Aquatic Herbicides

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ANS Control: Aquatic Herbicides – 2,4-D (both the amine and butoxy-ethyl ester formulations), Diquat, Fluridone, Glyphosate, Imazapyr, and Triclopyr

Targeted Species: Herbicides are used to control plants. Specific ANS of Concern – CAWS[1] that may be controlled with aquatic herbicides include Cuban bulrush (*Oxycaryum cubense*), dotted duckweed (*Landoltia* (*Spirodela*) *punctata*), marsh dewflower (*Murdannia keisak*), reed sweetgrass (*Glyceria maxima*), swamp sedge (*Carex acutiformis*), and water chestnut (*Trapa natans*).

Aquatic herbicides can be applied as a foliar spray to control emergent vegetation.

Selectivity: Aquatic herbicides can be selective or non-selective against plant species. Selectivity among plants species is dependent upon product selection, dose and timing of application, contact time (duration a herbicide is exposed to the plant), and plant species.

Developer/Manufacturer/Researcher: There are about 300 herbicides registered by the U.S. Environmental Protection Agency (USEPA); however, only 13 active ingredients (copper, endothall, diquat, carfentrazone-ethyl, flumioxazin, 2,4-D, triclopyr, glyphosate, imazapyr, imazamox, fluridone, penoxsulam, and bispyribac-sodium) are registered by the USEPA for use in and around aquatic habitats (Netherland 2009). Six of these 13 active ingredients can be considered as viable control technologies against ANS of Concern – CAWS. These six active ingredients include: imazapyr, diquat, fluridone, glyphosate, 2,4-D (both the amine and butoxy-ethyl ester formulations), and triclopyr[2]. There are numerous formulations and manufacturers of these active ingredients; a list of some of the aquatic herbicide formulations and their respective manufacturers can be found in Appendix F of Gettys et al. (2009).

Pesticide Registration/Application: Pesticides, including aquatic herbicides, must be applied in accordance with the full product label as registered by the U.S. Environmental Protection Agency (USEPA). Users must read and follow the pesticide product label prior to each application. The registration status, trade name, and availability of pesticides are subject to change. The listing of a pesticide in this fact sheet or Appendix B does not represent an endorsement by the U.S. Army Corps of Engineers or the USEPA regarding its use for a particular purpose.

Brief Description: Herbicides are pesticides that are specifically used to kill or suppress the growth of plants (Klingman et al. 1982; Ross & Lembi 1985). To be effective, herbicides must enter the plant through leaves and roots. Once inside the plant, herbicides target specific physiological processes

[1] For a complete list of the 39 specific ANS of Concern – CAWS, please see Table 1 of the main report.
[2] Manufacturers and products mentioned are examples only. Nothing contained herein constitutes an endorsement of a non-Federal entity, event, product, service, or enterprise by the U.S. Army Corps of Engineers or its employees.

such as inhibiting enzymes involved in amino acid synthesis, disrupting photosynthesis or mitosis (cell division), or interrupting the synthesis of important plant pigments. Herbicides are classified in many ways, either by their chemical family (e.g. triazines, imidazolinones, sulfonylureas, etc.), their mode and/or mechanism of action (e.g., photosystem II inhibitors, carotenoid biosynthesis inhibitors, etc.) or by their time of application in relation to growth of the weed (e.g. pre-emergence or post-emergence) (Netherland 2009). Herbicides can also be characterized as either "contact" or "systemic" products. A contact herbicide causes injury to only the plant tissues to which it is applied with little or no movement inside plant tissues (Ross & Lembi 1985; Senseman 2007). Contact herbicides are fast-acting and generally kill susceptible plants within hours or days of application. In contrast, systemic herbicides are those products which translocate downward into underground plant parts, from leaves to roots and rhizomes; activity is slow and death occurs within days to weeks (Ross & Lembi 1985; Senseman 2007). If herbicides are applied at the right dose and in accordance with application guidelines defined in the herbicide or product label, they can provide effective weed control at a reasonable cost. Aquatic herbicides can be applied as a foliar spray, sprayed or injected directly into the water column, or applied as a granular pellet.

