreated sites at two or four weeks following the first and second treatment applications (Larkin et al. 2018).

Copper is generally considered non-selective, and may have non-target impacts on native species, especially native macroalgaes such as muskgrasses (*Chara* spp.) and stoneworts (*Nitella* spp.). Copper does not degrade after application, but rather accumulates in the sediment, and repeated use in the same area may potentially increase toxicity risks for native biota, as well as potentially give rise to copper-resistant populations of undesirable species (Izaguirre 1992).

S.3.8. Understudied Management Techniques

S.3.8.1. Dyes

Primary producers like aquatic plants, algae, and cyanobacteria require sunlight to survive. Several management approaches exploit this dependency, using light limitation to affect primary producer populations. Light-attenuating dye is one tool available to modify the amount of sunlight available to aquatic plants, algae, and cyanobacteria. The dye is added to freshwaters in liquid form, where it acts to block light transmission through the water column. This ultimately results in reduced photosynthetic rates, decreased growth, and in some cases, death and senescence of plants, phytoplankton and filamentous algae. Manufacturers suggest early-spring applications timed to reduce light availability to young seedlings and to evergreen or vegetatively reproducing plants before they enter a period of active growth. Light-attenuating dyes are non-selective and must be applied on a waterbody-wide scale unless curtains or other devices are used to address dilution.

Aquashade® is a commonly used light-attenuating dye. Light attenuation from 1 to 3 ppm Aquashade® can lead to more than 50% reduction in photosynthetic rates for phytoplankton. In one laboratory study, reduced growth rates of green algal and cyanobacterial phytoplankton were observed only at higher concentrations of 5–10 ppm (Spencer 1984a). However, a whole-lake field application of Aquashade® at label-recommended levels (target 1.5 ppm) over the course of a growing season resulted in a 60% decrease in phytoplankton biomass (Batt et al. 2015).

Aquashade® has been shown to decrease the growth rate of hydrilla (*Hydrilla verticillata*) by approximately 50%, likely due to shading (Manker and Martin 1984). One study reports elimination of pondweeds (*Potamogeton* spp.) and muskgrasses (*Chara* spp.) with the application of blue dye (Buglewicz 1972). Other anecdotal reports associate Aquashade® with decreased growth of many other submersed plant species.

The department regulates the use of dyes on non-private ponds, and official guidance has been drafted to explain this process and justification. The department does not regulate the use of dyes in private ponds as public interest in these waterbodies is minimal.

Ecological Impacts of Dyes

Light limitation often prevents submersed aquatic plant species from succeeding, and the use of light-attenuating dyes in restoring aquatic plant communities is limited, especially when nutrient enrichment may support an algal-dominated state. The dye may be used to control algal populations, but it is unlikely to support a return to a clear-water state stabilized by aquatic plant communities. In addition, there are some ecosystem effects to consider. Decreases in phytoplankton biomass during a waterbody-wide dye treatment resulted in markedly decreased dissolved oxygen, while food webs shifted to rely more on terrestrial and pelagic versus littoral or benthic habitats (Batt et al. 2015).

When applied at twice the recommended rate, few differences in water quality, chlorophyll *a*, primary productivity, and biomass of phytoplankton, zooplankton, and aquatic plants were observed in experimental ponds; however, the concentration was not maintained over the course of the study and the experimental ponds were very shallow (1 m). These findings echo other studies employing single springtime dye applications (Ludwig et al. 2010). In a separate study, no effect on crayfish oxygen consumption was observed (Spencer 1984b). Dye applications have been found to increase walleye fry condition as measured by survival, length, weight and gas bladder inflation (Bristow et al. 1996).

S.3.8.2. Planting of Aquatic Plants

Native aquatic plant plantings may be helpful in restoring degraded ecosystems and may also be implemented following invasive species control. This management technique essentially involves introducing native plant seeds, propagules or fragments to a system while supporting their ability to successfully establish and form a self-sustaining population. Introducing any non-native aquatic plants to an ecosystem requires an approved NR 109 permit from the department. When restoring degraded ecosystems, species that are tolerant to disturbance are likely to be more successful in establishing relative to disturbance-sensitive species. Plantings may be logistically difficult, but when local propagules are abundant, trained staff have conducted successful pilot tests (Smart et al. 1996). However, this technique is difficult to evaluate and has not been implemented very often.

Native plantings as a management technique has been explored in particular to restore southern U.S. reservoirs (Smart et al. 1996). Many decisions need to be made with respect to a re-vegetation plan, and in general the establishment of small 'founder populations' is recommended by creating localized and protected regions. Studies suggest planted pioneer species should include muskgrasses (*Chara* spp.) and southern naiad (*Najas guadalupensis*) due to their potential for rapid expansion and water clarity improvement, horned pondweed (*Zannichellia palustris*) and small pondweed (*Potamogeton pusillus*) for their ability to grow when other species are dormant, and long-leaf pondweed (*Potamogeton nodosus*), sago pondweed (*Stuckenia pectinata*), and water celery (*Vallisneria americana*) for their ability to produce tubers. They also suggest water stargrass (*Heteranthera dubia*) for its contributions to structural heterogeneity and common waterweed (*Elodea canadensis*) because of its turbidity tolerance and stabilizing functions.

Smart et al. (1996) review multiple techniques for introducing propagules. In general, they recommend choosing sheltered locations with amenable environmental conditions, and protecting plantings from herbivory and wave action. For annuals, they report success in planting sprouted peat-pots containing sediment collected from a source population. Another successful technique involved introducing dried surface sediments to exclosures. Tubers from perennials may also be introduced, but they must be protected from herbivores. When herbivory rates are high, plants are unlikely to spread beyond protective enclosures (Smart et al. 1998), and protection is crucial for population establishment and persistence (Hauxwell et al. 2004). In one study, sago pondweed tubers introduced in weighted burlap sacks resulted in good germination rates and increased cover. Stem cuttings may also be used, though sprouting them first is recommended (Smart et al. 1996). Water stargrass cuttings were used in one instance and secured by a polyvinyl planting frame crossed with nylon cord. Two unsuccessful approaches included the distribution of dried mudballs containing propagules and introducing propagule-containing burlap 'incubated' in a source population.

Before undertaking any aquatic plant transplantation or restoration project, care should be taken to ensure environmental conditions are conducive to support a self-sustaining aquatic plant population. If disturbance, enrichment or other ultimate stressor exceeds the threshold survivable by aquatic plant populations, that stressor must first be reduced before a planting project is likely to be successful.

Plantings in one urban stream following non-native plant removal were largely unsuccessful due to re-establishment of the invasive and washing out of the planted propagules. Furthermore, the plantings were associated with an increase in the perception of a management problem (Suren 2009). However, contradictory results were observed in an earlier study in New Zealand urban stream, where restoration of native aquatic plants was assessed as successful by both researchers and riparian property owners (Larned et al. 2006).

Ecological Impacts of Native Plantings

When propagules are grown in greenhouses, great care must be given to eliminate the possibility of contamination by other undesirable species. Often, local harvest of propagules may be preferred, though cautionary steps to prevent spread of invasive species are important to consider. Additionally, genetic variability may be introduced when using propagules sourced from distant populations, and local propagule sources may be preferable. Some individuals have advocated for introducing disturbance-tolerant invasive species for the restoration of extremely degraded systems, with the idea that non-native invasive plants may be able to establish in highly degraded ecosystems, providing some degree of ecosystem services and habitat in an otherwise depauperate community. However, care must be taken to weigh these management problems against each other in light of the limited benefits associated with either the no-action alternative, or the introduction of an invasive species. There are likely a number of fast growing, disturbance-tolerant native species (e.g., coontail, common waterweed, water stargrass) that may have better application in restoring highly degraded systems.

S.3.8.3. Fire

Prescribed burns are commonly used in fire-dependent upland habitats for restoration and maintenance efforts and can be used in wetland systems for various management goals, including brush or non-native species removal and habitat or native plant restoration and maintenance (Hopple and Craft 2012). Despite evidence of frequent historical fires and many benefits of modern prescribed fire, the use of fire for APM is relatively uncommon in Wisconsin and there are a limited number of studies of its efficacy and impacts on Wisconsin wetland communities.

Prior to European settlement, fires in wetlands were common and likely played an important role in maintaining an open habitat structure and setting back succession (Curtis 1959; Vogl 1969). Additionally, dendrochronological (tree-ring dating) fire records within and adjacent to wetlands indicate pre-European settlement fires were common in both open and forested wetlands (Drobyshev et al. 2012; Jed Meunier, WDNR, *unpublished data*). Prescribed fire can promote herbaceous wetland vegetative growth and seed production and increase herbaceous plant diversity in the short-term (Laubhan 1995; Kost and Steven 2000). Today, prescribed burning is used in wetlands in Wisconsin (often in properties managed by the department) to suppress woody plants and promote native marsh vegetation. This can be beneficial to breeding birds preferring emergent rather than shrub dominated wetland habitat (Hanowski et al. 1999). For example, winter burning is used for removing cattails (*Typha* spp.) in Horicon Marsh, with the goals of decreasing fuel build-up and providing pockets of open water.

Not all wetland plant species are benefited by fire disturbance, and therefore community composition, habitat conditions, and individual species life history in relation to fire disturbance are important to consider (Laubhan 1995; McWilliams et al. 2007; Flores et al. 2011; Bixby et al. 2015). Similarly, densities of some invertebrate species may increase following burning while others may experience declines (de Szalay and Resh 1997; Kostecke et al. 2005). Nutrient cycling may also be affected and factors such as fire severity, soil moisture, and others may affect outcomes associated with burns (Neary et al. 1999; White et al. 2008; Liao et al. 2013), although burning does not necessarily result in soil nutrient changes (Laubhan 1995).

Time of year may also influence the outcome of a prescribed burn, as vegetation phenology is one of the determining factors in subsequent fire effects (Johnson and Knapp 1993; WIRCGMWG 2009). Burning during dormant seasons may increase shrub re-sprout response, while growing season burning, especially in conjunction with low water conditions, may reduce relative re-sprouting (Olson and Platt 1995). Repeatedly burning in the same season may also unintentionally favor some plant species over others by either disrupting or promoting flowering (Pavlovic et al. 2011). Time of year and associated soil moisture are particularly important when burning peatlands in order to avoid ground fires.

As with many management activities, it is critical to leave some areas undisturbed as refugia to preserve cover for wildlife, especially invertebrates, and maintain a diversity of seral stages on the landscape (Hanowski et al. 1999; Davis and Bidwell 2008). Fortunately, because many wetland complexes are a mosaic of open water and emergent vegetation they often naturally create unburned refugia within otherwise burned areas. Prescribed fire may be particularly useful in wetland systems with limited access for other management (e.g., mowing or haying) as fire can reach areas that are difficult to reach or are completely inaccessible by other means. Controlled burning may also be economically optimal, however cost estimates for prescribed fire implementation vary greatly, with lower cost per area at higher acreages.

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Appendix A. Authority for Aquatic Plant Management

A.A-1. Links to statutory authority for aquatic plant management in Wisconsin.

Statute	Subject	Link
s. 29.607	Wild rice	https://docs.legis.wisconsin.gov/statutes/statutes/29/IX/607
s. 30	Navigable Waters, Harbors and Navigation	https://docs.legis.wisconsin.gov/statutes/statutes/30/
s. 30.07	Transportation of aquatic plants	https://docs.legis.wisconsin.gov/document/statutes/30.07
s. 227.11 (2)	State agency rule-making authority	https://docs.legis.wisconsin.gov/statutes/statutes/227/II/11/2/
s. 281.01 (18)	"Waters of the State" definition	https://docs.legis.wisconsin.gov/statutes/statutes/281/I/01/18
s. 281.17 (2)	Chemical treatment supervision and historical APM authority	http://docs.legis.wisconsin.gov/statutes/statutes/281/II/17/2
s. 23.22	Invasive species	https://docs.legis.wisconsin.gov/statutes/statutes/23/22
s. 23.24	Aquatic plants and management	https://docs.legis.wisconsin.gov/statutes/statutes/23/24

A.A-2. Links to administrative rules related to aquatic plant management in Wisconsin.

