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### 4.6.11 Fluridone

Fluridone is a systemic herbicide introduced in 1979 (Arnold 1979) and in widespread use since the mid-1980's, although some states have been slow to approve its use. Fluridone currently comes in two formulations, an aqueous suspension and a slow release pellet, although several forms of pellets are now on the market. This chemical inhibits carotene synthesis, which in turn exposes the chlorophyll to photodegradation (Gangstad, 1986; Langeland, 1993). Most plants are negatively sensitive to sunlight in the absence of protective carotenes, resulting in chlorosisof tissue and death of the entire plant with prolonged exposure to a sufficient concentration of fluridone. When carotene is absent the plant is unable to produce the carbohydrates necessary to sustain life (Eshenroeder, 1989). Some plants, including Eurasian watermilfoil, are more sensitive to fluridone than others, allowing selective control at low doses.

For susceptible plants, lethal effects are expressed slowly in response to treatment with fluridone. Existing carotenes must degrade and chlorosis must set in before plants die off; this takes several weeks to several months, with 30-90 days given as the observed range of time for die off to occur after treatment. Fluridone concentrations should be maintained in the lethal range for the target species for at least 6 weeks and preferably 9 weeks. This presents some difficulty for treatment in areas of substantial water exchange.

Fluridone is considered to have low toxicity to invertebrates, fish, other aquatic wildlife, and humans. The USEPA has set a tolerance limit of 0.15 ppm for fluridone or its degradation products in potable water supplies, although some state restrictions are sometimes lower. Control of Eurasian watermilfoil has been achieved for at least a year without significant impact on non-target species at doses <0.01 mg/L (Netherland et al., 1997; Smith and Pullman, 1997). The slow rate of plant die-off minimizes the risk of oxygen depletion.

If the recommended 40-60 days of contact time can be achieved, the use of the liquid formulation of fluridone in a single treatment has been very effective. Where dilution ispotentially significant, the slow release pellet form of fluridone has generally been the formulation of choice. Gradual release of fluridone, which is 5% of pellet content, can yield a relatively stable concentration. However, pellets have been less effective in areas with highly organic, loose sediments than over sandy or otherwise firm substrates (Haller, Univ. FL, pers. comm., 1996). A phenomenon termed “plugging” has been observed, resulting in a failure of theactive ingredient to be released from the pellet. While some success in soft sediment areas has been achieved (ACT, 1994; Bugbee and White, 2002), pellets may be less efficient than multiple,sequential treatments with the liquid formulation in areas with extremely soft sediments and significant flushing. It may also be possible to sequester a target area with limno-curtains to reduce dilution effects in the target area (T. McNabb, AquaTechnex, pers. comm., 2001; G. Smith, ACT, pers. comm., 2002; L. Lyman, Lycott, pers. comm., 2002b).

#### 4.6.11.1 Effectiveness of Fluridone

Fluridone is the active ingredient in the registered herbicide Sonar and also in the newer competitor product, Avast, both of which have liquid and pelletized formulations. Fluridone can be a broad spectrum herbicide when applied at full label recommendations (Pullman, 1994). In most cases, however, fluridone is used as a selective herbicide. For example, treating *Myriophyllum spicatum* (Eurasian watermilfoil) or *Potamogeton crispus* (curly leaf pondweed) ata low dose (0.005-0.010 mg/L) may have little impact on surrounding vegetation (Pullman,1994; Harman, 1995; Langeland, 1993; Getsinger et al., 2000). Application rates recommended for control of non-native species such as Eurasian watermilfoil and curly leaf pondweed range from 0.007 to 0.015 ppm for a whole lake treatment (Pullman, 1994), although even lower doses have been tried with some success.

The selectivity of fluridone for the target species depends on the timing and the rate of application (G. Smith, ACT, pers. comm., 1995; Harman, 1995). Early treatment (April/early

May) with fluridone effectively controls overwintering perennials before some of the beneficial species of pondweed and naiad begin to grow (G. Smith, ACT, pers. comm., 1995). Additionally, *M. spicatum* begins growing earlier in the season than many native plants (Smith and Barko, 1990) and is thus susceptible to an early season treatment while native species are still dormant (Harman, 1995). For a complete list of plants that can be controlled by fluridone see Table 4-5 and Appendix III.

