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Use of Fluridone for Hydrilla Management in the Withlacoochee River, Florida.

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ABSTRACT

Fluridone at a theoretical sustained concentration of 10 to 12 μg l^{-1} was applied over a period of 13 weeks to several lakes along a section of the Withlacoochee river in central Florida, to control hydrilla. Residue analyses indicated that although the theoretical concentration of 10 to 12 μg l^{-1} fluridone was not sustained for 13 weeks, hydrilla was susceptible to lower concentrations over the long exposure periods that resulted from low water discharges that occurred in 1990. The combined fluridone concentrations and exposure times at a given site were expressed in Fluridone Exposure Days (FEDs), and these values were related to water flow data, particularly the influence of spring-fed tributaries. Hydrilla was controlled for 10 to 12 months in the upstream half of the target area, where fluridone exposure was in excess of 500 FEDs, but in downstream areas subject to 250 FEDs, hydrilla control lasted for only six to nine months. This treatment was repeated in 1991 under increased flow conditions, with only a 10-week application period. Effective weed control was achieved despite lower FEDs possibly because of the increased susceptibility of the actively growing plants and the stresses caused by high water levels.

Key words: herbicide exposure, herbicide residues, Sonar®, aquatic weeds, flowing water, vegetation mapping.

INTRODUCTION

In recent years, research on the control of hydrilla (*Hydrilla verticillata* (L.f.) Royle) in Florida has been focused on improving the efficacy and predictability of herbicide use in flowing waters, particularly lowland rivers. Fluridone (1-methyl-3-phenyl-5-[3-(trifluoromethyl)-phenyl]-4(1H)-pyridinone) treatments on the upper St. Johns River in 1989, where a low dose of fluridone (10 μg l^{-1}) was applied over a 10-week period, provided essentially hydrilla-free conditions in the target area for approximately one year (Haller et al. 1990). The Withlacoochee River is similar to the upper St. Johns River in that it is a series of lakes, connected by river runs, and its discharge varies from minimal flow in dry years to several million cubic meters per day during periods of high rainfall.

Hydrilla has been a severe weed problem in the middle reaches of the Withlacoochee River for about 20 years and until 1990, contact herbicides were applied twice a year (May and August) to the center of the river to allow navigation, at a total cost of approximately $100,000 yr^{-1} (W.M. Andrew, *pers. comm.*) Creation of central navigation trails, however, did not provide access to most of the lakes or backwaters, and the large expanses of hydrilla posed potential risks for fish-kills and flooding.

Following the successful treatment on the upper St. Johns River in 1989, a similar fluridone treatment and residue sampling regime was devised for the target area of the Withlacoochee River in 1990 and 1991. The primary objective was to sustain a fluridone concentration of 10 to 12 μg l^{-1} for at least 10 weeks, using an upstream lake with known inflow as the application site and mixing zone.

MATERIALS AND METHODS

Water discharge data. Water discharge data were obtained from four US Geological Survey (USGS) gauging stations, one at Croom, another downstream of Bonnet Lake, one in Jumper Creek, and the fourth in the Panasoffkee River (Figure 1). Discharges recorded during April to July 1989 were averaged to predict the relative influences of the two main tributaries on the target area. Daily discharge data obtained from the Croom gauging station for the 1990 and 1991 treatment periods were used to calculate herbicide application rates. Average monthly discharges for each gauging station were estimated during these periods also.

Herbicide application. Fluridone (AS) was applied to Lake Istachatta, (Figure 1) by airboat on Mondays, Wednesdays and Fridays. Application rates were calculated using Croom water discharge data to provided an average concentration of 10 to 12 μg l^{-1} fluridone. Most herbicide (over 60%) was applied to Lake Istachatta and Silver Lake (Figure 1; Table 1), with Bonnet Lake also receiving significant amounts (over 11%). In 1990 a total of 157 kg a.i. (active ingredient) of fluridone was applied over a 13 week period starting on 20 March, and in 1991, 218 kg a.i. were applied over 10 weeks starting on 8 April (Table 1). An additional small application (9.1 kg a.i.) of slow-release pellets of fluridone was made at the mouth of Jumper Creek in 1991. Annual fluridone herbicide costs were $78,000 and $103,166 for 1990 and 1991, respectively.

Residue sampling. Three replicate water samples for fluridone residue analysis, were collected in 0.5-liter polyethylene bottles at seven sites, from upstream of Lake Istachatta to Wysong (Figure 1). In 1990 these samples were collected at two or three week intervals from early April to early October, and in 1991 at three week intervals from late April to mid-July. Water samples were placed on ice in the field and were frozen within 12 hours of collection. Fluridone residues were

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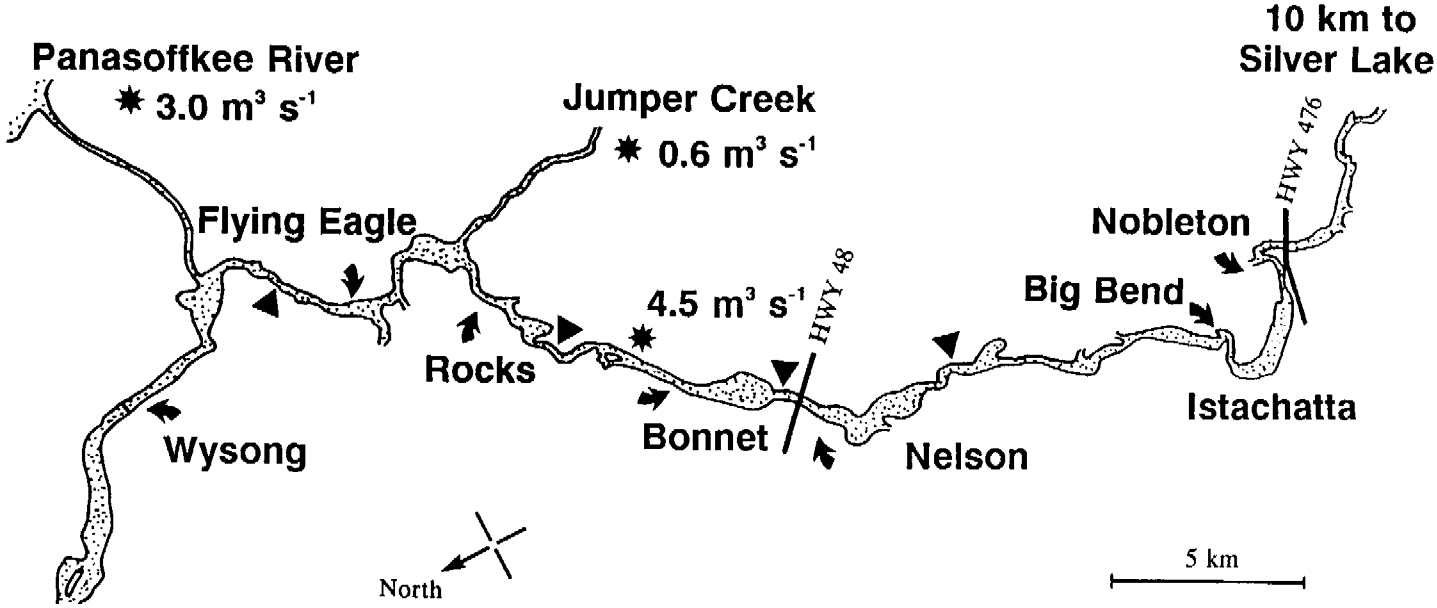