2,4-D (both the amine and butoxy-ethyl ester formulations) – 2,4-D is a selective systemic herbicide that acts similarly to the endogenous plant hormone auxin. Although the true mechanism of action is not well understood, the primary action of 2,4-D is that it affects cell wall plasticity and nucleic acid metabolism in plants (Senseman 2009). Plant death occurs slowly in susceptible plants, usually within 3 to 5 weeks. The liquid amine formulation of 2,4-D is typically used to control emergent and submersed plants and the granular butoxy-ehtyl ester formulation is used for submersed weeds only. 2,4-D has been registered by the USEPA for use in aquatic environments since 1959, and is active against Cuban bulrush and water chestnut.

Diquat – Diquat is a fast-acting contact herbicide that disrupts photosynthesis and destroys cell membranes in susceptible plants (Senseman 2009). Rapid wilting and desiccation of affected plant tissues occurs within hours of application and plant death occurs in1 to 3 days. Diquat is applied post-emergence and is primarily used for controlling submersed and free-floating aquatic plants. It is often mixed with copper-based herbicides to improve control and to expand the range of use on other target plants. Diquat was initially registered by the USEPA for use in aquatic environments in 1961; it can be used to control duckweed species including dotted duckweed and can be tank mixed with 2,4-D for control of Cuban bulrush.

Fluridone – Fluridone is a systemic herbicide used exclusively for control of unwanted aquatic vegetation. Fluridone inhibits the plant enzyme phytoene desaturase, which is a key enzyme in the synthesis of carotenoid pigments. Carotenoids are plant pigments that protect chlorophyll pigments from being destroyed by sunlight (photooxidation). Characteristic symptoms appear in 7 to 10 days as white or pink new growth. Fluridone is a slow acting herbicide and target plants must be exposed to a

Aerial application of aquatic herbicides

lethal dose for a minimum of 45 days (Netherland 2009). Under optimum conditions, plant death occurs within 30 to 90 days after exposure (Senseman 2007). Fluridone was registered by the USEPA for use in aquatic environments in 1986. Fluridone can be used to control duckweed species including dotted duckweed.

Glyphosate – Glyphosate is a widely used herbicide in agriculture, turf, and other specialty markets, and was registered by the USEPA for use on aquatic weeds in 1977. Glyphosate is a non-selective, systemic herbicide that inhibits the plant enzyme enolpyruvyl shikimate-3-phosphate synthase, which is required for the synthesis of aromatic amino acids; this subsequently disrupts protein production in plants (Senseman 2009). Growth of susceptible plants is inhibited soon after application, followed by foliar chlorosis (yellowing) within 4 to 7 days, and plant death within 10 to 21 days. Glyphosate has no soil activity and cannot be applied directly into water. It is applied post-emergence as a foliar spray and is primarily used to control emergent aquatic plant species. Glyphosate can be used to control marsh dewflower, reed sweetgrass and swamp sedge and can be tank mixed with 2,4-D for control of Cuban bulrush.

Imazapyr – Imazapyr is a systemic herbicide that inhibits the plant-specific enzyme, acetolactate synthase, which plays a critical role in production of branched chain amino acids (Senseman 2009). Inhibition of amino acids impacts protein biosynthesis in plants. Growth of susceptible plants stops within a few hours of application, but injury symptoms and plant death do not occur until weeks later. Imazapyr is typically applied post-emergence and is active on some floating and emergent aquatic weeds. It also has soil activity, and some aquatic formulations can be applied as draw-down treatments in certain areas described in the product label. Imazapyr was registered by the USEPA for use in aquatic environments in 2003, and can be used to control reed sweetgrass, Cuban bulrush, and most sedge species.

Triclopyr – Triclopyr is a selective systemic herbicide similar in activity to 2,4-D (auxin mimic) and was registered by the USEPA for aquatic use in 2002. Both liquid and granular formulations of triclopyr amine are available; triclopyr controls submersed, floating, and emergent dicotyledonous (and some broadleaf monocotyledonous) aquatic plants. The use of triclopyr in public waters is permitted in some states where 2,4-D use is not allowed (Netherland 2009). Triclopyr can be used to manage water chestnut.