Experience with fluridone since 1995 has included a wide range of treatments at more dosages, and the susceptibility and tolerance of many species has been determined. Variability in response has also been observed as a function of dose, with lower doses causing less impact on non-target species. However, lesser impact on target plants has also been noted in some cases,so dose selection involves balancing risk of failure to control target plants with risk of impact to non-target species.

Eurasian watermilfoil has been reduced with fluridone at average concentrations as low as 4 ppb in whole lake treatments for at least a year, and doses above 20 ppb appear unnecessary as long as dilution is not a serious influence (Pullman, 1993; Netherland et al., 1997; Smith and Pullman, 1997). As fluridone works slowly, it is essential that an adequate concentration be maintained for multiple weeks. This presents a challenge to application where dilution effects are appreciable, but multiple approaches have been developed to enhance effectiveness. Many native species will survive these doses, which are well below the maximum of 50 ppb (liquid form) or 150 ppb (pellet form) set for use in Massachusetts waters. Additionally, seeds are unaffected, and many of the desirable native species are seed-producing annuals. Such annuals include the highly desirable macroalgae *Chara* and *Nitella*, carpet forming species of *Najas*, and nearly all desirable *Potamogeton* species.

Multiple low dose treatments with fluridone have been successfully applied to whole lakes in an effort to minimize the effects on the native plant assemblage. An outdoor mesocosm evaluation concluded that fluridone concentrations between 5 and 10 ppb (residues remaining above 2 ppb) for an exposure period of $\geq$60 days effectively controlled Eurasian watermilfoil during the year of treatment while minimally affecting non-target species such as *Elodea canadensis*, *Potamogeton nodosus*, *P. pectinatus* and *Vallisneria americana* (Netherland et al. 1997). Data from Michigan provided in Getsinger 2001 suggest that many species do respond differently to fluridone at different doses, and that response may vary the year after treatment as well. The response of species the year after treatment at <6 ppb was variable but not extreme; no species remained in consistent decline, indicating recovery of many susceptible populations. However, this also applies to Eurasian watermilfoil, which showed signs of resurgence in a significant number of cases where the dose was <6 ppb.

Experience in Vermont (G. Garrison and H. Crosson, VTDEC, pers. comm., 2001) with low dose treatments indicates that recovery of Eurasian watermilfoil was substantial the year after treatment with an average of 6 ppb (range = 2 to 11 ppb over 6 weeks). A fluridone assay was used to track concentrations to the nearest 0.5 ppb. There was minimal damage to non-target flora, but relief from Eurasian watermilfoil infestation may be short-lived for a substantial cost. Use of the low dose was driven by concerns by the fishery agency in VT over loss of vegetative cover in the year of treatment.

By comparison, a 12 ppb treatment of Snyders Lake in New York (S. Kishbaugh and J. Sutherland, NYSDEC, pers. comm., 2002) with one booster treatment to raise the concentration back to near 12 ppb after a month resulted in near eradication of Eurasian watermilfoil and restoration of a highly desirable native community, based on four years of monitoring. Damage to some non-target species was indeed observed in the year of treatment, but substantial recoveryof native species was observed the same year. Both an increase in taxonomic richness and expansion of coverage were observed during the year after treatment. Subsequent plant community changes have been more subtle, and hand harvesting of sporadic Eurasian watermilfoil stems has maintained control.

Fluridone is also applied for the control of fanwort (*Cabomba caroliniana*), but typically at higher doses that used for Eurasian watermilfoil control (G. Bugbee and J. White, CT Agric. Exper. Station, pers. comm., 2002; G. Smith, ACT, pers. comm., 2002, L. Lyman, Lycott, pers. comm., 2002b). Doses >10 ppb are almost always applied for fanwort control, with doses of 12- 15 ppb showing signs of success and doses near 20 ppb providing nearly complete fanwort kill. Unfortunately, at doses approaching 20 ppb, nearly all other submergent vegetation will be impacted as well.