Figure 1. Map of principal target area of Withlacoochee River flowing north from Lake Istachatta to Wysong. = USGS gauging stations with average discharge for April to July 1989; discharge at Croom gauging station 9 km upstream of Lake Istachatta = 3.1 $m^3 s^{-1}$; ➡ = water sampling stations; ▼ = permanent vegetation mapping transects.

analyzed by HPLC following the methods of Fox et al. (1991) with a limit of quantification of 0.05 $\mu g\ l^{-1}$.

To estimate the concentration/exposure relations of the sampling sites and years, Fluridone Exposure Days (FEDs) were calculated. These were estimated for each site from the area underneath a graph of fluridone concentration against time, such that they represent a product of concentration and exposure period. Only concentrations greater than 1 $\mu g\ l^{-1}$ were included, with the required calculations described by the equation:

$$\Sigma\ [C_1\ (T_1 - T_0)] - [(T_1 - T_0)(C_1 - C_0)/2] \ldots\ldots$$
$$\ldots\ldots[C_n\ (T_n - T_{n-1})] - [(T_n - T_{n-1})(C_n - C_{n-1})/2]$$

Where:

C_x =fluridone concentration if greater than 1 $\mu g/l$ at sampling time x

T_x =number of days after start of treatment at sampling time x

n =final sampling time.

Such units relate to the concept of "availance" described by Hartley and Graham-Bryce (1980), and are similar to "degree frost days" used in horticulture and vegetable crop production.

Treatment evaluation. Permanent transects were established at four sites between Lake Istachatta and the Panasoffkee River (Figure 1) to determine the effectiveness of these treatments. The transects were mapped every three months using a modification of the rectangles method described by Wright et al. (1981). At each site three adjacent transects (U,M,D; upstream, middle, downstream) were divided into 2 by 2 m squares. Water depth, the dominant species and all species present were recorded for each square. The dominant species in a square was also recorded as present in that square, such that frequency of presence was always equal to, or greater than, the frequency of dominance for a species.

A species was determined to be dominant if it covered over 50% of a square, as evaluated by visual assessment or by three short sweeps with a 20 cm-wide garden rake. If no vegetation was initially sampled, longer or more numerous sweeps were used to determine if any plants were present. Two species were classified as co-dominant, and were assigned a coverage value of a 1/2 square each, if they were equally mixed and had a combined coverage of over 50% of the square.

If there was less than 50% plant coverage in a square, it was determined not to have any species as dominant. A square with 50% vegetation coverage would receive a coverage value of a 1/2 square with no vegetation and a 1/2 square of the single species that covered the most of the vegetated part of the square.

Because of the dark brown tannin coloration of the river water, the rake was generally necessary for coverage evaluation in water depths greater than 60 cm. Use of the rake was limited so as to minimize damage to the vegetation in the transects but this increased the possibility that sparsely distributed species might be missed.

At each site the percentages of all squares in each transect within which hydrilla was present or dominant were calculated. A one-way analysis of variance was used to compare the factors of time and transect position (U,M,D) at each site. The average percentage dominance and presence of hydrilla for each site and sampling time (averaged over U,M,D transects) were compared using a version of the conservative Ryan's Q means comparison test (as recommended by Day and Quinn 1989), the REGWF test in the SAS statistical software package.

TABLE 1. AMOUNTS OF FLURIDONE (AQUEOUS SUSPENSION; KG A.I.) APPLIED PER WEEK TO THE WITHLACOOCHEE RIVER IN 1990 AND 1991. APPLICATION RATE = 2.24 KG HA^{-1} (2 LB $ACRE^{-1}$). DAT = DAYS AFTER TREATMENTS STARTED.

Week begin	DAT	Silver	Istachatta	Nelson[a]	Bonnet[b]	Jumper
1990						
19 March	0	-	27.2	-	-	-
26 March	6	-	9.5	0.9	-	-
2 April	13	-	9.5	0.9	-	-
9 April	20	-	8.2	0.9	0.9	-
16 April	27	-	6.3	0.9	0.9	-
23 April	34	6.8	6.4	-	1.8	-
30 April	41	3.6	6.3	-	1.8	-
7 May	48	3.6	6.4	-	1.8	-
14 May	55	7.3	2.7	-	3.6	-
21 May	62	7.3	2.7	-	3.6	-
28 May	69	9.1	-	-	3.6	-
4 June	76	6.3	-	3.6	-	-
11 June	83	-	-	2.7	-	-
1991						
8 April	0	8.2	-	-	-	-
15 April	7	9.5	9.5	-	-	-
22 April	14	9.1	9.1	-	-	-
29 April	21	12.2	11.3	4.5	-	-
6 May	28	10.9	10.9	7.3	-	-
13 May	35	9.1	9.1	3.6	3.6	-
20 May	42	8.6	5.9	2.3	5.9	-
27 May	49	4.5[c]	-	14.5	5.4	-
3 June	56	-	-	-	16.3	-
10 June	63	-	-	-	19.0	9.1[c]

[a]Includes Lake Crump upstream of Nelson.
[b]Includes Shall Lake downstream of Bonnet.
[c]Slow release pellets.