Chapter	Title	Link
NR 19.09	Wild rice conservation	https://docs.legis.wisconsin.gov/code/admin_code/nr/001/19/I/09
NR 40	Invasive Species Identification, Classification, and Control	https://docs.legis.wisconsin.gov/code/admin_code/nr/001/40/
NR 102	Water Quality Standards for Wisconsin Surface Waters	https://docs.legis.wisconsin.gov/code/admin_code/nr/100/102
NR 103	Water Quality Standards for Wetlands	https://docs.legis.wisconsin.gov/code/admin_code/nr/100/103
NR 107	Aquatic Plant Management	https://docs.legis.wisconsin.gov/code/admin_code/nr/100/107/
NR 109	Aquatic Plants: Introduction, Manual Removal and Mechanical Control Regulations	https://docs.legis.wisconsin.gov/code/admin_code/nr/100/109/
NR 190	Lake Management Planning Grants	http://docs.legis.wisconsin.gov/code/admin_code/nr/100/190
NR 198	Aquatic Invasive Species Prevention and Control Grants	https://docs.legis.wisconsin.gov/code/admin_code/nr/100/198
ATCP 29	Pesticide Use and Control	http://docs.legis.wisconsin.gov/code/admin_code/atcp/020/29

A.A-3. Links to summaries of federal policies related to aquatic plant management in Wisconsin.

Subject	Links
Clean Water Act	https://www.epa.gov/laws-regulations/summary-clean-water-act
Federal Insecticide, Fungicide, and Rodenticide Act	https://www.epa.gov/laws-regulations/summary-federal-insecticide-fungicide-and-rodenticide-act https://www.epa.gov/npdes/pesticide-permitting-program-history

Appendix B. Overview of the Aquatic Plant Management Permitting Process

This Appendix provides a general overview of the typical steps followed in processing an aquatic plant management (APM) permit, from application to issuance. It also describes which and for whom permits are required for various situations, as well as exceptions for situations when a permit is waived. See Appendix A for links to complete rules and statutes related to APM permitting.

When a permit is required and who needs one

A ch. NR 107, Wis. Admin. Code permit is required for anyone who sponsors or conducts chemical management of aquatic plants or other organisms in waters of the state of Wisconsin. The DNR APM website provides a step by step description (see https://dnr.wi.gov/lakes/plants/forms). Applications can be submitted via mail or online.

There are some cases that are exempt from NR 107 permitting, including:

- Chemical treatments applied by a Native American tribal member to a site under the jurisdiction of the tribe
- Chemical treatments of a registered fish farm with a controllable outflow
- Chemical treatments of a drainage ditch or right-of-way which the DNR has determined not to have significant fish or wildlife resources
    - Typically, a site is deemed to have significant fish or wildlife resources by checking if the site has a Critical Habitat or Sensitive Area Designation or is a trout stream or other priority navigable waterway.
- Chemical treatments at a wastewater treatment facility with WPDES coverage for APM activities
- Chemical treatments to swimming pools, private wells, and plant-obstructed potable water supplies
- Dye treatments to private ponds

Management activities conducted by Wisconsin Department of Natural Resources (department) are not exempt from NR 107. See s. NR 107.11, Wis. Admin. Code for a full list of exemptions.

Chemical treatment of a site which has saturated soil (in excess of field capacity) requires a permit. Herbicide applications to wetlands or exposed lakebeds that are dry do not require NR 107 permits but some aquatic herbicide labels prohibit their use below the ordinary high-water mark. The user must verify that the right products are being used to remain compliant.

Depending on the choice of herbicide and target species, methods of treatment may utilize an application period when the plant is dormant, such as the winter. Permitting chemical treatments in waters of the state that are frozen at the time of chemical application is not well defined. These are usually addressed on a case by case basis.

For non-private pond herbicide treatments, a Wisconsin Pollutant Discharge Elimination System (WPDES) permit is also required. When applying for an NR 107 permit, the applicant must also agree to follow the conditions of the WPDES general permit. Pesticide applicators only need to complete the WPDES application once every five years or until notified by the department. By completing the WPDES application, they agree to follow the conditions of the general permit for all activities for that permit period. There are also some exemptions in which a WPDES permit is not required, such as when the chemical application site is a private pond or when the plant control activity is conducted by a tribal entity on tribally owned land. For a full list of exemptions, see the department's *General Permit to Discharge Under the Wisconsin Pollutant Discharge Elimination System* at: https://dnr.wi.gov/topic/wastewater/documents/WI0064556.pdf. Management activities conducted by DNR are not exempt from WPDES permitting.

A Wis. Admin. Code Ch. NR 109 permit is required for anyone who sponsors or conducts "manual removal, burning or using mechanical means or aquatic plant inhibitors to control aquatic plants in navigable waters, or introducing non-native aquatic plants to waters of the state". Some exemptions include:

- Manual removal of aquatic plants from a body of water that abuts the owner's property, under certain conditions
- Use of devices designed for cutting or mowing vegetation to control plants on an exposed lake bed that abuts the owner's property, provided that the removal does not exceed 30 feet in width
- Conducting any of the activities described above in a private pond
- Conducting any of the activities described above in any body of water less than or equal to 10 acres in size and entirely confined by property with only one owner, with permission of the owner
- Control of purple loosestrife (*Lythrum salicaria*) by manual removal or use of mechanical devices when performed in a manner that does not harm the native plant community or result in or encourage re-growth of purple loosestrife or other non-native vegetation
- Conducting any of the activities described above in the event that the individual conducting these activities already has a permit under state statutes 30.12, 30.20, 31.02, or Chapter NR 107
- Conducting any of the activities described above in the event that the individual conducting these activities is a Native American tribal member or entity on land owned by the tribe
- Conducting any of the activities described above in the event that the individual conducting these activities is conducted by DNR and the activities are consistent with the purposes of NR 109

For a full list of waivers from NR 109, see NR 109.06. Alum, lime, and dyes are considered inhibitors and thus require NR 109 and WPDES permits. Applicants are always required to have an APM plan for alum treatments.

There are special permissions and exemptions afforded to tribal and non-tribal entities conducting APM activities on tribal lands. These are described in Table A.B-1.

Table A.B-1. APM permit requirements for tribal and non-tribal entities on and off reservations.

Permit Type	On Reservation		Off Reservation and Boundary Waters[1]	
	Tribal Member	Non-Tribal	Tribal Member	Non-Tribal
NR 107/109	No	Yes	Yes	Yes
WPDES	No	Yes[2]	Yes	Yes
NPDES	Yes	Yes	Yes[3]	No

Note: "Yes" indicates when the permit in question is required, with the exceptions for footnotes 2 and 3 (described below).

1. "Boundary Waters" means any waterbody that is partially within the boundary of a reservation.

2. No WPDES permit is needed if a non-tribal entity has National Pollutant Discharge Elimination System (NPDES) coverage of the waterbody and was contracted by a tribe

3. If a tribal entity is conducting APM activities off-reservation or on boundary waters, a WPDES permit is needed and takes the place of an NPDES permit.

The permitting sequence

Generally, processing of NR 107 and NR 109 permits proceeds as follows:

- For large-scale NR 107 permits, the applicant must notify adjacent riparian property owners before applying for a permit. See the department's guidance on *Notification of Proposed Pesticide Treatment Application* at: (https://dnr.wi.gov/news/input/documents/guidance/NotificationPostingGuidanceFinal.pdf).
- The applicant submits an ch. NR 107 or NR 109 permit application, along with the required application fees ($20 plus an additional $25 per acre for chemical treatments larger than 0.25 acres under NR 107 and $30 for areas less than one acre or $30 per acre for areas an acre or larger under NR 109).
- All permits are sent to department Permit Central Intake in Madison or submitted on-line. Permit Central Intake staff disperse non-private pond permits to local staff. Upon receipt of the completed application, the department must make a decision within 15 business days.
    - For small-scale NR 107 permit applications (for proposed chemical plant control activities which would not exceed 10 acres or 10% of the area of the waterbody):
        - If the proposed treatment site is a private pond, the application is processed by the APM Central Permit Intake Coordinator.

        - If the proposed treatment site is not a private pond, the application is forwarded to and processed by the local department APM coordinator or LTEs under the supervision of the local department APM coordinator.
    - Large-scale NR 107 permit applications, along with proof of public newspaper notification, are forwarded to and processed by department staff
- Local APM coordinators may require an APM plan for NR 109 activities.
- Permits with proposed APM activities to sites in the Ceded Territory may need to be reviewed for wild rice impacts through the Voigt Task Force.
- The NR 107 or NR 109 permit application is evaluated based on existing information about the target site and plant community, according to the criteria outlined in s. NR 107.05 or NR 109.05, and a decision is made. To comply with Wisconsin's Endangered Species Law and the Federal Endangered Species Act, department staff must conduct an Endangered Resources Review for the target site of all APM permits. Herbicide formulations at concentrations which have been shown to negatively affect the taxon group (e.g., frogs, bats) of a state- and/or federally-listed Threatened or Endangered species that has been recorded within the vicinity of the project area (based on a search of the Natural Heritage Inventory (NHI) Portal) will not be permitted.
- All permit decisions by the department can be challenged by anyone, following appropriate state statutes (s. 227.52, s. 227.53, s. 227.42), within 30 days after the permit decision is sent to the applicant.
- Successful permit holders must post signage in the areas affected by the permit according to s. NR 107.08 (7). See the *Caution Warning Signs Posting for Pesticide Treatment* guidance (https://dnr.wi.gov/news/input/documents/guidance/NotificationPostingGuidanceFinal.pdf).

Applicants are encouraged to contact local APM coordinators with questions before applying. Staff can assist applicants with the permitting process, offer technical advice, and help assure compliance with state and federal regulations. The applicant may choose to proceed as intended, alter their approach, or even decide against applying. This can save the applicant and staff time by eliminating the need to proceed with a formal denial or special conditions in the approval. Because much of the work is often done up-front, permit denials are rare. However, there are occasions when a permit is denied. In most cases a denial is based on potential impact to human health, the lake ecosystem, the proposed treatment is determined likely to be ineffective, or there is not a clear navigational impairment or nuisance condition (see NR 107.05(3) for a complete list of issues that may lead to a denial of an application).

Department staff may recommend that individuals applying for an APM permit on public waterbodies first develop an APM plan to assure the public has adequate participation and to sufficiently assess ecosystem impacts (see Chapter 7.6). When a permit applicant has an approved plan, the permitting process is expedited because many of the issues under review have already been considered and documented during the planning process. Under NR 109, department staff can require an APM plan and for multi-year NR 109 permits, an APM plan is always required. In order to receive funding for APM activities through the department’s Surface Water Grants program, the applicant must have an APM plan in place.

APM permit applicants may put out a request for bids for APM service providers for both consulting and control work. The department is not involved in this process and the criteria considered by the project sponsors vary widely from one project to another.

The use of pesticides is regulated under the Clean Water Act and while private ponds are included as waters of the state and under NR 107, the department’s APM program recognizes there is less public interest in private ponds. Therefore, WPDES permitting is not required, and some techniques, such as dyes, do not require permits. In addition, applications for permits to conduct herbicide treatments of private ponds are processed by the APM Central Permit Intake Coordinator.

Another important note related to NR 107 permitting pertains to private ponds in which fish are stocked by the owner. There are more than 2500 of these ponds in the state. Private pond owners interested in stocking fish can either 1) apply for a free General Stocking Permit through the department’s Fisheries Management Bureau or 2) seek approval to become a certified fish farm through the Department of Agriculture, Trade, and Consumer Protection (DATCP). For the former option, an NR 107 permit is required for any herbicide treatments to the pond (fee of $20 per year). For certification through DATCP, a Natural Waterbody Use Permit issued through the department’s Bureau of Fisheries Management may be required (one-time fee of $50-$500 and annual registration $37.50-$125 per year). A DATCP-certified fish farm pond is only exempt from NR 107 if there is a controllable outflow or no outflow. In this case, herbicide application must still follow the Federal Insecticide, Fungicide and Rodenticide Act and EPA pesticide label guidelines.

Appendix C. Recent Statewide Strategic Efforts Toward Control and Containment of Non-Native Phragmites and Other Non-Native Species

The Wisconsin Department of Natural Resources (department) has been working with partners to strategically manage non-native phragmites (*Phragmites australis* subsp. *australis*) populations for the past four years (2014-present). Non-native phragmites is most frequently documented in the eastern part of Wisconsin (Figure A.C.1).

Management of phragmites in the state of Wisconsin is centralized and strategic, supported with federal funding, and reliant on collaboration with diverse partners. In 2014, the department received a grant from the U.S. Fish and Wildlife Service under the Great Lakes Restoration Initiative (GLRI) that was used to hire contractors to apply herbicide to small pioneer populations in the western Lake Michigan basin and adjacent counties, with the intent to eliminate the stands before they could colonize larger areas. The following year, relatively dense phragmites sites in the Eldorado Wildlife Area (Fond du Lac County) and in private wetlands to the south of that location were targeted along with many northwest phragmites populations in the Lake Superior basin, complimenting parallel efforts in Minnesota. Non-native phragmites control work has also been conducted in the upper peninsula of Michigan since 2012. Since 2015, non-native phragmites control work in Wisconsin has focused on moving eastward with an emphasis on protecting lakes, high-quality wetlands, and transportation corridors that contribute to the spread of phragmites. Approximately 556 acres of land populated by non-native phragmites was treated between 2014 and 2017 and post-treatment monitoring and evaluation is ongoing (Figure A.C.2). The Great Lakes Indian Fish and Wildlife Commission has agreed to monitor the northwestern sites and follow-up with control as needed. Where funds are available, the Wisconsin Department of Transportation conducts control work along right-of-ways in counties where phragmites is classified as "prohibited" under NR 40 (meaning it's not widespread in those areas), as well as bordering counties. Control efforts in the eastern part of the state have been complemented by work from numerous partners, non-profits, and Cooperative Invasive Species Management Areas (CISMAs).