#### 4.6.11.2 Specific Short-Term Impacts on Non-Target Organisms by Fluridone

Maximum label application rates are 8 lb per acre-foot and 0.4 quarts per acre foot for the Sonar SRP and Sonar AS formulations, respectively. The maximum concentrations of fluridone expected would be 0.15 ppm, but since the mid-1990s it has been extremely rare to have a target concentration greater than 0.02 ppm. With target levels as low a 0.006 ppm, impacts on the target species are not always achieved, and only the most sensitive non-target vegetation (e.g., water marigold, *Megalodonta beckii*) is impacted. At application rates more certain to kill milfoil, partial damage to many non-target plants has been observed, but recovery within 1-2 years is typical.

Research on degradation products of fluridone initially suggested some possible effects, but further testing indicated no significant threat. The potential formation of N-methylformamide (NMF), a compound that is toxic to humans, was investigated in field experiments by Smith etal. (1991) in Uxbridge and Grafton, Massachusetts, after it was observed as a breakdown productof fluridone in laboratory experiments. Their findings agreed with the results of a similar studyby Osborne et al. (1989), in that no NMF was detected in the field. The laboratory experiments were conducted in the absence of aquatic plants and sediments. The contrasting results suggest that either fluridone behaves differently in the laboratory than it does in the field or that NMF is broken down rapidly in natural aquatic environments (Smith et al., 1991).

Substantial bioaccumulation has been noted in certain plant species, but not to any great extent in animals. The USEPA has designated a tolerance level of 0.5 ppm (mg/L or mg/kg) for fluridone residues or those of its degradation products in fish or crayfish. The LC50 for sensitive fish species (excluding walleye, which is not common in the state) is 7.6 ppm (Paul et al., 1994), which is 50 times higher than the expected maximum concentrations and about 500 times higher than typical doses used today. Other studies report LC50s as high as 22 ppm (Westerdahl and Getsinger, 1988), but generally there is little variation from species to species.

Fluridone was not found to impact non-target organisms at concentrations of 0.1 to 1.0 ppm in contained field experiments. Mosquitofish (*Gambusia affinis*) were added to each container to evaluate the impacts of fluridone on the fish at concentrations of 4.0, 2.0, 1.0, 0.5 and 0.25 ppm. *G. affinis* survived and reproduced at all concentration levels. Additionally, fluridone did not accumulate in the fish tested. The fluridone level in pumpkinseed (*Lepomis gibbosus*) detected 7 days after an application of 0.1 ppm was 0.023 ppm. No detectable residue was found in *L. gibbosus* 27 days after application. Other non-target organisms present included bluegills, catfish, crayfish, frogs and water snakes. No adverse impacts to these organisms were observed (McCowen et al., 1979).

Fluridone has a low order of toxicity to mammals. Rat LD50s are >10,000 mg/kg (Appendix III).

#### 4.6.11.3 Specific Long-Term Impacts on Non-Target Organisms by Fluridone

Fluridone has not been identified as a carcinogen or mutagen. A "No Observed Effects Level" for teratogenic effects for fluridone is greater than 100 mg/kg/day (see appendix III for further toxicity information). Long-term negative impacts to non-target organisms are not expected from the use of fluridone. To the contrary, Schneider (2000) found that fluridone use at lowdoses in Michigan lakes resulted in improved fishery conditions, but not all species have been studied and a long-term loss of vegetation could be expected to alter the fish community.

#### 4.6.11.4 Specific Short-Term Impacts on Water Quality by Fluridone

Fluridone did not affect water quality in contained field experiments. The parameters measured included pH, BOD, color, dissolved solids, hardness, nitrate nitrogen, total phosphorus and turbidity (McCowen et al., 1979; Arnold, 1979). The slow die-off of plants susceptible tofluridone minimizes the potential for any water quality impacts.

Fluridone should not be applied within 1/4 mile of a potable water intake at levels greater than 0.02 ppm. Water treated with fluridone should not be used for irrigation for 7 to 30 days (irrigation restrictions vary depending on the size of the lake or pond, type of vegetation to be irrigated and which form of the product is used). Federal and Massachusetts registered Sonar labels do not include restrictions for swimming and fishing (SePRO, 1994a; 1994b). However, labels for use in New York prohibit swimming for 24 hours after application (Harman, 1995). Because this product has a relatively long environmental half-life and is not readily sorbed to the sediments, it has a greater tendency to disperse from the treated area than other herbicides. However, the apparent lack of impact on non-target fauna has allowed use of this herbicide in places where others are prohibited, and dispersion is more an issue for treatment effectiveness than impacts on water quality.

