ANALYSIS OF TREATMENT ALTERNATIVES FOR INVASIVE WATERMILFOIL IN NOXON RAPIDS AND CABINET GORGE RESERVOIRS, SANDERS COUNTY, MONTANA

Lisa A. DeBruyckere

Dr. Toni Pennington

July 2017

CONTENTS

LIST OF FIGURES

LIST OF TABLES

EXECUTIVE SUMMARY

The Sanders County Aquatic Invasive Plants Task Force (Task Force), in cooperation with the Montana Department of Natural Resources (DNRC) and Montana Fish, Wildlife & Parks (FWP), contracted with Creative Resource Strategies, LLC to conduct an analysis of management and treatment alternatives for invasive watermilfoil (Eurasian watermilfoil [*Myriophyllum spicatum*]; EWM and hybrid watermilfoil; HWM)and provide an objective analysis of treatment alternatives to address established invasive watermilfoil populations in Noxon Rapids and Cabinet Gorge reservoirs.

The process used to develop the alternatives included a review and compilation of:

- Background information on key components of the reservoirs, including management purposes and priorities, water quality, trends in aquatic invasive species through time, and public and private access;
- A compilation of information on the fisheries priorities for the reservoirs;
- A literature review on the association between macrophyte biomass and fish, and a summary of information on invasive watermilfoil;
- A compilation of management goals for Eurasian watermilfoil (EWM) in the region, state, county, and Noxon Rapids and Cabinet Gorge reservoirs as well as federal policies and plans associated with the prevention and introduction of invasive species;
- Permitting requirements associated with different treatment options;
- A compilation of information on the physical, mechanical, biological, and chemical methods used to control EWM, including costs, advantages, and disadvantages of each approach as well as the most appropriate locations and scenarios for each application;
- A summary of control efforts and funds expended to date to address invasive watermilfoil;
- Outcomes from a survey of and workshop with Task Force members; and
- Consequences/outcomes of a No Action versus an Adaptive Management Action option.

Task Force members redefined success moving forward: seek to contain and control existing Aquatic Invasive Species (AIS) populations as well as prevent new introductions of AIS within Cabinet Gorge and Noxon Rapids reservoirs; reduce the presence of AIS at or near public and private access sites, including boating access sites; and promote sustainable long-term management of EWM and other invasive aquatic plants to reduce negative impacts to natural resource communities while addressing broader reservoir uses. In addition, they defined how success would be measured, including assessing public recreation levels and satisfaction with recreational experiences; public awareness of AIS, which includes boats leaving the reservoirs clean, drained, and dry; reductions in AIS at public access and use sites in the reservoirs; compliance with state AIS laws; engagement in prevention efforts by local residents; and implementation of a monitoring program that informs annual treatment efforts as well as long-term trends.

Annual prioritization of treatment areas will incorporate the size/density of invasive plant infestations, location of infestations (e.g., sites with significant public use to reduce spreading by boats and trailers), upstream versus downstream sites (to minimize reinfestation), water exchange processes, areas that protect water intakes and improve fish and wildlife habitat, and the practicalities associated with managing these run-of-river reservoirs. The highest priority treatment areas are public or residential use sites, which include boat launches, dock access areas, and designated recreation and swimming areas; a suite of containment and control options were described for these three types of sites. In these areas, barriers, hand-pulling and herbicides are the primary control treatment options. The second highest priority treatment areas are those with large, high invasive plant density and shallow access areas with significant boat traffic. In these areas, herbicides are the priority control treatment option. Both priorities listed below will be addressed in the context of treating all sites upstream to downstream, assuming widespread presence of hybrid water milfoil (HWM), and basing prioritization on fall monitoring results crosschecked with spring monitoring results. At this time, the Task Force did not prioritize further because funding would likely be inadequate to completely address the second highest priority treatment areas.

A new two-phased process will be used to draft a set of annual treatment recommendations. The Task Force will create a Scientific Advisory Panel or Committee, which includes a subgroup of the Task Force, to draft a set of annual treatment recommendations for technical advisor review. The Committee, which would consist of invasive plant specialists, fish biologists, Avista employees with familiarity of benthic barrier sites, and others, will propose a prioritized list of treatment sites and control options for review and input by the technical advisors, who would then present the proposed plan of activities to the Task Force. Creation of this subgroup incorporates more site-specific knowledge of the system, recreational fishery activity, and other information into the proposed plan of action prior to determining the specifics of which herbicides will be applied.

Two types of surveys will advance the ability of the Task Force to achieve their goals: annual boat launch and public access site surveys as well as biannual (twice annually) whole lake surveys.[1] The data collected during these surveys will have consistent data collection and recording methodologies to enhance understanding

[1] Note: Annual surveys would be ideal, however, funding may preclude annual surveys. At a minimum, biannual surveys should be conducted.

and use of the data across years and between treatment plots. All contractors will adhere to consistent metadata requirements to provide consistency between sampling events.

Two recommendations should be implemented to enhance planning efforts and surety associated with plan implementation: develop a Funding Committee within the Task Force to seek new sources of funding to achieve the goals of the Task Force; and engage DNRC, FWP, and Montana Department of Agriculture (MDA) staff to discuss the potential to shift the timing of grant applications as well as consider grants on a 2-year funding cycle, which would allow the Task Force ample time to adequately prepare for and implement treatment options.

ANALYSIS OF TREATMENT ALTERNATIVES FOR INVASIVE WATERMILFOIL IN NOXON RAPIDS AND CABINET GORGE RESERVOIRS, SANDERS COUNTY, MONTANA

OUR APPROACH

This report summarizes the results of an analysis of treatment alternatives for invasive watermilfoil in two northwestern Montana reservoirs.

A significant amount of information has been summarized to date on the physical attributes of these reservoirs, different treatment options available to control aquatic invasive plants, permitting requirements, and past control efforts (e.g., Getsinger et al. 2017, Duncan 2011, Tetra Tech 2010). Although we reference and summarize some of this published information, our intent was not to replicate previously published and widely available information. Rather, this effort was focused on analyzing past control efforts, identifying key gaps, anticipating major challenges, and developing a suite of recommendations that best positions entities interested in aquatic invasive plant control in these reservoirs and adjacent wetlands and rivers to achieve their conservation and management goals in both the short and long term.

Lisa A. DeBruyckere
Dr. Toni Pennington

PURPOSE

The purpose of this document is to present the results of an analysis of methods for treating Eurasian watermilfoil (*Myriophyllum spicatum*) (EWM) and hybrid invasive watermilfoil (HWM) in Noxon Rapids and Cabinet Gorge reservoirs in Sanders County, Montana. The analysis includes a discussion of benefits and challenges to each type of treatment, and the extent to which each treatment method, or combination of methods, addresses the management goals and objectives developed by the Aquatic Invasive Plants Task Force (Task Force). The results of this analysis will be used by the Task Force, Montana Department of Natural Resources and Conservation (DNRC), and Montana Fish, Wildlife & Parks (FWP), to prioritize various treatment alternatives to determine the methods that will provide the greatest control of invasive watermilfoil (EWM and HWM) with the most support for management goals and objectives within existing environmental, operational, and financial parameters.

BACKGROUND

Noxon Rapids Reservoir was created by the Noxon Rapids Dam, which was completed in 1959 and is operated by Avista Utilities. The reservoir is on the Clark Fork River in Sanders County near the city of Trout Creek, Montana (Figure 1). The 35.5-mile long reservoir is 2.5 miles wide and bound upstream by the base of Thompson Falls Dam, which is owned and operated by NorthWestern Energy. At full pool, Noxon Rapids Reservoir is 7,852-surface acres with an average depth of 65 feet and a maximum depth of 200 feet (Washington Water Power, 1995). Drawdowns in Noxon Rapids rarely exceed 12 feet.

Cabinet George Reservoir was created by the Cabinet Gorge Dam in Idaho in 1952 and is also operated by Avista Utilities. The reservoir spans the Montana and Idaho border (Figure 1). The 18-mile reservoir is about one-third of a mile wide and is bound upstream by the base of Noxon Rapids Dam. At full pool, Cabinet Gorge Reservoir is 2,879-surface acres with an average depth of 67 feet. Drawdowns in Cabinet Gorge rarely exceed five feet.

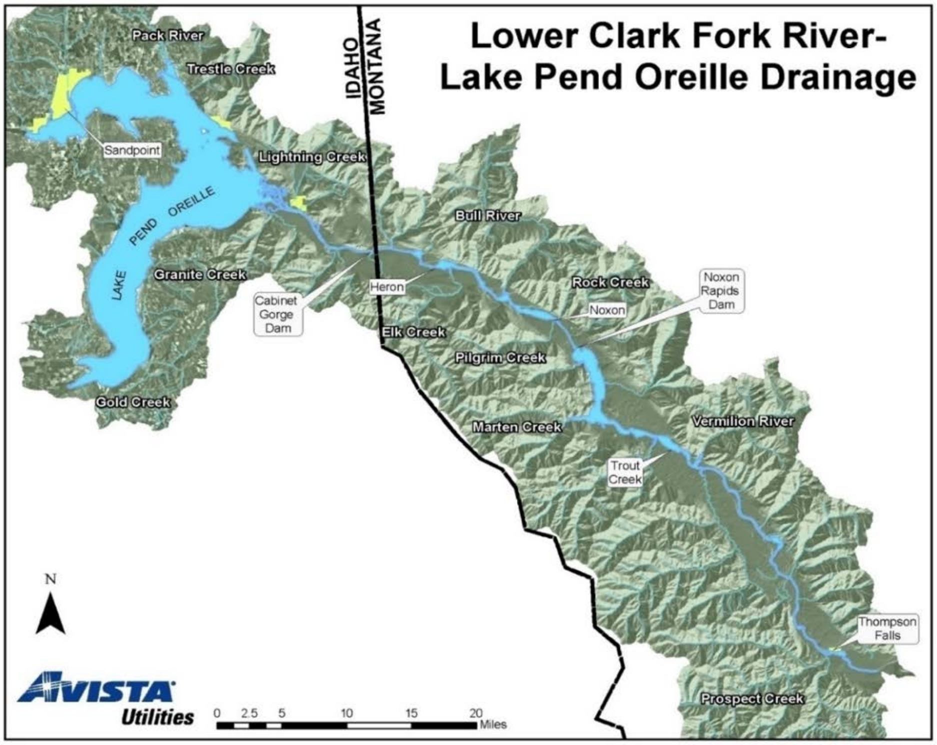

Figure 1. Lower Clark Fork River- Lake Pend Oreille Drainage, showing the locations of Noxon Rapids Dam and Cabinet Gorge Dam.

The two reservoirs were created from the largest hydroelectric dams in Avista's hydropower portfolio. Noxon Rapids and Cabinet Gorge reservoirs are "run-of-the-river" reservoirs, which means there is a significant amount of water fluctuation and movement through these systems. The primary purpose of the dams is to generate hydroelectric power, followed by flood control as a secondary purpose. Water discharge from the Noxon Rapids Dam corresponds to summer-time peak electric power demand, and ranges from 50–100 cfs between 11pm and 8am to 26,500 cfs during the day (USACE 2014). Other uses of the dams and reservoirs include providing fish and wildlife habitat, protecting cultural and historic resources, and offering recreational opportunities.[2]

Littoral Areas in Noxon Rapids and Cabinet Gorge Reservoirs

Littoral zones of lakes and ponds are often both physically complex and spatially patchy (Crowder and Cooper 1982). The slope/depth of the littoral zone, along with sediment type and water quality characteristics (e.g., transparency) have been used to predict the potential maximum submersed macrophyte biomass (Canfield et al. 1985; Duarte and Kalff 1986; Duarte and Kalff 1987; Bornett and Puijalon 2011). The *Invasive Aquatic Plant Control for Noxon Rapids and Cabinet Gorge Reservoirs, Montana: An Adaptive Management Plan* (Getsinger

[2] https://www.avistautilities.com/environment/clarkfork/pages/default.aspx

et al. 2017) documents the extent of the littoral zone in both reservoirs and that “based on the 2008 survey results, the maximum extent of the littoral zone (and thus the maximum potential for EWM infestation), based on deepest extent of plants observed, was set at a depth of 25 feet for both Noxon Rapids and Cabinet Gorge reservoirs. Using these data, a littoral zone of 2,200 acres for Noxon Rapids (30% of surface area at full pool), and 1,200 acres for Cabinet Gorge (40% of surface area at full pool) were calculated, which represents the total acreage where aquatic plants are likely to occur. Of this amount, it was estimated that 83% of the littoral zone in Noxon Rapids (1,830 acres) and 90% in Cabinet Gorge (1,080 acres) could support problematic levels of EWM. These estimates were based on the presence of native plants occurring up to 25-feet deep, and the fact that EWM can grow at depths near 20 feet.” Similar estimations using a depth of 10 feet where plants have been observed growing at the greatest nuisance levels, it was estimated that up to 813 acres could be colonized in Noxon Rapids and up to 523 acres in Cabinet Gorge (Avista personal communication). These values are based on the Maximum Forebay Elevation of 2,175 feet above mean sea level (FMSL) for Cabinet Gorge and 2,330 FMSL Noxon Rapids[3] and do not incorporate previously described factors known to influence the distribution of aquatic plants; however, they likely represent the greatest potential in the absence of additional information.

Access

Numerous public access points are located along the lower Clark Fork River (Figure 2). The Clark Fork Project Recreation Resource Management Plan Draft (March 2017) describes 57 recreation sites (21 developed sites and 36 dispersed sites) associated with Noxon Rapids and Cabinet Gorge reservoirs, such as dam overlooks, access sites, boat ramps and launches, recreation areas, parks, trailheads, swimming holes, and RV parks (Pinnacle Research & Consulting 2017). Of the 57 sites, 63% are dispersed recreation sites, 37% are developed recreation sites, 48% of all developed sites are located within Noxon Rapids Reservoir, 33% of all developed sites are located within Cabinet Gorge Reservoir, and 19 % of all developed sites are downstream of Cabinet Gorge Dam (Pinnacle Research & Consulting 2017). A total of 43% of the proportion of total visitation by site type during the park recreation season in 2015 consisted of people at boat launch sites.

[3] Full pool is reached year-round. Neither reservoir experiences drawdowns for flood control. Fluctuations are a result of meeting the daily and weekly customer demand for power within the operational limits set by Avista’s Federal Energy Regulatory Commission License

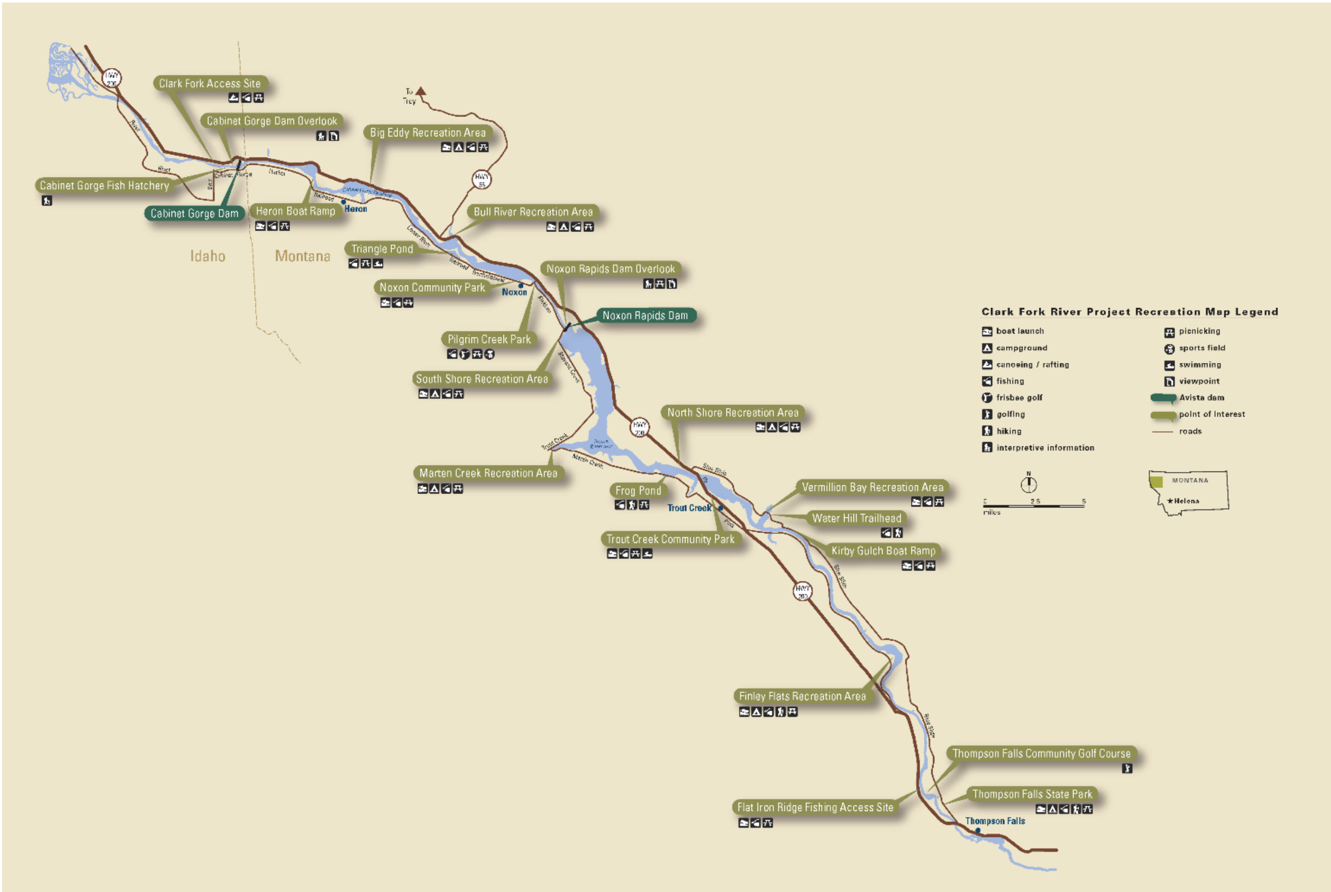

Figure 2. Map depicting public access points along the lower Clark Fork River. Source: Avista.

Water Quality

Water quality is monitored in the Clark Fork Basin to evaluate temporal trends in nutrient concentrations in the mainstem Clark Fork River and its tributaries (13 monitoring stations), evaluate temporal trends for periphyton standing crop in the Clark Fork River (seven monitoring stations), and estimate nutrient loading rates to Lake Pend Oreille from the Clark Fork River (one station below Cabinet Gorge Dam). Results of data collected from 1998–2012 (Hydrosolutions 2014) indicate:

- Overall, total nitrogen (TN) and total soluble inorganic nitrogen (TSIN) concentrations remained steady in the Clark Fork River. A marginally significant decreasing trend in TSIN was found in the Clark Fork River at Noxon.

- Summertime total phosphorus (TP) concentrations were generally declined after 1998 in the upper and middle Clark Fork River above the confluence with the Flathead River. No trends in TP concentrations were found at any lower Clark Fork River monitoring stations.

- Summertime soluble reactive phosphorus (SRP) concentrations increased after 1998 in the upper and lower Clark Fork River.

- Algal trends held steady in the Clark Fork River upstream of Missoula. No trends were detected in summertime mean or maximum chlorophyll-a at four monitoring stations upstream of Missoula.

- Nutrient loading from the Clark Fork River to Lake Pend Oreille varied year to year and was proportional to the volume of inflow from the watershed. Generally, in years when inflow exceeds the annual average, the TP load exceeded the Montana-Idaho Border Agreement allocated target load of 259,500 kilograms per year. The estimated TP load exceeded the allocated target load four times since 1998—in 2006, 2008, 2011, and 2012.

- Turbidity is primarily influenced by reservoir inflow (Beak 1997a; Beak 1997b). The Montana Department of Environmental Quality classifies the project waters in Montana as B-1 (MDEQ 1996), thus water quality must be maintained to support the beneficial uses protected under administrative rules implementing the Montana Water Quality Act. This includes no turbidity increases greater than 5 nephelometric turbidity units. Nutrient loading, erosion, and sedimentation can increase turbidity and water temperatures in the reservoirs (FERC 2000). Exposure of previously inundated areas to wind and wave action could locally increase turbidity (FERC 2000), or change shoreline sediment transport patterns. Significant reservoir drawdowns could result in extended periods of unusually high flows, and affect turbidity (FERC 2000).

- Water quality in the lower Clark Fork River is impacted by mercury from the geology of the area as well as upstream industrial activities. Permanent fish advisories for several popular sport fisheries, including walleye (*Sander vitreus*), northern pike (*Esox lucius*), mountain whitefish (*Prosopium williamsoni*), brown trout (*Salmo trutta*), and rainbow trout (*Oncorhynchus mykiss*).

NOXON RAPIDS AND CABINET GORGE FISHERIES

(Compiled from 2013 Statewide Fisheries Management Plan)

About 62 miles of the lower Clark Fork River has been inundated by the Thompson Falls, Noxon Rapids, and Cabinet Gorge reservoirs, which has converted about 66% of the Lower Clark Fork River from riverine to reservoir habitat. The drainage supports important habitat for native species, including threatened bull trout (*Salvelinus confluentus*) which exhibits both resident and migratory life histories, mountain whitefish (*Prosopium williamsoni*), westslope cutthroat trout (*Oncorhynchus clarki lewisi*), longnose sucker (*Catostomus catostomus*) and largescale sucker (*Catostomus macrocheilus*), northern pikeminnow (*Ptychocheilus oregonensis*), peamouth (*Mylocheilus caurinus*), longnose dace (*Rhinichthys cataractae*), redside shiner (*Richardsonius balteatus*), Columbia slimy (*Cottus cognatus*) and Rocky Mountain sculpin (*Cottus* spp). Native species management is focused on salmonids, and in particular, bull trout recovery, and the lower Clark Fork River is designated bull trout critical habitat. Fish passage is facilitated by fish ladders, and trap and haul facilities.

The Clark Fork Settlement Agreement (CFSA), which was adopted in 1999 with 27 signatories representing 42 interest groups, includes the Native Salmonid Restoration Plan aimed at bull trout, westslope cutthroat trout, and mountain whitefish.