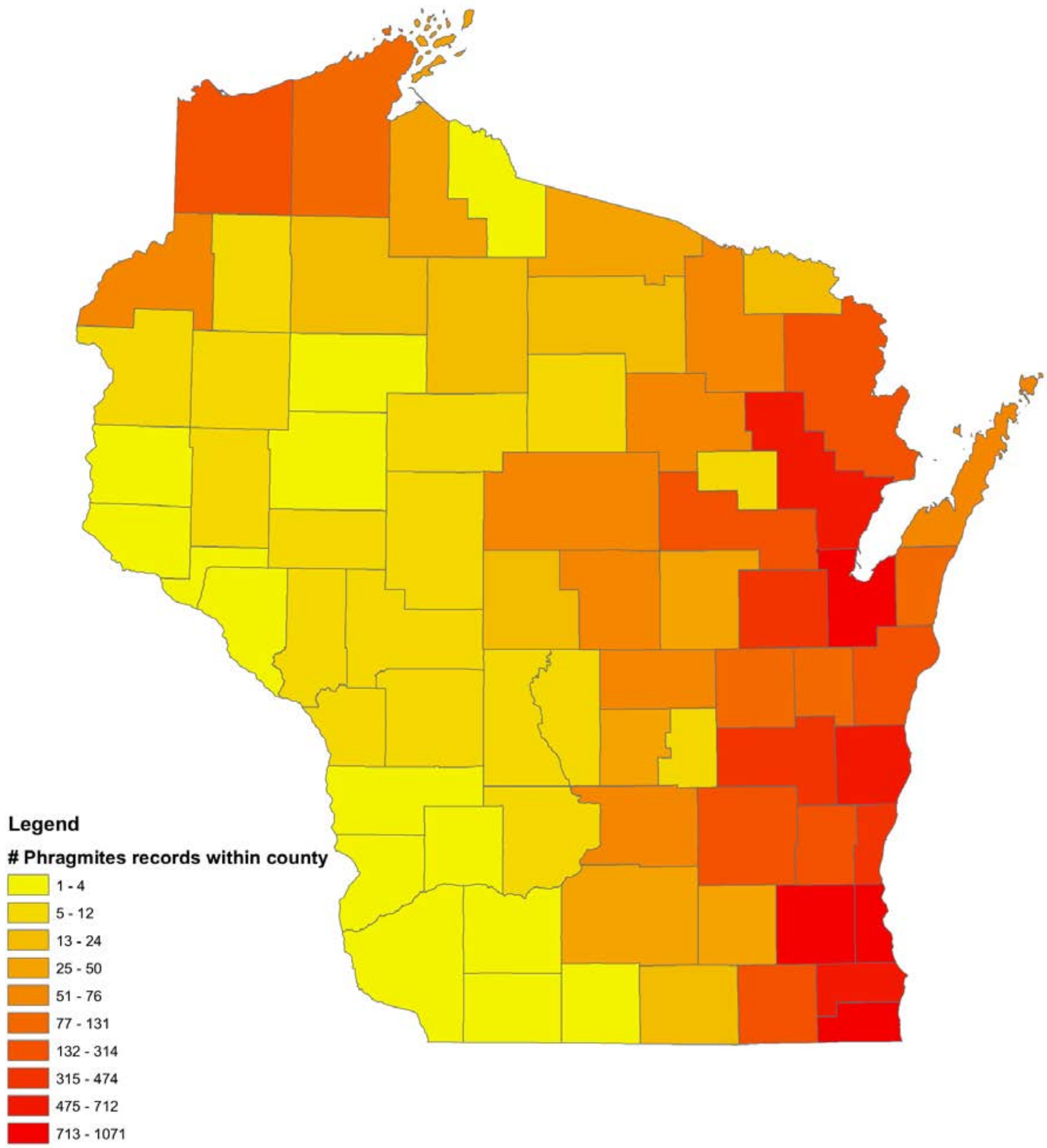

Figure A.C.1. Non-native phragmites records in each of Wisconsin's 72 counties.

Note: This map was created in February 2018. Non-native phragmites (*Phragmites australis* subsp. *australis*) is most common in the eastern part of the state. Note that many small, nearby, coastal populations near one another along the Saint Louis River Area of Concern and Lake Superior have been reported as part of an intensive mapping effort, which makes the species appear relatively more common in on northwestern portion of this map than it is on the landscape. Non-native phragmites is not common inland in northwest Wisconsin.

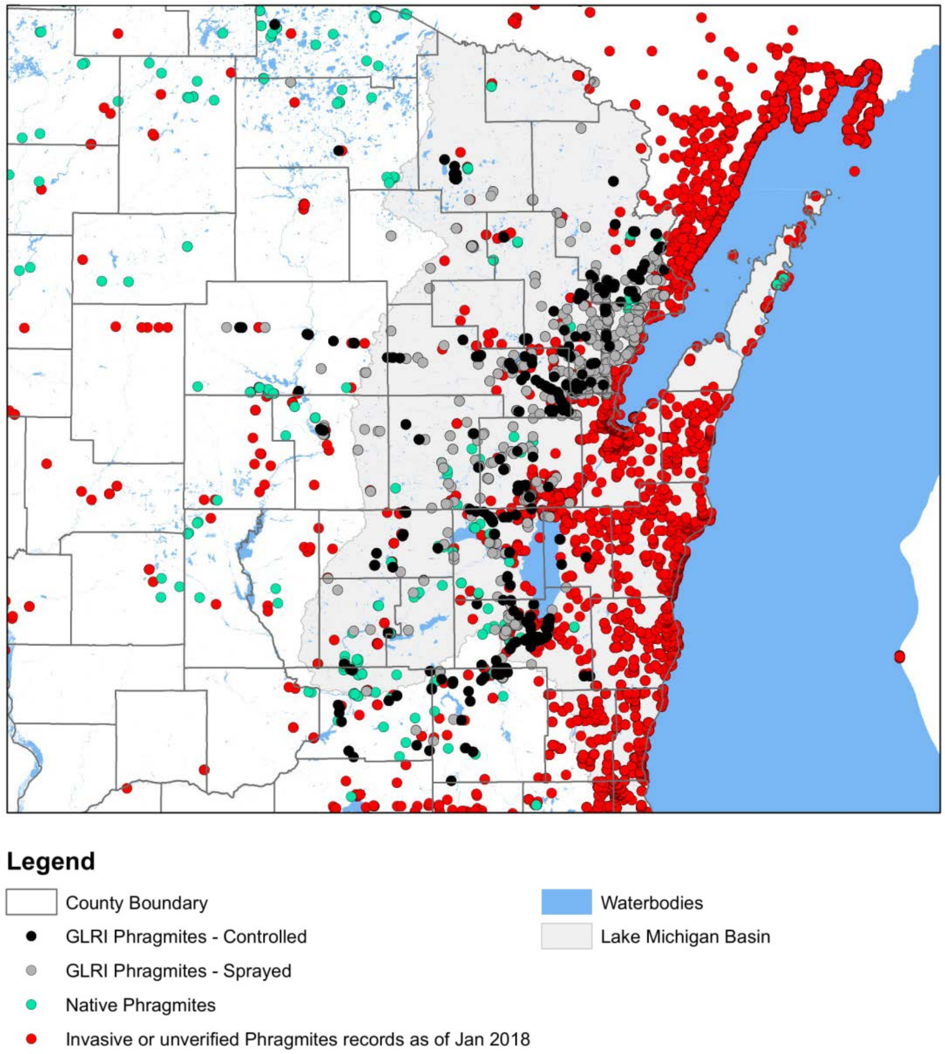

Figure A.C.2. Native and non-native phragmites records and control (2014-2017).

Note: This map was created in February 2018. Sites where chemical control activities were conducted, and sites where non-native phragmites (*Phragmites australis* subsp. *australis*) was treated from 2014-2017. GLRI stands for the Great Lakes Restoration Initiative. Sprayed sites are those that have been treated and controlled sites are those at which no living phragmites was found at the time of assessment.

The department recognizes that a long-term strategy for non-native phragmites control is necessary to prioritize management actions and prevent its continued spread. In spring of 2018, the department hosted meetings with potential partners, many of whom now have federal grants for non-native phragmites control, to facilitate discussion towards developing a comprehensive statewide plan for the future of wetland invasive plant control work.

Additionally, the department has also received funding from GLRI to begin control of other aquatic and wetland invasive species. The work described above also included efforts to control reed manna grass (*Glyceria maxima*) in southeast Wisconsin, primarily in Jefferson, Waukesha, Dane, Calumet, and Racine counties. In 2018, control plans include managing lesser celandine (*Ranunculus ficaria*), giant hogweed (*Heracleum mantegazzianum*), hairy willow herb (*Epilobium hirsutum*), and starry stonewort (*Nitellopsis obtusa*) in the Great Lakes basin. The populations of many of these species in Wisconsin are within the early stages of invasion and it is hoped that control actions now will prevent further establishment and spread. Department staff and regional partners are working to further survey and catalog these species and their distributions and develop long-term control and monitoring plans.

Appendix D. Stakeholder Interview Questions

For Stakeholders Not Actively Conducting APM Activities

1. Please describe your ideal lake with respect to aquatic plants.
    a. Do the lakes you care about match up with that ideal? Why or why not?
2. WDNR has a permitting process for aquatic plant management activities in the state. These activities may include herbicide application, mechanical removal, and other approaches. Are there, or are you aware of, aquatic plant management activities that have taken place on the lakes you care about? Please describe how the management of aquatic plants affects your use of Wisconsin's lakes.
3. What situations merit managing aquatic plants?
4. What are your concerns in regard to aquatic plant management?
5. Aquatic plant management can improve certain aspects of lakes, but it can sometimes pose risks to fish, native plant communities, water clarity, and other things. What tradeoffs are you willing to accept to achieve plant management goals?
    a. How and why does species origin (whether the species is native or non-native) influence this (your risk tolerance)?
    b. There are some non-native plant species that have become widespread in Wisconsin lakes and others which are more recent arrivals. How does whether a non-native species is well-established or recent influence this (your risk tolerance)?
6. Is there anything else you'd like to share regarding aquatic plants and their management?

For Stakeholders Who Conduct APM Activities

1. What situations merit managing aquatic plants?
2. What is your goal in conducting aquatic plant management (APM)? Please describe the situations on the lake(s) you care about.
3. How do the following factors influence your APM decisions and actions?
    a. Potential effects on non-target species (including other plants as well as fish and wildlife)
    b. Time of year and the life cycle of the target species
    c. Characteristics of the lake, such as size, water movement, temperature, water chemistry and clarity, and others
    d. Whether the target species is native or non-native to WI
        i. For non-native species, whether the population is new or well-established
    e. For herbicide treatments:
        i. Potential to develop herbicide resistance over the long-term
        ii. Recommended concentration and exposure times
4. What does Integrated Pest Management (IPM) mean to you? How do you implement IPM in conducting APM activities? What are one or two reasons for doing so?

5. What tradeoffs are you willing to accept regarding risks for fish and wildlife, macrophyte diversity and habitat complexity, altering water clarity, nutrient pathways, hydrology, sediment stability, and other issues?
6. How do you work with the Wisconsin Department of Natural Resources in regards to aquatic plant management? Please describe your experience. How could your experience working with WDNR's APM program be improved?
7. Is there anything else you'd like to share regarding aquatic plants and their management? We are particularly interested in any further concerns you may have.

For WDNR APM Staff

1. What situations merit managing aquatic plants?
2. What is your goal in conducting aquatic plant management (APM)?
3. How long have you been involved in APM in Wisconsin? How have APM practices changed over the course of time you've been involved in WDNR's APM program, both in your region and statewide?
4. How do APM practices in your region of the state differ from others? What challenges do you face that are unique to your region? What challenges to you expect to see in the future?
5. How do the following factors influence your APM decisions and actions?
    a. Potential effects on non-target species (including other plants as well as fish and wildlife)
    b. Time of year and the life cycle of the target species
    c. Characteristics of the lake, such as size, water movement, temperature, water chemistry and clarity, and others
    d. Target species origin/Whether the target species is native or non-native to WI
        i. For non-native species, whether the population is new or well-established
    e. For herbicide treatments:
        i. Potential to develop herbicide resistance over the long-term
        ii. Recommended concentration and exposure times
6. What does Integrated Pest Management (IPM) mean to you? How do you implement IPM in conducting APM activities? What are one or two reasons for doing so?
7. What tradeoffs are you willing to accept regarding risks for fish and wildlife, macrophyte diversity and habitat complexity, altering water clarity, nutrient pathways, hydrology, sediment stability, and other issues?
8. For what reasons might you deny an APM permit or discourage applicants from conducting a particular APM activity? How do you work with stakeholders in situations when your recommendations differ from their desired management actions?
9. How could WDNR's APM program be improved?