RESULTS AND DISCUSSION

Water discharge and herbicide treatments. Discharge data from 1989 (Figure 1) indicated that there was a significant inflow of water from various small, unquantified creeks and sloughs feeding into the lakes (e.g., into Little Lake Annie, between Big Bend and Lake Nelson) between Croom and Bonnet Lake. The difference in discharge between Croom and Bonnet Lake would account for a 31% herbicide dilution, while the Jumper Creek inflow would be expected to cause an 11% dilution in the main river. The resulting herbicide concentrations would be reduced by a further 38% downstream of the Panasoffkee River. Thus, a fluridone concentration in Lake Istachatta of 10 $\mu g\ l^{-1}$ would be reduced to 6.9 $\mu g\ l^{-1}$ by Bonnet Lake, to 6.1 $\mu g\ l^{-1}$ downstream of Jumper Creek, and to 3.8 $\mu g\ l^{-1}$ downstream of the Panasoffkee River. The secondary fluridone applications in Lake Nelson and Bonnet Lake were made partly to compensate for some of these dilution effects, and to ensure that any isolated coves of these lakes were exposed to the herbicide.

Water discharges at Croom decreased throughout the 1990 treatment period (Figure 2) to extremely low flows in June and July. As a result of the decreasing discharges the total amount of herbicide allocated to treat the system was more than would be needed to maintain 10 to 12 $\mu g\ l^{-1}$ fluridone downstream of Lake Istachatta for 10 weeks. To use this herbicide allocation in the most efficient manner possible, applications were made upstream of Lake Istachatta in Silver Lake, and the total treatment period was extended to 13 weeks (Table 1). In 1991, because water discharges were very low at the start of the treatment period (April), Silver Lake was again included in the treatment schedule. However, river discharges increased rapidly in June and July resulting in high application rates at that time and the termination of the treatment after 10 weeks (Table 1).

Average water discharges in the Withlacoochee River were calculated for the fluridone treatment periods (April to July in 1990 and April to June in 1991) based on data from the USGS gauging stations (Table 2). Predicted dilutions of fluridone applied to Lake Istachatta between Big Bend and Lake Nelson, downstream of Jumper Creek, and downstream of the Panasoffkee River were also estimated (Table 2). These reductions were anticipated to be greatest in 1990 under low discharge conditions when the influence of the relatively constant inflow of spring-fed tributaries would be proportionately larger.

The reduction in water discharge between Croom and Bonnet Lake in 1991 may have resulted from a diversion of water into the Tsala Apopka lakes via two regulated canals connected to Bonnet Lake. Because this discharge was not quantified it was not possible to estimate what inflows caused the herbicide dilution observed between Lakes Istachatta and Bonnet in 1991. Fluridone symptoms were reported in the canals and near their mouths in Tsala Apopka in 1991.

Fluridone residues. The influence of the two different discharge regimes was apparent in the fluridone residue data (Tables 3 and 4). In 1990 residues were found at all sampling stations within 13 days of the first application, and continued to be detectable for up to 200 days after the start of treatments (d.a.t.) (Table 3). Some high concentrations resulted from a local treatment the same or preceding day (e.g., in

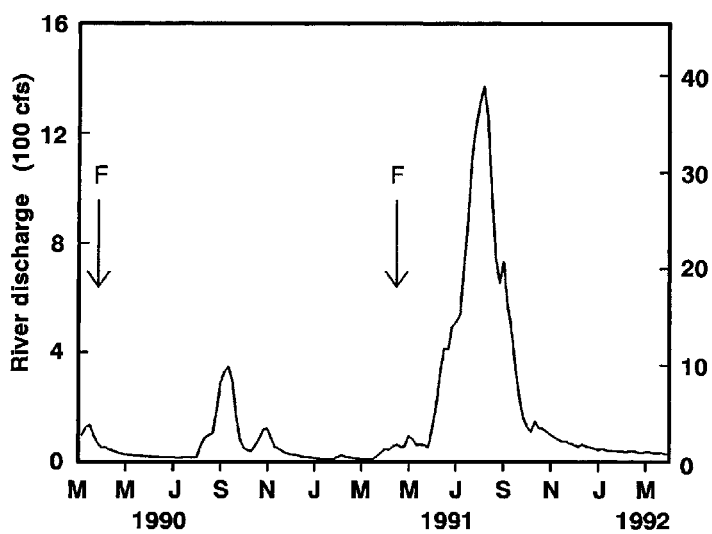

Figure 2. Withlacoochee River water discharges averaged over five day intervals at Croom (9 km upstream of Lake Istachatta) in 1990 and 1991. Arrows indicate start of fluridone treatments.

TABLE 2. AVERAGE WATER DISCHARGES ON WITHLACOOCHEE RIVER DOWNSTREAM (D/S) FROM TRIBUTARIES AND USGS GAUGING STATIONS (APRIL TO JULY IN 1990; APRIL TO JUNE IN 1991) WITH PREDICTED AND MEASURED CHANGES IN FLURIDONE CONCENTRATIONS AND FEDS COMPARED TO THE PRECEEDING MEASUREMENT UPSTREAM.

	Discharge ($m^3 s^{-1}$)	Predicted concentration ($\mu g\ l^{-1}$)	Reduction in predicted concentration	Measured Reduction in FEDs[1]	Reduction in average concentration[1]
1990					
Croom	0.6	10			
d/s Bonnet Lake	1.1	5.6	- 44%	- 30%	- 26%
d/s Jumper Creek	1.9	3.4	- 40%	- 53%	- 49%
d/s Panasoffkee R.	4.4	1.4	- 58%	- 98%	- 58%
1991					
Croom	5.0	10			
d/s Bonnet Lake	4.8	10	0%	- 48%	- 54%
d/s Jumper Creek	5.5	8.7	- 13%	- 81%	- 77%
d/s Panasoffkee R.	10.4	4.6	- 47%	- 100%	- 74%

1 Measured fluridone reductions between: Big Bend and Nelson (thus, excluding Bonnet Lake application) = d/s Bonnet Lake discharges; Rocks and Flying Eagle = d/s Jumper Creek discharges; Flying Eagle and Wysong = d/s Panasoffkee River discharges.