The drainage also supports opportunities for recreational fishing, primarily for largemouth bass (*Micropterus salmoides*) and smallmouth bass (*Micropterus dolomieu*), northern pike (*Esox lucius*), walleye (*Sander vitreus*)—illegally introduced in the

BULL TROUT

Bull trout in the Clark Fork River system were listed as a threatened species under the Endangered Species Act in 1998. Their recovery goal aims to ensure the long-term persistence of self-sustaining, complex, interacting groups of bull trout distributed throughout the species' native range so that the species can be delisted (USFWS 2002). Within the lower Clark Fork subunit, the goal is a sustained net increase in bull trout abundance and increased distribution of some local populations within existing core areas (Montana Bull Trout Restoration Team 2002).

In both the reservoirs and rivers, they exhibit adfluvial and resident life histories (FERC 2000).

Migratory bull trout use Noxon Rapids Reservoir as feeding and rearing habitat and as a migratory corridor to rearing habitat in Lake Pend Oreille (Montana Fish, Wildlife and Parks 2013b). Westslope cutthroat trout are common throughout Noxon Rapids Reservoir and its tributaries, and migratory individuals use the mid to late 1980s—yellow perch (*Perca flavescens*), and several trout species, including rainbow trout (*Oncorhynchus mykiss*), bull trout, brown trout (*Salmo trutta*), cutthroat trout (*Oncorhynchus clarkia*), and brook trout (*Salvelinus fontinalis*). Noxon Reservoir hosts numerous bass fishing tournaments.

The state's "fisheries management direction" for Noxon Rapids and Cabinet Gorge reservoirs is to assess habitat use, survivorship, and limiting factors of reservoir-reared bull trout, establish adult bull trout passage through Noxon Rapids Dam, administer the Montana portion of the Avista fisheries mitigation program; continue the angling closure on bull trout; and monitor the population trends of all other wild fish species. In Cabinet Gorge reservoir, additional direction includes suppressing walleye populations and protecting spawning largemouth and smallmouth bass as well as monitoring the impacts of fishing derbies.

INVASIVE WATERMILFOIL

EWM is a perennial aquatic plant that remains fully submerged throughout its growth cycle. Native to Eurasia, this species is highly adaptive and can quickly occupy the water column, forming dense submerged stands and surface mats, shading native vegetation (Aiken 1981) and impeding recreation activities, hydroelectric projects, water delivery, and other human uses. EWM can adapt to environments with varying ranges of pH, salinity, water depth, temperature, and water flow (Smith and Barko 1990). EWM was first reported in the United States in the 1940s, and is currently the most widespread submersed aquatic weed in the northern half of the United States (Madsen 2014). It has been introduced to the United States multiple times and was likely first brought to North America in ship ballasts, or as an ornamental plant for aquariums or water gardens.

EWM perpetuates itself by seed, vegetative fragmentation, and by overwintering in an evergreen condition (Grace and Wetzel 1978). EWM spreads prolifically by stem fragments that are produced both naturally (when stem sections detach from the plant at abscission sites) and from mechanical breakage (when plants contact boat motors and intense wave action). EWM is easily transported on watercraft and trailers, the predominant vector of long distance spread (Parkinson et al. 2011). Spread of EWM by sexual reproduction is considered less important than spread by vegetative fragmentation, however, it has been demonstrated that seed germination occurs in EWM (Madsen and Boylen 1989; Hartleb et al. 1993; Xiao et al. 2010). Some researchers speculate that EWM may be spread by wildlife or waterfowl; however, no direct evidence exists to support this theory. One study noted the most important factors affecting the presence or absence of EWM were those that influence water quality factors known to impact EWM growth rather than factors associated with human activity and dispersal potential, such as the number of game fish species and number and types of boat ramps or proximity to roads (Buchan and Padilla 2000).[4] In one study, the presence of EWM in a lake appeared to be determined by the duration of infestation in surrounding areas and the volume of boat traffic (in less heavily infested areas, EWM beds often occurred only off docks) (Hatfield Consultants, Ltd. 1996). The spatial extent of the EWM beds appears to be primarily dictated by the width of the littoral zone of suitable depth, and the density appears to be primarily determined by substrate (i.e., mud/sand), likely due to reduced rooting and nutrient availability in coarser substrates (Hatfield Consultants, Ltd. 1996). Lakes with moderately turbid water and widespread shallow areas with nutrient-rich sediments experience the most severe EWM problems because these conditions support luxuriant milfoil growth and encourage canopy formation. In these lakes, multiple biomass peaks will often necessitate repeated control (Smith et al. 1991).

[4] The authors noted that the lower statistical significance of public boat launch sites in their analysis could have been attributable to accuracy of data and adequate data on the number of private boat launches on water bodies.

The best predictors of EWM dominance were water column total phosphorus and Carlson's Trophic State Index (Madsen 1998). EWM seems most abundant in mesotrophic lakes and moderately eutrophic lakes, and is inversely related to cumulative native plant cover (Madsen 1998). Lakes with more than 50% EWM dominance had less than 60% cumulative native plant cover.

Northern watermilfoil (*Myriophyllum sibiricum*) is native to North America. Hybrid watermilfoils (HWMs) are genetically diverse and reflect hybridization between the native northern watermilfoil and Eurasian lineages (Zuellig and Thum 2012). Morphological characteristics are not conclusive in distinguishing EWM from HWMs; however, molecular tools are available to identify various genotypes (Moody and Les 2002; Zuellig and Thum 2012). Although hybrids remain relatively understudied, they have similar nuisance characteristics as EWM (Thum 2003). There is increasing concern that HWM exhibits both more aggressive growth tendencies as well as increased tolerance to herbicides and biological controls (Roley and Newman 2006; Zuellig and Thum 2012; LaRue et al. 2012; Netherland and Willey 2017). EWM and HWM both form thick stands of vegetation that can grow 1–10 meters high in the water column. These stands provide poor habitat for fish, waterfowl and other wildlife due to the density of stands, decreased dissolved oxygen conditions caused by rapid growth and decomposition of the plants, increased pH within the water column, and increased temperature within the water column caused by absorbing solar radiation more efficiently than in open water (Valley and Bremigan 2002a, 2002b; IISC and ISDA 2007; Gettys et al. 2014). Surface mats also create mosquito breeding habitat (Jacobs and Mangold 2009).

EWM was too widespread to be listed as a Federal Noxious Weed when Montana's state noxious weed list was first developed; however, the species is listed on numerous state noxious and prohibited plant lists, and is categorized as a Priority 2A species in Montana. The first identified infestation of EWM in Montana was confirmed in Noxon Rapids and Cabinet Gorge reservoirs in 2007. The Sanders County Commissioners established a task force of agency, tribal, private industry, and nonprofit representatives in 2008 to develop and implement an integrated weed management approach to contain and manage invasive watermilfoil. The task force serves in an advisory capacity to the Sanders County Board of County Commissioners.

MACROPHYTE BIOMASS AND FISH

Invasions of aquatic communities by exotic species can lead to extensive ecological changes in community structure and function (Mooney and Drake 1986; Drake et al. 1989; Lodge 1993; Mills et al. 1993). The introduction of invasive species is one of the primary factors threatening biodiversity (Ehrenfeld 1970, Diamond and Case 1986, Mooney and Drake 1986) and is probably second only to the destruction of tropical rain forests as a general threat to the diversity of natural systems (Duffy and Baltz 1998). The expansion of EWM and subsequent formation of dense bends not only creates an impairment of human uses, but significantly alters the diverse littoral zone vegetation of lakes in which this invasive species occurs (Madsen et al. 1991).

Plant complexity

Macrophytes with a complex morphological structure are the most important factor in determining fish distributions throughout the year, and are essential for promoting a diverse fish assemblage (LaPointe et al. 2007). Macrophyte beds are important nursery habitats for a variety of fish species (Kiviat 1993; Limburg et al. 1986). Submerged macrophytes function as fish sanctuaries and feeding stations; their growth and senescence impose a structurally complex and energetic environment on interacting fishes (Engel 1987).

Habitat structural complexity may have a profound effect on ecological interactions (Crowder and Cooper 1982). Most comparative studies of plant and fish abundance conclude that intermediate vegetation levels, defined as 10-40% coverage of study sites, including areas ranging from individual coves to entire water bodies, promote high species richness and are optimal for growth and survival (Killgore et al. 1989; Dibble et al. 1997; Grenouillet et al. 2000). Habitat with moderate amounts of aquatic vegetation enhance fish diversity, feeding growth and reproduction (Crowder and Cooper 1982; Dibble 2014). Predator growth rates seem to be higher in intermediate structure habitats (Crowder and Cooper 1982).

Habitats with significant structural complexity reduce fish predatory efficiency by inhibiting foraging and reducing prey capture rates (Crowder and Cooper 1982; Engel 1987; Dibble et al. 1997). Growing shoots of macrophytes, arranged in three overlapping tiers, form a dynamic meshwork to selectively restrict fish movements (Engel 1987). A decrease in habitat complexity changes the availability of certain prey types, resulting in a more even distribution of prey items (Webb et al. 2016). Sparse structure allows efficient foraging and generally contains few highly profitable prey (Crowder and Cooper 1982). In a study by Webb et al. (2016), herbicide use reduced invasive plant biomass in the littoral zone which was rapidly colonized by native plants, and some types of prey became more available with the corresponding decrease in plant complexity.

In a study by Keast (1984) conducted in a lake in Ontario, shifts in fish and invertebrate species diversity and abundance occurred in the littoral zone, particularly in late summer. In that study, three to four times as many fish occurred during the daytime feeding period in the native plant community than in EWM bed. Beneath the native beds, five major taxa of prey invertebrates were three to seven times more abundant and the foliage of native plants supported twice as many invertebrates per square meter in late summer than did EWM stands. Although the net impact of the habitat change on the fish populations was not considered significant, the author expressed cause for concern if EWM were to replace the rich native macrophyte beds in littoral zones. EWM stands that replace native plants harbor fewer species of invertebrates, which creates food shortages for fish (Engel 1995).

Plant density and diversity

Dense plant beds obstruct the swimming space of pelagic fishes and shelter a disproportional number of juvenile fish (Engel 1995). Despite the presence of higher biomass of prey available, fish at high macrophyte densities experience reduced prey capture rates, slower growth (Crowder and Cooper 1982), and reduced encounter rates, which lead to reduced attempts to capture prey (Glass 1971). The biomass and growth form create a dense upper canopy that contributes substantially to reduced light intensity available to plants below the canopy (Madsen and Boylen 1989). High densities of macrophytes can harm the quality of a fishery (Wiley et al. 1984; Bettoli et al. 1992). For example, dense plant beds growing to the water surface are often associated with stunted fish communities (Parsons et al. 2011). Dense EWM stands support fewer macroinvertebrates and decrease fish foraging efficiency (Dibble et al. 1997; Sloey et al. 1997; Heck and Thoman 1981; Dvõraki and Best 1982; Savino and Stein 1982; Keast 1984; Dionne and Folt 1991; Engel 1995; Harrell and Dibble 2001; Cheruvelil et al. 2002; Valley and Bremigan 2002a; Theel and Dibble 2008). Both limited plant growth (i.e., less dense plant growth) and excessive plant growth provides a less suitable environment for fish (Crowder and Cooper 1982; Dibble 2014).

There are apparent benefits to fish avoiding dense patches of vegetation for both energetic and water quality reasons (Frodge et al. 1995). In a Texas lake, lower crappie growth rates corresponded to elevated macrophyte coverage and reduced threadfin shad (*Dorosoma petenense*) abundance (Maceina et al. 1991). Predator feeding rates and thus growth rates may be maximized at intermediate structure density (Frodge et al. 1995). Bluegill sunfish (*Lepomis macrochirus*) experienced higher overall habitat profitability (i.e., growing best) at intermediate macrophyte density (Crowder and Cooper 1982). When openings are created in dense macrophyte stands, through plant senescence or other means, structural heterogeneity and expanded feeding opportunities increase (Engel 1987).

Although experimental studies have shown that fish prefer areas of intermediate macrophyte density because of increased foraging success (Crowder and Cooper 1982), the results from field studies have shown that higher fish abundances may occur in areas of either high (Killgore et al. 1989; Petry et al. 2003) or intermediate macrophyte density (Killgore et al. 1989; Grenouillet et al. 2000). In a lake in New York state previously void of EWM, the introduction and subsequent expansion of EWM throughout the lake resulted in an overall decline in plant diversity as well as the diversity and abundance of the fish community whereas the bluegill population increased 24%, and chain pickerel (*Esox niger*) and largemouth bass (*Micropterus salmoides*) increased in abundance (Prisciandaro and Kuhlmann 2015).

In the Lake Pontchartrain estuary, EWM was used by fishes as much as, and even more than native macrophytes (Duffy and Baltz 1998). The authors attributed this to high wave energy in the open system, possibly preventing EWM from growing densely enough to strongly alter microhabitat characteristics. EWM can be used as a fisheries management tool, improving fish production, particularly in waters too turbid to support native plant growth, by increasing the surface area for invertebrate colonization, and thus expanding the food base for benthivores while protecting emerging year classes from piscivores (Engel 1995). Seasonal growth and senescence of the plant creates a dynamic littoral zone with expanding and shrinking openings in plant beds, cruising lanes for piscivores, and edge effect for certain fish species (Engel 1995). In a lake in Canada, the establishment of EWM beds resulted in an increase in local productivity, indicated by greater abundance of benthic and planktonic invertebrates within and outside EWM beds than at sites without any vegetation (Hatfield Consultants, Ltd. 1996). The littoral ecology of the lake was changed by the EWM infestation, but the effects were deemed neutral with respect to fish and fish habitat (Hatfield Consultants, Ltd. 1996).

Changes in water quality

Dissolved oxygen—Changes in littoral zone water quality associated with the dense growth of aquatic macrophytes can have adverse effects on the distribution of fishes (Frodge et al. 1995). Invasive plants in large, dense beds can cause extremely low dissolved oxygen (DO), particularly during periods of plant respiration (Caraco and Cole 2002). In one case, DO values below 2.5 mg/L occurred up to 40% of the time compared to large macrophyte beds dominated by native species, in which the DO never declined below 5 mg/L during the summer growing season (Caraco and Cole 2002). Dense EWM stands block sunlight penetration and water movements, depleting DO that can cause fish kills when shoots decay in autumn (Engel 1995). Dense stands of EWM in deep waters resulted in near anoxic daytime DO levels near the sediment-water interface, and significantly fewer fishes were associated with EWM beds than with the native plant beds (Keast 1984). Chronic effects of low DO concentrations include decreased feeding recruitment, limitation, or decreased population size, which may impact the number, survival, and distribution of fish in these areas (Frodge et al. 1995). Avoidance of heavily vegetated areas and migration to less densely vegetated parts of a lake, where DO concentrations are higher, would increase the density of fish in less densely vegetated areas (Frodge et al. 1995).

Chlorophyll—Macrophyte-dominated water bodies often display reduced planktonic chlorophyll levels, resulting in an artificially lower tropic state (Canfield et al. 1983) directed towards oligotrophy in the limnetic zone (Maceina et al. 1991).

Allelopathic chemicals—EWM exudes allelopathic chemicals, and researchers have shown that epiphyton growth is negatively affected by the presence of EWM (Gross et al. 1996, Nam et al. 2008). Because epiphyton is a major food resource for primary consumers, allelopathic effects of EWM likely have an indirect negative effect on macroinvertebrate abundance and, as an extension, fish foraging (Webb et al. 2016).

Particulate matter—EWM changes the average size of the particulate matter along with the carbon content of the bottom sediment (Keast 1984). In a lake in Ontario, Canada, most of the substrate in EWM areas consisted of an "organic ooze" comprised of an average particle size <0.005 mm along with an organic carbon content between 40 and 70% in comparison to areas without EWM that had a particle size between 0.07 mm and 0.17 mm, and an organic carbon content average of 4.8% (Keast 1984). Most bottom feeders tend to prefer the larger particle size and stay away from the "organic ooze" (Keast 1984).

Largemouth bass anglers often report a preference for fishing in or near submersed vegetation such as hydrilla (*Hydrilla verticillata*) which is common throughout the south, and are generally not supportive of vegetation removal or reduction programs, believing that any such programs will reduce largemouth bass abundance and negatively affect the fishery (Klussman et al. 1988, Wilde et al. 1992, Slipke et al. 1998). In a study by Sammons et al. (2003), largemouth bass did not abandon areas where hydrilla was reduced, but they did respond differently to habitat changes, inhabiting deeper water, exhibiting greater movement within their home ranges, and using woody structure and other vegetation, such as emergent or floating-leaved plants that were present following hydrilla reduction.

MANAGEMENT GOALS

Numerous entities have established management goals for EWM in the region, state, county, and Noxon Rapids and Cabinet Gorge reservoirs. In addition, federal policies and plans direct the prevention and introduction of invasive species.

Sanders County

Each Montana County implements the Montana County Weed Control Act (Title 7, Chapter 22, Section 7-22-2116), which states it is "unlawful for any person to permit any noxious weed to propagate or go to seed on his land." EWM is a Priority 2A species on the Montana Noxious Weed list.

Sanders County seeks to "manage aquatic invasive plants at a level that sustains a healthy aquatic environment supportive of native plant populations, fisheries, wildlife, water quality, recreation, and local economies" (Sanders County 2016). Target species include EWM and HWM. Comprehensive management objectives include:

- Sustaining native and recreational fisheries as well as native habitats and species that rely on riparian and littoral areas and habitats, such as amphibians, birds, and native plants.
- Maintaining water quality at acceptable levels, considering turbidity, water temperature, and dissolved oxygen, as well as localized and reservoir-wide water exchange.
- Improving access to land- and water-based recreational opportunities, and maintaining or improving aesthetic values.
- Maintaining the ability for hydropower generation, considering the impacts of management alternatives on power generation as well as the potential impacts of aquatic invasive plant management to resource values supported through power generation to help protect those investments.
- Sustaining local economies that depend on recreation.
- Managing aquatic invasive plant populations in the context of regional natural resources.

The Sanders County Weed Management Plan (2016)[5] goals include supporting the efforts of local landowners for containment or eradication, reviewing the distribution and abundance of noxious weeds in and near the county, identifying new and potential infestations, controlling noxious weeds, and distributing biological control agents, when available.

State of Montana

- The Montana Aquatic Nuisance Species Management Plan was produced in 2002 to minimize the harmful ecological, economic, and social impacts of aquatic nuisance species through prevention and management, population growth, and dispersal into, within, and from Montana (Montana ANS Technical Committee 2002). Completion of the plan supported the creation of a Montana AIS coordinator as well as federal support for implementation of plan strategies. The plan lists EWM as a Priority Class 3 species (note: this plan is outdated – the species is currently a Priority 2A species in Montana).

- Montana's Noxious Weed Management Plan (Fish, Wildlife & Parks 2008) is currently outdated. At the time of the publication, EWM was characterized as a Category 3 noxious weed, citing "immediate action to eradicate infestations" for all populations. That has since changed with its current designation as a Priority 2A plant on the state noxious weed list.

- The Montana State Wildlife Action Plan (SWAP) states, "To avoid spread of aquatic invasive species, follow guidance in Montana's Aquatic Nuisance Species Management Plan (Montana Fish, Wildlife & Parks 2015)." The SWAP plan emphasizes terrestrial invasive species, and defers management actions and issues associated with aquatic invasive species to the statewide Aquatic Nuisance Species Management Plan.

- The State of Montana Aquatic Invasive Species Program seeks to "minimize the harmful ecological, economic, and social impact of AIS through prevention and management of introduction, population growth, and dispersal of AIS into, within, and from Montana (State of Montana 2014)." EWM is listed as a priority species in this statewide plan.

[5] http://co.sanders.mt.us/wp-content/uploads/2016/06/2016-Sanders-County-Weed-Management-Plan.pdf

- EWM is listed as one of the top four aquatic invasive species in the State of Montana because of its potential impact to aquatic environments, agriculture, hydropower, and water-based recreation. The other three species include dreissenids (quagga and zebra mussels), curlyleaf pondweed (*Potamogeton crispus*), and flowering rush (*Butomus umbellatus*) (State of Montana 2014).

- The Montana Management Assessment of Invasive Species (Creative Resource Strategies 2016) listed EWM as the top priority aquatic plant that Montana entities spent resources on in 2015.

- Management of the tributaries of both reservoirs emphasizes maintenance or enhancement of native salmonids, where possible (Avista 2003).

- The Montana Statewide Fisheries Management Plan (FWP 2012) highlights habitat needs and activities for Noxon Rapids and Cabinet Gorge reservoirs. In both reservoirs, goals are to assess habitat use, survivorship and limiting factors of reservoir-reared bull trout, establish bull trout passage past each dam through trap and haul programs, administer the Montana portion of the Avista fisheries mitigation program, maintain year-long closure on angling for bull trout, and monitor population trends of all other wild species. In Noxon Rapids Reservoir, the plan also emphasizes suppression of illegally introduced walleye, maintaining later spawning closure to protect spawning largemouth and smallmouth bass, and monitoring impacts of fishing derbies and general harvest on bass longer than 12 inches. In Cabinet Gorge reservoir, the plan emphasizes working with the Idaho Game and Fish Department to assess potential for passage of westslope cutthroat from Lake Pend Oreille to upstream of Cabinet Gorge Dam.

- The Clark Fork Project Recreation Resource Management Plan (2017) is intended to facilitate the management of existing and future recreation resources associated with the Noxon and Cabinet Gorge reservoirs, describing goals for 57 recreation sites associated with the reservoirs. An objective in the plan describes preventing resource damage from spreading invasive species as part of an adaptive management strategy.

- The EWM Management Plan for Noxon and Cabinet Gorge reservoirs (2008) noted that EWM outcompetes and shades out native vegetation, which can alter the species composition of the water, reducing the plant diversity and can ultimately result in a near monoculture of EWM. The document described many of the detrimental effects of dense EWM stands, including supporting a lower abundance and diversity of invertebrates, reducing food availability for juvenile and forage fish, reduced preferability by waterfowl as a food source, loss of fish habitat, and reduced foraging space that contributes to imbalanced fish communities. The plan calls for maintaining healthy stands of native vegetation and reducing disturbance to native vegetation to help reduce EWM impacts. The Aquatic Nuisance Species (ANS) Management Plan emphasizes prevention of introductions, early detection, and appropriate and timely management responses to new and existing populations while protecting and restoring native plant and animal communities. The plan states: *"Management activities must be focused on populations of established species where there is a clear and significant impact on native species, and where the control or eradication of specific populations is feasible both economically and technically."* The management approach for EWM must contain aspects that address prevention of spread, containment, monitoring and surveillance, and where feasible control strategies.