Is there anything else you'd like to share regarding aquatic plants and their management? We are particularly interested in any further concerns you may have.

Appendix E. Detailed Summary of and Quotes from Stakeholder Interviews

The following are quotes representing the range of viewpoints encountered in the stakeholder interviews described in Chapter 6. The parentheses following each quote indicate the stakeholder group represented by the individual the quote is attributed to. Groups with fewer interviewees are indicated as "other stakeholder groups" together to ensure anonymity (L = lake organizations, M = private management companies, C = private consulting companies, O = other stakeholder groups, DNR = DNR APM staff). Similarly, an X in a quote replaces the name of a person or waterbody. Any parenthesis within the quotes indicate that a pronoun was replaced with what or who was being referred to. Brackets provide extra context for the quote.

E.1. Management Goals

Stakeholders' primary APM goals are preserving waterbody use, non-native species control, ecological restoration, and public outreach.

Goal: Reduce aquatic plant abundance when waterbody use is impaired.

Multiple interviewees described situations where plant density was high enough to impede use of a waterbody. In such cases, management can provide relief, allowing individuals to enjoy water-related activities.

> *You could not go from one part of the lake to the other part of the lake in some instances, because the milfoil was so thick. (L)*

> *Once we get to the lake, we can sail you know, everything's good. For us, we have trouble getting to the lake. And that's a big problem for us. (O)*

> *When you look out at the lake in August, it doesn't look like a lake. It looks like a swamp. And that is not what we want. (O)*

> *If I live on my lake and milfoil is just in this one spot and we're able to keep it there and it doesn't interfere with my boating and it's not preventing me from fishing and my native plants seem to be doing ok, that seems successful to me. Even if I don't get two or three years of relief out of it. (C)*

> *Many [APM permit] applicants are older people who want to get recreational activities in with their grandchildren while they have the chance. (DNR)*

A few stakeholders noted that keeping waterbodies usable by reducing overabundant plant cover can improve the economic climate of an area.

> *The [property] values on Lake X are so out-of-sight, normal people can't even begin to own a piece of property there. Well guess what, we're going the same place, IF the lake was that clean [of plants or algae]. (O)*

> *It not only affects everyone's leisure, but there are a lot of people who are dependent on the livelihood of the northwoods. Whether you're a restaurant owner, whether you're a fisherman guy, it has an economic impact. It also affects the economic impact, of not only business, but every homeowner, whether you're on the lake or off. (L)*

Goal: Non-native species control or eradication.

Because some non-native plant species can reach high densities and outcompete native vegetation, some seek to remove non-native species from the waterbody entirely.

> *…you can't get an AIS grant unless your goal is 10% or above for Eurasian watermilfoil. My goal is zero. Of course that's premised on the fact that, one, you can get the permits to do it and two, you can get the money to do it. (L)*

> *It depends on the exact type of species you're dealing with. If you're working with, say phragmites, on a property owner scale or a landowner group scale, you want to completely eradicate it. (M)*

> *Some of them, and this is mostly almost exclusively with exotic plants, but some of them want all of their exotic plants gone, you know, they don't want to have ANY of them left in the lake. And others concede to the fact that they're going to have some small number of aquatic plants even if we work really, really, really hard at it. And others are quite content with having larger amounts and not pursuing it quite as actively. (M)*

Recognizing that population eradication can be difficult and costly for some species, many stakeholders may instead seek management to keep non-native plant abundance low.

> *The simple answer is, you want to, at a minimum you want maintain. Best case, you want to improve. (L)*

> *Protect the good (plants), and at least control the bad ones. It seems impossible to get rid of them. That is what I tell people, that is the crux of our APM plan. (L)*

> *Everybody knows that eradication is probably next to impossible, so we're looking for control. (L)*

Goal: Ecological protection and restoration.

For some lake and outdoor sporting groups, APM is a means for preserving biodiversity and fish and wildlife habitat. They feel management should only be conducted if it will provide ecological improvement to the waterbody.

> *Those situations [meriting APM are those] where you have an invasive species that is negatively impacting an ecosystem. (O)*

> *From our perspective, managing aquatic plants is primarily a biodiversity issue. So when invasive aquatic plants begin to outcompete native aquatic plants we definitely see it's appropriate to manage them. (L)*

> *The goal is a natural, naturally functioning, healthy ecosystem. So that would include a wide variety of native plants and animals. The goal is to keep that, restore that. (L)*

For the majority of folks, it still comes down to nuisance control for them. I see a big shift, I see that shift coming more towards understanding they need a balanced ecosystem versus 5, 10, 15 years ago when it was all about nuisance conditions. (DNR)

APM professionals consider ecological protection as a critical aspect of their work.

(The goal) is to try to satisfy everybody and fulfill the Public Trust Doctrine. (DNR)

[Our goals are] either, to restore ecosystem services, you know, so people can fish and swim and boat. Or more importantly, to restore the ecosystem itself. (C)

Always protecting the habitat the best we can, looking at it from the fisheries standpoint. (M)

Goal: Public education and outreach.

A subset of individuals from nearly all stakeholder groups feel that being involved in APM is an opportunity to build partnerships, provide public outreach on the ecological benefits of aquatic plants, and share personal experiences with various management scenarios.

One of the first things we try to do is point out that plants are part of a healthy lake. They're there for the fisheries, they're there for the wildlife, they're part of a healthy lake. (L)

Unsightliness, that's an educational thing. If people perceive aquatic plants as a nuisance because they don't like the way it looks and other things are still in order, we try to educate them on the benefits those plants are providing. (M)

The first [goal] is to build strong partnerships with the lake groups and the applicators themselves, when you're both on the same page and working towards the same goal, it makes management more effective. (DNR)

E.2. Management Considerations

Stakeholders actively involved in APM activities are knowledgeable about the factors influencing management outcomes.

There is general understanding among stakeholder groups that optimal management timing depends on the life cycle of the target species. Interviewees described social and ecological considerations influencing when management should occur such as management goals, target species life-cycle (phenology), and potential for non-target impacts to native plants, fisheries, or water quality.

Most stakeholders involved in APM considered timing in their APM decisions. Interviewees described several factors influencing management timing, including the target plant's growth and life cycle, and the potential for algal blooms.

The main thing is to time those herbicide applications when the plant [curly-leaf pondweed] is actively growing but the natives, they haven't started growing yet. (O)

We want to pull (Eurasian watermilfoil) before it starts to auto-fragment (L)

For a particular plant, you know curly-leaf pondweed, if we're going to gain any ground on that and actually succeed, it's important that those plants are [chemically] treated prior to the turions being produced. (M)

If it's hot, we're not going to do (herbicide treatment) because that's the life cycle of blue-green algae. (DNR)

Plant life cycles, basically, they dictate when you're going to apply [herbicides]. (M)

Some interviewees added caveats regarding management timing or managing too early in the growing season and explained situations where it may be appropriate to manage later in the growing season, depending on temperature, plant presence, fish spawning, management goals, and the target species.

Ok, let's treat Eurasian watermilfoil in the spring before the natives are up. But if you go out there and really look, the natives are there. (DNR)

The timing of receiving permit applications can be a little bit tough as far as the early-season control efforts. You're not quite exactly positive what's there is there. (DNR)

I think that depends on the lake. If you have a deeper-water lake that doesn't warm up as fast, your milfoil may not be ready to treat until you get to the end of May. (C)

Eurasian seems to be really, really sensitive to 2,4-D even at low levels but it's really got to be actively growing. (C)

If there's a management action like mechanical harvesting, often [fisheries biologists] want to see that happen after a spawning period. (C)

In private lakes and ponds, if we see plants actively growing, they're not calcified, they're not covered with algae, mid-summer, late fall, even up to November, we'll target non-native nuisance species. (M)

There are a couple of situations where we would potentially [use fall treatments]. If there are wild rice issues, is one, and another is if it was an early detection and response project. And the key to that would be monitoring and showing what the results are, that the situation warrants a fall treatment. (DNR)

As far as control, or what the customer wants, I mean, we still get very good control, even if it's getting into mid-summer. (M)

We didn't treat phragmites in August. Now we're treating phragmites in early August and sometimes in July. So it's evolving as we learn more. (M)

There is widespread recognition among stakeholder groups that waterbody characteristics influence the plant community and the appropriate management technique. Some stakeholders rely on APM professionals to make recommendations on how these factors should influence management.

The particular waterbody characteristics discussed by each interviewee varied depending on their experience and included water movement and clarity as well as waterbody size and depth.

Without a doubt, if you've got a lot of water movement, your [herbicide] contact time is going to be greatly reduced as a function of how much movement there is. (L)

The size and depth of the lake prohibit chemical treatments in the body of the lake. (L).

Water clarity, especially when you start looking at hand harvesting, is a real big factor. Not just for visibility but for the depth at which the plants grow. (O)

We can't create a plan that fits every lake. We have to look at every lake as an individual and then figure out a plan based on that lake and the stakeholders around it. (C)

Some lake organization representatives rely on their regional DNR APM coordinator, county water resources staff, or management and consulting firms to consider these characteristics appropriately. Encouragingly, these APM professionals in turn noted that they work with citizens to explain how waterbody characteristics can influence management and help to set expectations and reasonable goals.

I would leave that largely to the experts as well, although another goal that [we] have is water quality. (L)

We have some very shallow, eutrophic or hypereutrophic systems, which just facilitate a lot of plant growth, whether it's invasive or native plant growth. And those are always going to be challenging systems. A lot of times it's a matter of educating the public that they're not going to be Lake X. (C)

APM stakeholders are aware of the potential for development of herbicide resistance or appearance of herbicide tolerance in aquatic plants. Some interviewees expressed concern and some felt that more research on this topic is needed.

Some were concerned about how herbicide resistance could affect APM or had altered their management strategies to some degree as a result of this.

…it's like antibiotics right? I've heard about it. I haven't heard anything relative to curly-leaf. I thought I heard of something that Eurasian watermilfoil has hybrids but they've had hybrids for a while. (L)

When I was first here, they used to spray the entire shoreline the week before the 4th of July to make it look pretty. We stopped doing that because basically, the plants had some resistance to it eventually. (L)

We addressed (herbicide resistance) in our plan and that's another reason that they want to back off on their aggressive herbicide use. Because (resistance) is a concern and was one of the contributing factors, amongst others. (C)

Part of best management practices and integrated pest management in general is utilizing different products and rotating products so that we're not using the same thing year over year and creating hybrid issues. (M)

That's why I recommend them taking off a few years between large-scale treatments. (DNR)

I know with the milfoil and the hybridization, I don't think there's any way that we're going to be able to keep up with that, just because of how fast it can manipulate itself. I hope we don't get to the point where we can't do anything about it and then we have to bring a biological agent in. But at some point in time you're going to have to throw your hands up and say, we can't do anything with herbicides anymore, what's our next step? In some cases, manual removal is showing promise. And what that goes into is, you have to look at managing in another way. (M)

Some stakeholders feel herbicide resistance is an important problem but warrants further research.

So is there risk, maybe? I think the DNR needs to maybe put a bit more effort into finding out if that really is the case…if you're forced into a management scenario, or a maintenance scenario, what are you supposed to do? I don't know the answer to whether these plants can be resistant or not. (C)

Until I see good sound science behind it, I guess I'm not going to pay much attention to that ability…I don't know, I think we need to do more science. (M)

You're banging your head against a wall if you're trying something that doesn't work and you know it doesn't work. And that's why monitoring is so important. To understand what's happening. (DNR)

Perspectives vary on optimal herbicide concentrations and exposure times (CET) for APM depending on management goals and scale. Preferences on the appropriate scale of APM actions also differ. This was another area where interviewees felt more research is necessary to better predict and improve management outcomes.

Some interviewees favor employing maximum allowable herbicide application rates while others prefer to employ lower rates. This often depends on the management scenario. Additionally, there were some interviewees who do not use herbicides for APM for whom our question on herbicide CET was not applicable.