Bonnet Lake 59 d.a.t.). Few samples contained the target concentration range of 10 to 12 $\mu g\ l^{-1}$. Most samples during the treatment period of 91 days had less than 6 $\mu g\ l^{-1}$ fluridone. Variation between replicate samples was generally small (as indicated by the standard errors in Tables 3 and 4).

Low discharges early in 1991 resulted in little downstream distribution of herbicide within 11 d.a.t. and some high concentrations (e.g., 13.6 $\mu g\ l^{-1}$) at upstream sampling stations by 32 d.a.t. (Table 4). However, increased discharges at the end of the treatment period rapidly moved the herbicide downstream, so that little fluridone was detected in the river even within 4 days of the end of the applications.

The influence of prolonged exposure under the 1990 flow regime was evident with FEDs for that year on average twice as great as those for 1991 (Tables 3 and 4). Differences between sampling sites could also be detected. There were relatively low FEDs at Nobleton resulting from the Silver Lake treatment 10 km upstream, but maximum values occurred downstream of Istachatta at Big Bend. The 30% reduction in FEDs between Big Bend and Nelson corresponded fairly well with the rate of dilution predicted from the water discharge data at Croom and Bonnet Lake (Table 2). The fluridone applications to Lake Nelson would account for the lesser reduction in FEDs than predicted. The FED values increased again at Bonnet Lake as a result of secondary applications there. Reductions in FEDs between Bonnet and Rocks were probably due to dilution by unquantified inflows, photolytic degradation (Mossler et al. 1989) and plant uptake. Hydrilla has been shown to absorb fluridone at these concentrations in a linear fashion which is directly proportional to the concentration in the water column (Van and Conant 1988).

TABLE 3. AVERAGE FLURIDONE CONCENTRATIONS (µG 1-1) AND FEDS (FLURIDONE EXPOSURE DAYS) IN THE WITHLACOOCHEE RIVER IN 1990. SUBSCRIPT = STANDARD ERROR OF THREE REPLICATE SAMPLES; DAT = DAYS AFTER TREATMENTS STARTED ON 20 MARCH 1990; KM = KM DOWNSTREAM OF PRINCIPAL AREA OF TREATMENT AT LAKE ISTACHATTA.

	Nobleton		Big Bend		Nelson		Bonnet		Rocks		Flying Eagle		Wysong	
km	0		2		11		14		18		23		29	
DAT														
13	0.3	0.3	8.9	0.6	-		0.73	0.03	0.33	0.2	0.27	0.1	0.15	0.08
26	0.07	0.03	5.7	0.3	5.9	0.4	3.6	0.3	1.9	0.07	0.5	0.06	0.27	0.27
41	1.4	0.2	4.6	0.4	5.5	0.7	7.8	0.5	5.8	0.2	1.9	0.1	0.53	0.2
59	2.4	0.3	8.8	0.8	4.3	0.5	10.3	0.5	4.1	0.1	3.4	0.4	0.7	0.03
69	2.7	0.1	4.2	0.2	3.2	0.2	5.0	0.7	6.0	0.2	2.8	0.04	0.77	0.03
83	10.7	1.2	7.0	0.1	9.3	0.6	3.4	0.4	5.8	0.6	2.7	0.2	1.17	0.1
97	3.4	0.6	10.4	0.8	1.3	0.3	7.4	0.6	4.2	0.5	2.9	0.2	1.3	0.7
111	1.57	0.1	2.6	0.1	3.1	0.2	5.3	0.7	5.6	0.8	1.2	0.4	0.57	0.1
130	1.3	0.5	2.1	0.1	3.5	0.1	3.2	0.2	3.2	0.2	2.2	0.1	0.93	0.3
154	0.53	0.1	0.87	0.3	0.57	0.3	0.67	0.1	0.97	0.1	0.73	0.1	1.07	0.3
175	0.13	0.07	0.57	0.07	0.43	0.1	0.30	0.1	0.50	0.1	0.47	0.1	0.43	0.03
200	0.33	0.03	0.40	0.2	0.87	0.3	0.73	0.2	0.50	0.3	0.70	0.1	0.37	0.2
FEDs	340		775		547		691		553		258		5	

Table 4. Average fluridone concentrations (µg l[-1]) and FEDs in the Withlacoochee River in 1991. Subscript = standard error of three replicate samples; DAT = days after treatments started on 8 April 1991; km = km downstream of principal area of treatment at Lake Istachatta.

	Nobelton		Big Bend		Nelson		Bonnet		Rocks		Flying Eagle		Wysong	
km	0		2		11		14		18		23		29	
DAT														
11	3.3	0.1	10.8	2.1	0.07	0.03	0.13	0.03	0	0	0.03	0.03	0	0
32	6.3	0.6	13.6	1.3	9.4	0.6	8.2	0.2	3.3	0.03	0.06	0.07	0	0
53	0.13	0.07	0.5	0.06	2.0	0.03	3.6	0.3	7.9	0.33	2.1	0.34	0.23	0.07
74	0	0	0	0	0	0	0.1	0	0.17	0.03	0.43	0.23	0.43	0.07
94	0	0	0	0	0	0	0	0	0.03	0.03	0.03	0.03	0.03	0.03
FEDs	185		458		239		248		235		44		0	

Reductions in fluridone concentrations between the Rocks and Flying Eagle, and between Flying Eagle and Wysong resulted from dilution by Jumper Creek and the Panasoffkee River, respectively. However, in both years the actual percentage reduction in FEDs downstream of each confluence was greater than would have been predicted from dilution alone (Table 2). Part of this disparity was because concentrations of less than 1 µg L[-1] were excluded from the FED calculations, resulting in very low FED values at Wysong for example. If average fluridone concentrations for all sampling times rather than FEDs were compared for samples from Flying Eagle and Wysong, the percentage reduction in 1990 was as predicted (Table 2). In 1991 there was still a greater than predicted reduction in average con-