Regional and Basin-wide Goals

- The management goal for the Clark Fork-Pend Oreille basin (USEPA 2007) is to restore and protect designated beneficial water uses. The Clark Fork-Pend Oreille Basin Management Plan includes objectives to:
    - Reduce and manage EWM populations in the Pend Oreille and Clark Fork basins.
    - Take measures to prevent spreading milfoil into waters not currently infested.
    - Raise awareness and knowledge about viable non-chemical methods for controlling EWM as well as increasing the use of non-chemical treatments.
    - Protect and restore the integrity of all water bodies, and promote water quality and ecological conditions that foster the expansion of native aquatic and terrestrial species across their former extent.

- The Pend Oreille Watershed Management Plan (Golder Associates 2005) documents EWM and other aquatic invasive species posing a threat to native habitats and public safety, and has a goal of reducing EWM and other aquatic invasive weeds in the watershed.

- Avista Utilities participates on the Sanders County Aquatic Invasive Plants Task Force (AIPTF) to implement an Integrated (EWM) Management Plan, including education and outreach, brochures, EWM signage, promotional items, bottom barriers, and task force facilitation (Avista 2015).

- In 1999, Avista Utilities and 26 other parties signed the Clark Fork Settlement Agreement (CFSA), establishing more than 40 years of protection, mitigation, and enhancement measures associated with environmental, cultural, public recreation, fishery, wildlife, operational, and related activities for the Noxon Rapids and Cabinet Gorge hydroelectric facilities. The Native Salmonid Restoration Plan (NSRP) (Kleinschmidt 1998) is a significant component of the CFSA, and includes mitigation measures that span habitat acquisition and restoration, access and recreational use development, and a trap and haul program for juvenile and adult bull trout to provide connectivity to Lake Pend Oreille. Westslope cutthroat trout and mountain whitefish are also important components in the NSRP. The NSRP seeks to reestablish connectivity for native species, investigate and monitor fish pathogens, categorize stock genetics, investigate non-native impacts and possible control, determine native stock abundance and distribution, and evaluate, protect and enhance habitat.

- The Lower Clark Fork Trail Concept Plan (Avista 2003) has a goal to expand recreation, alternative transportation, and health enhancement opportunities to residents and visitors of the lower Clark Fork area by providing recreation and multipurpose trails, bicycle routes, and opportunities for snowmobilers as well as opportunities for people to learn about cultural and natural resources and have public stewardship opportunities.

- Both the Noxon Rapids and Cabinet Gorge reservoirs are within the US Forest Service Kootenai National Forest Boundary. The Kootenai National Forest Land Management Plan (2015) has a watershed and aquatic species goal of facilitating native salmonid passage over the Noxon Rapids and Cabinet Gorge dams, and improving habitat conditions in tributaries.

- The Confederated Salish and Kootenai Tribes support the position to improve fish passage at all mainstem Clark Fork River dams if it is demonstrated to be biologically feasible (Confederated Salish and Kootenai Tribes 2000).

Federal

- Executive Order 13751—In December of 2016, President Barak Obama amended Executive Order 13112, which called upon executive departments and agencies to prevent the introduction and spread of invasive species. The amended executive order, Executive Order 13751, titled "Safeguarding the Nation from the Impacts of Invasive Species," maintains the National Invasive Species Council and expands its membership, maintains the Invasive Species Advisory Committee, clarifies the operations of the Council, incorporates considerations of human and environmental health, climate change, technological innovation, and other emerging priorities into Federal efforts to address invasive species, and strengthens coordinated, cost-efficient Federal action. The National Invasive Species Management Plan identifies high priority, interdepartmental actions for the Federal government and its partners to take to prevent, eradicate, and control invasive species as well as restore ecosystems and other assets adversely impacted by invasive species.

- National Invasive Species Act— The Aquatic Nuisance Species Task Force (ANSTF) was established in 1991 with the passage of the Nonindigenous Aquatic Nuisance Prevention and Control Act (NANPCA) in 1990 and reauthorized with the passage of the National Invasive Species Act (NISA) in 1996. The ANSTF is an interagency committee established by Section 1201 of the Act and serves to develop and implement an aquatic invasive species program for waters of the United States (ANSTF and NISC 2015). The NANPCA called for the development of state and regional management plans to control aquatic invasive species. Montana produced its state ANS plan in 2002 (Fish, Wildlife and Parks 2012).

PERMITTING

In *Montana's Statewide Strategic Plan for Invasive Aquatic Plant Management and Resource Protection* (Montana Noxious Weed Summit Advisory Council 2011) and the draft *Montana Field Guide for Aquatic Invasive Plants: Survey, Monitoring, and Sampling* (Montana Fish, Wildlife & Parks and Montana Department of Natural Resources and Conservation), the permitting process for bottom barriers, exclusion barriers in the water column, diver-operated suction, manual removal techniques, and herbicide application for aquatic plant control are described in detail.

To comply with the Montana Water Quality Act (Title 75, Chapter 5) and the federal Water Pollution Control Act (33 U.S.C. 1251 *et. seq.*), DEQ issues MPDES permits (note: DEQ's current MPDES permit was approved November 1 of 2016 and expires October 31, 2021) under permit #MTG870000. Any person that applies pesticides to, over, or near state surface waters must have permit coverage either under the Pesticide General Permit (PGP) or through an MPDES permit, and must complete a Pesticide Discharge Management Plan (PDMP), which is incorporated into the PGP. The PGP applies to all areas within Montana, except tribal sovereign nation lands, in which the EPA Pesticide General Permit applies. Only pesticides that are labeled under the Federal Fungicide, Insecticide, and Rodenticide Act (FIFRA) to be used in, on, or near water are subject to the requirement to obtain an MPDES permit. Applying pesticides that are not labeled for aquatic use in, or near water is a violation of FIFRA.

Entities seeking to discharge pesticides complete a Notice of Intent (NOI) package, which is a notification to DEQ that the applicator will comply with the terms and conditions of the PGP.

Annual thresholds limit the total acres of pesticide applications can occur in any given year based on the Pesticide Use Pattern. "Weeds and Algae" applications have a maximum annual treatment area of 100 acres per application. In the case of Noxon Rapids and Cabinet Gorge reservoirs, the total acreage eligible to be treated once in any calendar year is 200 acres. A total of 100 acres treated twice would be considered a 200-acre application. Planning for the annual acreage threshold limits for pesticide applications in the reservoirs is an integral part of a comprehensive control strategy.

TREATMENT ALTERNATIVES

Physical, mechanical, biological, and chemical methods are used to control EWM (Table 2). The effectiveness of each method depends on the extent of the infestation, availability of funding, personnel time and effort, follow-up efforts, and physical/environmental conditions in each water body (Zhang 2012). Because there is no way to eradicate milfoil from a lake once it has been introduced, control efforts focus on controlling new infestations, preventing further spread of milfoil in established infestations, and reducing the nuisance level of well-established infestations (Zhang 2012).

A diversity of control methods has been described to combat EWM and HWM, yet no single method offers consistent and complete eradication of the plant. Instead, multiple and integrated approaches have been shown to yield the highest success (Aiken 1981; ISSC and ISDA 2007). Early control approaches included the integration of mechanical methods, chemical methods, and diver operated dredges (Nichols and Cottam 1972; Aiken 1981). More recently, control plans include human dimensions and biological control agents that supplement traditional methods (Netherland and Schardt 2009; Smith et al. 2012). Prevention proves to be the most successful and cost-effective approach to controlling invasive milfoils as well as most aquatic invasive species (ISSC and ISDA 2007). Areas that have invasions should follow an integrated and well-tailored approach to eradication that includes prioritizing water bodies within the area based on location and use characteristics, developing a management plan, engaging stakeholders, and establishing a monitoring program (Hart et al. 2000; ISSC and ISDA 2007). Biomass sampling programs should tailor the level of effort to the scale of the management effort.

A. Physical

Benthic/bottom barriers—Benthic barriers comprised of PVC, fiberglass, rubber, burlap, nylon, or other synthetics compress and block sunlight and inhibit plant growth (Laitala et al. 2012; Bellaud 2014) (Table 1). The barriers are heavier than water, and are generally anchored to the water body bottom using steel rebar in PVC pipes, sand bags, bricks, or steel pins. In deep water, SCUBA divers are involved in installation. Barriers need to remain in place for at least 1–2 months, and can remain in place for years, however, if they remain in place for long periods of time, they must be maintained, which involves removing the barriers to clean silt so that plants do not grow on top of the barrier (IISC and ISDA 2007; Laitala et al. 2012; Bellaud 2014). The use of benthic barriers is most effective in small patch situations, and allows for maneuverability around objects, such as boat docks. Benthic barriers are not selective, and will impact all plants within the treatment area

(Stockman and Associates 2016). Bottom barriers immediately clear the water column of invasive submergent plants, while minimizing fragmentation of vegetation (Laitala et al. 2012). Barriers are non-selective and may affect benthic organisms and fish as well as gas evolution and macroinvertebrates (Stockman and Associates 2016). Benthic barriers are expensive when used in large areas, may cause anoxia at sediment-water interface (Mattson et al. 2004), and require annual maintenance (IISC and ISDA 2007).

Costs: Benthic barriers cost $10,000-$20,000 per acre for materials plus professional installation (Stockman and Associates 2016).

Table 1. Benthic barrier options for control of aquatic plants (adapted from Wagner 2001).

	Mode of Action	Advantages	Disadvantages
Porous or loose-weave synthetic materials	▪ Laid on bottom and usually anchored by weights or stakes ▪ Removed and cleaned or flipped and repositioned at least once per year for maximum effect	▪ Allows some escape of gases, which may build up underneath ▪ Panels may be flipped in place or removed for relatively easy cleaning or repositioning	▪ Allows some plant growth through pores ▪ Gas may still build up underneath in some cases, lifting barrier from bottom
Non-porous or sheet synthetic materials	▪ Laid on bottom and anchored by many stakes, anchors or weights, or by layer of sand ▪ Not typically removed, but may be swept or "blown" clean periodically	▪ Prevents all plant growth until buried by sediment ▪ Minimizes interaction of sediment and water column	▪ Gas build up may cause barrier to float upwards ▪ Strong anchoring makes removal difficult and can hinder maintenance

Hand harvesting—Hand harvesting, or hand pulling, is the manual removal of plant structure using tools, such as rakes, chains, or mechanized weed rollers (IISC and ISDA 2007).

- Weed rollers roll the bottom of the water body, wrapping and dislodging plants from the sediment, and compressing the sediment to prevent reestablishment of weeds. Weed rollers are practical in small areas, e.g., adjacent to docks, but can disrupt benthic organisms and fish (Bellaud 2014).
- Hand rakes can enhance weed transfer through fragmentation. SCUBA divers are often used in water greater than 4–5 feet (Bellaud 2014). Hand harvesting is used around docks and shore lines, but may produce greater infestation and spread of EWM because of fragmentation. Hand harvesting is often

used as a short-term solution and should not be incorporated into a management plan with the goal of eradication (Hart et al., 2000; IISC and ISDA 2007). Hand harvesting techniques are often most successful in more shallow waters (less than three feet deep), where specialized equipment is not necessary and repeated treatments are more easily performed. Hand removal can be highly selective. Due to the associated sediment disturbance, hand pulling can affect benthic organisms, however, given that this method is slow and labor intensive, it is typically not applied to large areas, thus reducing impacts associated with sediment disturbance. Hand pulling can immediately remove invasive plants and clear the water column, is highly selective if target species can be identified, and is an effective follow-up strategy to herbicide applications (Bellaud 2014). Hand pulling effectively targets new infestations with plant density less than 500 stems/acre, but it is important to ensure the root of the plant is taken (Bellaud 2014). Hand pulling can be a viable management technique for achieving whole-lake control of EWM and reducing infestations to levels that can be realistically financed on an annual basis, however, hand harvesting requires an intensive management approach and a significant financial investment (Kelting and Laxson 2017), is short-term (generally less than one season), and produces vegetation fragments that lead to increased new propagations (IISC and ISDA 2007).

Costs: Hand removal is often performed on a volunteer basis, thus minimizing costs. In deeper sections that may require specialized hand removal via SCUBA divers, costs will increase. Maintenance costs of hand harvesting are about 33% the annual average cost of intensive management (Kelting and Laxson 2017). It is estimated that a SCUBA diver can pull about 90 plants per hour at a cost of $400–$1,000 per acre.

Water drawdown—Drawdown lowers the water level of a water body, ideally for 6–8 weeks and generally during the Fall, with the intent to change the availability of water in the littoral zone and, in turn, change the composition of the plant community and reduce invasive plant biomass (Mattson et al. 2004). It is primarily used in northern latitudes to expose plants to freezing and drying conditions (Bellaud 2014). Drawdowns are most effective on target species that reproduce vegetatively (e.g., through root structures, and fragmentation), but can foster an increase in other aquatic plants, such as hydrilla, that reproduce by seed (Bellaud 2014). Understanding downstream channel configuration, capacity and flow requirements is critical to avoiding negative impacts on adjacent wells and wetlands (Bellaud 2014). Factors that determine effectiveness of drawdowns for rooted plant control include sensitivity of species to dehydration, sediment composition and slope, the depth of the drawdown, weather during drawdown, pattern and rate of groundwater seepage into lake sediments, and plant density at time of drawdown (Mattson et al. 2004).

EWM will decrease in response to winter drawdowns, however, it is able to survive even during low temperatures if the plant remains moist and the hydrosoil does not freeze for several weeks (Cooke et al. 2005). Periodic exposure of 2–3 days duration to subfreezing temperatures had no effect on watermilfoil rootcrown viability whereas prolonged exposure (three weeks or longer) sufficient to freeze the hydrosoil was considered necessary to reduce rootcrown viability (Goldsby et al. 1978). A similar evaluation conducted by Lonergan (2014) in a laboratory setting found shoots did not regrow from roots exposed to -5º C (23º F) for 24 hours under 10 cm of snow, or with roots in standing water at the same temperature. Thus, in the Noxon Rapids and Cabinet Gorge systems, there is concern that snow insulation prevents drawdowns from having the desired effect on aquatic invasive species.

Numerous other considerations need to be addressed to assess the potential efficacy and practicality of a drawdown in the Noxon Rapids and Cabinet Gorge reservoirs. Unlike the 30-foot drawdowns that once occurred in this system, the current FERC license prohibits drawdowns greater than 10 feet. Realistically, drawdowns in this system greater than four feet are impractical because of the cost to Avista, whose operations are not negatively impacted by the presence of aquatic invasive species, but may be significantly impacted by large-scale drawdowns. From October 31 through May 15, up to a 10-foot drawdown (no more than two feet per day) is allowed, but from a cost-effective standpoint, drawdowns greater than four feet are considered cost-prohibitive (Avista, pers. comm.). In addition, the timing of drawdown in the spring can overlap with the spawning of warm water fish species.

In Lake Pend Oreille in Idaho, the reservoir has traditionally been drawn down 11 feet annually. In recent years, some modifications to the drawdown regime were implemented to assess potential benefits to kokanee spawning gravels, though current operations include annual 11-foot drawdowns. Although drawdown-induced water level fluctuations have had some impacts on EWM, this practice may be encouraging the growth of other aquatic plants, including non-native flowering rush. Further, one of the primary mechanisms of transport in the Lake Pend Oreille system is ice. Plants become trapped in the ice in shallow areas, which is then is rafted away when water levels rise (B. Hull pers. comm.). Similar increases in flowering rush have been observed in the Flathead Lake hydropower facility where low pool is routinely reached during the spring (Rice and Dupuis 2009). This lowering allows flowering rush to establish in previously uncolonized areas in the drawdown zone.

Costs: Drawdowns can be low-cost to implement and used as part of an overall integrated management program (Bellaud 2014), however drawdowns may have significant financial impacts to utility companies that operate reservoirs for power generation.

B. Mechanical

Mechanical controls consist of suction harvesting, and the use of large equipment with various cutters, shredders, rotovators, or dredgers to harvest aquatic weeds and transport the biomass from the water body (Haller 2014).

- **Rotovators**—Rotovators are rototillers that till the sediments and chop and cut loose submerged plants. Rotovators are usually used with a floating boom, which contains the plants that float to the surface that can then be extracted by hand or mechanical means. Rotovators are most commonly used in the Pacific Northwest for EWM because the equipment can move rock and uproot weeds. They are also best used in large waterbodies with established extensive invasions of invasive aquatic plants (IISC and ISDA 2007). This method immediately reduces plant density in a waterbody allowing for recreation and other human use. Rotovation has limited maneuverability, can produce plant fragments, is costly and labor intensive, is not species specific, and can impact native vegetation (Gibbons and Gibbons 1988; IISC and ISDA 2007). Rotovation works best when river sediment is soft and milfoil roots can be broken up via underwater rototilling (Lance Dohman, Aquatic Environments, pers. comm.). A harvester and boom collect the plant fragments.

  Costs: Rotovators cost about $250,000 for equipment, 3 gallons per hour of diesel fuel, and costs to hire an operator (Lance Dohman, Aquatic Environments, pers. comm.).

- **Mechanical harvesting**—Harvesting is a mechanized control technique in which plants are cut about six feet below the surface of the water, leaving the roots intact. Removed plants are then disposed of on land to avoid further contamination. This method allows for the immediate clearing of the water column and availability of fish and wildlife habitat (Nichols and Cottam 1972). Mechanical harvesting is site-specific and is environmentally neutral, and thus has broad public acceptance, effectively removes EWM from a specific area of a water body, provides for immediate use of the water after harvesting because there are no residual chemical issues, and removes plant biomass from the water immediately, thus there is no decrease in water body oxygen levels as a result of plant decomposition (Haller 2014). Harvest and removal harvesters, capable of operating in as little as 12 inches of water, are most commonly used to remove EWM from lakes in the Upper Midwest (Haller 2014). The harvesters cut the plants off with a cutter head and transfer the plants to a storage bay on the harvester, where the plants are then offloaded to a barge and transported to shore for disposal on land. Cutters consist of underwater sickle bars or circular saws that slice and chop the vegetation, which then flows downstream. Recent advancements that involve the use of a GPS-assisted larger harvester to manage submersed target weeds in deeper water shows promise. Mechanic harvesting can reduce above-soil biomass for two or more seasons (IISC and ISDA 2007). Although lake bottom habitat is not disturbed because plants are clipped above the sediment, effectiveness of this technique is short term because regrowth begins soon after clipping. The amount of area harvested depends on the capabilities of the equipment, and native species, such as native plants, amphibians, and fish, can be harvested with target invasive plants (Haller 2014). Mechanical harvesters produce floating plant fragments, which can be a concern to landowners downstream of a harvested site because of settling and growth of those fragments and issues associated with fragment cleanup. Disposal of harvested vegetation can be expensive, and can be challenging on water bodies with undeveloped or minimal access because of the need for paved or concrete surfaces to support heavy equipment. Mechanical harvesters are labor intensive, decrease water quality (turbidity), and suspend excess nutrients and metals in the sediment (IISC and ISDA 2007).

Costs: Because the demand for aquatic weed harvesters pales in comparison to other types of agricultural equipment, harvesters are often custom made and expensive. Costs vary widely depending on the size of the harvester, transport time, distance to disposal site, and density of weeds harvested, and is generally more expensive than other methods because of these variables and the purchase of specialized equipment that can be used in most northern climates one-third of the year (Haller 2014). Mechanical harvesting costs $100,000-$200,000 for equipment and $200-$300 per acre for operations (Quantitative Environmental Analysis 2008).

- **Suction harvesting/dredging**—Suction dredging uses a diver operated suction dredge to vacuum plants, roots, and sediment from a water body (Eichler et al. 1997). Although labor intensive, slow, and expensive, this method can successfully target certain species, while leaving native plants. Depending on site conditions, removal rates may range from 0.25-acres to 1-acre per day. Typically, this method is used in medium density beds and smaller treatment areas that are too large for hand-pulling (Quantitative Environmental Analysis 2008). Turbidity curtains are typically installed around the treatment area to contain the disturbed sediment. Suction dredging has been shown to be most effective on plant species that do not propagate via seed, winter buds and tubers, such as EWM and Brazilian elodea (Stockman and Associates 2016). Disruption of the lake sediments may affect benthic organisms and fish spawning. The use of hydraulic fluids and other petroleum products could potentially leak into the water column if machinery is not properly maintained, or if an unexpected leak occurs. It has been recorded as highly effective in controlling EWM with the ability to minimize fragmentation and further infestation of EWM. Success using this technique is based on sediment type, sediment condition, density of aquatic plants, and underwater visibility. Suction dredging can be used after chemical treatment to enhance success (Eichler et al. 1997), or can be used in place of herbicides in water bodies with high density vegetation stands in patches (IISC and ISDA 2007).

Costs: Suction dredging with one or more SCUBA divers, dredge operator, and plant material disposal has been estimated at $1,000 to $2,500 per acre, excluding equipment costs. Other estimates, which depend on the density of the plants, specific equipment used, and disposal requirements, range from a minimum of $1,500 to $2,000 per day (Washington Department of Ecology).[6] Suction harvesting costs $20,000–$30,000 for equipment and $1,000–$4,000/acre depending on the chemical nature of the sediment and need for offsite disposal (Menninger 2011), and $140/hr (2007 costs) for two divers at 30 hours per acre for light infestations (ISSC and ISDA 2007).

C. Biological

Biological controls, also termed biocontrols, are the planned use of one organism to control or suppress the growth of another organism (Cuda 2014), and generally require extensive research and testing before being introduced. Biological controls incorporate a species-specific targeted approach that traditionally has used the introduction of another non-native agent or support of a native species to control the invasive target species (Van Driesche et al. 2002). Biocontrols are key components of a systems approach to integrated pest management because they counteract insecticide-resistant pests, and lessen the use of pesticides (Bale et al. 2007), however, this type of control will not eliminate a plant entirely from a water body (Menninger 2011), but can be used to control vegetation and impede it from growing to the surface and interfering with human and wildlife use. Biocontrols have had varying degrees of success and are impacted by the control species' ability to reproduce at high enough numbers to put stress on the target species (IISC and ISDA 2007). Biocontrols can reduce total biomass substantially in some scenarios (Lord and Pokorny 2012).