We've left (determination of appropriate herbicide CET) up to the DNR and our spray guys who've worked with us for probably 10 years. (L)

That's a learning curve by experience but I would say definitely not following maximum label rates most of the time. Again, site specific. Plant densities, water temperatures, any water movement beside the treatment area, native species present. (M)

We've partnered with the DNR, and with our consultant, and with the State Lab of Hygiene. So we've gone out and we've, the first few years that we treated, we went out and did the sampling to better understand the right concentration levels. And I think we've got things figured out, you know, and it's not an exact science…obviously, with water flow, that's harder. (L)

By [DNR staff] trying to lessen chemical usage or by trying to limit acreage on treatment, we're actually using much more chemical as an outcome…We all want to do a better job. We all want to use less chemical. And using more chemical, initially, up front, within the label range, but up front sometimes, it would definitely be advantageous on specific sites. (M)

Stakeholders recognize that optimal herbicide CET varies with treatment scale and preferences for management scale differ.

We rely on whole-lake scale management more than spot treatments for ecosystem restoration goals. They're just more predictable in efficacy and selectivity. (C)

I think we should continue to do what we're doing because we're seeing results…I've heard that before, they might not fund [smaller] curly-leaf treatment anymore and that's a little disconcerting when you go through all the work to make sure you're doing it the right way. (L)

We just prefer to see management on a small continuing scale, rather than large-scale, one-shot, management. (O)

Usually, the larger the scale the lower the rate. But even when we're doing quite small areas, I think we're always, even on small areas, at a mid-range rate. Half of the maximum at most. I don't think we ever go higher than half of the maximum. As long as we get the results, it's less product, less chemical going in the water, and less cost involved. (M)

You can't just read the label and recommend that anymore if you're treating a large portion of the volume of the water. (M)

We'd been doing treatments for several years on X Lake for Eurasian watermilfoil. So, finally got to the point where we had to have a big enough area to make the treatment effective. So it's kind of like, well you know, there's these threshold limits, we almost had to have a certain size before it became feasible to actually do an herbicide treatment on that patch. (O)

Some stakeholders noted that more research is needed regarding herbicide CET.

Who does that [concentration monitoring] privately? They can't find anybody. From a management standpoint, I don't have all the answers and I always like multiple opinions. (C)

My reaction to that issue is just that, I am a proponent in some cases certainly of dye studies and anything that that can do to help us anticipate those kinds of things. But I understand that even those things have implementations that, um, conditions on the day of application can be so variable and difficult to control for. It certainly is a big concern for us that regardless of what sort of application rate is suggested, to actually recreate that under field conditions is a huge obstacle. (O)

I think that when we start looking at these different types of herbicides that we can use, we have to be diligent about continuing the monitoring that's associated with these so we can build up a database and an understanding of what herbicides work well where. (C)

Perspectives on management of non-native and native aquatic plants are variable; stakeholders are generally more accepting of non-native than native plant management.

Overall attitudes are more accepting towards non-native APM than for management of native plant species. For newly-established non-native populations, some feel early response is critical to stop the spread while others prefer to reserve management depending on whether the invader becomes an issue. Management of well-established non-native plant populations warrants careful consideration of management goals, tradeoffs, and resources.

Representatives from each stakeholder group feel that management of native plant species should be more conservative, though there is a spectrum to this. Acceptance of native plant management seems to be greater in the southern part of the state relative to the northern portion.

They're good native plants, they're a benefit to the ecosystem…Yeah, you can get a lot of plants and it can be a pain in the butt because now their swimming beach in front of their dock isn't there but there's, we don't agree with that, doing that, so I don't foresee us doing any native plant control. (O)

We would try to remove some of (the native plants) just in case, you know, keep boating traffic clear. (L)

That would be site specific…If (the management area is) a small percentage [of the lake] and the lake is full of (a native plant species), it's not as much of an issue as, ok this is a native species that we're targeting but there's very little habitat in the lake. (M)

We put together plans for groups to help control native plants to restore ecosystem services. We don't get into that a lot and if we do, we do a very thorough job of documenting the issue, that there is definitely abundant native plant growth there that has reached a level that makes it difficult or impossible or for a riparian property owner to make it out to open water. (C)

If it's a native plant, we really steer towards a harvesting kind of a strategy. (DNR)

Native species in certain circumstances can be as problematic as non-native species…There are times when management of native stuff probably should be considered. (C)

Stakeholders are generally more accepting of non-native plant management than native plant management.

Our primary goal is just to help manage invasive species. (M)

[We're] much more lenient toward [management of] non-natives. I think it all comes down to access and ease-of-access…I guess I would say, in principle, I want to keep the native plants. (O)

I think we should be pretty liberal in allowing for the treatment of non-native species…There are varying degrees of invasiveness and different abilities of different plants to really take over and dominate an aquatic environment…We should be more aggressive with the plants that are more aggressive. (M)

There are also stakeholders who noted that non-native species can perform the same ecosystem functions and contribute to the ecosystem in similar ways to native species, acting as "just another plant" and therefore, management may not be necessary.

Here's where we come from. Fish don't care what kind of vegetation is in the lake. People care what kind of vegetation is in the lake. (O)

A lot of lakes (curly-leaf pondweed)'s in, even though it's exotic, it doesn't matter. Relax. It's photosynthesizing, just let it be. (C).

When asked how management of new non-native populations differs from those that are well-established, many stakeholders emphasized the importance of early response to new populations and clear definition of goals for controlling well-established populations.

I think if it's a new infestation, I would feel very strongly about taking care of that immediately. (M)

If you have limited resources, I would key in on those initial areas of establishment and try to get rid of those. (O)

When you're dealing with certain, rapidly changing situations, we have to be willing to say 'we need to do this, we need to try something'. And we need to be able to do parallel approaches rather than linear approaches. In other words you have to be able to go in, yes you need data to support and figure out what's working and what's not, but you don't need to say 'ok we're going to study something for 6 months and then come in and do our management'. You need to either get in there and study it while you're trying the management things or get out of the way and let management occur. It seems like kind of a radical approach but as these invasives come in, you don't have the time to sit around and take 6 months' worth of surveys to see how it responds or how it, you can't say 'well maybe it won't be a problem here'. (C)

If it's new then, even though eradication might be a dream, we're going after it much more aggressively. And where it's well-established, really thinking about the objective of what the treatment is. (C)

If it's new, a lot of times, you want to get on top of it right away. And if it's well-established, you want to make sure that they have realistic goals for what to expect following treatment, and recolonization. (DNR)

You don't just automatically go after a bed [of a well-established population] just because it's there. You scrutinize its impact. (C)

Other interviewees preferred to observe new non-native plant populations to determine whether the species would indeed be a problem before deciding to manage.

Who knows, it may coexist just fine. So I guess our first line of defense would be to really study this and see if it's going to be a problem. (O)

Trying to eliminate those species purely because they're not originally from here is not something we're terribly interested in. (O)

Integrated Pest Management (IPM) is a familiar concept to APM professionals and they identified several benefits of and barriers to the approach.

The U.S. EPA defines IPM as "an environmentally friendly, common sense approach to controlling pests…involving the integration of multiple control methods based on site information obtained through inspection, monitoring, and reports," as well as setting action thresholds and emphasizing prevention. Some interviewees felt they were employing IPM while others did not.

Most lake group representatives interviewed were not familiar with this terminology, although when it was described to them they explained several ways they were implementing the approach. Others were open to trying various management techniques, while a few did not feel they were implementing IPM in any way and were unaware of how they could implement it. Aquatic plant managers often defined IPM as incorporating all appropriate management options and some expanded this definition to include planning and monitoring efforts.

Integrated pest management, to me, would be including all the tools in the toolbox and seeing what all is available and utilizing as many as you can that makes sense to gain long-term control of invasive species and cultivate your native ones. (M)

A situation would be, let's say we do a whole-lake treatment, that gets about 100% control of Eurasian watermilfoil and you start to see that come back, so in those in-between years, integrating different strategies would be really important. So not necessarily going in and doing the same thing again, or not necessarily just letting it all grow back until you need to do it again, but implementing mechanical removal, hand removal, things like that are really important. But (IPM) also falls into the different herbicide choices and different strategies. (M)

Well, first of all you have to start someplace. You have to start and you have to figure out what's going on. There's no way that you could do hand-pulling on X Lake. It's just acres and acres and acres and acres. You're going to have to knock it back first. (L)

On X Lake, we're working on water clarity improvement efforts through an alum treatment. I think while it's going to improve plant growth, it's going to help us in our Eurasian watermilfoil management because we couldn't see, the water clarity was so poor we couldn't see to hand-pull. (C)

We utilize biocontrol to manage the purple loosestrife. (L)

For instance, one thing we did that I thought was a great combination of two different management techniques was we did a fall drawdown on a reservoir and after the Eurasian watermilfoil was exposed to the freeze-thaw cycle, it was actually a pretty good management technique to get a couple years of control of Eurasian watermilfoil. But because we only drew the reservoir down 4 feet I believe, we still had quite a bit of Eurasian that was in the water and survived the winter so after the drawdown we did a fall treatment. (M)

We will look at the different tools and use the one that's most appropriate at the time. So it might vary from year-to-year depending on what the population looks like. Of course, that means you have to kind of track the population or have a pretty good idea of what's going on with it, so you can decide is it time then to switch methods or to maybe do a year where you don't do anything because the population is real low and it just doesn't pay. (O)

I try to present pros and cons of everything. Do nothing, chemicals, manual, DASH, mechanical. (DNR)

Stakeholders discussed many benefits of implementing IPM in APM, including consideration of all available management techniques for optimal decision-making and feasibility, avoiding herbicide resistance, and providing alternatives for individuals who prefer not to employ herbicides or have not been successful with previously employed techniques.

I think you should consider all options in any decision-making that you do. Whether it's a personal finance decision, whether it's buying a car, or whether it's treating the lake. I mean, to me that's just common sense. (L)

It's a good concept of looking at the situation. I would look at it like that. Where's the problem? How big is the problem? What's the cost ramifications? What's the effect of not dealing with it versus dealing with it? (L)

So the idea is to use a variety of management techniques to address things like resistance and try to avoid those things. (M)

Sometimes it appeases landowners. Landowners, sometimes, they don't want chemicals. So you have to figure out how to do it without using it. Sometimes it's, can you even get into the environment that you're working in, with certain types of equipment or, the type of management that you would like to do may not be able to be done because you can't physically get there. (M)

There are a lot of people out there that are doing the same thing over and over and that doesn't quite really, yield any different results. (M)

Some stakeholders also noted potential barriers to employing IPM in APM, including costs and difficulty of implementation. APM professionals also stressed the importance of choosing the most appropriate management techniques for a given situation and not favoring any one management technique.

Individuals conducting APM activities may not have the available funds to employ IPM approaches.

Either way they're looking at some sort of a bill for what they do. So I think it's, at that point for them, a lot of times, it just comes down to cost. (M)

We'd like to manage milfoil but the cost of the management and the monitoring is too much for the lake group, so what do you do then? (M)

Unless you're using less chemicals or they're less expensive, you have a hard time convincing owners…and from a consultant standpoint, a lot of the time those are phone calls that then end and you end the relationship with the client. (C)

For management companies whose primary APM services include herbicide treatments, IPM involving the use of other management techniques can be difficult to implement.

The idea is good and we often tell the customers that it's a good idea to involve different things where applicable but it's something that's difficult for us to implement ourselves. I mean, it has to be part of a group effort or education of the lake owners or decision-makers, the people paying for it. (M).

Whenever there's a shift away from herbicide treatments, it's going to mean less work for us. I mean, we're not trying to push treatment or management on a lake that isn't needed. (M)

Several interviewees emphasized that employing IPM means selecting the appropriate tool for any given management situation and should not favor any one management technique.

There's been a few times we've gotten off of conference calls and the client doesn't feel like there's many options except for what the person that was going to be issuing their permit, whatever they're looking to do, they feel they have to follow their recommendations. I don't feel that's integrated pest management. (M)

If you're like, well, we're in a lake that we won't let you do chemical aid because it's got the dwarf lake iris and no matter what you do you're going to kill some of those and we won't let you do that so you have to use this method B and C. And then, well that's great but not every, we've got 17,000 lakes and you're telling me that every lake is like that we have to do the same thing? I mean, we've got some lakes where it's hard to paddle a canoe through because there's so many weeds and if you're going to get a little bit of incidental killing of some of these other aquatic plants, well to me that sounds like darn good idea. (C)

Our grant program relies on a match from these [lake or other applicant] organizations and it's our responsibility to see these grant dollars are used wisely. For example, using diver-assisted suction harvesting in an area where herbicide has proven itself at 1/10th of the cost, is not a prudent use of grant money. (M)

Without the community support and the property support and the lake user support, you know, the department is a wasteland. People are going to do what they're going to do, and if you can't convince them to do the right thing, they're going to do something and it may not be good. So there really has to be a better connection to the public and a more-realistic approach to managing things. (C)

DASH is a nice tool in certain situations. It's really good at selectively removing plants. You can target one particular species and really get at it. So, in some instances where mechanical harvesters can't get at it and you might not necessarily want to use chemicals, I think DASH can really step up. But it is very labor-intensive and it is pretty expensive so I don't see everybody using it. It can't solve all of our problems. (DNR)

If we're doing spot-treatments and you look at the cost of getting divers in there to remove a half acre or an acre of dense vegetation, be it milfoil or whatever it is, would benthic barriers and things be a better option? (M)

APM stakeholders are conscious of potential ecological tradeoffs of management, and the weight these tradeoffs carry in management decision-making is variable among stakeholders.