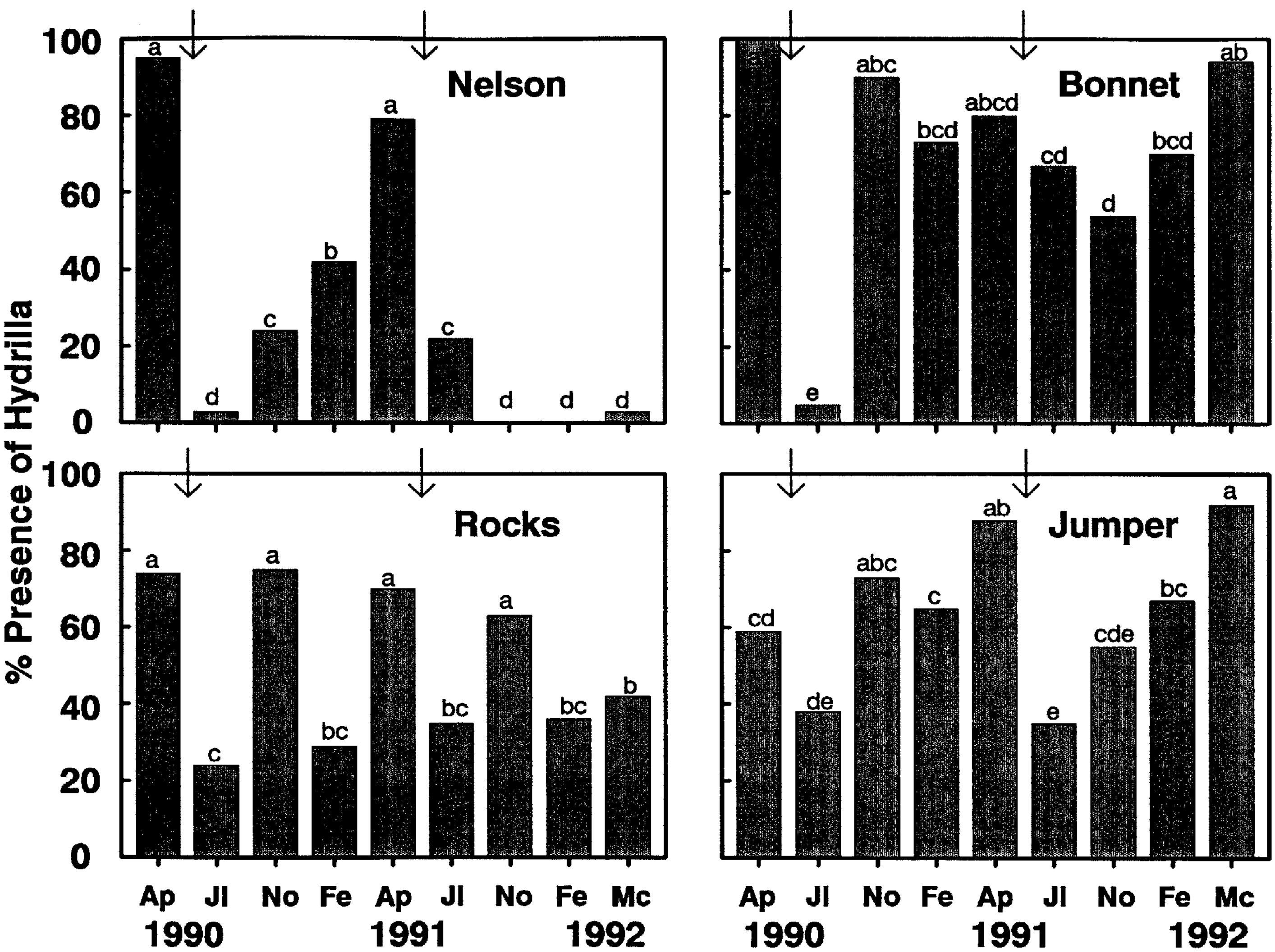

Figure 3. Percentage of transects in which hydrilla was present from April 1990 to March 1992. Each bar represents average percentage for three transects per site. Within a site, bars with the same letter are not significantly different. Arrow = fluridone treatment upstream.