There are two types of biocontrols: classical and non-classical. Classical biocontrol is the planned introduction and release of nonnative target-specific organisms from the weed's native range to reduce the vigor, reproductive capacity or density of the target weed in its adventive (new or introduced) range (Cuda 2014). Nonclassical biocontrol, also called the new association approach, is the mass rearing and periodic release of

[6] http://www.ecy.wa.gov/programs/wq/plants/management/dredging.html

resident or naturalized nonnative aquatic weed biocontrol agents (Cuda 2014), which creates new associations between the target plant and the agent—the agent has not previously played a role in the evolutionary history of the target. Successful biological control agents may contribute substantially to an integrated approach using several methods of eradication (Lord 2004; IISC and ISDA 2007; Lord and Pokorny 2012). Classical biocontrols tend to be inexpensive to develop and use long term, offer selective, long-term control of the target weed, and spread through natural reproduction (Cuda 2014). The use of effective biocontrols reduces the need and cost of other control methods. Other supporting stressors, such as environmental conditions, or competition with other plants, may need to be present for the biocontrol to reach its full potential (Cuda 2014). Classical biocontrols may also attack native species in addition to the target invasive species, may take years to have a major impact, and cannot be recalled. Nonclassical biocontrols should be used in locations where the target has few or no closely related native relatives in the introduction area (Cuda 2014). Fish predation may impede the full potential of the biocontrol (Cuda 2014).

Biocontrol programs are initially expensive and take a significant amount of time to develop. The use of biocontrols is more effective than chemical controls—cost-benefit ratios are 30:1 for biocontrol and 5:1 for chemical control (Tisdell 1990; Neuenschwander 2001). Biocontrols bring about desired ecological changes without repeated cost or treatment of the entire infested area (Van Driesche et al. 2008). The cost of a classical biological control agent incorporates the cost of the baseline research, foreign exploration, shipping, quarantine processing, mass rearing, field releases, and post-release evaluation. Stocking herbivorous insects cost about $1,000/acre.

Biological controls for EWM include an adventive moth from Europe (*Acentria ephemerella*[7]), an adventive midge from China (*Cricotopus myriophylli*), and a native weevil (*Eurychiopsis lecontei)* (Cuda 2014) as well as predator reduction to increase herbivory, and pathogens. Although all three insects noted below have caused declines of EWM in localized areas of lakes (Cuda 2014), there are currently no biological control agents that effectively control EWM (Madsen 2014). The efficacy of the role of these three insects as biocontrol agents is contested by the fact that all three species exist within the current geographic scope of EWM in North America.

- ***Acentria* moth**—This exotic aquatic macrophyte moth feeds on both stems and leaves of milfoil and other broadleaf plant species as adults (Batra 1977; Lord 2004; Lord and Pokorny 2012). The moth causes defoliation by feeding in and on the stems and leaves of both EWM and native plants. The control potential of this species is diminished by its dislike for algae covered EWM as a food source

[7] Formerly *Acentria nivea*

(Buckingham and Ross 1981; Lord and Pokorny 2012). This moth uses milfoil apical meristems as a reproduction site, and larvae grow in this location and within veins of the plant causing damage (Johnson et al. 1998; Lord 2004; Lord and Pokorny 2012), which inhibits the growth of the plant to the surface and reduces EWM's ability to outcompete native species. *Acentria* requires water temperatures of about 10°C to become active, and adults survive for no more than 48 hours whereas larvae survive for 2–11 months (Lord and Pokorny 2012).

- ***Crictopus myriophylli* midge** (note: not the same species that is a biocontrol agent of hydrilla)—*C. myriophylli*, commonly referred to as the milfoil midge, has been little studied as a control for EWM in comparison to other insect control species. *C. myriophylli* feeds on the apical meristem of milfoil, using this location as both a shelter and reproduction site (Lord 2004; Lord and Pokorny 2012), and causing considerable damage such that it is considered a potential control agent for EWM (Kangasniemi 1983). A population density of one midge per apical meristem has successfully controlled EWM (MacRae et al. 1990; Kangasniemi et al. 1992; Lord and Pokorny 2012). The midge becomes active once water temperature reaches 10–15°C, but can overwinter in the apical meristem of milfoil. This midge prefers EWM over native milfoils and aquatic vegetation (MacRae et al. 1990; Lord and Pokorny 2012).

- ***Eurychiopsis* weevil**—*E. lecontei* is an aquatic weevil native to North America that has been associated with the decline of EWM populations in many water bodies because of its high specificity to watermilfoil (Hutchinson 1997; Creed 1998; Newman et al. 2002; Sheldon and Creed 2003; Lord 2004; Parsons et al. 2011). *Eurychiopsis* weevil develops faster and has enhanced survivability on EWM versus its native host plant (Cuda 2014). Weevils damage watermilfoil through herbivory and a process termed as stem mining in which the plant buoyancy is compromised (Newman et al. 2002; Lord and Pokorny 2012). Once destroyed, it sinks to the bottom of the water column, losing the ability to form a dense canopy and shade competition (Creed and Sheldon 1992; Sheldon and Creed 1995; Lord 2004; Lord and Pokorny 2012). Although this insect has proven to successfully control EWM, its life cycle has been observed as out-of-synchrony with non-native EWM, diminishing some of its ability to control the invasive species (Creed and Sheldon 1995). Persistent populations of *E. lecontei* have successfully reduced watermilfoil abundance in shallow waterbodies (Jester et al. 2000; Johnson et al. 2000; Newman et al. 2002). Research studies documenting the control of EWM due to the milfoil weevil may have observed the impact of herbivory from both the *Eurychiopsis* weevil and *Acentria* moth (Johnson et al. 2000; Gross et al. 2001). The cost to stock this weevil in a Massachusetts Lake in was $1,600/ acre in 1995.

- **Predator reduction to increase herbivory**—Herbivorous insect communities can often fall below densities needed to control milfoil communities because of predation from fish (Cornwell 2001; Newman et al. 2002). Suppressing predation on these insects is a method used to allow insect densities to flourish (Sheldon and O'Bryan 1996; Creed 2000; Lord 2004; Ward and Newman 2006; Lord and Pokorny 2013). Stocking fish species that prey on insect-eating fish can be achieved by introducing both adult and fingerling predatory fish species. In New York inland lakes, walleye facilitate EWM herbivory (Lord 2004; Lord and Pokorny 2013) while creating a successful recreational fishery within many lakes.

- **Grass carp** (*Ctenopharyngodon idella*)—Grass carp are a prohibited species in the State of Montana (Rule 12.6.2215). Sterile triploid grass carp have been introduced in water bodies outside of Montana to control aquatic vegetation. They are not target species-specific and can reduce or eradicate native plant species (Menninger 2011), and prefer food sources, such as hydrilla, pondweeds and eloda relative to EWM (Pine and Anderson 1991; Dibble and Kovalenko 2009), must be contained when introduced in systems to avoid spreading into other water bodies, and are difficult to remove once they have been introduced. Grass carp can be effective when introduced into systems in which EWM is the primary vegetation. Grass carp can significantly reduce or eradicate desirable native plant species, reducing diversity and altering habitat structural complexity (Dibble and Kovalenko 2009). Changes in habitat structure may then negatively impact the abundance and diversity of macroinvertebrates, fish, and other aquatic invertebrates (Dibble and Kovalenko 2009). Moreover, the feeding and defecation of grass carp can negatively affect water quality and clarity (Bain 1993; Cuda et al. 2008). Grass carp are somewhat unpredictable, should be used to supplement other control methods, and should have effective barriers to prevent escape from a water body (Cooke et al. 2005). Grass carp have primarily been used in the Northeast United States where their introduction into isolated ponds and farm reservoirs have removed the concern for further species distribution (Lubnow et al. 2003). Stocking grass carp costs $50-$100/acre (Menninger 2011) at an estimated stocking rate of 20/acre.

- The fungal pathogen, *Mycoleptodiscus terrestris* (Mt)—*M. Terrestris* has been used in combination with low doses of the herbicide triclopyr to reduce EWM by 90 percent. The combination of an herbicide with this pathogen minimizes impacts to sensitive non-target vegetation, reduces application costs, and may minimize impacts of label-imposed use restrictions (Nelson and Shearer 2008). Fungal and bacterial pathogens have been of interest in the control of EWM since a major die off was observed in Lake Venice and Northeast River, Maryland during the 1960s (IISC and ISDA 2007; Lord and Pokorny 2013). Although laboratory research has documented the fungus has the potential of decreasing EWM biomass, field studies have yet to conclusively solidify it as a successful control agent (Shearer 2002; IISC and ISDA 2007). No pathogenic control agents have yet to be released for commercial use (Cofrancesco 1998, 2000; Shearer 2002; Lord and Pokorny 2013).

D. Chemical

A total of 14 contact and systemic herbicides are registered by the Environmental Protection Agency (EPA) for use in aquatic systems (Netherland 2014). Contact herbicides cause cellular damage at the point of uptake and are fast acting, but they do not have a sustained effect, meaning they may not kill the root crowns, roots or rhizomes (Madsen 2000). Contact herbicides may be used where eradication strategies are too cost prohibitive (ISSC and ISDA 2007). Contact herbicides approved by the EPA for use in aquatic systems include carfentrazone, copper, diquat, endothall, flumioxazin, and peroxides. Systemic foliar herbicides affect the biochemical pathway of the plant and take days or weeks for plant death to occur. Systemic herbicides approved for use in aquatic systems include 2,4-D, bispyribac, fluridone, glyphosate, imazamox, imazapyr, penoxsulam, topramezone, and triclopyr. Both contact and systemic foliar herbicides are used to control floating, floating-leaved, and emergent aquatic weeds, and are applied directly to the plant. Herbicides registered for aquatic systems, applied as concentrated liquids, granules, or pellets require calculating the volume of water to be treated to ensure effective herbicide concentrations. Reduced herbicide sensitivity and herbicide tolerance occur in hybrid EWM (LaRue et al. 2012, Berger et al. 2015).

In 2010, an Environmental Assessment (EA) was completed that identifies aquatic herbicides approved to control EWM in Noxon Rapids and Cabinet Gorge reservoirs (Tetra Tech 2010), including the systemic herbicide triclopyr, and contact herbicides endothall, and a combination of endothall and diquat (Table 2).

- Triclopyr: The liquid and granular amine formulations of this systemic herbicide disrupt enzyme systems specific to plants, which readily absorb and translocate the herbicide (Mattson et al. 2004). Triclopyr can affect native non-target emergent plants, and requires an intermediate length of contact time to be effective (Parkinson et al. 2011). Early-season treatments conducted in cooler water prevent oxygen depletion that occurs when dense mats of vegetation are treated in warm water conditions (Netherland 2014). Triclopyr is selective to many native aquatic grasses and is a good alternative to fluridone in water bodies in which EWM is not abundant, however, it is not suitable for use on large water bodies (ISSC and ISDA 2007). Under experimental conditions, integrating low doses of triclopyr with an indigenous pathogen, *M. terrestris*, can improve control of Eurasian watermilfoil (Nelson and Shearer 2008). Lower use rates of triclopyr can minimize impacts to sensitive non-target vegetation, reduce application costs, and may minimize impacts of label-imposed use restrictions (Nelson and Shearer 2008).

- Endothall: Endothall is a liquid or granule fast-acting herbicide with limited translocation potential that inhibits protein synthesis (Mattson et al. 2004) and quickly breaks down stems in water using varying rates and methods of application (Netherland 2014). Because it is so fast acting, it does not transfer chemical into the roots, and plants grow back after a contact treatment, therefore it has been combined with other herbicides, such as diquat, to enhance its efficacy. Alkalinity and turbidity of water do not influence its effectiveness. Endothall has limited toxicity to fish at recommended dosages and results in moderate control of some submersed plant species and moderately to highly effective control of floating and submersed species (Mattson et al. 2004). Endothall is non-selective in treatment areas, can to be toxic to aquatic fauna, and incurs time delays on use for water supply, agriculture, and recreation. In recent years, endothall has been used for early-season treatments of large areas of EWM that survived the winter to avoid killing native plants that generally grow later in the season (Netherland 2014).

  Diquat: Diquat is a contact-type, herbicide used to control submersed plants in small treatment areas or in areas in which dilution may reduce the amount of time that plants are exposed to the herbicide (Netherland 2014). Diquat is a broad-spectrum herbicide; its efficacy increases with water clarity; turbid water conditions can significantly decrease its efficacy (Poovey and Getsinger 2002). Diquat is often mixed with copper-based herbicides to control multiple target weeds and improve control of target plants. Contact herbicides are used where eradication strategies are cost prohibitive, or in larger water bodies (IISC and ISDA 2007). Diquat used in combination with endothall is fast acting (plant tissue death occurs within 1–2 weeks after application), and low dosage applications suppresses EWM while allowing for the growth of native vegetation (IISC and ISDA 2007). The combination of Diquat and Endothall effectively help to control EWM in the short term, but only plant parts in direct contact with the herbicides are killed, and elimination of the entire plant is not possible using only this method (IISC and ISDA 2007).

Table 2. Different types of EWM control, including methods, advantages, disadvantages, and costs.

	Method	Advantages	Disadvantages	Est. Costs[8]
Physical	Bottom barriers	Effective at treating very dense beds; controls growth in localized and small patch areas; immediately removes submersed plants; highly flexible control; can improve fish habitat by creating edge effects	Non-selective and may affect benthic organisms, fish, gas evolution, and macroinvertebrates; may interrupt spawning of warm water fish; may eliminate some benthic invertebrates; maintenance can be labor intensive; may cause anoxia at the sediment-water interface	$10,000-$20,000 per acre for professional installation
	Hand harvesting	Selective - removes only target plants; low equipment costs; trained volunteers can work in shallow water; specialized equipment is not necessary; can be used around docks and shorelines; can be effective on light infestations	Very labor intensive; harvesting dense beds is inefficient; short-term tool; can cause fragmentation; short-term turbidity.	$400-$1,000 per acre (diver)
	Drawdown	Can be very effective for smaller water bodies with control structures; inexpensive to implement.; requires only outlet control to affect large area; may provide widespread control in increments of water depth if appropriate sub-freezing conditions occur; complements other techniques; opportunity for shoreline cleanup and structure repair; impacts vegetative propagation species with limited impact to seed producing populations	Negatively impacts the ecosystem and recreational use of the water body; can foster increases in aquatic plants that reproduce by seed; potential issues with water supply, flooding, non-target flora and fauna; possible impacts on contiguous emergent wetlands, overwintering reptiles and amphibians, and well production; alteration of downstream flows; potential shoreline erosion and slumping; may result in greater nutrient availability for algae; effectiveness can be influenced by the presence of snow cover; potential for significant costs to hydropower operations.	NA
Mechanical	Rotovating	Both stems and roots are removed; best used in large water bodies with established and extensive invasions; immediately reduces plant density.	Severe disturbance to sediments can lead to recolonization by invasive species; fragmentation of EWM can lead to colonization of new areas; limited maneuverability; can produce plant fragments; costly; labor intensive; not selective; can impact native vegetation; creates substantial turbidity	$250,000 for equipment, 3 gallons per hour of diesel fuel, and costs to hire an operator
	Mechanical harvesting	Provide habitat for fish; leaves benthic community intact; allows for balance of habitat and recreational needs; highly flexible control; may remove other debris	May have to be repeated more than once a year; fragmentation of EWM can lead to colonization of new areas; possible impacts on aquatic fauna, non-selective removal of plants in treated area, possible generation of turbidity; leaves root systems and part of plant for regrowth; not selective within applied area	$100,000- $200,000 for equipment, and $200-$300 per acre for operations
	Suction harvesting/dredging	Removes only target plants; more effective in medium density beds; minimizes fragmentation; can be used after chemical treatment to enhance success; can be used in place of herbicides in water bodies with	Labor intensive; added equipment costs; some difficulty with very dense beds; slow; expensive; may affect benthic organisms and fish spawning; may create turbidity, possible impacts from containment area	$20,000-$30,000 for equipment and $1,000-$25,000 per acre for operations

[8] Costs are estimates and vary because of a variety of factors, from local wages to severity of infestation and size of area being treated.

	Method	Advantages	Disadvantages	Est. Costs[8]
		high density vegetation stands or patches; can reduce pollutant reserves and sediment oxygen demand; can improve spawning habitat for fish species;	discharge; and dredged material disposal; interference with recreation and other uses; expensive	and disposal of harvested plants; $1,500-$2,000 per day
Biological	Herbivorous insects	Milfoil weevil and the aquatic moth target only EWM and are native species; slow reduction in plant biomass; minimizes chance of increased eutrophication; expected little to no negative effect on non-target species; may facilitate longer-term control with limited management	Slow method; results from introduction are inconsistent; incomplete control likely; oscillating cycle of control and regrowth; predation by fish may complicate control; other lake management actions may interfere with success	Stocking costs range from $1,000-and upward per acre
	Grass carp	Very little labor involved; very effective at removing vegetation in a single season; may provide multiple years of control from a single stocking; relatively inexpensive	Removal of non-target species; grass carp prefer moving water and are very likely to migrate from the lake; highly regulated; funnels energy into algae; alters habitat; population control issues; persistent; cannot control feeding sites	Stocking costs $50-$100 per acre
	Fungal pathogens	May be highly species-specific; may provide substantial control after minimal inoculation effort	Effectiveness and longevity of control not well known; infection ecology suggests incomplete control likely	Operational applications not yet available
Chemical	Aquatic herbicides	Effective on EWM; can provide short- and long-term control.	Removal of non-target species; decomposing vegetation can reduce dissolved oxygen and cause algal blooms; use restrictions may be placed on the lake after application.	$200-$2,000 per acre (depending on factors, such as chemical uses, travel, access, and other logistics)
	Triclopyr (systemic)	Selective to many native aquatic grasses; good alternative to fluridone in water bodies in which EWM is not abundant; integrating low doses of triclopyr with a pathogen (*M. terrestris*) can improve control; low toxicity to aquatic fauna; fast acting	Can affect native non-target emergent plants; requires intermediate length of contact to be effective; used primarily for spot treatments versus application to large water bodies	
	Endothall (contact)	Fast acting; quickly breaks down EWM stems; used of early-season treatments of large areas of EWM that survived the winter to avoid killing native plants that grow later in the season.	Because it is fast acting, it does not transfer chemical into the roots, and the plants grow back after a contact treatment, therefore, it is often combined with other herbicides to enhance efficacy; non-selective in treated area; toxic to aquatic fauna – varying degrees by formulation; time delays on use for water supply, agriculture and recreation	
	Diquat (contact)	Used in small treatment areas or areas in which dilution may reduce the amount of time plants are exposed to the herbicide; broad spectrum; fast acting; low doses suppress EWM while allowing for growth of native vegetation; can be used in larger water bodies	Elimination of the entire plant is not possible using only this method	

Sources: Zhang (2012), Montana Noxious Weed Summit Advisory Council (2011), Quantitative Environmental Analysis (2008), IISC and ISDA (2007), Mattson et al. (2004), Madsen (2000).

CONTROL EFFORTS TO DATE

EWM was confirmed in Noxon Rapids and Cabinet Gorge reservoirs in 2007, the first identified infestation of invasive watermilfoil in Montana. Initial studies indicated EWM covered 247 acres in Noxon Rapids Reservoir and 117 acres in Cabinet Gorge Reservoir, and spread at a rate of about 9.8% annually in the reservoirs (Wersal et al. 2009). The Sanders County Commissioners established the Aquatic Invasive Plants Task Force (Task Force) in 2008 to develop and implement an integrated weed management approach to contain and manage invasive watermilfoil. An Environmental Assessment (EA) prescribed herbicide treatments on a maximum of 200 acres per year, and trial studies of herbicide applications were conducted in 2009 and 2010.

The goal of the milfoil treatment program has been to achieve a "maintenance level", in which invasive watermilfoil can be managed through numerous techniques, including bottom barriers, boat inspections, boater education and diver dredging/removal, while herbicide treatments are applied in small acreages as needed. "Maintenance control" of aquatic plants is described as the effort to keep populations in check to acceptable levels in a body of water (Netherland and Schardt 2009), considering the characteristics of the plant, water body characteristics (e.g., size of the littoral zone), and the detrimental effects to the water body if the designated threshold is exceeded (Getsinger et al. 2017). The goals of maintenance control include reduced environmental damage, enhanced use of water bodies, reduced herbicide use, less management costs, improved public engagement and support, and tailored water body treatments that are able to consider unique characteristics, such as recreational events or fish spawning seasons.[9] Getsinger et al. (2017) cites acceptable maintenance levels for EWM is 10% of EWM-supporting littoral zones, which equates to about 180 acres for Noxon Rapids Reservoir and about 100 acres for Cabinet Gorge Reservoir, noting the potential exists to achieve maintenance levels of 2–5% of the littoral zone, or 30–75 acres after several years. These lower maintenance levels were, in fact, achieved in 2014, when less than 2% of the littoral zone was comprised of dense stands of EWM.

Herbicide treatments

Trial and small scale treatments began in Noxon Rapids Reservoir 2008. Using an upstream-to-downstream approach, the Task Force began annual large-scale herbicide treatments in 2012 on 172 acres in Noxon Rapids Reservoir (Figure 3). In 2014, treatments were expanded to include plots in Cabinet Gorge Reservoir (Figure 4). Since 2009, more than 60 plots have been treated with herbicides, mostly in Noxon Rapids Reservoir, and plots

[9] http://plants.ifas.ufl.edu/manage/developing-management-plans/maintenance-control-strategy/

treated have varied across years with only five sites in Noxon Rapids Reservoir and two in Cabinet Gorge Reservoir being treated in consecutive years (Table 3). Specific acreage and products applied to each plot are summarized in Table 4.

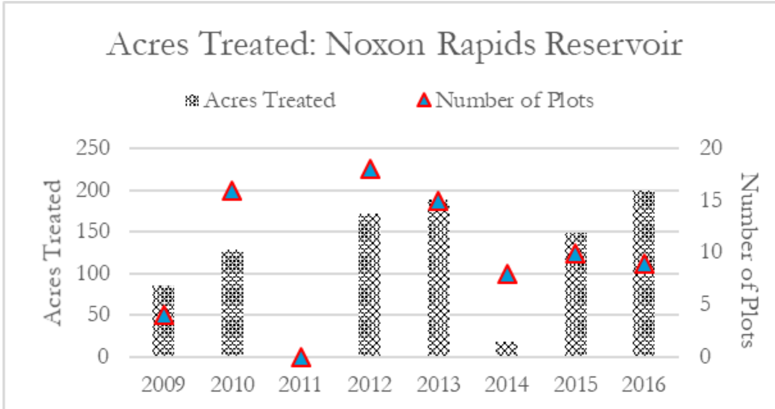

Figure 3. Number of plots and acres treated by year in Noxon Rapids Reservoir from 2009 to 2016.