APM stakeholders consider potential ecological tradeoffs of APM activities and work to minimize non-target impacts. Most interviewees sought to find a balance between tradeoffs and management goals. Unpredictability of management outcomes and differences in stakeholder values, available resources, and lake-uses contribute to the complexity of APM issues.

Several interviewees explained that they strive to do no more ecological harm by managing than the target plant population.

I think that there's always going to be a secondary impact, no matter what your management or management tool is, even if it's, don't do anything. So you have those impacts whether you do something or not. And, which is worse? (C)

I think we want to minimize any of those impacts. I think it's really misdirection to think that managing invasive species is the be-all-end-all. Because in a way we're managing invasive species because of the impacts that they have on all the other characteristics than you mentioned. And if we lose sight of that and become only concerned about eliminating invasive species, or even primarily concerned about eliminating invasive species, and in the meantime, we've severely impacted the native plant growth or had serious impacts on fish and wildlife, we're really missing the boat. (C)

The lakes that we will avoid, if there is such a thing, are lakes that are undergoing some sort of specific pressure. Something that's been very recently sprayed, that will tend to drive us away because it tends to just generate bad fishing. Not forever, in fact usually a year or two later it creates very good fishing for some time. But after it's a detriment. So we're just looking for those lakes that are being well-managed and haven't recently undergone any catastrophic events. (O)

Some interviewees felt that some non-target impacts to native plants were acceptable in the short-term.

Generally, you may shift the population but you're not eliminating natives. What you're doing is favoring a few over the others. I guess we're looking at that as an acceptable tradeoff there. (O)

I think to a certain extent, we and lake property owners or lake groups are ok accepting a certain amount of decrease in native plant diversity, especially given the risks that invasive species pose. (M)

I see a lot of data either asked for by the department or presented by the department that's year-of, with less attention paid to year-after. And the other thing is, when you start talking about Integrated Pest Management, you're talking more long-term so I think it's more important that you look long-term rather than short-term at effects of these management actions. (M)

Some stakeholders opined that non-target impacts should not have as much weight on managed waterbodies which are used very heavily for recreation.

Fish, toads, frogs, salamanders, there's all of those things I wouldn't want to lose. Keeping a good mix of aquatic plants is great but that would be one tradeoff I'd be willing to make, for ease of access and quality of access. (O)

These boat harbors that have sailboat usage and you can't treat native species. Sailboats can't get in and out. It's like, ok well, the boat harbors are there and it's all sailboat usage and these guys are trying to fight their way through it. And you got all this other body of water that's got lots of vegetation. It's site specific. I understand we're never going to be on the same page but it's just sometimes, the rules have to bend. (M)

Others are not willing to accept any ecological tradeoffs as a result of management activities.

The lake's been here a lot longer than we have and it's going to take care of itself. The new normal is lakes have Eurasian watermilfoil, so be it. Who's to say these lakes haven't changed over the eons? What's going to happen to the environment around our lake? As the Earth warms around these lakes, all that's going to change anyway. Water temperatures are going to be higher in the summer and we're certainly not going to have, near the [amount of] ice in the winter, so you're going to have much longer growing seasons for plants. From that aspect, it's all a brand new ball game anyway. (L)

I would say I'm not willing to give a lot of tradeoffs. I mean if you're completely altering the nutrient cycling on a lake because you have a bed of Eurasian watermilfoil in the northwest corner of your lake, to me that is not a wise allocation of money, resources, or anything. You know, fish and wildlife habitat, that's why people come here. (O)

Finally, some individuals also noted that tradeoffs of APM are important to consider but are often difficult to predict, and that available funds may determine the degree to which plants can be controlled and negative tradeoffs can be minimized.

> *To me, I think that question is almost impossible to answer in its entirety because there's too many things to consider and there's the reason why you want to have an APM plan. (L)*

> *If it was A = B, then it would be far easier to answer that question. (DNR)*

> *Alright well, we'll go out there once a week for the next 5 years and spend $25,000. But if you had $75,000, we'd get rid of it this year. Nobody has that capability but from an ecological standpoint, that may be even better. But you don't have the financial wherewithal to do it. (C)*

E.3. Suggestions for Improving Aquatic Plant Management in Wisconsin

Relationships and Resources: Interviewees often described the need for more of DNR APM coordinators' time or faster permit approvals. Suggestions for improving this included having more APM staff with permanent positions, streamlining of permit and grant processes, and increased prioritization of APM-related work.

The stakeholder interviewees that chose to characterize their relationships with DNR APM staff felt their relationships were generally positive, ranging from excellent to straight-forward.

> *Our relationship with the DNR up in X and elsewhere in the state, I view it as excellent. I think we're on the same page. They understand our needs and I think we understand what they are charged to be doing. (L)*

> *The approach we have on aquatic management is very much of a cooperative relationship. Everybody's goal is to maintain and improve the water resources. (L)*

> *With the DNR it's pretty much permits, contracts, and work. I don't think there's a lot of play with that because usually the contract is set up a certain way that there's really no alternative. (M)*

> *My relationship with the DNR is fine, as far as I know. I mean, I never had much of an issue with anyone from the DNR. (M)*

> *In general, I find that they're willing to work with you, sometimes less than I would like. (C)*

Some would prefer more frequent check-ins, one-on-one time, or faster permit approval time. In some cases, these requests came with the recognition that there are few DNR APM staff and their workloads are high.

> *I'm not happy that there seems to be more cutbacks and it would be better to have my Lakes Biologist not have 8 counties. So I'm just going to spit that out. It would be better to talk to him once every two weeks instead of once a month. (L)*

That was really a nice cooperative effort to have the DNR more involved with the plant survey than hiring a private contractor, because I think that gives the DNR more hands-on and awareness of what's going on in the lake. (L)

So kind of, using that consultant theory in saying, DNR should be the consultant. You know, I appreciate people creating businesses out of, you know, this need and being able to provide expertise. But, the DNR has all the information, all the experience, all the history, and the ability to move on anything. (O)

The only thing that we did have a problem with last year was the amount of time it took for our over-10 acre permit. (M)

At times, review of plans doesn't meet the regulatory deadlines. And that causes concerns for implementing the plans. If we don't get the plan review in time, we can't get the grants written in time and you know people are waiting for our results. (C)

In one aspect I think the permitting process could be a little easier, a little more efficient. Case and point with X Lake, we basically have to start applying for the permit, well we already have. We don't get approval for this crazy thing until the day before we're allowed to treat it seems like sometimes. You know it shouldn't take that long. (O)

Several individuals suggested that more funding and staff could be beneficial for improving work between DNR staff and stakeholders.

Unfortunately, I feel like we have cut back on the money that we're spending for the DNR and Fish and Wildlife. To me, they're incredibly valuable agencies. (O)

I would say to improve anything it would be nice you guys had a little extra money for more staff. (O)

Staffing is an issue. In northwest Wisconsin we have one and a half positions dealing with how many thousands of lakes. And the biggest complaint I get from the public on my side is, you know, well, 'I can't get a hold of them.' Well, unfortunately, X is tremendous but there's only so much people can do. (C)

More money, for more positions to do more surveys. (DNR)

I have a myriad of things that I'm responsible for. When people have retired I've taken over their areas. My PD [position description] doesn't even represent. I have 3 additional counties, plus the X system, grants, that's not even in my PD. (DNR)

Some also noted that permanent employees with more institutional knowledge should be making management decisions rather than limited-term employees (LTEs).

Oh boy, I should be talking to my legislator on this one. We've got to be able to make sure that those folks have stability. Have stability in their jobs, have stability in their expectations of what they are charged to be doing. (L)

I worry about funding and staffing for the program. I worry about loss of expertise as long-serving people retire. (O)

So the answer for a lot of people because it's the only thing we have to do, is we hire LTEs and you train them. But initially it's a workload with an LTE because you have to train them. In my case, I had the same LTE for over 3 years and he ended up being very, very good and saved me time but now he's moved on an I'm back to where I was. And it's just, we just don't have enough staff. (DNR)

Other suggestions for reducing DNR staff workloads and improving connections with stakeholders were to develop streamlined APM grant and permitting process and for DNR staff to give greater priority to their APM duties.

My strongest interest in our APM improvements is to come up with a streamlined APM planning process and form. (DNR)

With the grant program and permitting process, and all of that, I think there's some opportunity to streamline that process a little bit…It just seems that sometimes that process holds us from taking action. (M)

I think the program's evolved so much in the last 10 years that one person per region can't do it anymore because the amount of decisions, the amount of information now that goes into every permit is so much different than what it used to be. And that makes it harder, it's a bigger time-sink now and it requires a lot more thought and if people don't have the time for that between their other work duties, and if it's not a priority because people don't like it, it gets set aside. (DNR)

Collaborative Approach: Stakeholders suggested increased collaboration between DNR APM staff and stakeholders. They described the benefits of a collaborative approach, the need for APM staff to communicate their rationale for making permitting decisions, and their current concerns over a prescriptive model.

Interviewees from various stakeholder groups emphasized the importance, benefits, and rationale for having a collaborative approach to APM, saying it could help optimize the decision-making process and make it more efficient.

I would prefer that our interaction with DNR and working with DNR would be a bit more collaborative and have a bit more equality between the different stakeholders, rather than being for the most part completely defined by the county and the city. A more public and open process would be appreciated. (L)

My impression, personally speaking, is that the State often times sort of designs things in a certain way and then sort of tries to tack on how they're going to deal with this requirement with the tribes. (O)

I feel Wisconsin DNR has been more willing to listen to applicators. And I think that's really, really important because applicators or water management companies, you know, they're out in the field a lot and everybody and anybody that is should all kind of share notes, so to speak. So you can see what's going because if notes are compiled on that, it's going to make the best decisions. (M)

Having a good relationship where you can approach, and talk about different products to be permitted and what they think about this or that or trying different things, is really important. But I think, having your applicator and your consultant and your DNR all open and on the same page, or at least on the same page once strategies are implemented, is key. (M)

We've always looked at working with the department as a team, to meet the same endpoint. That is what we expect from them as well. (C)

What good would come from a poorly executed management plan? I would think it's everyone's intention to maintain the clients they have, while obtaining new ones. In this respect, all of what we suggest for management is self-regulating. It's in our best interest to promote native species, a healthy fishery, and ultimately an improved recreational resource. With social media today, a poor decision in the field has long-term ramifications. (M)

Private consultants and management professionals described that DNR needs to better communicate up-front what management actions may or may not be allowed, and circulate the research findings prompting their reasoning more quickly and effectively.

One thing that would be really helpful from the agency is to have a better understanding of policy as it develops. And I think part of that is understanding the research. I think the research that DNR does and may have available to make policy decisions is really important to share, the results. And so, sometimes there's policy changes that are coming about and it's unclear what those changes are going to be for quite some time. And the research, or the information that is leading to those policy changes isn't really readily available. (C)

You send in the permit application and then you get a call back, like so, 'Why are you doing this?' or 'Why are you still doing this or still doing it the way you've always done it?' But until we have an alternative or more guidance, I'm at a loss. It just feels like the information that's being presented should come with more guidance or expectations on how they expect treatments to take place. (M)

We talked about tradeoffs [earlier in this interview]. What are (DNR's) tradeoffs, as far as, ok you're going to do this at this particular site. If you see potential for harm to something, over and above what we do, let's talk about it. (M)

Multiple lake organization representatives and private managers stressed the value of the input and assistance provided by the commercial managers or consultants they work with regarding decision-making and understanding the APM process. Several private managers also feel that a more collaborative and respectful, rather than prescriptive, approach would be an improvement.