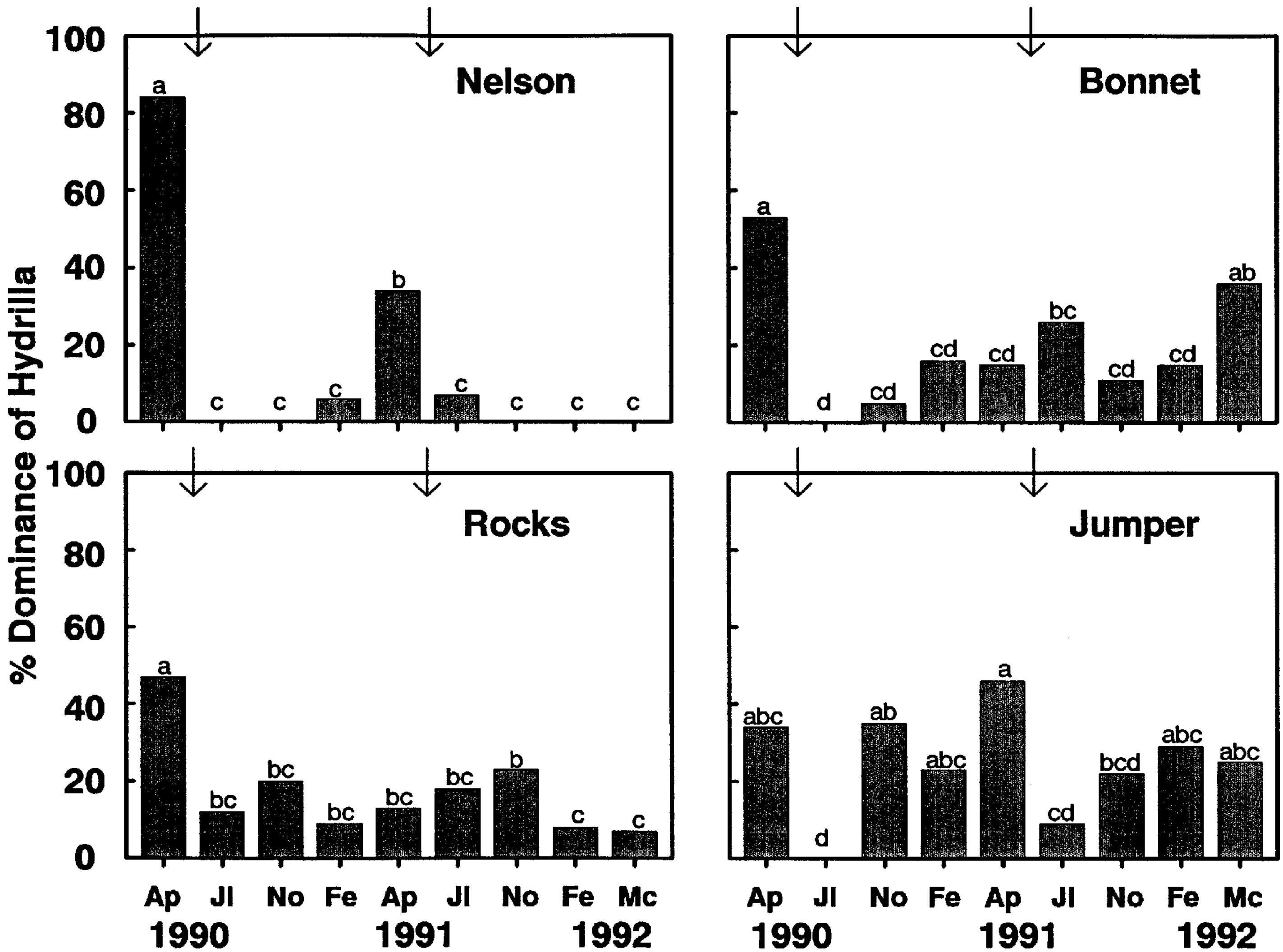

Figure 4. Percentage of transects in which hydrella was dominant from April 1990 to March 1992. Each bar represents average percentage for three transects per site. Within a site, bars with the same letter are not significantly different. Arrow = fluridone treatment upstream.

centrations downstream of the Panasoffkee River, despite the application of slow-release fluridone pellets at the mouth of Jumper Creek.

Factors other than dilution, such as photolytic degradation and plant uptake, must have contributed to the reduction in fluridone concentrations. Such factors, combined with the differences in the predicted dilution effects of the tributaries from year to year (e.g., comparing 1989 and 1990) illustrate the difficulties of modelling residue behavior in such complex river systems.

Impact of fluridone on hydrilla. From an operational viewpoint, adequate hydrilla control was estimated to have been obtained for almost 12 months of each year, over 38 km and 400 ha of river and lakes (from Silver Lake to Panasoffkee outflow). The annual fluridone cost was \$195 ha^{-1} in 1990 and \$258 ha^{-1} in 1991 (\$78 and \$103 $acre^{-1}$ respectively).

Regrowth in the St. Johns River after the 1989 fluridone treatment had first occurred near the upstream treatment site and progressed downstream (Haller et al. 1990). In the Withlacoochee River regrowth advanced upstream from Flying Eagle (December 1990) to Bonnet Lake (January 1991) to Istachatta in March 1991. This regrowth pattern corresponded well with the lower FEDs found at the downstream sites in 1990.

By the beginning of 1991, only 10% to 15% of the target area was impacted by dense hydrilla mats, with much of the rest of the vegetation below the water surface and actively growing. This active growth could have made the hydrilla particularly susceptible to fluridone and may explain why good weed control was obtained in 1991 despite the reduced fluridone exposure time and FEDs (MacDonald et al. 1993).

Quantitative information on hydrilla control and regrowth was provided by the transect data (Figures 3 and 4). Only statistically significant differences in plant coverage will be discussed, unless otherwise indicated. While the optimal result of hydrilla control would be its elimination from a site (i.e., continuous zero percentage presence) this rarely occurs with such herbicide applications. Hence, the goal of these treatments was the greatest and longest-lasting reduction in percentage presence of hydrilla possible. However, from an operational perspective, a long-term reduction in the dominance of hydrilla was an adequate result.

In the transects upstream of Lake Nelson the presence of hydrilla had been reduced by July 1990 after the first fluridone treatment, which had resulted in over 500 FEDs in Lake Nelson. The coverage of hydrilla gradually recovered until April 1991 when it was found in 80% of the transect squares. The maximum reduction in hydrilla presence in the Nelson transects occurred later in 1991 (possibly related to the slightly delayed fluridone treatment dates in 1991 and/or the lesser exposure to 239 FEDs), with no hydrilla found in November, and minimal regrowth by March 1992.

The dominance of hydrilla at this site changed in a similar pattern to its presence. There was a virtual elimination of hydrilla dominance for six months after the 1990 treatment, with dominance restored to only 37% of the site by the start of the 1991 treatment. Although total elimination of dominance in 1991 was delayed until November, there remained no areas dominated by hydrilla in March 1992.

General observations of the system indicated that the reductions in hydrilla noted in the transects upstream of Nelson were typical of conditions throughout the rivers and lakes between Lake Istachatta and the downstream end of Lake Nelson.

As in the transects upstream of Nelson, there was a reduction in the presence and dominance of hydrilla in the transects upstream of Bonnet Lake following the 1990 fluridone treatment, when fluridone exposure was in excess of 500 FEDs. Hydrilla had reappeared in most of this site by November 1990, but it did not reestablish its original dominance for another two years. The 1991 fluridone treatment (239 FEDs in Lake Nelson) did not have a significant effect on hydrilla presence or dominance as compared to its condition at the time of the 1991 treatment. However, both hydrilla parameters were significantly reduced from July 1991 through February 1992 in comparison to the pretreatment conditions of April 1990.