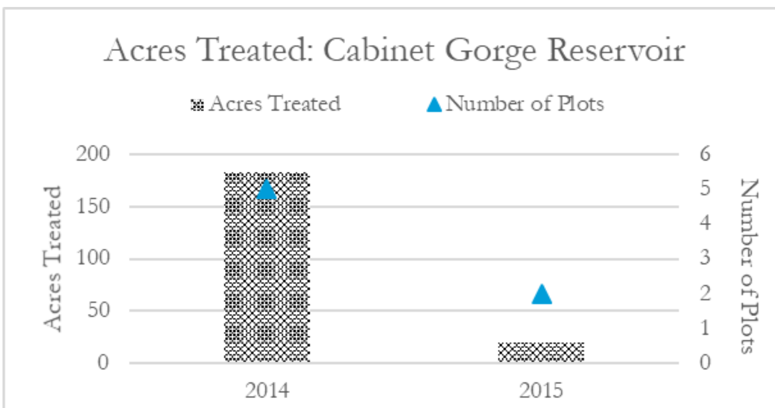

Figure 4. Number of plots and acres treated by year in Cabinet Gorge Reservoir in 2014 and 2015.

Table 3. Frequency of herbicide treatments for each year by plot.

	2009	2010	2012	2013	2014	2015	2016
NOX-1	x						x
NOX-2			x				x
NOX-3	x						
NOX-4			x			x	x
NOX-5			x			x	
NOX-6			x			x	
NOX-7		x					x
NOX-8		x	x		x		x
NOX-9			x				
NOX-10			x			x	x
NOX-11			x				
NOX-12			x				
NOX-13			x				
NOX-14		x					
NOX-15			x				
NOX-16		x			x		
NOX-17			x				
NOX-18		x			x		
NOX-20		x			x	x	
NOX-21		x					
NOX-22			x				
NOX-23		x					
NOX-24			x				
NOX-25			x			x	
NOX-26			x				
NOX-28			x				
NOX-29			x				
NOX-30		x		x			x
NOX-31		x		x	x		x
NOX-32		x		x			
NOX-33		x		x			
NOX-34		x					
NOX-36		x					
NOX-37				x			
NOX-38				x			
NOX-39				x			
NOX-40				x			
NOX-41				x			

	2009	2010	2012	2013	2014	2015	2016
NOX-42				x			
NOX-43				x			
NOX-44				x			
NOX-45				x			
NOX-46				x			
NOX-47				x			
NOX-53					x		
NOX-54					x		
NOX-55					x		
NOX-56						x	
NOX-57						x	
NOX-58						x	
NOX-59						x	
NOX-60							x
CAB-1					x		
CAB-2					x	x	
CAB-3					x	x	
CAB-4					x		
CAB-5					x		

Table 4. Herbicide treatment by year and plot in Noxon Rapids and Cabinet Gorge reservoirs, 2009–2016.

Year	Plot Name	Reservoir	Treatment	Acres Treated[10]
2009	NOX-1	Noxon	Triclopyr + Endothall	**20**
	NOX-3	Noxon	Triclopyr + Endothall	19
2010	NOX-7	Noxon	Triclopyr	28
	NOX-8	Noxon	Triclopyr + Endothall	16
	NOX-14	Noxon	Endothall + Diquat	2
	NOX-16	Noxon	Endothall + Diquat	4
	NOX-18	Noxon	Endothall	2
	NOX-20	Noxon	Endothall + Diquat	3
	NOX-21	Noxon	Endothall	5
	NOX-23	Noxon	Endothall	3
	NOX-31	Noxon	Endothall	5
	NOX-32	Noxon	Diquat	2
	NOX-33	Noxon	Diquat	3
	NOX-34	Noxon	Diquat	1
	NOX-36	Noxon	Diquat	1
2012	NOX-2	Noxon	Triclopyr + Endothall	24
	NOX-4	Noxon	Triclopyr + Endothall	28
	NOX-5	Noxon	Triclopyr + Endothall	16
	NOX-6	Noxon	Triclopyr + Endothall	14
	NOX-8	Noxon	Triclopyr + Endothall	11
	NOX-9	Noxon	Triclopyr + Endothall	22
	NOX-10	Noxon	Triclopyr + Endothall	15
	NOX-11	Noxon	Triclopyr + Endothall	19
	NOX-12	Noxon	Endothall	3
	NOX-13	Noxon	Diquat	2
	NOX-15	Noxon	Diquat	1
	NOX-17	Noxon	Diquat	2
	NOX-22	Noxon	Diquat	2
	NOX-24	Noxon	Endothall	4
	NOX-25	Noxon	Diquat	1
	NOX-26	Noxon	Endothall	3
	NOX-28	Noxon	Endothall	1
	NOX-29	Noxon	Diquat	4
2013	NOX-30	Noxon	Triclopyr + Endothall	19
	NOX-31	Noxon	Triclopyr + Endothall	5
	NOX-32	Noxon	Diquat	7
	NOX-33	Noxon	Diquat	5
	NOX-37	Noxon	Triclopyr + Endothall	15
	NOX-38	Noxon	Diquat	1

[10] Acres treated and plot size were similar.

Year	Plot Name	Reservoir	Treatment	Acres Treated[10]
	NOX-39	Noxon	Endothall	1
	NOX-40	Noxon	Diquat	2
	NOX-41	Noxon	Diquat	4
	NOX-42	Noxon	Diquat	2
	NOX-43	Noxon	Triclopyr + Endothall	21
	NOX-44	Noxon	Triclopyr + Endothall	21
	NOX-45	Noxon	Triclopyr + Endothall	74
	NOX-46	Noxon	Triclopyr + Endothall	9
	NOX-47	Noxon	Triclopyr + Endothall	2
2014	CAB-1	Cabinet	Triclopyr + Endothall	71
	CAB-2	Cabinet	Triclopyr + Endothall	61
	CAB-3	Cabinet	Triclopyr + Endothall	22
	CAB-4	Cabinet	Triclopyr + Endothall	20
	CAB-5	Cabinet	Triclopyr + Endothall	9
	NOX-8	Noxon	Triclopyr + Endothall	9
	NOX-16	Noxon	Endothall	1
	NOX-18	Noxon	Endothall	3
	NOX-20	Noxon	Endothall	1
	NOX-31	Noxon	Triclopyr + Endothall	2
	NOX-53	Noxon	Triclopyr + Endothall	2
	NOX-55	Noxon	Endothall	1
2015	CAB-2	Cabinet	Diquat	10
	CAB-3	Cabinet	Diquat	10
	NOX-4	Noxon	Triclopyr + Endothall	28
	NOX-5	Noxon	Triclopyr + Endothall	12
	NOX-6	Noxon	Triclopyr + Endothall	23
	NOX-10	Noxon	Triclopyr + Endothall	3
	NOX-20	Noxon	Triclopyr + Endothall	1
	NOX-25	Noxon	Endothall	13
	NOX-56	Noxon	Triclopyr + Endothall	3
	NOX-57	Noxon	Triclopyr + Endothall	7
	NOX-58	Noxon	Triclopyr + Endothall	2
	NOX-59	Noxon	Triclopyr + Endothall	58
2016	NOX-1	Noxon	Triclopyr + Endothall	86
	NOX-2	Noxon	Aquastrike (Endothall + Diquat)	51
	NOX-4	Noxon	Aquastrike (Endothall + Diquat)	5
	NOX-7	Noxon	Triclopyr + Endothall	19
	NOX-8	Noxon	Aquastrike (Endothall + Diquat)	20
	NOX-10	Noxon	Aquastrike (Endothall + Diquat)	4
	NOX-30	Noxon	Aquastrike (Endothall + Diquat)	7
	NOX-31	Noxon	Aquastrike (Endothall + Diquat)	5
	NOX-60	Noxon	Triclopyr + Endothall	3

Use of triclopyr and endothall have demonstrated 75% to 100% EWM control among most of the plots treated between 2009 and 2014 at one-year post-treatment (Getsinger et al. 2017). In large EWM stands, herbicide treatment control rates were 75% to 98% in most of the treated plots in Noxon Rapids Reservoir and 85% to 88% in Cabinet Gorge Reservoir plots (Getsinger et al. 2017). Monitoring indicates that treatments have been somewhat less effective on narrow strips along the shoreline due to challenges with water depth and the contour of the reservoir bed.

Unfortunately, in 2015, an unexpected re-expansion of invasive watermilfoil into previously treated plots and the establishment of several new infestations in Noxon Rapids Reservoir were discovered and attributed to a mild winter, low spring runoff, and extremely warm spring and summer temperatures. Although this was a widespread phenomenon throughout the Pacific Northwest, this event caused many to question the long-term ability to control invasive watermilfoil, including the effectiveness of herbicides as a treatment method, and particularly as it relates to recent discoveries of hybrid watermilfoil.

After invading a new location, populations of exotic submersed macrophytes often exhibit a pattern of explosive growth, followed after 10 to 15 years by a noticeable decline (Carpenter 1980, Smith and Barko 1990). During the summer of 1988, the eastern U.S. experienced a severe drought, and macrophyte coverage in Tennessee Valley Authority reservoirs reached record levels (Smith and Barko 1996). The next three years, spring rainfall was above normal, resulting in high water flows and increased turbidity, and a corresponding macrophyte coverage decline occurred during that period (Smith and Barko 1996). Improved growing conditions led to a partial recovery of aquatic vegetation by 1992 or 1993 in most of these reservoirs (Smith and Barko 1996).

Diver dredging

Control measures have also included diver dredging in small, narrow plots where herbicide use has proved challenging.

Bottom barriers

Bottom barriers have been used successfully at high-use docks and ramps (both private and public) to reduce the risk of boats transporting weed fragments. Each year, about 25,000 square feet of heavy duty plastic porous landscape fabric with PVC pipe frame filled with sand are installed at public boat ramps/docks, and at selected private docks that are permitted to be on the Avista-owned shoreline. Avista staff and contractors installed the bottom barriers at public boat launches, removing them each fall. In addition, the Noxon-Cabinet Shoreline Coalition installs and removes the barriers for private docks. Avista staff note that if the barriers are installed correctly (i.e., they are properly weighted, installed prior to vegetation growth so that air bubbles do not float the barriers, and are placed after high flows), they are effective in reducing EWM growth, however they must be removed each fall because of siltation that occurs as well as the potential for ice scour (Nate Hall, pers. comm.).

Other efforts

Hybrid watermilfoil was discovered in Noxon Rapids Reservoir in 2015. In 2016, a two-year research project was initiated by Dr. Ryan Thum of Montana State University (MSU) to determine genotype and distribution of the hybrid species. It is hoped this information may be used to evaluate the effectiveness of contact herbicide treatment on hybrid milfoil and improve control efforts where hybrid milfoil is known or suspected to occur.

Management efforts also include monitoring surveys, education and outreach, coordinating with Montana Fish, Wildlife & Parks, and Idaho Department of Agriculture on mandatory boat check stations to prevent invasive aquatic plants from being transported to non-infested areas, and monthly meetings to evaluate the program and plan next steps.

Treatment Costs

Since 2008, a total of $1,966,303 (plus $315,000 in in-kind support) has been expended to address EWM and HWM in Noxon Rapids and Cabinet Gorge reservoirs (Table 5, Figure 5). Of the $1,966,303 expended, 47% was spent on herbicide treatment, 25% on research (reservoir mapping, vegetation assessments, water exchange, herbicide trial treatments, and hybrid research), 6% on monitoring, 5% on technical assistance, 5% on bottom barriers, 5% on education, 5% on task force facilitation, 2% to support local watercraft inspection programs, and less than 1% on diver dredging (Figure 6). The average annual cost per acre for herbicide treatments was $1,005 from 2012–2016.

Table 5. Annual funds expended to implement aspects of EWM and HWM treatment programs in Noxon Rapids and Cabinet Gorge reservoirs, 2008–2016.

Program	2008	2009	2010	2011	2012	2013	2014	2015	2016	TOTAL
Research[11]	$64,300	$70,000	$327,563							**$461,863**
Operational herbicide treatments				$0	$183,689	$192,979	$203,120	$153,989	$200,407	**$934,184**
Monitoring					$13,087	$38,050	$14,000	$26,265	$22,000	**$113,402**
Technical Assistance				$15,000	$15,000	$15,000	$30,000	$15,000	$15,000	**$105,000**
Bottom barriers	$15,000	$15,000	$10,000	$8,600	$8,600	$8,600	$8,600	$8,600	$8,600	**$91,600**
Education/ outreach		$19,120	$23,721	$27,150	$15,000	$6,000	$3,600	$2,663	$3,000	**$100,254**
Local contribution to state's boat check stations			$7,500	$10,000	$10,000	$10,000	$10,000			**$47,500**
Diver dredging							$2,000	$0	$0	**$2,000**
Hybrid research									$21,000	**$21,000**
Task Force facilitation				$12,000	$12,500	$15,000	$15,000	$17,500	$17,500	**$89,500**
In-kind support	$25,000	$30,000	$30,000	$30,000	$40,000	$40,000	$40,000	$40,000	$40,000	**$315,000**
TOTAL	**$104,300**	**$134,120**	**$398,784**	**$102,750**	**$297,876**	**$325,629**	**$326,320**	**$264,017**	**$327,507**	**$2,281,303**
Herbicide treatments, cost per acre					$1,067	$1,024	$1,015	$916	$1,006	

[11] Including reservoir mapping, vegetation assessments, water exchange and herbicide trial treatments.

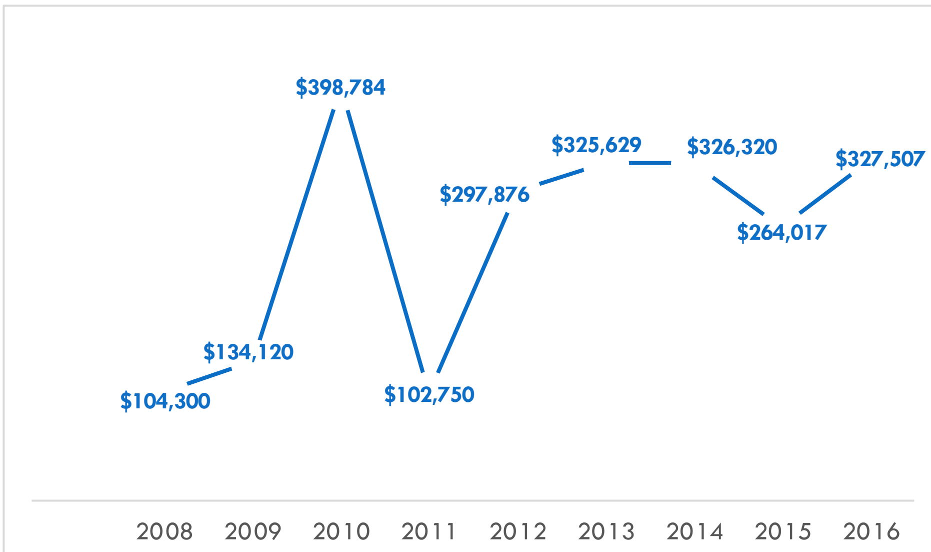

Figure 5. Funds expended annually to implement a EWM and HWM control and maintenance program in Noxon Rapids and Cabinet Gorge reservoirs, 2008–2016.

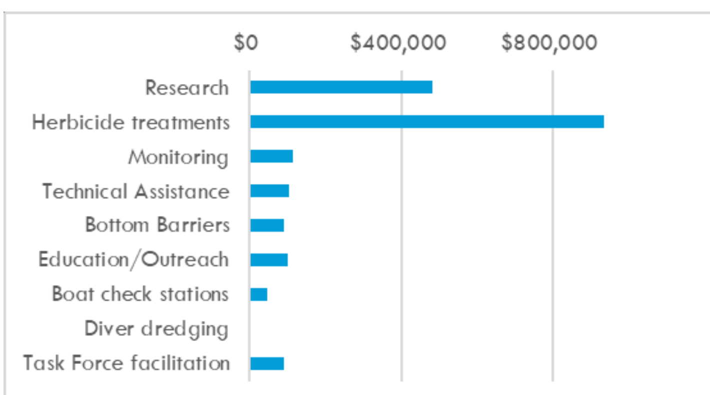

Figure 6. Categories of expenditure and effort on EWM and HWM treatment programs in Noxon Rapids and Cabinet Gorge reservoirs, 2008–2016. *Note:* The amount shows for boat check stations represents only the local contribution to those stations, not the amount contributed by the state through the FWP watercraft inspection and decontamination program.

STAKEHOLDER SURVEY

A total of 33 individuals with varying levels of expertise and backgrounds in addressing aquatic invasive species issues were asked to complete a survey (Appendix A) to provide their perspectives on analysis of treatment alternatives for the management of invasive watermilfoil in Noxon Rapids and Cabinet Gorge reservoirs. A total of 17 individuals (52%) completed the survey. Survey respondents represented state agencies in Montana, Idaho and Washington (6), federal agencies (2), Avista (3), private companies in the herbicide application/plant control industries (3), conservation district (1), academia (1), and a nonprofit organization—the Noxon-Cabinet Shoreline Coalition (1). The following is a summary of the survey results (the number of individuals that responded to the question is in parenthesis):

Defining Success (16)—Respondents were asked to define success relative to the basin goals for invasive watermilfoil in both reservoirs. The ability to administer a proactive, long-term aquatic invasive species program requires a shared understanding of the goals, including consensus on how success is defined and measured. Although treatment programs for invasive watermilfoil have been in existence since 2009 (in Noxon Rapids Reservoir), the results of the survey indicate lack of consensus on how success is defined. Responses included comments, such as “managing invasive plants,” to “selective management of invasive milfoils to achieve a low-level maintenance control situation on an annual basis.” One respondent described the need to acknowledge invasive milfoil will never be eradicated from the system, and three respondents expressed support for achieving a target acreage/density that can be sustained over time to meet the state natural resource management objectives and public use of these resources. One respondent commented the program has been successful, basing that conclusion on densities of milfoil in treated plots, while another noted in-season treatments and short-term treatment have provided excellent control. Another respondent documented the importance of preventing nuisance milfoil growth at public access and high use areas. Two respondents noted that containing EWM to these two reservoirs would be considered a success, while two stated that success would mean EWM does not expand beyond its current locations. Two respondents were very specific in describing the maximum amount of invasive milfoil as a goal—one noted it should be maintained to less than 1-5% of the littoral zone, whereas the other noted the program was sold to funding agencies with the objective of achieving sustainable management levels at 10–15% of the original infestation levels. One respondent noted success would be achieving an annual maintenance level. One respondent commented that despite the challenges, one positive outcome of treatment efforts is a raised awareness about aquatic invasive species.

No Action Alternative (16)—Respondents were asked to estimate the effects on beneficial uses of the reservoirs in both three and five years, and were further asked if they concur with using 25 feet as the maximum depth of colonization to estimate coverage. The overwhelming majority of respondents anticipated negative effects from a no action alternative. Survey respondents predicted EWM populations would "infest most of the littoral zone within 5+years," "beneficial uses would be seriously jeopardized . . . and negatively impact the economy, natural resources," "we would see definite increases in milfoil densities in some stands within three years, and a significant increase in both density and acreages infested within 10 years," which would "decrease diversity of habitats available, hence decreasing fish numbers and diversity," and thus have a "devastating impact on recreational fisheries," and would "severely limit recreational opportunity" and result in "major fish kills." One respondent suggested there would be restricted lake access because of milfoil encroachment in high use areas. Two respondents estimated that in the short term, there would likely be no effect. These same respondents predicted potential impacts in the future; one acknowledging that EWM treatments may be causing an increase in other aquatic invasives, such as hybrid milfoil; and one predicted fishing success to decline, resulting in potential for less public use. One respondent predicted negative impacts in the short term, which would lead to infestations "beyond the point of recovery." One respondent stated that a no action alternative could result in both reservoirs looking like Pend Oreille Lake did in 2005.

Regarding maximum depth of colonization, one respondent stated "EWM doesn't grow to problematic levels in waters deeper than 25 feet," while others state 25 feet would be a worse-case scenario, or at the high end of infestation depth. One respondent noted the depth at which it grows and the response through time depends on the constancy of the water level. Three respondents supported the 25-foot maximum depth whereas one suggested 15 feet should be considered, noting that milfoil in the 15 to 20-foot contour zone aren't observable to boats. Two disagreed with the 25-foot depth; one noted the literature supports 3.4–13.5 feet, and in depths greater than 16 feet, it rarely reaches the surface. One respondent noted if hybrid milfoil grows beyond the 25-foot depth, then the maximum depth should not be limited to 25 feet.

Controls (17)—Respondents were asked to describe controls or combination of controls that would be the most effective in reducing the density of invasive milfoil to meet the goals of basin partners. Several respondents suggested more than one control.

Location (3)

- Focus efforts near boat ramps and docks (2)
- Prioritize treatment areas
- Prevent upstream spread

Chemical (8)

- Species-selective use of herbicides with mop-up operations using Dash Delivery System, which allows applicators to keep chemicals separate while treating individual plants
- Herbicides allow us to maintain biological diversity
- Most effective
- Controlled-release granular herbicides
- Use in localized, high priority areas based on monitoring results

Mechanical (4)

- Diver dredging
- Localized mechanical removal

Drawdown (2)

Bottom barriers (4)

Prevention (1)

Experience in flowing systems (8)—Survey respondents were asked if they had experience controlling invasive watermilfoil in flowing systems, and if so, to provide an example of a positive success achieved as well as a failure experienced, and the factors that contributed to those outcomes. Of the eight respondents that had experience, one noted multiple successes in the Noxon-Cabinet system (>85% control) as well as failures (<50% control), and attributed water-dilution of herbicides as well as herbicide tolerance by hybrid watermilfoil for the failures. One respondent described numerous successful treatments in flowing systems, such as the Columbia River and Pend Oreille River using liquid and granular herbicide treatments. One respondent commented on the success in control plots in Noxon Rapids Reservoir until 2015 (>90% control as well as less acreage comprised of dense milfoil beds). One respondent commented on the challenges that flowing systems present, including lateral currents and elevational changes. A respondent noted that limited contact time results in marginal control whereas another respondent noted that the faster the water flows, the lower the control outcomes. Another respondent emphasized the importance of adequate concentration and exposure time. One respondent described the rotovation in the Pend Oreille River that resulted in fragmentation and spread of milfoil throughout the river.