We're all striving to achieve the same goal. The DNR and those of us in the private sector need to work together and our thoughts need to be considered with equal weight. Currently, I don't feel our professional ideas or opinions are taken seriously. (M)

If I were to ask if (DNR APM staff are) open-minded about chemical application as a viable tool, more often than not as our group would look at it, they're more anti-chemical. And to have that classification up-front to start with, that lessens an open-window for negotiation. (M)

I don't think that the DNR, I think they're starting to cross some boundaries that they shouldn't when they recommend specific herbicides, specific doses. I don't know that that is their spot, especially when we have environmental engineers here that could be doing that. (M)

If we're on site and have those situations and we can't talk to anybody, and say 'this is a much better way of doing it', we're going to be back in here treating it again and again and again. And it's going to spread and now *we have to do a whole-lake treatment versus, 'oh man we could have just done this'. As a group we should be working together instead of, yeah, you guys have to regulate, we have to have regulators in our field. (M)*

Without private aquatic plant management companies and consultants, our state's entire APM program and those employed through the DNR for APM would cease to exist. (M)

Enhanced Public Outreach: The need for enhanced communications to the public relating to APM issues was another commonly noted area for improvement when interviewing APM stakeholders. Interviewees described why APM outreach is needed by DNR, some specific topics needing communications, and the importance of engaging a variety of stakeholder groups.

Interviewees across stakeholders groups suggested that DNR should put greater emphasis on APM-related public outreach to increase awareness and support. Some individuals noted that the DNR is well-positioned to do this because of our work throughout Wisconsin.

I think in general, the exposure to the literally millions of people in our state is what should be the focus. (C)

The lake districts that I work with have evolved into advocates but they serve a public that's only loud when they have a plant bed that's too thick. (DNR)

A lot of the smaller individual lakes and areas, you know, we don't have the statewide perspectives of what's going on. It's harder for us to share information, to know what's going on. So I think the more we can share information, and work with the DNR and the State, you know I think there's a tendency for someone on a lake to think that when something's happening, it's happening just to them. And most of the time it's not. And I think that's a big thing to understand. (L)

Because you guys [DNR] manage the entire state, you see best practices so you could help in developing best practices throughout the entire state. (O)

Some interviewees described specific topics for which public outreach is needed such as management tradeoffs, AIS prevention, updates on new AIS, Citizen Lake Monitoring Network (CLMN) efforts, and what has been learned from CLMN data. Some also noted that DNR needs to make use of various media outlets to communicate with stakeholders.

There needs to be more education. The public needs to be better educated. One, to keep stuff out. And two, about the effects of what they're doing has on the lake, really. (O)

Just keep us in the loop. People we've worked with have always kept us in the loop, even the local conservation officers. One thing, it seems like the DNR collects a lot of data but what do you do with it? How is all this data helpful? You have to let us know how it's helpful. I took all those water samples, measure the half-life of the endothall, it's a lot of work. So, what? (L)

They need more than a little poster, saying this is what you do from keeping the contamination going from one lake to another. There should be some workshops that are being done. And there may be but you're sure as heck not telling us about it. So we don't know if there is and if it's not, there should be. (L)

(Minnesota DNR is) telling us what's been discovered where, and when, and what they're doing about it. And a new invasive has come down the pike and details of letting your plants go. You name it, there is something on (their email communications) every time. That is not the case with Wisconsin at all. (L)

Stakeholders are more aware than ever and are demanding more engagement, I think, than ever, and communicating in new ways. And DNR, from what I hear a lot of it is no fault of your own, is somewhat limited in its ability to communicate. (O)

Some interviewees stressed that outreach efforts should target audiences who may not be actively involved in APM, but otherwise influence or are affected by it.

If I had one recommendation to make, it's how do you get to a broader audience? How do you get to the point where you've got everybody on the lake aware and helping to manage the aquatic community? (L)

Finding ways to make sure that we're reaching out to stakeholders and understanding that stakeholder doesn't necessarily always mean local anymore. (O)

When it comes to aquatic plant management, what very often happens is there's kind of the same input by the same people who tend to be people like your lake association, that isn't always guided by best practices for an environment. (O)

Additionally, some individuals representing lake and conservation groups have expressed that it can be difficult for individuals interested in initiating APM activities to navigate the grant and permitting processes, including understanding the roles of DNR, counties, and other entities, who to talk to at DNR, and where to start.

The concern is that there's not clear communication, or a clear path of how to request [permits] or get those things through. (O)

I think that a pretty significant number of the 'issues' between various stakeholders and DNR have a lot to do with the fundamental structure of DNR, the number of biologists scattered across the state and their high level of autonomy, it can be a very byzantine organization to navigate without years of relationship building. (O)

Some interviewees also noted that DNR should strive to have a better rapport with the public by moving away from a strictly regulatory approach.

I think (DNR staff) need to get out a little more and, so the general public's not, I think the general public's afraid of them. And you know, the people that we're dealing with, there's nothing to be afraid of. I don't think people differentiate between, 'DNR is the warden'. That's what they see. I didn't know that you guys did all this other stuff until I got totally involved in it. I really didn't. (L)

The public is so anti-DNR in so many respects. The public does not look at the DNR as much as they should as a helping hand. (M)

I think we need to get folks, DNR staff, to start taking a little more proactive role in APM instead of treating it as something they don't want to do because it's unpopular. A lot of folks don't like regulatory programs. I guess it comes down to how you want to make it, if you come in thinking it's strictly a regulatory program, of course *you're going to think that but if you come in thinking that APM is a tool to change peoples' philosophies with regulatory as a back-up, that's a whole different way to approach it. (DNR)*

APM Research: Many APM stakeholders feel that APM policies and decisions should be science-based. Interviewees suggested that DNR continue to support internal APM research and communicate and integrate research from other sources. They also described how DNR's research has benefited their APM.

Individuals from across stakeholder groups feel that APM and APM-related decisions should be based on scientific research.

We would ask for more science. More and better data on what's going on with trends. When we do have questions, we look for a timely responses and accurate responses that are based on some science. That's very important to us. (L)

I'm okay with all of that [APM activities], as long as it's done like it is now, which is scientific. (O)

If it's an exotic plant and it's in a lake where its population is not crowding out any of the native species, if it just becomes another member of the crowd, so to speak, I don't see any point in adding herbicides to that lake. But, I think we need to understand those reasons <u>why</u> when we make those calls. (M)

Interviewees also recognized that more scientific research is needed on APM activities, their efficacy, tradeoffs, and new AIS.

We have to keep our finger on it. We have to do everything in an intelligent manner. (O)

I think we need to put a lot of time and research into figuring out how these things (AIS) are getting here and how they're adapting to the environment so quickly and spreading. (M)

And those are discussions we need to have. Hopefully research will continue to be conducted where we can have some viable answers to that. That, 'oh, you know well, really it's not true – we can use 2,4-D, the side effects aren't that bad. And we can be a little more aggressive.' Or, contrary to that would be, 'yes, our concerns are realistic and this data suggests that these tradeoffs are just too harmful.' (C)

Zooplankton is hardly ever included in a management plan as a parameter to monitor. Considering I just killed 20 acres of curly-leaf pondweed, how did I change the zooplankton community within that bed of curly-leaf pondweed? It's never been done, as far as I know. And maybe it should. (C)

I think we need to put some more research time into a lot of these species. I think we have a pretty good grasp on our wetland and shoreline species, I think we've maybe dropped the ball a little bit on some emergent aquatics. And with the research, I think we also need to get it to the contractors quicker. (A)

More research. On everything. Effectiveness of treatments, negative impacts of treatments, harvesting, long-term control, biological control, Integrated Pest Management, all those things. I think we could improve the program by having more knowledge to base our decisions on and being able to share that knowledge and everyone being on the same page. (DNR)

Some interviewees pointed out that DNR's research efforts have provided valuable and useful new knowledge about APM issues.

> *I could use the DNR's statistics and show them lakes right in here in our neighborhood that cycled through this stuff and they're no worse off today than they were before they did nothing. Yeah, so, just need to keep studying and understanding this. Well and the other thing, there's obviously going to be more invasives we don't even know about yet. As these lakes warm, they're going to be much better habitat for other kinds of aquatic species. So, if you don't study them from the get-go, you'll never understand 10-15 years from now what's the best strategy. (L)*

> *You know, a lot of what we do in managing these plants is from information that [DNR scientists have] generated. And if we didn't have that information we wouldn't be where we are right now. And my concern is that down the road, we're going to be lacking in those areas. Now more than ever we need even more data, more studies, more information if we're going to do right by these lakes. That's a huge concern of mine. So I would say, improvement would be more from the State and less from the DNR personnel that I work with. (C)*

> *We need researchers to help us advance our knowledge. I felt like we made such incredible progress in the years that X were working in Science Operations [Science Services]. And I feel like that was just an incredible blow to the progress that were making as a leader in this country on aquatic plant management knowledge. (DNR)*

Some interviewees also felt that DNR should not only support its own research on APM but take on the role of compiling and communicating research from other sources.

> *I would also add that if there's an opportunity for DNR to be involved in compiling and sharing information from other states such as Minnesota, that would be very helpful too. (C)*

> *(Wisconsin DNR has) a hard time learning lessons that other states have learned, who may have been dealing with these things longer. We tend to, on a scientific level for whatever reason, think that Wisconsin's an island. (O)*

> *You know that Science Services work that was done for APM was really vital. It added a lot of information to what we do and I'd like to see that keep coming. We also have neighbors to the west that are doing quite a bit of APM science. So sharing with them, seeing what they're doing, that's really important. (DNR)*

Consistency and Flexibility: APM professionals have noticed a need for consistency in decision-making by DNR APM staff statewide to make APM processes more efficient and reduce uncertainty among partners. However, individuals representing various stakeholder groups also recognize that APM decisions need to account for differences across waterbodies and therefore, some flexibility in the decision-making process is also needed. Several approaches towards consistency were suggested.

DNR and private APM professionals recognize the need for consistency in APM grants and permitting processes throughout the state.

> *There isn't consistency throughout the department. I have clients that get frustrated, we get frustrated. We sign a permit in one part of the state which will be approved which would never be approved in another part of the state. All those permits are well within the confines of administrative code. (M)*

If we're out with a half dozen aquatic plant coordinators, I guarantee I'd get a half dozen different answers to it. A particular question or a concern at the time or whatever. (M)

There's sometimes a large inconsistency in what's allowed and what's not from a particular task member. Even within the same general X Wisconsin region. So that's hard. It's one of those things I haven't completely understood. (M)

It seems every year there's a shift in the focus for what's being considered most important in management planning. Certainly in the grants program. You know, I think you could rank the same grant exactly word for word every year, and every year, someone's going to have a different take on it and focus on something else in it. So this makes writing grants extremely difficult because you never quite know what's going to be focused on in any given year. (C)

There is in my mind still a lot of, I guess the best way to say it is confusion, in the state trying to figure out exactly how they want to move forward, support, and develop the Aquatic Plant Management program. (C)

Currently, inconsistency has resulted in uncertainty regarding what APM actions are permissible, inefficiencies in program processes, and loss of trust from permitees.

Sometimes we're unclear if the opinion of the lake management coordinator or aquatic invasive species specialist is their particular opinion or if that's something that's the State of Wisconsin's standpoint. (C)

Right now, our lake groups really think that with the inconsistency that something is broken. And that's where we get these outcries. (C)

DNR APM staff and private managers have suggested several approaches for becoming more consistent in APM decisions statewide, including development of a decision-making protocol, hosting more training for DNR staff and relying on permanent staff for permitting, definition of what constitutes nuisance aquatic plant conditions, revision of the legal guidance for APM in the state, better enforcement of APM legal guidance, and compiling relevant APM information into one accessible location.

They should ultimately be following the same protocol, at least within the same region of the state. I can certainly see decisions being different when you get to central Wisconsin or northern Wisconsin. (M)

Relying less on our LTE staff to run the program. I think we should have permanent staff all on the same page and run the program. (DNR)

If you eat, live, and breathe APM, I mean that's your job and you don't have these other responsibilities. And I think the State could afford to send these people to trainings. You know, they could be coordinating for a region, and I think we'd have a more consistent approach statewide. (DNR)

What is a nuisance condition? That really isn't a north-south thing. That's a condition of the community thing. Can you get your boat through? If we had a policy that had been vetted through the 21-day process, here are the criteria, that's going to make life easier for everybody, right? (DNR)

I could see combining 107 and 109 in the future. That would be a great help. (DNR)

If a formal request for a review of an aquatic plant management plan is made, I seem to recall that the State was maybe given like 40 days to review that plan and get back to the person. So what happens if those 40 days aren't met? (C)

We would have, I don't care if it's electronic or physical or whatever, but we would have information, in writing, compiled that we could refer to. So I don't have to go all over the place trying to find information. Tapping my memory, reading old meeting notes, calling people, it would just kind of be in one place. Someone would be in charge of maintaining that. And adding to it and organizing it and weeding out old stuff that's no longer relevant. (DNR)

Interviewees representing various stakeholder groups also noted it was critical that there be enough flexibility for regional DNR APM staff to make decisions based on differences across waterbodies. While acknowledging this, private managers and consultants have also requested set standards for what DNR APM coordinators expect in APM permits, plans, and grant applications. In addition, several DNR APM coordinators cautioned to avoid policies that are too lenient by moving toward consistency.