Prior Applications: Herbicides can be used to control many invasive plant species, but they are typically applied once the plant has been identified and is present on a site. Aquatic herbicides are not used as a "preventative" control measure or as a permanent chemical barrier. Using herbicides to control or eradicate plants can reduce the risk of spread, however, monitoring the success of herbicide treatments is important to identify any surviving plants and or "skips" in application technique. Re-application may be necessary to achieve long-term control and/or eradication of the weed species being treated. Aquatic herbicides will not kill seeds of plants; however, seed dispersal can be reduced if herbicides are applied before plants produce seed. The following information summarizes what has been reported in literature on the use and effectiveness of aquatic herbicides for each ANS of Concern – CAWS.

Swamp sedge, "Carex acutiformis": There is currently no peer-reviewed, published literature specifically describing the use and/or effectiveness of herbicides against swamp sedge, however, the Center for Ecology and Hydrology [(CEH) 2004] reported that all rushes, reeds and sedges are susceptible to glyphosate. Applying glyphosate to actively growing plants in mid to late summer maximizes translocation and control of underground rhizomes (CEH 2004). Imazapyr is also effective for controlling some sedge species and may have activity on swamp sedge.

Reed sweetgrass, "Glyceria maxima": Imazapyr and glyphosate can be used to control reed sweetgrass [The Nature Conservancy Global Invasive Species Team (TNC-GIST) 2005; Department of Primary Industries, Parks, Water and Environment (DPIPWE) 2002; King County Noxious Weeds 2011]. Imazapyr (rate of application not reported in publication) is best applied in summer or early fall, when water levels are low and plant stems are not submerged. Efficacy is reduced if more than one third of stem height is flooded (King County Noxious Weeds 2011). A 3% solution of glyphosate applied to foliage during early to late summer will control this weed; additionally, follow-up treatment the year after application is recommended to eliminate re-growth from surviving rhizomes (TNC-GIST 2005). Barrett (1976) reported that glyphosate applied at a rate of 2 kg ai (active ingredient)/ha (equivalent to 1.78 lbs ai/acre) controlled 96% of *G. maxima* in England. Studies by Loo et al. (2009) found that glyphosate was cost-effective for controlling reed sweetgrass and recommended that small, young populations be eradicated as soon as detected. Glyphosate has also been effective for reed sweetgrass control in Tasmania (DPIPWE 2002). Reed sweetgrass is a perennial grass species, and large, well-established populations may require follow-up treatment for 2 to 3 years to completely kill plants (King County Noxious Weeds 2011; Loo et al. 2009).

Dotted duckweed, "Landoltia (Spirodela) punctata": The herbicides diquat and fluridone are most often used to control duckweed species and are efficacious on dotted duckweed (Grodowitz et al. 2009; Lembi 2009; Netherland 2009). Diquat applied as a foliar spray at a rate of 1 to 2 gallons of formulated product per surface acre will control duckweeds (Lembi 2009). Multiple diquat applications are required during the growing season to keep this plant in check. Diquat has been successfully used to control duckweeds in Florida for more than 20 years, however, in 2006, a population of dotted duckweed was identified in Lake County, Florida that had developed resistance to this herbicide (Koschnick et al. 2006). Studies by Koschnick and Haller (2006) found that applying copper chelating agents with diquat can enhance the activity of diquat on diquat-resistant dotted duckweed. While diquat resistant dotted duckweed is currently confined to Florida, care should be taken to rotate the use of effective herbicides on this plant to prevent the development and potential spread of new resistant populations.

Fluridone will control duckweed if applied as an in-water treatment at a rate of 1 quart formulated product per surface acre in a split application, 10 to 14 days apart (Lembi 2009). Fluridone works best on duckweed when applied as soon as plants appear, typically in the early spring growing season.

Marsh dewflower, "Murdannia keisak": Chemical treatment, with glyphosate applied to actively growing plants prior to seed set, can be effective against this annual weed species (Swearingen et al. 2010). Repeat applications of glyphosate will be required to eradicate this plant if a significant seed bank is present (i.e., germinating seed will cause re-infestation).