Fish (12)—Respondents were asked to describe their understanding of the relationship between aquatic plants and fish, focusing on the habitat provided by invasive versus native aquatic vegetation. Two respondents referenced Chapter 2 Biology and Control of Aquatic Plants (Dibble 2014), while several noted that it is well documented in the literature that moderate levels of plant density are optimal for fish production. One respondent commented that more fish are observed in areas not treated regardless of the type of vegetation; another noted aquatic plants provide habitat for a diversity of species and life cycle needs. Several commented that a diversity of aquatic plants provides more and better fish habitat than dense monocultures, and one commented that excessive weed growth has resulted in excessive fish kill. One respondent noted that research conducted in northwest Montana demonstrate that invasive fish demonstrate a preference for invasive plant species. Another noted that recreational fish increase with increasing levels of vegetation up to a certain point.

Hybrid milfoil effects on treatment protocols (11)—Respondents were asked if the identification of hybrid milfoil potentially impacted the efficacy of current treatment protocols in western waterways. Although one respondent stated researchers were "still in the process of determining this," the remainder of the respondents believed hybrid milfoil was impacting the efficacy of treatment protocols based on actual experience, what was read in the literature and reports, and/or correspondence with others who experienced such effects.

Correlation of hybrid milfoil with increased herbicide controls (12)—Survey respondents were asked to describe what they believe to be the real or perceived correlation that exists between increased herbicide controls and increased identification of hybrid milfoil. Two respondents said it is unknown, two said there is no correlation, and the remaining eight respondents provided a range of responses leaning toward support of a correlation. For example, one stated the data was inconclusive but that it could potentially enhance growth of hybrids, another said it was "highly probable," and another noted the use of herbicides "may have sped up hybridization." One respondent commented that herbicide use is selecting against the more susceptible pure EWM plants.

Additional comments—When asked if respondents would like to add additional comments, one respondent noted that future management "must include a no action alternative." Another stated that based on the best available information on Noxon Rapids Reservoir that success of chemical treatment is short-lived, removal of weeds "immediately reduces apparent abundance of all aquatic life, dense macrophyte beds were common in Noxon Rapids Reservoir prior to EWM establishment . .," ". . . only a fraction of the water body is susceptible to dense surface-reaching blooms of EWM," and nuisance blooms occur more frequently during warmer, low-water years and less frequently in years with more river discharge.

THE CONTEXT FOR DEVELOPING MANAGEMENT ALTERNATIVES

Management is not based on science alone, but requires blending an understanding of interrelated and complex natural processes and balancing societal needs and desires. The best management plan will incorporate a balance between local needs and the concerns of resource managers (Mattson et al. 2004), which have been articulated through a series of management and other plans at the national, regional, state, and county levels (see Management Goals section of this document).

An Integrated Weed Management Approach includes education and prevention as well as mechanical, biological, and chemical controls as the most effective approaches for addressing EWM (Tetra Tech 2010). Integrated management is the selection, integration, and implementation of economically efficient and environmentally sound control methods that generally span several years based on predicted economic, ecological, and sociological consequences, is predicated on the concept that no single control method will be totally successful (Washington State Department of Ecology 2010), and is based on implementing a variety of techniques to provide long-term invasive plant control (Bottrell 1979). Any action alternative proposed is based on the tenets that (a) under no circumstances should management be discontinued once plant densities are low; and that the (b) control techniques should be scaled to the level of infestation, the priority of the site, and the availability of resources (Madsen 2000).

No management technique is intrinsically superior to another, nor will one management technique be sufficient for all situations in a management program. All techniques should be considered tools in the manager's toolbox (Madsen 2000). This is especially true for Noxon Rapids and Cabinet Gorge reservoirs, in which environmental conditions, significant public use, and available resources for annual control efforts fluctuate considerably.

The growth of EWM varies considerably from year to year in most lakes (Smith et al. 1991). The selected management approach should be flexible in design to deal with declines, and conversely increases, in EWM population densities, guaranteeing cost savings by increasing the overall treatment efficiency (Smith et al. 1991). Maintenance strategies concentrate control efforts in areas where nuisance species are in greatest conflict with recreational or other lake uses; however, these strategies do not seek to achieve long-term reductions in plant growth (Smith et al. 1991). Once nuisance plant populations become well established and extensive, maintenance is the only realistic management option (Smith et al. 1991). In such cases, plant growth typically greatly exceeds the capacity for plant control, and plant management resources need to be applied only where they will produce the greatest benefit (Smith et al. 1991). The plan should (a) articulate aquatic plant management goals, (b) determine the extent and location of areas to be managed to meet goals, (c) prioritize management needs, and (d) distribute available plant control resources to maximize the extent to which goals are met (Smith et al. 1991).

Reductions in dense vegetation, rather than eradication, should increase predator-prey interactions, improve fish growth (Bettoli et al. 1992, Bettoli et al. 1993) and augment fish production (Smith 1993). Selective removal or treatment of monospecific vegetation stands to create the optimum amount of edge should be considered when improved fisheries are a consideration (Unmuth et al. 1998). Aquatic macrophyte management plans should consider reducing plants sufficiently to prevent reduction of DO concentrations, if sport fish populations are to be maximized (Frodge et al. 1995).

A key driver used to evaluate potential alternatives is the Sanders County goal of "managing aquatic invasive plants at a level that sustains a healthy aquatic environment supportive of native plant populations, fisheries, wildlife, water quality, recreation, and local economies." Based on this goal, each method was evaluated for:

- The degree to which the alternative effectively controls EWM and HWM and achieves desired maintenance levels, prevents further spread within the reservoirs and to systems outside the reservoirs;
- The degree to which the alternative does not promote the growth and spread of other aquatic invasive species in the reservoirs as well as enhanced resistance to methods of control (i.e., herbicide resistance);
- The extent the alternative supports beneficial prioritized uses of the reservoirs; and
- Potential adverse environmental and human health impacts.

A. The No Action Alternative

This alternative would take no further management or control actions to reduce EWM and HWM populations. The risk for introduction, establishment, and spread of invasive watermilfoil would be expected to continue at rates observed prior to the implementation of operational controls beginning in 2010, 2012–2016 (Noxon Rapids Reservoir), and 2014–2015 (Cabinet Gorge Reservoir).

It has been widely documented that dense populations of EWM detrimentally affect water quality, reduce fish and wildlife habitat, decrease abundance and diversity of macroinvertebrates, affect recreation and tourism, and reduce commercial and other property values (Madsen et al. 1991; Boylen et al. 1999; Cheruvelil et al. 2002; Okanagan Basin Water Board 2009; Wilson and Ricciardi 2009; Olden and Tamayo 2014; Yellow Wood Associates 2014; Liao et al. 2016; Kujawa et al. 2017). EWM is associated with negative impacts on native aquatic plants, waterfowl and some mammals, fish, and water quality (Parkinson et al. 2011). Dense foliage increases survival of young fish, however, it reduces foraging space for large predator fish and requires them to expend more energy to obtain prey, and lowers the abundance and diversity of invertebrates, reducing food for fish (Parkinson et al. 2011). The function of water ecosystems is altered, including biomass turnover and nutrient cycling (Parkinson et al. 2011). Lower branches and leaves constantly slough, adding nutrients to the water column throughout the growing season. The release of nitrogen and phosphorus can be rapid, and can be a significant source of internal nutrient loading (Parkinson et al. 2011). Dense mats of EWM cause reduced levels of dissolved oxygen and are associated with changes in water temperature (Parkinson et al. 2011).

The maximum potential acreage that could be colonized by EWM in Noxon Rapids reservoir has been estimated assuming varying water depths for the littoral zone where maximum colonization is known to occur. In the range of 0 to 10 feet, it has been estimated that milfoil could occupy as much as 813 acres, 1,521 acres in the depth range of 0 to 20 feet (Avista, pers. comm.), and as much as 1,830 acres between 0 and 25 feet (Getsinger et al. 2017). Although EWM is known to grow in waters deeper than 25 feet, the greatest impacts are typically observed from about 1–15 feet of water. Plants growing deeper remain sources of plant fragments for further spread.

Even in natural waterbodies, it is difficult to predict what will happen to unmanaged EWM populations through time. In fact, uncontrolled EWM populations exhibit high variability between seasons in natural waterbodies (Wisconsin DNR 2010).

This no action alternative would significantly lessen the ability to achieve any of the goals interested stakeholders have in these reservoirs, including hydropower, recreation, water quality, aesthetics, and economics, and would very likely interfere with achieving the desired suite of ecosystem services these reservoirs can provide. Eliminating control measures may only serve to unnecessarily increase the cost of managing invasive plants in the future, or allow infestations to grow unchecked to the point where available tools or resources are not capable of managing the population (Greenfeld et al. 2004). Invasive plants that reach problem levels before control actions are taken require more resources long term to address the infestation (Getsinger et al. 2017).

Under the no action alternative, existing aquatic weeds in Noxon Rapids and Cabinet Gorge reservoirs would continue to expand. An expansion of aquatic invasive plants in these two reservoirs could have direct, indirect, and cumulative consequences, including displacing native plants, fisheries, and aquatic recreational activities, causing algal blooms, and increasing overall costs associated with future weed control. (Tetra Tech 2010).

B. Adaptive Management Alternative

This alternative uses a suite of tools in an adaptive management context (Figure 7) to address EWM and HWM in Noxon Rapids and Cabinet Gorge reservoirs. The adaptive management framework is a process to help practitioners assess which actions are working, improving the process by which people plan, implement and assess actions in the context of a project cycle (Conservation Measures Partnership 2013). The framework is intended to provide clear guidance on how to maximize the effectiveness and efficiency of projects for maximum conservation gain. All elements of the framework are significant to the work the AIS Task Force is implementing in Noxon Rapids and Cabinet Gorge reservoirs relative to aquatic invasive plant management.

Figure 7. Adaptive Management Framework. Source: Miradi.org.

The following recommendations are a combination of recommendations from the *Invasive Aquatic Plant Control for Noxon Rapids and Cabinet Gorge Reservoirs, Montana: An Adaptive Management Plan* (Getsinger et al. 2017), outcomes from this analysis of treatment alternatives for invasive watermilfoil in Noxon Rapids and Cabinet Gorge reservoirs, and outcomes of a June 2017 workshop with Task Force members.

This framework establishes specific goals and well-defined maintenance and control strategies driven by densities and locations of EWM and HWM populations, provides the flexibility needed to manage these species in a dynamic reservoir with variable water fluctuation schedules and complex circulation patterns, considers economic and environmental constraints, and incorporates each element of an adaptive management framework.

Conceptualize—Step 1: Step 1 of the framework included the creation of the Task Force and its initial goals to control and contain EWM in both reservoirs, preventing further spread downstream and to other systems.

Plan Actions and Monitoring—Step 2: Step 2 of the framework was developed during the June 2017 workshop, in which Task Force members defined success and how it will be measured, described their prioritization scheme, and determined how best to monitor the reservoirs to assess success and trends through time.

> **<u>Defining Success</u>**—Implementing any plan requires a clear articulation of the issue, concise goals and objectives, links between objectives and proposed actions, action implementation, a monitoring plan, data analysis, synthesis, and evaluation, communication about the scientific understanding, and course corrections to adapt to the findings. This plan-do-evaluate and response approach is defined as adaptive management. Sanders County has clearly defined the goals for management of EWM in Noxon Rapids and Cabinet Gorge reservoirs, yet the results of a survey conducted to affirm consensus on goals (Appendix A) revealed significant differences of opinion and perspectives relative to goals and desired outcomes. Achieving consensus on how success is both defined and measured is critical to long-term sustainability and implementation of EWM and HWM in the reservoirs. At the June 2017 workshop, Task Force members discussed how they would define success with the following outcomes:
>
> - Seek to contain and control existing AIS populations as well as prevent new introductions of AIS within Cabinet Gorge and Noxon Rapids reservoirs.

- Reduce the presence of aquatic invasives at or near public and private access sites, including boating access sites.
- Promote sustainable long-term management of EWM and other invasive aquatic plants to reduce negative impacts to natural resource communities while addressing broader reservoir uses.

Task Force members also described the measurable elements that would help determine the level of success or failure, including monitoring of:

- The number of infested watercraft leaving Noxon Rapids and Cabinet Gorge reservoirs.
- Public awareness of AIS (*Clean, Drain, Dry*).
- The presence of AIS at public access points during the boating season.
- The percentage of the littoral zone of both reservoirs infested by dense EWM beds.
- The number of public use visits to the reservoirs.
- Visitor satisfaction with reservoir experiences.
- State noxious weed laws and state priorities for AIS addressed by Sanders County.
- The number of bass tournaments held annually in both reservoirs.
- Resident participation in AIS plant removal (e.g., raking when allowed and use of barriers through the Shoreline Coalition).
- An acceptable monitoring program developed and implemented annually to determine the change in plots and densities through time.

Prioritizing Treatment Areas

At the June 2017 stakeholder workshop, members developed a scheme that prioritizes treatment areas annually that incorporates the location of infestations (e.g., sites with significant public use to reduce spreading by boats and trailers), size/density of plant infestations, upstream versus downstream sites (to minimize reinfestation), water exchange processes, areas that protect water intakes and improve fish and wildlife habitat, and the practicalities associated with managing these run-of-river reservoirs.

Task Force members developed a prioritization scheme tied to the definition of success, which includes containment and control of existing EWM and HWM populations (and other AIS) in both reservoirs. Priorities listed below will be addressed in the context of treating all sites upstream to downstream, assuming widespread presence of HWM, and basing prioritization on fall monitoring results crosschecked with spring monitoring results.

Prioritization Scheme

1. Public or residential use sites, which include boat launches, dock access areas, and designated recreation and swimming areas, are the highest priority for treatment:

    1.1 Boat launch treatment areas include a 40-foot minimum swath around a boat launch; depending on the bathymetry associated with each boat launch. Herbicides, diver hand-pulling, and benthic barriers are potential control options.

    1.2 Dock access areas include those in the immediate vicinity of docks. Control options include herbicides and benthic barriers, and potentially raking. Herbicides will be used at docks where benthic barriers are not used, or in areas past the edges of the benthic barriers to incorporate a wider radius surrounding the docks. Avista will explore allowing shoreline residents to rake aquatic vegetation adjacent to their docks and properties. Raking would likely require a 310 permit, but Avista will explore this option on behalf of the Shoreline Coalition to help residents address aquatic invasive plants during the time of year (summer) when residents participate in in-water activities.

    1.3 Designated recreation and swimming areas include areas in the immediate vicinity of docks; control options include herbicides and diver hand-pulling.

2. Large, high density (e.g., >50% invasive plant coverage) shallow access areas with significant boat traffic (e.g., Nolan Slough, Dody Flats, Finley Flats, pond near Trout Creek, etc.) are the second highest priority for treatment. Treatment areas will be prioritized based on the highest AIS impacted areas concurrent with significant

recreational use with input from FWP staff. Herbicides are the primary control option in these areas. The percent of acreage treated will be based on available funding.

Implement Actions and Monitoring—Step 3:

Annual Process to Determine Treatment Areas

Step 3 of the process includes developing an annual treatment plan and process to monitor the results of plan implementation. At the June 2017 workshop, stakeholders developed a new process to determine treatment areas, and refined and achieved consensus on a monitoring strategy that both informs annual treatment plans as well as builds baseline information to assess long-term trends and changes through time. The Task Force will review the outcomes from previous control efforts each year, assess the status of existing AIS populations, address emerging issues, and develop a plan for the next season of control efforts. This process is critical for the Task Force to function effectively and efficiently within an adaptive management framework. In the past, the Task Force provided technical advisors with information from prior monitoring results to propose a set of control recommendations. The new protocol proposed the creation of a Scientific Advisory Panel. The Panel, which would consist of invasive plant specialists, fish biologists, Avista employees with familiarity of benthic barrier sites, and others, will propose a prioritized list of treatment sites and control options for review and input by the technical advisors, who would then present the proposed plan of activities to the Task Force. Creation of this subgroup incorporates more site-specific knowledge of the system, recreational fishery activity, and other information into the proposed plan of action prior to determining the specifics of which herbicides will be applied to which plots. A list of potential members of the Panel is included in Appendix B.

Monitoring

Getsinger et al. (2017) (as described by Turnage and Madsen 2014) recommended conducting an annual reservoir-wide survey in each water body in late July or early August using a point-intercept regular grid pattern with sampling intervals of 150 meters. They also recommended conducting assessments and developing management strategies for other problematic invasive aquatic plants (growth, vegetative spread, and treatment efficacy of hybrid milfoils, curly-leaf pondweed, and flowering rush) in the Noxon Rapids/Cabinet Gorge system.

At the June 2017 workshop, the Task Force considered these recommendations in the context of how they define success as well as cost, and determined two types of surveys would advance their ability to achieve their goals:

- Survey high priority treatment areas annually in the spring/early summer.
- Conduct a whole lake survey, including all previously treated sites, following the standard format developed in 2008 (to allow for comparisons through time), and compiling a comprehensive summary of all survey data. Although annual surveys are ideal, the surveys should be planned every other year at least until results suggest a different frequency to best inform management decisions.

All invasive plant monitoring and survey data collected in Noxon Rapids and Cabinet Gorge reservoirs should have consistent data collection and recording methodologies to enhance understanding and utility of the data across years and between treatment plots. All contractors should adhere to consistent metadata requirements to provide consistency between sampling events. Specific recommendations include:

- Consistent nomenclature across all data fields, including:
    - Plant species (decide ahead whether data will be collected for ALL observed species, or just Eurasian watermilfoil, curly-leaf pondweed, and flowering rush)
    - Consistent reporting (e.g., percent occurrence and/or injury rank)
- Consistent datum (e.g., WGS 84)
- Consistent significant digits where applicable (e.g., 2.7 acres not 3 acres)
- Provide GIS layers for waypoint data for each plot
- Provide GIS layers for polygon data for each plot

Analyze, Use, and Adapt–Step 4: Step 4 of the process is completed each year when the Scientific Technical Advisory Panel/Committee reviews the results of post-treatment monitoring and crosschecks that with spring invasive plant surveys.

Capture and Share Learning—Step 5: Step 5 occurs after the Scientific Technical Advisory Panel/Committee and two technical advisors to the project present their recommendations for discussion with the entire Task Force.

LITERATURE CITED

Aiken, S.G. 1981. A conspectus of *Myriophyllum* (Halloragaceae) in North America. *Brittonia* (31)1: 57–69.

Aquatechnex. 2013. 2012 Noxon Reservoir evaluation of invasive aquatic plant management treatments. AquaTechnex, LLC, Bellingham, WA.

Aquatechnex. 2014. One-year post treatment evaluation of Noxon Reservoir 2013 Eurasian watermilfoil control program. AquaTechnex LLC, Bellingham, WA.

Aquatic Nuisance Species Task Force and National Invasive Species Council. 2015. Federal Policy Options: Addressing the movement of aquatic invasive species onto and off of federal lands and waters. 55pp.

Avista. 2003. Lower Clark Fork Trail System Concept Plan. 91pp.

Avista. 2015. 2015 Annual Implementation Plan. Clark Fork Project, FERC No. 2058. Cabinet Gorge and Noxon Rapids Hydroelectric Developments.

Bain, M.B. 1993. Assessing impacts of introduced aquatic species: Grass carp in large systems. *Environmental Management* 17(2): 211–224.

Bale, J.S., J.C. van Lenteren, and F. Bigler. 2007. Biological control and sustainable food production. *Philosophical Transactions of the Royal Society of London* (363)1492: 761–776.

Batra, S.W.T. 1977. Bionomics of the macrophyte moth, *Acentropus niveus* (Oliver), a potential biological control agent for Eurasian watermilfoil and hydrilla. *New York Entomological Society* (LXXV)3: 143–152.

Beak Consultants. 1997a. Observations on reservoir limnology and water quality data. Memorandum to the Clark Fork Relicensing Team, Water Resources Work Group, Spokane, WA from Ken Carlson.

Beak Consultants. 1997b. Evaluation of feasibility/effectiveness of water temperature manipulation. Report prepared by Beak Consultants Inc. for WWP.

Bellaud, M. 2014. Chapter 6: Cultural and Physical Control of Aquatic Weeds. *In*: Biology and control of aquatic plants: a best management practices handbook (Gettys LA, WT Haller and D.G. Petty, eds.). Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pages.

Berger S., G.E. MacDonald, and M.D. Netherland. 2015. Laboratory documentation of multiple herbicide tolerance to fluridone, norflurazon, and topramazone in a hybrid watermilfoil (*Myriophyllum spicatum* x *M. sibiricum*) Population. *Weed Science* 63(1): 235–241.

Bettoli, P.W., M.J. Maceina, R.L. Noble and R.K. Betsill. 1992. Piscivory in largemouth bass as a function of aquatic vegetation abundance. *North American Journal of Fisheries Management* 12: 509–16.

Bettoli, P.W., M.J. Maceina, R.L. Noble, and R.K. Betsill. 1993. Response of a reservoir fish community to aquatic vegetation removal. *North American Journal of Fisheries Management* 13:110–124.

Bornette, G. and S. Puijalon. 2011. Response of aquatic plants to abiotic factors: a review. *Aquatic Sciences* 73(1): 1-14.

Bottrell, D.R. 1979. Integrated Pest Management. Council on Environmental Quality. #041-011-00049-1, US Government Printing Office, Washington, DC 120pp.

Boylen, C.W., L. Eichler, and J.D. Madsen. 1999. Loss of native aquatic plant species in a community dominated by Eurasian watermilfoil. *Hydrobiologia* 415: 207–211.

Bradley, P., and S. Yee. 2015. Using the DPSIR Framework to develop a conceptual model: Technical Support Document. US EPA. EPA/600/R-15/154. 70pp.

Buchan, L.A.J., and D.K. Padilla. 2000. Predicting the likelihood of Eurasian watermilfoil presence in lakes, a macrophyte monitoring tool. *Ecological Applications* 10(5):1442–1455.

Buckingham, G.R. and B.M. Ross. 1981. Notes on the biology and host specificity of *Acentria nivea* (=Acentropus niveus). *Journal of Aquatic Plant Management* (19): 32–36.

Canfield, D.E., Jr., M.J. Maceina, and J.V. Shireman. 1983. Effects of hydrilla and grass carp on water quality in a Florida lake. *Water Resources Bulletin* 19: 773–778.