It was observed that results from these transects were representative of conditions in the shallower sections of river between Lakes Nelson and Bonnet, with an overall reduction in the dominance of hydrilla but only temporary reductions in its presence. Although such results may not seem too encouraging in relation to long-term hydrilla control, they provided highly satisfactory weed management in relation to operational objectives (e.g., navigation).

Showing similarities to the results from the Bonnet transects, the reduction in presence of hydrilla at the Rocks subsequent to the 1990 fluridone treatment (553 FEDs) was followed in November 1990 by a recovery of hydrilla in most of the transects. Unlike results from the Bonnet transect, there was a reduction in hydrilla coverage at the Rocks following the 1991 fluridone treatment (235 FEDs), and there were reductions in the dominance of hydrilla after both fluridone treatments.

Reductions in the presence and dominance of hydrilla were also observed in February 1991 and 1992. These resulted from the effects of low-rate bensulfuron methyl treatments (25 $\mu g\ l^{-1}$) made to Lake Bonnet in the preceding December and/or January (Fox and Haller, unpublished data). Hydrilla regrowth at the Rocks occurred within 6 months after each herbicide treatment, resulting in peaks of hydrilla presence during each November and April through 1991, which were not significantly different from the initial conditions in April 1990. These peaks showed a pattern of decline over the two years, such that by March 1992 the presence of hydrilla was significantly lower than early in the preceding two years. Unlike results from the Bonnet transects, the dominance of hydrilla at the Rocks was never restored to the April 1990 level.

Data from the Rocks transects were typical of hydrilla coverage within Bonnet Lake and downstream to the confluence with Jumper Creek. Despite the noticeable impacts of fluridone on the hydrilla in this section of river, the effects of each treatment tended to be shorter-lived than observed in Lake Nelson and upstream.

Although the dominance of hydrilla in the transects downstream of Jumper Creek was eliminated following the 1990 fluridone treatment (258 FEDs), the reduction in presence of hydrilla was not significant. There was appreciable regrowth prior to the 1991 fluridone treatment, resulting in April 1991 in a 50% increase in the presence of hydrilla since the previous April, and the highest percentage dominance recorded at that transect.

Despite the much lower fluridone exposure in 1991 (44 FEDs), there was a reduction in the presence and dominance of hydrilla at the Jumper transects, following the second fluridone treatment. Subsequent regrowth was more gradual following this treatment than it had been in 1990, but by March 1992 neither hydrilla presence nor dominance was significantly different from the previous April.

However, hydrilla in the Jumper transects was not only affected by the herbicide treatments. Reductions in water level during late 1990 at this relatively deeper site (Figure 5), allowed hydrilla to expand into the middle of the transect where it had previously been excluded by shading in the tannin-stained water. This explains why hydrilla coverage and dominance increased in the Jumper transects between April 1990 and April 1991.

Higher water levels in mid-1991 would have contributed, along with the exposure to fluridone of actively growing plants, to the suppression hydrilla regrowth. It should be noted that significant reductions in coverage of hydrilla during periods of high water levels, such as in July 1991, cannot be discounted as simply reduced efficiency of sampling when the river bed could not be seen. For example, plants could not be seen in most of the transect downstream of Jumper Creek even when water levels were at their lowest, so sampling with the rake was always used at this site and was no less efficient in July 1991 than at other times.

The temporary response of hydrilla to the fluridone treatments in the transects downstream of Jumper Creek was typical of conditions seen at the water sampling station at Flying Eagle, and throughout the river between the Jumper Creek and Panasoffkee River confluences. Recovery after fluridone treatments was very noticeable at Flying Eagle, where shallow water condi-