Cuban bulrush, "Oxycaryum cubense": Although there is currently no peer-reviewed, published literature on herbicide effectiveness against Cuban bulrush, this invasive perennial plant has been successfully managed with herbicides in Florida and Alabama. In Florida, Cuban bulrush is often managed with 2,4-D applied alone or in combination with diquat or glyphosate (Jeff Schardt, Florida Fish and Wildlife Conservation Commission, E-mail communication, 2011). High rates of 2,4-D (2 to 4 quarts of formulated product/acre) applied to foliage early in the growing season (March-April) is effective against Cuban bulrush in Florida; however, the efficacy of 2,4-D is reduced if applied later in the growing season. 2,4-D is often tank mixed with diquat (0.5 gal/acre 2,4-D + 0.25 gal/acre diquat) or glyphosate (0.5 gal/acre 2,4-D + 0.25 gal/acre glyphosate) to improve efficacy when treating dense, well established stands of Cuban bulrush. Imazapyr applied to foliage at a rate of 48 oz of formulated product/acre in late summer or fall was effective for controlling Cuban bulrush in Alabama wetlands (Mike Netherland, USACE-ERDC, E-mail communication, 2011). The Aquatic Plant Information System also contains guidance for using imazapyr and 2,4-D to control this plant (Grodowitz et al. 2009).

Water chestnut, "Trapa natans": The most widely used herbicide to manage water chestnut is 2,4-D; triclopyr is used to a lesser extent (Hummel & Kiviat 2004, Poovey & Getsinger 2007; Kishbaugh 2009; Grodowitz et al. 2009; Rector 2010). Countryman (1978) reported that 2,4-D was used to successfully reduce water chestnut populations in Lake Champlain, Vermont. Both the liquid and granular formulations of 2,4-D can be used against water chestnut (Rector 2010). According to Kishbaugh (2009), applying 2,4-D in early summer, when water chestnut plants are just reaching the water surface, will provide the best results. The maximum level of water chestnut control achieved in laboratory studies when 2,4-D and triclopyr were applied as a subsurface injection, was 66% (Poovey & Getsinger 2007).

General Effectiveness: When properly applied and in accordance with product label directions, herbicides can be effective for controlling unwanted vegetation. According to Ross and Lembi (1985), the most frequently used method of aquatic weed control in the United States is the application of aquatic herbicides.

Operating Constraints: Constraints for using herbicides in aquatic environments will be defined on the manufacturer product label and may include: restrictions on water use after herbicide application (e.g. potable water and irrigation uses); when, where, and how a herbicide can be applied; frequency and maximum rate of application; conditions that can reduce herbicide efficacy (e.g. flowing water, turbidity, pH, temperature, etc.); and potential impacts to sensitive, non-target species. Appropriate state and local regulatory agencies must be contacted and manufacturer product label directions followed prior to application of an aquatic herbicide to any body of water. Some states may require applicators of aquatic herbicides to be certified and licensed.

Herbicide resistance can develop in some plant species after continuous use of a single herbicide, and has been reported in dotted duckweed in Florida (Koschnick et al. 2006). Resistance to fluridone has also been reported in another aquatic plant, hydrilla (*Hydrilla verticillata*) (Michel et al. 2004). Therefore, rotating the use of herbicides with different mechanisms of action is important for preventing further development of resistance in any plant species.

Cost Considerations: Cost of herbicide and application varies with product choice, size of area to be treated, water depth (if treating a submersed weed), method of application, density and age of plants to be treated, and management objective.

Implementation: Implementation costs would include development of a management plan, purchase and application of aquatic herbicide, potential costs associated with monitoring residues in water (if required to determine Maximum Contamination Levels related to water use restrictions imposed by the label), and possible costs for obtaining required permits. Planning and design activities in this phase may include research and development of this Control, modeling, site selection, site-specific regulatory approval, plans and specifications, and real estate acquisition. Design will also include analysis of this Control's impact to existing waterway uses including, but not limited to, flood risk management, natural resources, navigation, recreation, water users and dischargers, and required mitigation measures.

Operations and Maintenance: Operations and maintenance costs would include monitoring effectiveness of herbicide treatment and reapplication if target plants reappear.

Mitigation: Design and cost for mitigation measures required to address impacts as a result of implementation of this Control cannot be determined at this time. Mitigation factors will be based on site-specific and project-specific requirements that will be addressed in subsequent, more detailed, evaluations.

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