Canfield, D.E., K.A. Langeland, S.B. Nelson, and H.G. Haller. 1985. Relations between transparency and maximum depth of macrophyte colonization in lakes. *Journal of Aquatic Plant Management* 25: 23-28.

Caraco, N.F., and J.J. Cole. 2002. Contrasting impacts of a native and alien macrophyte on dissolved oxygen in a large river. *Ecological Applications* 12(5): 1496–1509.

Carpenter, S.R. 1980. The decline of *Myriophyllum spicatum* in a eutrophic Wisconsin lake. *Canadian Journal of Botany* 58: 527–535.

Cheruvelil, K.S., P.A. Soranno, J.D. Madsen, and M.J. Roberson. 2002. Plant architecture and epiphytic macroinvertebrate communities: the role of an exotic dissected macrophyte. *Journal of the North American Benthological Society* 21: 261–277.

Clean Lakes. 2014. Cabinet Gorge and Noxon Rapids Reservoirs Sanders County, Montana: 2014 AIS Aquatic Pesticide Application Report, 53pp.

Clean Lakes, Inc. 2015. Cabinet Gorge and Noxon Rapids Reservoirs, Sanders County, MT, 2015 AIS aquatic pesticide application report (APAR). Clean Lakes, Inc., Couer d'Alene, ID.

Clean Lakes, Inc. 2016. Noxon Rapids Reservoir, Sanders County, Montana 2016 aquatic invasive pesticide application report (APAR). Clean Lakes, Inc., Couer d'Alene, ID.

Cofrancesco, A.F. 2000. Factors to consider when using native biological control organisms to manage exotic plants. *Journal of Aquatic Plant Management* (28): 117–119.

Cofrancesco, Jr., A.F. 1998. Overview and future direction of biological control technology. *Journal of Aquatic Plant Management* 36: 49–53.

Confederated and Salish Kootenai Tribes. 2000. Wetland/Riparian Habitat and Bull Trout Restoration Plan. 53pp.

Conservation Measures Partnership. 2013. Open Standards for the Practice of Conservation. Version 3.0. 48pp.

Cooke, G.D., E.B. Welch, S.A. Peterson, and S.A. Nichols. 2005. Restoration and Management of Lakes and Reservoirs, Third Edition. Taylor & Francis Group. 592pp.

Cornwell, M.D. 2001. Walleye (*Stizostidion vitreum*) reintroduction update: Walleye stocking and electrofishing summary 2000–1. SUNY Oneonta biology MA candidate. Biological Field Station, Cooperstown, NY.

Creative Resource Strategies. 2016. Montana Management Assessment of Invasive Species: A report prepared for the Montana Invasive Species Advisory Council. 66pp.

Creed, R. P. 1998. A biogeographic perspective on Eurasian watermilfoil declines: additional evidence for the role of herbivorous weevils in promoting declines. Journal of Aquatic Plant Management 36: 16-22.

Creed, R.P. 2000. The weevil-watermilfoil interaction at different spatial scales: What we know and what we need to know. *Journal of Aquatic Plant Management* (28): 78–81.

Creed, R.P., Jr. and S.P. Sheldon. 1995. Weevils and watermilfoil: Did a North American herbivore cause the decline of an exotic plant? *Ecological Applications* 5(4): 1113–1121.

Creed, R.P., Jr., S.P. Sheldon, and D.M. Cheek. 1992. The effects of herbivore feeding on the buoyancy of Eurasian watermilfoil. *Journal of Aquatic Plant Management* 30: 75–76.

Crowder, L.B. and W.E. Cooper. 1982. Habitat structural complexity and the interaction between bluegills and their prey. *Ecology* 63: 1802–1813.

Cuda, J. 2014. Chapter 8: Introduction to Biological Control of Aquatic Weeds and Chapter 9: Insects for Biocontrol of Aquatic Weeds. In: Biology and control of aquatic plants: a best management practices handbook (Gettys, L.A., W.T. Haller and D.G. Petty, eds.). Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pages.

Cuda, J.P., R. Charudattan, M.J. Grodowitz, R.M. Newman, J.F. Shearer, M.L. Tamayo, and B. Villegas. 2008. Recent advances in biological control of submersed aquatic weeds. *Journal of Aquatic Plant Management* 46(1): 15–32.

Diamond, J., and T.J. Case. 1986. Community Ecology. Harper and Row, New York.

Dibble, E. 2014. Chapter 2: Impact of Invasive Aquatic Plants on Fish. *In*: Biology and control of aquatic plants: a best management practices handbook (Gettys LA, WT Haller and D.G. Petty, eds.). Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pages.

Dibble, E.D. and K. Kovalenko. 2009. Ecological Impact of Grass Carp: A Review of the Available Data. *Journal of Aquatic Plant Management* 47: 1–15.

Dibble, E.D., K.J. Killgore, and S.L. Harrel. 1997. Assessment of fish-plant interactions, Miscellaneous Paper A-97-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Dionne, M. and C.L. Folt. 1991. An experimental analysis of macrophyte growth forms as fish foraging habitat. *Canadian Journal of Fisheries and Aquatic Sciences* 48:123–131.

Drake, J. A., H.A. Mooney, F. di Castri, R.H. Groves, and F.J. Kruger.1989. Biological invasions: a global perspective. John Wiley and Sons.

Duarte, C.M. and J. Kalff. 1986. Littoral slope as a predictor of maximum submersed macrophyte biomass. *Limnology and Oceanography* 31(5): 1072-1080.

Duarte, C.M. and J. Kalff. 1987. Maximum colonization and maximum biomass of submersed angiosperms in lakes. *Canadian Journal of Fisheries and Aquatic Sciences* 44(10): 1759-1764.

Duffy K.C. and D. M. Baltz. 1998. Comparison of fish assemblages associated with native and exotic submerged macrophytes in the Lake Pontchartrain estuary, USA. *Journal of Experimental Marine Biology and Ecology* 223:199–221.

Dvõraki, J., and E.P.H. Best. 1982. Macro-invertebrate communities associated with the macrophytes of Lake Vechten: structural and functional relationships. *Hydrobiologia* 95:115–126.

Ehrenfeld, D.W. 1970. Biological Conservation. Hole, Rinehart, and Winston, New York. Xii + 228pp.

Eichler, L.W., R.T. Bombard, J.W. Sutherland, and C.W. Boylen. Suction harvesting of Eurasian watermilfoil and its effect on native plant communities. *Journal of Aquatic Plant Management* 31(1993): 144–144.

Engel 1987. The impact of submerged macrophytes on largemouth bass and bluegills. *Lake and Reservoir Management* 3(1):227–234.

Engel, S. 1995. Eurasian watermilfoil as a fishery management tool. *Fisheries* 20(3):20-27.

Federal Energy Regulatory Commission. 2000. Final Environmental Impact Statement: Cabinet Gorge and Noxon Rapids Hydroelectric Projects, Idaho and Montana. FERC/FEIS-0126.

Fish, Wildlife and Parks. 2012. Montana Statewide Fisheries Management Plan, 2013–2018. 478pp.

Frodge, J. D., G. L. Thomas, and G. B. Pauley. 1995. Water quality effects of stocking sterile triploid grass carp in Keevies Lake and Bull Lake. Pages 8-1–8-25 in G. B. Pauley and S. A. Bonar, editors. The biology, management, and stocking rates of triploid grass carp, *Ctenopharyngodon idella*, and their effects on the plant community, fish assemblage, and water quality of several Pacific Northwest lakes. Final report to Washington Department of Ecology, Washington Cooperative Fish and Wildlife Research Unit, University of Washington, Seattle.

Getsinger, K.D., A.M. Fox, and W. Haller. 1996. Herbicide application technique development for flowing water: Summary of research accomplishments. MP A- 96-3. Vicksburg, MS: US Army Engineer Waterways Experiment Station.

Getsinger, K.D., J.D. Madsen, G. Turnage, and J. Badger. 2017. Invasive aquatic plant control for Noxon and Cabinet Gorge reservoirs, Montana: An adaptive management plan. A report prepared for the Sanders County Aquatic Invasive Plants Task Force. Geosystems Research Institute Report #5074. 57pp.

Getsinger, K.D., J.G. Skogerboe, J.D. Madsen, R.M. Wersal, J.J. Nawrocki, R.J. Richardson, and M.R. Sternberg. 2013. Selective control of Eurasian watermilfoil and curlyleaf pondweed in Noxon Rapids Reservoir, Montana: Aquatic Herbicide Evaluations, 2009–2010. ERDC/EL TR-13-5, 97 pp.

Getsinger, K.D. 1993. Chemical control technology: Long Lake Project. Proc. Aquatic Plant Control Research Program, MP A-93-2, US Army Engineer Waterways Experiment Station, Vicksburg, MS, pp. 10–16.

Getsinger, K.D., E.G. Turner, J.D. Madsen, and M.D. Netherland. 1997. Restoring native vegetation in a Eurasian watermilfoil dominated plant community using the herbicide triclopyr. *Regulated Rivers: Reservoir Management* 13: 357–375.

Getsinger, K.D., E.G. Turner, and J.D. Madsen. 1992. Field evaluation of the herbicide triclopyr for managing Eurasian watermilfoil. USACE Waterways Experiment Station. Aquatic Plant Control Research Program. 6pp.

Getsinger, K.D., A.M. Fox, and W.T. Haller. 1996. Herbicide Application Technique Development for Flowing Water: Summary of Research Accomplishments. Miscellaneous Paper A-96-3. U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Gettys, L.A., W.T. Haller, and D.G. Petty (eds). 2014. Biology and Control of Aquatic Plants. A Best Management Practices Handbook: Third Edition. Aquatic Ecosystem Restoration Foundation, Marietta, GA. 237pp.

Gibbons, M.V., and H.L. Gibbons, Jr. 1988. Efficacy of rotovation in controlling Eurasian watermilfoil in the Pend Oreille River, Washington. *Lake and Reservoir Management* 4(1): 153–160.

Glass, N.R. 1971. Computer analysis of predation energetics in the largemouth bass. pp. 325–363. In: B.C. Patten (ed.) Systems Analysis and Simulation Ecology, Vol. 1, Academic Press, New York.

Glomski L.M., and M.D. Netherland. 2010. Response of Eurasian and hybrid watermilfoil to low use rates and extended exposures of 2,4-D and triclopyr. *Journal of Aquatic Plant Management* 48:12.

Golder Associates, Inc. 2005. Pend Oreille (WRIA 62) Watershed Management Plan. 023-1289-003.3040. 128pp.

Goldsby et al. 1978. Eurasian Watermilfoil in Melton Hill Reservoir. *Journal of Aquatic Plant Management* 16:34–38.

Grace, J.B. and R.G. Wetzel. 1978. The production biology of Eurasian watermilfoil (*Myriophyllum spicatum* L.): A review. *Journal of Aquatic Plant Management* 16:1–11.

Greenfield, B.K., N. David, J. Hunt, M. Wittmann, and G. Siemering. 2004. Aquatic Pesticide Monitoring Program: Review of alternative aquatic pest control methods for California waters. San Francisco Estuary Institute. 106pp.

Grenouillet, G., J. Olivier, and D. Pont. 2000. Habitat occupancy patterns of juvenile fishes in a large lowland river: Interactions with macrophytes. *Hydrobiology* 149(2): 307–326.

Grenouillet, G., D. Pont and K.L. Seip. 2002. Abundance and species richness as a function of food resources and vegetation structure; Juvenile fish assemblages in rivers. *Ecography* 25: 641–650.

Gross, E.M., R.L. Johnson, and N.G. Hairston, Jr. 2001. Experimental evidence for changes in submersed macrophyte species composition caused by the herbivore *Acentria ephemerella* (Lepidoptera). *Oecologia* 127: 105–114.

Gross, E.M., H. Meyer, and G. Schilling. 1996. Release and ecological impact of algicidal hydrolysable polyphenols in *Myriophyllum spicatum*. *Phytochemistry* 41:133–138.

Groves, T., P. Tyning, and P. Hausler. 2014. Hybrid milfoil: Emerging issues and management implications. Progressive AE, Grand Rapids, Michigan. 2pp.

Haller, W.T. 2014. Chapter 7: Mechanical Control of Aquatic Weeds. In: Biology and control of aquatic plants: a best management practices handbook (Gettys LA, WT Haller and D.G. Petty, eds.). Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pages.

Hanson Environmental. 2015. Post-treatment assessment of 2014 treatment plots on Noxon and Cabinet Gorge Reservoirs. Hanson Environmental, Missoula, MT.

Hanson Environmental. 2016. Post-treatment assessment of 2015 treatment plots on Noxon and Cabinet Gorge Reservoirs. Hanson Environmental, Missoula, MT.

Harrell, S.L., and E.D. Dibble. 2001. Foraging efficiency of juvenile bluegill, *Lepomis macrochirus*, among different vegetated habitats. *Environmental Biology of Fishes* 62:441–453.

Hart, S., M. Klepinger, H. Wandell, D. Garling, and L. Wolfson. 2000. Integrated pest management for nuisance exotics in Michigan inland lakes. Water Quality Series: WQ-56 Michigan State University Extension Bulletin, 34 pp.

Hartleb, C.F, J.D. Madsen, and C.W. Boylen. 1993. Environmental factors affecting seed germination in *Myriophyllum spicatum* L. *Aquatic Botany* 45(1): 15–25.

Hatfield Consultants, Ltd. 1996. Effects of Eurasian watermilfoil on the ecology of Shuswap Lake. Final Report prepared for the Department of Fisheries and Oceans Canada.

Heck, K.L., Jr., and T.A. Thoman. 1981. Experiments on predator-prey interactions in vegetated aquatic habitats. *Journal of Experimental Marine Biology and Ecology* 53:125–134.

Hobbs, R.J., and S.E. Humphries. 1995. An integrated approach to the ecology and management of plant invasions. *Conservation Biology* 9: 761–770.

Honnell, D., J.D. Madsen, and R.M. Smart. 1992. Effects of aquatic plants on water quality in pond ecosystems. Proceedings: 26th Annual Meeting, Aquatic Plant Control Research Program. Report A-92-2. U.S. Army Corps of Engineers Waterways Experiment Station, Vicksburg, MS.

Hutchinson, B. 1997. Use of aquatic weevils to control a nuisance weed in Lake Bomoseen, Vermont. EPA Watershed Protection: Clean Lakes Case Study. No. 3. pp. 1-8. EPA841-F-97-002.

Hydrosolutions. 2014. Clark Fork River Water Quality Trends Report 1998–2012. Helena, MT. Prepared for Montana Department of Environmental Quality, Helena, MT and Avista Corporation, Spokane, WA.

Idaho Invasive Species Council and Idaho State Department of Agriculture. 2007. 2008 Statewide Strategic Plan for Eurasian watermilfoil in Idaho, Idaho State Department of Agriculture, Boise, ID, 84 pp.

Idaho State Department of Agriculture. 2008. Proposed Eurasian Watermilfoil Control Plan for 2008: Kootenai River, Boundary County, Idaho.

Jacobs, J., and J. Mangold. 2009. Ecology and management of Eurasian watermilfoil (*Myriophyllum spicatum* L.) USDA NRCS Invasive Species Technical Note No. MT-23.

Jester, L.L., M.A. Bozek, D.R. Helsel, and S.P. Sheldon. 2000. *Euhrychiopsis lecontei* distribution, abundance, and experimental augmentations for Eurasian watermilfoil control in Wisconsin Lakes. *Journal of Aquatic Plant Management* 38: 88–97.

Johnson, R.L., P.J. Van Dusen, J.A. Toner, and N.G. Hairston, Jr. 2000. Eurasian watermilfoil biomass associated with insect herbivores in New York *Journal of Aquatic Plant Management* 38: 82–88.

Johnson, R.L., E.M. Gross, and N.G. Hairston, Jr. 1998. Decline of the invasive submersed macrophyte Myriophyllum spicatum (Haloragaceae) associated with herbivory by larvae of *Acentria ephemerella* (Lepidoptera). *Aquatic Ecology* 31(3): 273–282.

Kangasniemi, B.J. 1983. Observations on herbivorous insects that feed on Myriophyllum spicatum in British Columbia. Lake Restoration, Protection, and Management Proceedings of the Second Annual Conference; North American Lake Management Society. October 26–29, 1982, Vancouver, British Columbia. U.S. Environmental Protection Agency. Washington, D.C. pp. 214–218.

Kangasniemi, B. J., H. Speier, and P. Newroth. 1992. Review of Eurasian watermilfoil biocontrol by the milfoil midge. Proceedings, 27th Annual Meeting, APCRP. pp. 17–22.

Keast, A. 1984. The introduced aquatic macrophyte, *Myriophyllum spicatum*, as habitat for fish and their macroinvertebrate prey. *Canadian Journal of Zoology* 62:1289–1303.

Kelting, D.L. and C.L. Laxson. 2017. Cost and effectiveness of hand harvesting to control the Eurasian watermilfoil population in Upper Saranac Lake, New York. *Journal of Aquatic Plant Management* 48: 1–5.

Killgore, K.J., R.P. Morgan, and N. Rybicki. 1989. Distribution and abundance of fishes associated with submersed aquatic plants in the Potomac River. *North American Journal of Fisheries Management* 9:101–111.

Kiviat, E. 1993. Under the spreading water-chestnut. *Hudsonia* 9:1–7.

Kleinschmidt (Kleinschmidt Energy and Water Resource Consultants: Ault, S., and K.L. Pratt). 1998. Clark Fork River native salmonid restoration plan. Report to Washington Water Power. Spokane, Washington. Kleinschmidt Energy and Water Resource Consultants, 33 West Main Street, Strasburg, Pennsylvania. 85pp.

Klussman, W.G., R.L. Noble, R.D. Martyn, W.J. Clark, R.K. Betsill, P.W. Bettoli, M.F. Cichra, and J.M. Campbell. 1988. Control of aquatic macrophytes by grass carp in Lake Conroe, Texas, and the effects on the reservoir's ecosystems. Texas Agricultural Experiment Station, Miscellaneous Report 1664, Texas A & M University, College Station, TX.

Kujawa, E.R., P. Frater, A. Mikulyuk, M. Barton, M.E. Nault, S. Van Egeren, and J. Hauxwell. 2017. Lessons from a decade of lake management: Effects of herbicides on Eurasian watermilfoil and native plant communities. *Ecosphere* 8(4):e01781.10.1002/ecs2.1718.

Laitala, K.L., T. Prather, D. Thill, B. Kennedy, and C. Caudill. 2012. Efficacy of benthic barriers as a control measure for Eurasian watermilfoil (*Myriophyllum spicatum*). *Invasive Plant Science and Management* 5(2): 170–177.

Lapointe, N.W.R., L.D. Corkum, and N.E. Mandrak. 2007. Seasonal and ontogenic shifts in microhabitat selection by fishes in the shallow waters of the Detroit River, a large connecting channel. *Transactions of the American Fisheries Society*. 136: 155–166.

LaRue, E.A., M.P. Zuellig, M.D. Netherland, M.A. Heilman, and R.A. Thum. 2012. Hybrid watermilfoil lineages are more invasive and less sensitive to commonly used herbicides than their exotic parent (Eurasian watermilfoil). *Evolutionary Applications* 6: 462–471.

Liao, F.H., F.M. Wilhelm, and M. Solomon. 2016. The effects of ambient water quality and Eurasian watermilfoil on lakefront property values in the Coeur d'Alene area of Northern Idaho, USA. Sustainability 8(1):44. doi:10.3390/su8010044.

Lillie, R.A., and J. Budd. 1992. Habitat architecture of *Myriophyllum spicatum* L. as an index to habitat quality for fish and macroinvertebrates. *Journal of Freshwater Ecology* 7(2): 113–125.

Limburg, K. E., M. A. Moran, and W. H. McDowell. 1986. The Hudson River ecosystem. Springer-Verlag, New York, New York, USA.

Lodge, D.M. 1993. Species invasions and deletions: Community effects and responses to climate and habitat change. *In* Dareiva, P.M., J.G. Kingsolver, and R.B. Huey (eds.), Biotic interactions and global change. Sinauer, pp. 367–387.

Lonergran, T. 2014. A laboratory examination of the effectiveness of a winter seasonal lake drawdown to control invasive Eurasian watermilfoil (*Myriophyllum spicatum*). *Lake and Reservoir Management* 30(4): 381-392.

Lord, P. H. 2004. Biocontrol of Eurasian water-milfoil in Central New York State: *Myriophyllum spicatum* L., its insect herbivores and associated fish. BFS Occ. Ppr. #38. SUNY Oneonta Bio Fld. Sta., Cooperstown, NY. pp. 1–69.

Lord, P. H. and T. N. Pokorny. 2013. 2011 & 2012 Eurasian watermilfoil (*Myriophyllum spicatum*) Growth and Milfoil Herbivorous Insect Impacts in DeRuyter Reservoir. Submitted to Madison County Planning Department. SUNY Oneonta Bio. Fld. Sta., Cooperstown, NY. (only available on the web as 2012 draft report).

Lord, Paul H. (N.D.) Physiological mechanisms of "selective" aquatic herbicides. State University of New York at Oneonta.

Lubnow, F. S., S. J. Souza and C. Borek. 2003. Invasive species macrophyte control using grass carp (*Ctenopharyngodon idella*): Lessons learned. NEAPMS 4th Annual Meeting.

Maceina, M.J., P.W. Bettoli, W.G. Klussmann, R.K. Betsill and R.L. Noble. 1991. Effect of aquatic macrophyte removal on recruitment and growth of black crappies and white crappies in Lake Conroe, Texas. *North American Journal of Fisheries Management* 11: 556–63.

MacRae, I. V., N. N. Winchester, and R. A. Ring. 1990. Feeding activity and host preference of the milfoil midge, *Cricotopus myriophylli* Oliver (Diptera: Chironomidae). *Journal Aquatic Plant Management* 28: 89–92.

Madsen, J.D. 1993. Biomass techniques for monitoring and assessing control of aquatic vegetation. *Lake and Reservoir Management* 7(2):141–154.

Madsen, J.D. 1998. Predicting invasion success of Eurasian watermilfoil. *Journal of Aquatic Plant Management* 36: 28-32.

Madsen, J.D. 2000. Advantages and disadvantages of aquatic plant management techniques. ERDC/EL MP-00-1, US Army Engineer Research and Development Center, Vicksburg, MS. 32pp.

Madsen, J. D. and C. W. Boylen. 1989. Eurasian watermilfoil seed ecology from an oligotrophic and eutrophic lake. *Journal of Aquatic Plant Management* 27: 119–121.