This idea that we can manage from Madison, I've got a real problem with that. Yeah, we gotta have a hierarchy of structure. But the people that know what's going on are the people out in the trenches. (L)

The way it sounded to me was that (the local department APM coordinator) got (the permit) and then he had to send it to Madison and wait for Madison, then they would send it back to him. And so I don't know, something didn't seem real efficient in that whole process. And if we're going to deal with X, let the guy do it. (O)

I think if you're going to hire people to be the front line of your organization, then you're going to expect a certain level of knowledge and education and background when you hire those people. Then, you need to let them do their job. (C)

Wisconsin is diverse, especially in its lakes, you know. And there is a marked difference between northern Wisconsin and southern Wisconsin. The geology's different, the plant species are different, the land use practices are different. And there is no single line that divides northern Wisconsin from southern Wisconsin but having a little more regional autonomy to manage the lakes in your area would be a little bit better. (DNR)

Moving forward we would like to see consistency in standards. There's a lot of talk in the past year about aquatic plant management plans, what that is, who needs one, and timing. That's so far all over the board and can be applied differently. We acknowledge that there isn't a one-size-fits all when it comes to lake management. But that should not be based on some kind of latitudinal gradient. It needs to be based on the quality of the ecosystem and the parameters of the ecosystem. (C)

I think that there needs to be some leeway in the way things are handled. You know, if we're getting cooperation and being successful with having in place our northern APM strategy, without forcing it down anybody's throat, without actually saying it's a rule, just saying it's a way we would like to operate and we're being successful at it, I'd hate to have it be thrown out the window because that same strategy can't be used in another part of the state. (DNR)

Some commercial managers suggested that DNR's APM program develop a set of standards or guidelines to assist with the bidding process for companies competing for APM contracts.

The lowest responsible bid should be up to whoever's making that decision on what they feel is responsible. So again, I think that goes back to equipment capabilities, things like that and maybe this bid vetting process needs to be looked at and maybe even standardized, or at least guided. So if a homeowner or anybody's looking at these bids, they'll be able to tell the difference. (M)

We've seen, where we're not necessarily the lowest bid in the project, so a lot of times we don't get hired for that reason. But we've also seen other firms that are also not the lowest bid get hired for the same type of jobs. And it seems there's companies that seem to have more influence in the state. (M)

Grants and Fees: Representatives of each interviewed stakeholder group feel that DNR funding for APM projects is extremely valuable and suggested increasing funding allocated toward APM projects and personnel. At the same time, some stakeholders requested reduced application fees. Some suggested updating the grant criteria to accommodate a wider range of project types and that DNR consider how APM in Wisconsin could proceed if available funding were reduced.

Interviewees from across stakeholder groups emphasized the value of DNR grant funding and felt that grant funding is critical for supporting their APM activities. Several individuals suggested there be more funding allocated to APM to support more projects, longer projects, and county coordinators.

We should probably have an increase in the amount of funding we have for all of our lakes and lake studies and planning grants and harvesters, you know. I don't want to say jack up the gas tax that funds that all but we should probably jack up the gas tax that funds that all because that's how you connect with the people. So they understand why, 'hey we got this Lakes Tax'. Well yeah, no kidding because we have 17,000 lakes and our #1 industry in the State of Wisconsin is tourism. And without those lakes in their current condition, that's going to be a problem. (C)

It would be nice to see a little more funding freed up or at least to help fund the counties in their AIS efforts. We have these AIS coordinators coming and going and the grant funding being there and not being there. It's nice to have some staff that's here and going to be here in the future to work with these lake groups because we have a working relationship with them, a little closer than DNR can manage with the larger areas that they have. (O)

For the aquatics on the shoreline and wetlands, sometimes with our project funding, that'll only go 1 or 2 years, and very rarely 3 years. Sometimes we need more than that on these projects to complete the job. (M)

Some interviewees also suggested expanding grant program criteria or partitioning funding between different pools for different types and scales of projects. They also suggested that available grant funding should cover a wider variety of APM techniques.

There's a lot of criteria in those grants ranking-wise and so on, that a small lake group, flat out can't get points for it. So the discussion has been, is it possible, is it reasonable, is it even worth considering, to divide the grant funding into other categories. (C)

Reconsidering some of the management options and the grant funding associated with them. Even if, they're still just like, 'harvesting is just a maintenance option you know', but so is a lot chemical control. So I think we need to look critically at all the management options and figure out how we're going to fund them. (DNR)

More money needs to be in the grant program to help pay for lake districts to do the Integrated Pest Management measures. (DNR)

Some interviewees suggested DNR reduce the amount of grant funding allocated for herbicide treatments of established non-native plant populations or developing an approach for conducting APM if grant funding were not available in the future.

I guess the one thing I would say is, as far as aquatic plant management goes, I would not allocate so much funds to do herbicide treatments on curly-leaf pondweed, or herbicide treatments at all. After you've had a population for 4 or 5 years, if you haven't managed to get it under control, I think you do it on your own dime because that money could be used better someplace else. (O)

I'd really like to know what the DNR has in store if this money starts drying up. You know, getting less and less. What's their plan of action for combatting aquatic plants when these funds…you know, I just can't see it being sustained like this forever and so what's going to happen? That's what I'm interested in seeing is what is the long-range goal for the DNR with aquatic invasives, under the assumption that they're not going to be throwing 6 million dollars a year at this problem? (O)

While some interviewees suggested increases in grant funding, others also requested reduced application fees to encourage APM activities.

I think there's definitely room for improvement when it comes to restoration practitioners out on the landscape. I want to protect our resources and do everything we can but I think in some cases the fees associated with good people doing good work, that can be a hindrance to getting good restoration work done. (O)

I understand that folks in the DNR have to get paid some way and one way is to charge a fee for your activity in the permitting process. But now that so much of it is electronic it really takes the personal commitment or time out of the process. (L)

E.4. Other Aquatic Plant Management-Related Concerns

Emerging AIS and Climate Change: Some interviewees expressed concern over up-and-coming AIS and how climate change will affect APM, as well as the need to have a plan in place for confronting these challenges.

Two things bother me. One is climate change. Mainly the things we can't control. Climate change and the other thing is invasive species. And so, you know, we can control, we're working on reducing phosphorus delivered to our lake, which is a lot of peoples' big challenge right now. But I think we can win that. I think we are making progress there. But, with some of these things, aquatic invasive species and invasive species in general, are very scary. (L)

With how important this program is, you know, AIS is this never-ending saga with new species coming in constantly. The problem, the issue, that we face right now, which you're probably going to discover with an exercise like this, an analysis like this, is it's probably going to get more profound as more and more species enter the fray. (DNR)

Personally I'm concerned about new invaders and catching them and managing them quickly. That's really the gist of it. I think there's, in our case, there's an awful lot of time and money spent on just managing milfoil and I think there's other things certainly in a riparian area that are growing quickly in severity. (L)

AIS Prevention: A few lake and outdoor sporting group representatives discussed the importance of invasive species prevention efforts when asked about their response to non-native populations. Interviewees also suggested strategies for enhanced AIS prevention efforts, including heightened penalties for boater violations, interrogation of commercial entities that may introduce AIS, and restricting access to invaded waterbodies.

The better process is to stop them from being there in the first place. (O)

We try to stay linked with people so we can see this stuff coming, it's really critical in all of this. We're finding out stuff just by having these meetings. Central communications is really important. (L)

If people are violating, and I'm not saying it's the law enforcement, but boy I don't think it hurts to have a picture taken of that weed and that boat and license and a little follow-up with them. (L)

I think there should be much more aggressive interrogation of all of the commercial entities that may bring these kinds of, interrogation and regulation of any organization or entity that will bring a non-native species into the lake or into the state. (O)

One thing that the DNR seems sort of oblivious to, and I don't think they're totally oblivious to it but, the way that they manage boat traffic from lake-to-lake. Obviously these exotic plants are traveling from lake-to-lake, they're spreading…I think the access to lakes needs to be restricted in some way. (M)

Established AIS Messaging: In light of new research showing Eurasian watermilfoil remains at low abundance in many Wisconsin lakes, some DNR staff have suggested a "wait-and-monitor" approach to management to help save resources. In response, some interviewees would like for DNR to have a plan in place for those waterbodies where Eurasian watermilfoil and other established AIS populations grow to high abundance.

What if Eurasian watermilfoil all of a sudden shows a spike? What's the DNR's position, you know? Would you come in and take care of it? Or is it up to the lake people, the people on the lake, to pool the money? (L)

If the DNR is recommending you take time off and see what happens because granted the data is showing in some lakes it doesn't become a problem, that it stays below nuisance levels, that's understandable. But on a lake where it has been a problem and you're telling the lake group to take some time off, that doesn't come with any sort of assurance that if it becomes a problem and it becomes beyond their financial means, that there's some sort of guarantee that the DNR will step in and help them financially. It's still going to be their primary financial burden. (M)

What I would like to know is, to see done is, for the DNR to selectively help people out if you've got an invasive species that's gonna overtake your lake. (L)

Nutrient Reduction and Watershed Health: Some lake groups highlighted the need for big-picture approaches addressing issues at the watershed scale or identification of watersheds for tax purposes to support waterbody improvements.

We try to take a broader picture approach. So we move from the specific example to talking about plants being part of a healthy lake, that we're a mesotrophic lake, probably moving towards eutrophic, and eventually try to move the discussion to a larger question about the watershed and non-point pollution. (L)

We're a runoff lake you know, but huge. And that's where the people in that watershed need to all be working together or at least funding together, projects. And that's just not happening. Trying to do projects on such a small group of people, the burdens are excessive. And if you spread it out or force counties to do a county tax or something and so much money had to go towards lake projects, even if they did it by drawing straws, great. But once one lake is up to par, then you work on the next. (L)

APM Code Revision: Some consultants and many DNR APM staff made suggestions for a revised administrative code and the benefits a revised code could have, in addition to improving statewide consistency in APM decision-making and incorporating some of the other topics described earlier. A small subset of these suggestions is included here.

NR 107 and 109, it should be put together and updated, it's so old. There's still, you can't do treatments within 150 feet of shore, you need to notify affected riparians but no one knows what an affected riparian is. And then there's, you have to send a copy of the permit? (C)

How do potential effects on non-targets affect my decision? I don't think it does as much as it should because the code doesn't allow that. I mean, we are really kind of bound by what the administrative codes say. (DNR)

I think we've learned a lot about concentration and exposure times, especially with herbicides like 2,4-D. We should probably get to a point where we permit more based on that than anything, where we're sure that it's going to work in the first place. If we're going to be putting herbicides into a waterbody and potentially causing impacts, at least we need to know that it's doing its job. (DNR)

I'd really like to see it put in administrative code, that if you're doing any sort of aquatic plant management, two consultants need to be involved. One consultant who does the surveying part of it and then a separate chemical applicator who implements what the survey consultant recommends. So there's not a conflict of interest. (DNR)

Balance of Social and Ecological Concerns: Some stakeholders feel DNR's APM program should put greater emphasis on environmental protections than it does currently. On the other hand, multiple interviewees noted that DNR's APM goals are currently inconsistent with the goals of lake property owners and need to better accommodate social concerns.

Our first responsibility is ecosystem protection and to the future generations coming here. In some ways, I'm very concerned that we've become far too responsive, or the State has become far too responsive to appeasing their customers in the short-term instead of taking care of the future generations of the state. (O)

From our perspective, which is of course different from others, the goal of lake management should always tends towards making a healthy ecosystem in a lake. We're not willing to make, at least not happily, very many compromises on the side of recreational boating. (O)

I think that lakes are human-coupled systems. There's a lot of humans that live around the lakes. There's a lot of humans that use the lakes. And they need to be managed considering that humans are a part of the ecosystem. (C)

Appendix F. APM Resources

- University of Wisconsin-Extension Lakes APM Guide - https://www.uwsp.edu/cnr-ap/UWEXLakes/Pages/ecology/aquaticplants/default.aspx
- Wisconsin DNR Aquatic Plant Information - https://dnr.wi.gov/lakes/plants/
- Wisconsin DNR Aquatic Plant Information, Tools and Research - https://dnr.wi.gov/lakes/plants/research/
- Wisconsin DNR Invasive Species Information - https://dnr.wi.gov/topic/Invasives/
- Wisconsin APM Permit Search Instructions: How to Search for an APM Permit - https://dnr.wi.gov/lakes/plants/WaterPermitSearchGuide.pdf
- Wisconsin Healthy Lakes Program - http://healthylakeswi.com/
- Online Virtual Flora of Wisconsin - http://wisflora.herbarium.wisc.edu/