#### 4.6.11.5 Specific Long-Term Impact on Water Quality by Fluridone

The degradation of fluridone is dependent on sunlight and temperature. The half-life of fluridone in Pout Pond, Uxbridge, Massachusetts was 40 days, but fluridone was more persistent in winter than in summer (Smith et al., 1991). Half-life values as short as 20 days have been recorded.

#### 4.6.11.6 Implementation Guidance for Fluridone

Adhere to all label restrictions. Licensed professionals must perform the treatments. Most treatments with fluridone are conducted in the spring, when target plants are most actively growing. Treatment could occur as early as late March, with an early ice-out, with booster treatments occurring several weeks after as needed in order to maintain the desired average concentration for 40-60 days. The physiological advantage of this time period is sometimes offset by the logistical disadvantage of higher flows and dilution effects during spring. In some cases, treatment has been postponed until summer or even autumn to minimize the volume of water that must be treated. Some successes have been achieved in this manner (Burns, SePRO, pers. comm., 2001), but it has also been suggested that residues remaining until the next spring are an important cause of target plant decline.

Starting at a lower dose (<0.02 ppm) and tracking the concentration has been made possible by immunoassay technology. This allows the herbicide concentration to be “bumped” or “boosted” as needed if dilution and degradation are substantial, while minimizing herbicide use and associated costs and possible unwanted impacts (Getsinger et al., 2002; Madsen et al., 2002). The level of sophistication achieved with fluridone has moved herbicide treatments into a new era, with flexible applications and considerable creativity on the part of experienced applicators. Licensed professionals must perform the treatments.

Holding the chemical within a target area smaller than the lake remains a challenge, but progress has been made there as well. Sequestered treatments were conducted in 2000 in a Washington lake (T. McNabb, AquaTechnex, pers. comm., 2001), in which a 20 acre area and a 5 acre area impacted by Eurasian watermilfoil were surrounded with an impermeable barrier and treatedwith fluridone at 0.01-0.03 ppm. Follow-up monitoring has indicated success through 2002. Dilution and degradation of fluridone were still factors, but much less so than for partial lake treatments or whole lake treatments where flushing is high. A higher initial concentration of fluridone is normally used (≥20 ppb) in such treatments to ensure that the milfoil is killed. It is assumed that nearby native plants will colonize the area once the milfoil is gone.

A treatment in Connecticut for Eurasian watermilfoil (G. Smith, ACT, pers. comm., 2002) and another in Massachusetts for fanwort (L. Lyman, Lycott, pers. comm., 2002b) applied limno-curtains to sequester a section of each lake. In these cases, the lakes had hourglass shapes, making division of the lake at the isthmus much simpler than attempting to isolate major portionsof a lake without such a constriction. Both treatments appear to have been successful throughthe year of treatment, with doses of 0.006 (CT) to 0.012 (MA) ppm.

Fluridone is still sometimes used for partial lake treatments without sequestration, but the risk of failure is higher. At issue are the high diffusion and dilution factors for fluridone, which reduce the concentration in the target area in most cases. Usually a pelletized form of fluridone is used for such treatments, providing gradual release of fluridone into the target area to offset diffusion and dilution. Results have been quite variable. Application to two 100-acre plots in Saratoga Lake in 2000 provided minimal relief from milfoil in the year of treatment and only limited effects in 2001 (G. Smith, ACT, pers. comm., 2001). Treatment of a 5 acre cove in a lake in CT with Sonar SRP in 2000 (Bugbee and White, CT Ag. Exp. Station, pers. comm., 2002) showedno effects for 60 days after treatment, but provided a complete kill of target plants by 90 days after treatment. Newer pellet formulations (Sonar PR or Sonar Q) may improve predictability of such treatments. However, increased cost and continued dilution impacts remain impediments toapplication. Re-infestation from untreated areas may quickly ameliorate whatever benefits are realized, and partial lake treatments do not appear to be an efficient way to address extensive growths.