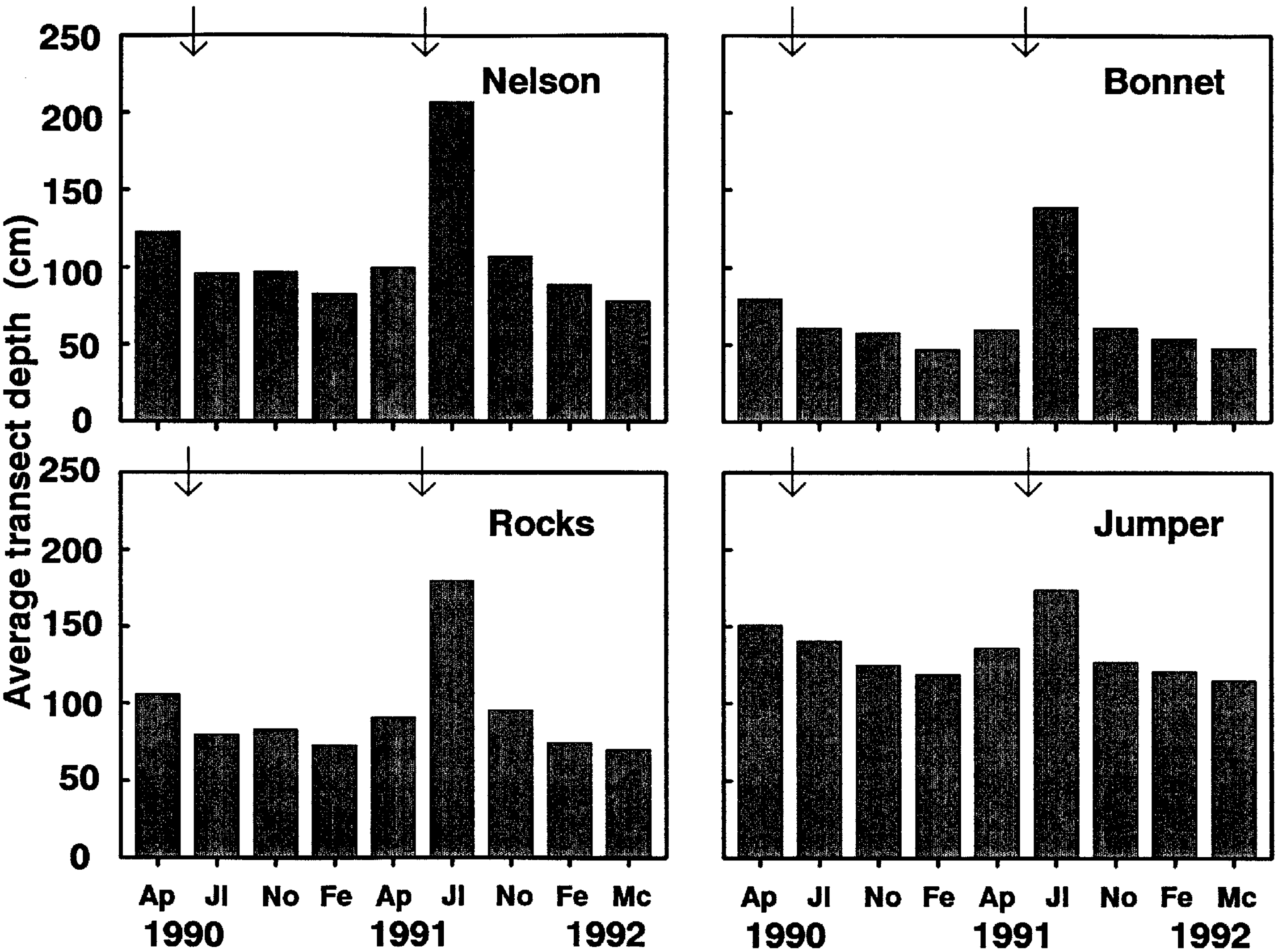

Figure 5. Average water depth at transect sites from April 1990 to March 1992. Arrow = fluridone treatment upstream.

tions promoted rapid hydrilla regrowth. Negligible impacts of fluridone were noted on the hydrilla downstream of the confluence with the Panasoffkee River.

These results have shown that prolonged applications of fluridone to lakes upstream of a targeted river length can provide predictable and cost-efficient hydrilla control. In the upper St. Johns River, high water levels in some years have made such treatments prohibitively expensive and yet abundant hydrilla growth continues. The dark coloration of the Withlacoochee water however, means that in very high discharge years hydrilla grows poorly and there is little need for herbicide applications.

Caution must be used when interpreting the significance of herbicide exposure as indicated by FEDs (Fox and Haller 1993). The frequency and overall duration of the residue sampling program must be adapted in relation to water discharge. For example, more frequent sampling for fluridone after the 1991 treatment would have been more satisfactory in view of the rapid dissipation of fluridone residues (Table 4). Unless herbicide residue concentrations can be determined within a few days of collection, the planning of a sampling regime must be estimated in relation to discharge data. If necessary, it is preferable to collect more samples than can be analyzed (e.g., more often and for longer duration than may be needed). By careful selection of which samples to analyze first (e.g., single replicates from a wide range of sampling times at two extreme sites) it should be possible to optimize the choice of samples for final analysis.

Further examples of relating herbicide concentration/exposure estimates (FEDs) to hydrilla control will be needed in order to fine-tune the predictability of this management tool, but some preliminary conclusions can be drawn from these studies.

The relationship between estimates of FEDs and the severity and duration of hydrilla control and regrowth at a site can vary between years. In 1990 when mature and mostly surface-matted plants were treated, and subsequent water levels remained low, fluridone exposures in excess of 500 FEDs were necessary to cause a 12-month suppression of hydrilla dominance. Significant amounts of hydrilla reappeared at sub-dominant levels within six months of treatment unless fluridone exposure was in excess of 700 FEDs. Fluridone exposures of approximately 250 FEDs resulted in only a six month suppression of hydrilla dominance with little influence on the presence of hydrilla.

In 1991, similar levels of hydrilla control were achieved at much lower exposures to fluridone. The increased susceptibility of young, regrowing plants, and the additional stress provided by high water levels undoubtedly had an influence on the efficacy of this treatment. The dominance of hydrilla remained suppressed for at least nine months even when fluridone exposures were only between 200 and 250 FEDs. Reductions in the presence of hydrilla, however, lasted only six months at these values. Significant and long-lasting reductions in both hydrilla dominance and presence occurred upstream of Lake Nelson, where approximately 450 FEDs were recorded in 1991. Most surprisingly, significant suppression of hydrilla was observed downstream of Jumper Creek in 1991, despite exposures of less than 50 FEDs.

It should be cautioned that if a fluridone exposure of 500 FEDs throughout the target area is regarded as a suitable objective, the herbicide must be applied at a higher rate than the required number of FEDs. These application rates (10 to 12 $\mu g\ l^{-1}$ for 13 or 10 weeks) could have been expected to achieve between 700 and 1,100 FEDs. Maximum fluridone concentrations rarely approach the theoretical, calculated concentration, particularly downstream of the application site, due to dilution, photolytic degradation, and plant uptake. Thus, only under very low discharge conditions, when exposure periods are substantially longer than the treatment period, will measured FEDs approach the theoretical FEDs applied.

The concept of FEDs implies that it is the product of concentration and exposure (total FEDs) that is important, regardless of the actual concentration or exposure. Hence, exposure to 4 $\mu g\ l^{-1}$ fluridone for 125 days would be expected to yield the same results as exposure to 10 $\mu g\ l^{-1}$ fluridone for 50 days (both 500 FEDs). It would seem likely that there are minimum limits for both parameters (i.e., could 0.5 $\mu g\ l^{-1}$ fluridone be effective even if maintained for 1,000 days?; would 3.3 days be long enough exposure to 150 $\mu g\ l^{-1}$ fluridone?). Laboratory testing of such limits would be more cost-effective than field evaluations but they are notoriously difficult with the long exposures needed for fluridone. The collection of residue data from a variety of field treatments, both successful and otherwise, may reveal useful information.

Since it is not practical to sample, analyze, and calculate FEDs during the treatment period, application rates must continue to be estimated based on target concentrations and exposure periods with continuous adaptation to water discharge conditions. Important reasons for evaluating FEDs are: to explain and prevent the reoccurrence of unexpected treatment failures or over-dosages; to fine-tune the different fluridone exposures needed for control under varying conditions (e.g., mature vs. actively growing plants); to allow the adaptation and expansion of fluridone applications to supplement FEDs reaching downstream areas so that the target area can be most efficiently expanded.

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