Madsen, J.D. 2014. Chapter 15.2: Eurasian Watermilfoil. *In*: Biology and control of aquatic plants: A best management practices handbook (Gettys, L.A., W.T. Haller and D.G. Petty, eds.). Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pages.

Madsen, J. D., J. W. Sutherland, J. A. Bloomfield, L. W. Eichler, and C. W. Boylen. 1991. The decline of native vegetation under dense Eurasian watermilfoil canopies. *Journal of Aquatic Plant Management* 29: 94–99.

Madsen, J.D., R.M. Wersal, and T.E. Woolf. 2015. Operational control of Eurasian watermilfoil (*Myriophyllum spicatum*) and impacts to native submersed aquatic macrophyte community in Lake Pend Oreille, Idaho. *Invasive Plant Science and Management* (8)2: 219–232.

Martin, C.W. and J.F. Valentine. 2011. Impacts of habit-forming exotic species on estuarine structure and function: An experimental assessment of Eurasion milfoil. *Estuaries and Coasts* 34: 364–372.

Mattson, M., P. Godfrey, R. Barletta and A. Aiello. 2004. Generic Environmental Impact Report for Lake Management in Massachusetts. University of Massachusetts.

McKnight, W. 1993. Biological Pollution: The Control and Impact of Invasive Exotic Species. Proc. Symp. Biol. Pollution Ind. Acad. Sci. Oct. 25–26, 1991.

Menninger, H. 2011. A Review of the Science and Management of Eurasian Watermilfoil: Recommendations for Future Action in New York State. 46pp.

Mills, E.L., J.H. Leach, J.T. Carlton, and C.L. Secor. 1993. Exotic species in the Great Lakes: A history of biotic crises and anthropogenic introductions. *Journal of Great Lakes Research* 19: 1–54.

Montana Department of Environmental Quality. 1996. Administrative Rules of Montana. State of Montana, Title 17, Chapter 30 – Water Quality, Helena, MT.

Montana Fish, Wildlife & Parks. 2016. Noxious Weed Management, Fiscal Year 2016. 46pp.

Montana Fish, Wildlife & Parks. 2015. Montana's State Wildlife Action Plan. Helena, MT. 441pp.

Montana Fish, Wildlife & Parks. 2013a. Statewide Fisheries Management Plan. 80pp.

Montana Fish, Wildlife & Parks. 2013b. Draft Environmental Assessment to Investigate Suppression of Walleye in Noxon Reservoir. 26pp.

Montana Fish, Wildlife & Parks. 2008. Statewide Integrated Noxious Weed Management Plan. 36pp.

Montana Aquatic Nuisance Species Technical Committee. 2002. Montana Aquatic Nuisance Species (ANS) Management Plan. 142pp.

Montana Noxious Weed Summit Advisory Council. 2011. Montana’s Statewide Strategic Plan for Invasive Aquatic Plant Management and Resource Protection. Montana Department of Agriculture, Helena Montana.

Moody, M.L., and D.H. Les. 2002. Evidence of hybridity in invasive watermilfoil (*Myriophyllum*) populations. *Proceedings of the National Academy of Sciences, USA* 99:4867–14871.

Mooney, H.A., and J.A. Drake (eds.). 1986. Ecology of biological invasions of North America and Hawaii. Ecological Studies 58. Springer, Berlin, Heidelberg, NY.

Nam S., S. Joo, S. Kim, N.I. Baek, H.K. Choi, and S. Park. 2008. Induced metabolite changes in *Myriophyllum spicatum* during co-existence experiment with the cyanobacterium *Microcystis aeruginosa*. *Journal of Plant Biology* 51:373–378.

National Invasive Species Council. 2016. Management Plan: 2016–2018. Washington, DC, 2016. 43pp.

Netherland, M.D., and J. Schardt. 2009. A manager's definition of aquatic plant control. *Aquatics* 31(2): 6–19.

Nelson, L.S., and J.F. Shearer. 2008. Evaluation of Triclopyr and *Mycoleptodiscus terrestris* for control of Eurasian watermilfoil (*Myriophyllum spicatum*). *Invasive Plant Science and Management* 1(4): 337–342.

Netherland, M. 2014. Chapter 11: Chemical Control of Aquatic Weeds. In: Biology and control of aquatic plants: a best management practices handbook (Gettys LA, WT Haller and D.G. Petty, eds.). Aquatic Ecosystem Restoration Foundation, Marietta, GA. 210 pages.

Netherland, M.D. and J. Schardt. 2009. A manager's definition of aquatic plant control. *Aquatics* 31(2): 6–19.

Netherland, M.D. and L. Willey. 2017. Mesocosm evaluation of three herbicides on Eurasian watermilfoil (*Myriophyllum spicatum*) and hybrid watermilfoil (*Myriophyllum spicatum* x *Myriophyllum sibiricum*): Developing a predictive assay. *Journal of Aquatic Plant Management* 55: 39–41.

Neuenschwander, P. 2001. Biological control of the cassava mealybug in Africa: a review. *Biological Control* 21: 214–229.

Newman, R. M., D. W. Ragsdale, and D. Biesboer. 2002. Factors influencing the control of Eurasian watermilfoil with native or naturalized insects. Final report for 1999–2001 submitted to Chip Welling, Eurasian Watermilfoil Program, Ecological Services Section, Box 25, Minnesota Department of Natural Resources, 500 Lafayette Rd., St. Paul, MN. 55155–4025.

Nichols, S. and G. Cottam. 1972. Harvesting as a control for aquatic plants. Water Resources Bulletin, American Water Resources Association 8(6): 1205–1210.

Okanagan Basin Water Board. 2009. Management plan for Eurasian watermilfoil (*Myriophyllum spicatum*) in the Okanagan, British Columbia. 25pp.

Olden, J.D. and M. Tamayo. 2014. Incentivizing the public to support invasive species management: Eurasian milfoil reduces lakefront property values. PLoS ONE 9(10): e110458. https://doi.org/10.1371/journal.pone.0110458.

Olson, M.H., S.R. Carpenter, P. Cunningham, S. Gafny, B.R. Herwig, N.P. Nibbelink, T. Pellett, C. Storlie, A.S. Trebitz, and K.A. Wilson. 1998. Managing macrophytes to improve fish growth: A multi-lake experiment. *Fisheries* 23(2): 6-12.

Ortenblad, Angela L., Allison M. Zappa, and Abby R. Kroken Robert C. Anderson. 2006. Effectiveness of Granular 2, 4-D Treatment on Hybrid Watermilfoil (*Myriophyllum sibiricum* x *spicatum*) in Oconomowoc Lake, Wisconsin. *Technical Bulletin*.

Parkinson, H., J. Mangold, J. Jacobs, J. Madsen, and J. Halpop. 2011. Biology, Ecology, and Management of Eurasian watermilfoil (*Myriophyllum spicatum* L.). Montana State University Extension. 16pp.

Parsons, J.K., G.E. Marx, and M.A.R.C. Divens. 2011. A study of Eurasian watermilfoil, macroinvertebrates and fish in a Washington lake. *Journal of Aquatic Plant Management* 49:71-82.

Petry, P., P.B. Bayley, and D.F. Markle. 2003. Relationships between fish assemblages, macrophytes and environmental gradients in the Amazon River Floodplain. *Journal of Fish Biology* 63: 547–579.

Pine, R. T. and L. W. J. Anderson. 1991. Plant preferences of triploid grass carp. *Journal of Aquatic Plant Management* 29: 80–82.

Pinnacle Research & Consulting. 2017. Clark Fork Project Recreation Resource Management Plan (DRAFT). Prepared for Avista Utilities. 95pp.

Poovey, A.G., and K.D. Getsinger. 2002. Impacts of inorganic turbidity on diquat efficacy against *Egeria densa*. *Journal of Aquatic Plant Management* 40:6–10.

Poovey, A. G., J. G. Skogerboe, K. D. Getsinger, J. D. Madsen, R. M. Stewart, T. Koschnick, and A. Staddon. 2000. Low dose applications of triclopyr for the selective control of Eurasian watermilfoil. 40th Annual Meeting and International Conference of The Aquatic Plant Management Society, Inc. San Diego, Ca. (online PDF unavailable)

Poovey, A.G., K.D. Getsinger, J.G. Skogerboe, T.J. Koschnick, J.D. Madsen, and R.M. Stewart. 2004. Small-plot, low-dose treatments of triclopyr for selective control of Eurasian watermilfoil. *Lake and Reservoir Management* 20(4): 322–332.

Prisciandaro, A., and M. Kuhlmann. 2015. Effects of the introduction of an invasive plant species (*Myriophyllum spicatum*) on the fish community structure of pine lake. 11pp.

Quantitate Environmental Analysis. 2008. Black Lake Eurasian Watermilfoil Management Plan. Black Lake Invasive Weeds Committee, Hammond, New York.

Rahel, F.J., and J.D. Olden. 2008. Assessing the effects of climate change on aquatic invasive species. *Conservation Biology* 22(3): 521–533.

Reed, C. F. 1977. History and distribution of Eurasian watermilfoil in the United States and Canada. Canada. *Phytologia* 36: 417–436.

Rice, P. and V. Dupuis. 2009. Flowering Rush: An invasive aquatic macrophyte infesting the headwaters of the Columbia River System. Available: http://www.weedcenter.org/research/docs/Flowering%20Rush%20white%20paper.pdf.

Roley, S.S., and R.M. Newman. 2006. Developmental performance of the milfoil weevil, *Euhrychiopsis lecontei* (Coleoptera: Curculionidae), on northern watermilfoil, Eurasian watermilfoil, and hybrid (northern x Eurasian) watermilfoil. *Environmental Entomology* 35(1): 121–126.

Sammons, S.M., M.J. Maceina, and D.G. Partridge. 2003. Changes in behavior, movement, and home ranges of largemouth bass following large-scale hydrilla removal in Lake Seminole, Georgia. *Journal of Aquatic Plant Management* 41:31–38.

Savino, J.F., and R.A. Stein. 1982. Predator-prey interaction between largemouth bass and bluegills as influenced by simulated, submersed vegetation. *Transactions of the American Fisheries Society* 111(3):255–266.

Shearer, J. F. 2002. The potential role of endophytic fungus in the decline of stressed Eurasian watermilfoil. *Journal of Aquatic Plant Management* 40: 76–78.

Sheldon, S. P. and L. M. O'Bryan. 1996. Life history of the weevil *Euhrychiopsis lecontei*, a potential biological control agent of Eurasian watermilfoil. *Entomological News* 107(1):16–22.

Sheldon, S. P. and R. P. Creed, Jr. 1995. Use of a native insect as a biocontrol for an introduced weed. *Ecological Applications* 5(4): 1222–1132.

Sheldon, Sallie P., and Robert P. Creed. 2003. The effect of a native biological control agent for Eurasian watermilfoil on six North American watermilfoils. *Aquatic Botany* 76(3): 259–265.

Slipke, J.W., M.J. Maceina, and J.M. Grizzle. 1998. Analysis of the recreational fishery and angler attitudes toward *Hydrilla* in Lake Seminole, a southeastern reservoir. *Journal of Aquatic Plant Management* 36:101–107.

Sloey, D.J., T.D. Schenck, and R.P. Narf. 1997. Distribution of aquatic invertebrates within a dense bed of Eurasian watermilfoil, *Myriophyllum spicatum*, Fish Lake, Wisconsin. *Journal of Freshwater Ecology* 12:303–313.

Smith, K.D. 1993. Vegetation-open water interface and the predator-prey interaction between largemouth bass and bluegills. Ph.D. dissertation. University of Michigan, Ann Arbor.

Smith, C.S., and J.W. Barko. 1990. Ecology of Eurasian watermilfoil. *Journal of Aquatic Plant Management* 28:55–64.

Smith, C.S., and J.W. Barko. 1996. Evaluation of a *Myriophyllum spicatum* decline in reservoirs of the Tennessee and Cumberland rivers. Technical Report A-96-6, U.S. Army Engineer Waterways Experiment Station, Vicksburg, MS.

Smith, C.S., J.W. Barko, and D.G. McFarland. 1991. Ecological considerations in the management of Eurasian watermilfoil in Lake Minnetonka, MN. Aquatic Plant Control Research Program. Technical Report A-91-3.

Smith, C.S., K.D. Getsinger, A.G. Poovey, W.F. James, M.D. Netherland, R.M. Stewart, M.A. Heilman, S. McNaught, A. Groves, P. Tyning, and P. Hausler. 2012. Selective control of Eurasian watermilfoil in Houghton Lake, Michigan: 2002 – 2006. ERDC/EL TR-12-15, US Army Engineer Research and Development Center, Environmental Laboratory, Vicksburg, MS, 182 pp.

State of Montana. 2014. Montana Aquatic Invasive Species Program. 2014 Annual Report. 30pp.

Stockman and Associates. 2016. Memorandum to Michael Germain of the Friends of Lake Garfield from Ms. Emily Stockman of Stockman Associates LLC re: Management of invasive Eurasian watermilfoil.

http://www.montereyma.gov/Public_Documents/MontereyMA_About/MilfoilMgmtMemo.pdf Accessed June 8, 2017.

Tetra Tech. 2010. Environmental Assessment – Eurasian Watermilfoil/Curlyleaf Pondweed Research and Implementation Project: Phase 2. Sanders County, Montana.

Theel, H.J., and E.D. Dibble. 2008. An experimental simulation of an exotic macrophyte invasion and its influence on foraging behavior of Bluegill. *Journal of Freshwater Ecology* 23:79–89.

Tisdell. C.A. 1990. Economic impact of biological control of weeds and insects. In: Mackauer, M., Ehler, L.E., Roland, J. (Eds.), Critical Issues in Biological Control. Intercept, Andover. pp. 301–316.

Thum, R. A. 2003. Genetic identification of native, exotic, and hybrid water milfoils in northern New England. North American Lake Management Society. 23rd International Symposium, Foxwoods Resort, Mashantucket, Connecticut. (Online PDF unavailable)

Turnage, G. and J.D. Madsen. 2014. Littoral survey of Noxon and Cabinet Gorge Reservoirs, Montana, 2013. GRI Report #5061, Geosystems Research Institute, Mississippi State University, 82pp.

Unmuth, J.M.L., D.J. Sloey, and R.A. Lillie. 1998. An evaluation of close-cut mechanical harvesting of Eurasian watermilfoil. *Journal of Aquatic Plant Management* 36:93–100.

USACE. 2011. Control of Eurasian water milfoil: For Peck Project Area, Various Counties, Montana. Environmental Assessment & Finding of No Significant Impact. USACE Omaha District. 29pp.

USACE. 2014. Selective control of Eurasian watermilfoil and curlyleaf pondweed in Noxon Rapids Reservoir, Montana. USACE Engineer Research and Development Center. 41pp.

US EPA. 2007. Clark Ford-Pend Oreille Watershed Management Plan: Management Strategies for the Next Decade, 20072017. 109pp.

US Fish and Wildlife Service. 2002. Chapter 3, Clark Fork River Recovery Unit, Montana, Idaho, and Washington. 285 p. U.S. Fish and Wildlife Service. Bull Trout (*Salvelinus confluentus*) Draft Recovery Plan. Portland, Oregon.

US Forest Service. 2015. Kootenai National Forest Land Management Plan, 2015 Revision. 179pp.

Valinoti, C.E., C.-K. Ho, and A.R. Armitage. 2011. Native and exotic submerged aquatic vegetation provide different nutritional and refuge values for macroinvertebrates. *Journal of Experimental Marine Biology and Ecology* 409: 42–47.

Valley, R. D. and M. T. Bremigan. 2002a. Effects of selective removal of Eurasian watermilfoil on age-0 largemouth bass piscovery and growth in southern Michigan lakes. *Journal of Aquatic Plant Management* 40: 79–87.

Valley, R. D. and M. T. Bremigan. 2002b. Effects of macrophyte bed architecture on largemouth bass foraging: implications for exotic macrophyte invasions. *Transactions of the American Fisheries Society* 131: 234–244.

Van Driesche, R., B. Blossey, M. Hoddle, S. Lyon, and R. Reardon. 2002. Biological control of invasive plants in the Eastern United States. Biological control of invasive plants in the Eastern United States. 424pp.

Van Driesche, R.G., Hoddle, M., and T. Center. 2008. Control of Pests and Weeds by Natural Enemies: An Introduction to Biological Control. Blackwell, Malden, MA, USA. 473pp.

Wagner, K.J. 2001. Management techniques within the lake or reservoir. Chapter 7 in Managing Lakes and Reservoirs, edited by Holdren, Johnes, and Taggart. USEPA/NALMS, Madison, WI.

Ward, D. M. and R. M. Newman. 2006. Fish predation on Eurasian watermilfoil (Myriophyllum spicatum) herbivores and indirect effects on macrophytes. *Canadian Journal of Fisheries and Aquatic Sciences* 63(5): 1049–1058.

Washington State Department of Ecology. 2010. Final Supplemental Environmental Impact Statement for Freshwater Aquatic Plants Management. WSDE Water Quality Program: 00-10-040. 137pp.

Washington Water Power. 1995. Initial Stage Consultation Document for Noxon Rapids and Cabinet Gorge Hydroelectric Projects.

Webb, K.M., R.E. Schultz, and E.D. Dibble. 2016. The influence of invasive aquatic plant removal on diets of bluegill in Minnesota lakes. *Journal of Aquatic Plant Management* 54:37–45.

Wersal, R.M, and J.D. Madsen. 2011. Plant community response in small plots one year after treatment with triclopyr and endothall in Noxon Rapids Reservoir, MT. Geosystems Research Institute Report #5049.

Wersel, R.M., J.D. Madsen, and J.C. Chesier. 2009. Eurasian Watermilfoil monitoring and mapping in the Noxon Rapids Reservoir for 2009. A summary report submitted to Avista and Montana Weed Trust. November 2009.

Wersal, R.M., J.D. Madsen, and J.C. Cheshier. 2010. Aquatic plant monitoring in Noxon Rapids Reservoir and Cabinet Gorge Reservoir for 2010. A summary report submitted to AVISTA and the Montana Weed Trust. Geosystem Research Institute Report #5042. 18pp.

Wilde, G.R., R.K. Richers, and J. Johnson. 1992. Angler attitudes toward control of freshwater vegetation. *Journal of Aquatic Plant Management* 30:77–79.

Wiley, M.J., R.W. Gorden, S.W. Waite, and T. Powless. 1984. The relationship between aquatic macrophytes and sport fish production in Illinois ponds: A simple model. *North American Fisheries Management* 4:111–119.

Wilson, S. J. and A. Ricciardi. 2009. Epiphytic macroinvertebrate communities on Eurasian watermilfoil (*Myriophyllum spicatum*) and native milfoils *Myriophyllum sibericum* and *Myriophyllum alterniflorum* in eastern North America. *Canadian Journal of Fisheries and Aquatic Sciences* 66: 18–30.

Wisconsin DNR. 2010. EWM Research Facts. 2pp.

Yellow Wood Associates. 2014. The actual and potential economic impact of invasive species on the Adirondack Park: A preliminary assessment. 78pp.

Xiao, Chan, Xiufang Wang, Jing Xia, and Guihua Liu. 2010. The effect of temperature, water level and burial depth on seed germination of *Myriophyllum spicatum* and *Potamogeton malaianus*. *Aquatic Botany* 92(1): 28–32.

Zhang, C. 2012. Essays on the use of hedonic price models to measure welfare for quality changes in the public goods. PhD thesis. 153pp.

Zuellig M.P. and R.A. Thum. 2012. Multiple introductions of invasive Eurasian watermilfoil and recurrent hybridization with northern watermilfoil in North America. *Journal of Aquatic Plant Management* 50: 1–19.

Appendix A. Survey to obtain perspectives on alternatives associated with control of EWM and HWM in Noxon Rapids and Cabinet Gorge Reservoirs.

Name, Organization, E-mail, Phone Number

1. The Sanders County Aquatic Invasive Plants Management goal is to manage aquatic invasive plants at a level that sustains a healthy aquatic environment supportive of native plant populations, fisheries, wildlife, water quality, recreation, and local economies. What role(s) have you and your organization played in establishing the goals and/or implementing control actions for invasive watermilfoil in Noxon and Cabinet Gorge Reservoirs?
2. How would you define success relative to the basin goals for invasive watermilfoil in Noxon Rapids and Cabinet Gorge reservoirs?
3. If you played any role in the collection of pre- and post- survey data, please outline how the data were collected and summarized to adequately assess treatment outcomes.
4. It has been estimated that milfoil could occupy as much as 83% of the littoral zone in Noxon (1,830 acres) and 90% in Cabinet Gorge (1,080 acres). These estimates assume milfoil growth to 25 feet. If a "no action alternative" were implemented for Noxon and Cabinet Gorge Reservoirs, what do you believe the effects would be on beneficial uses in the short (3 years) and long term (10 years)? Further, if you agree or disagree that using 25 feet as the maximum depth of colonization to estimate coverage is appropriate, please elaborate on why this number is or is not appropriate.
5. What control or combination of controls would be the most effective in reducing the density of invasive milfoil in Noxon Rapids and Cabinet Gorge Reservoirs to meet the goals of basin partners?
6. If you have experience in controlling invasive milfoil in a flowing water system, please provide one example each of a positive success achieved and a failure experienced. What factors contributed to the success and failure?
7. Please describe your understanding of the relationship between aquatic plants and fish. Specifically, how native versus invasive vegetation provides for or inhibits suitable habitat for various life stages of fish species in Noxon and Cabinet Gorge Reservoirs.
8. To your knowledge, has the identification of hybrid milfoil (*Myriophyllum spicatum* x *M. sibiricum*) potentially impacted the efficacy of current treatment protocols in western waterways?

9. What real or perceived correlation exists between increased herbicide controls and increased identification of hybrid milfoil?
10. Is there anything else you would like to add?

Appendix B. List of potential members of Scientific Advisory Panel/Committee

Tom Woolf—Fish, Wildlife, and Parks Aquatic Invasive Species Bureau Chief

Dr. Jane Mangold—Montana State University Professor

Curtis Spindler—Montana BASS Federation

Tanner Mitchell—Avista Fisheries Technician

Celestine Duncan—Weed Management Services

Technical Experts to determine specific treatment options for herbicides:

Dr. Kurt Getsinger, Research Leader, Chemical Control and Physiological Process Team, US Army Engineer Research and Development Center

Dr. Ryan Thum, Montana State University