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Feasibility of stocking grass carp (Ctenopharyngodon idella; Cyprinidae) to control hydrilla (Hydrilla verticillata; Hydrocharitaceae) in Lake Anna, Virginia

Paul Matthew Overton

FEASIBILITY OF STOCKING GRASS CARP (CTENOPHARYNGODON IDELLA; CYPRINIDAE) TO CONTROL HYDRILLA (HYDRILLA VERTICILLATA; HYDROCHARITACEAE) IN LAKE ANNA, VIRGINIA

by

PAUL MATTHEW OVERTON

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Abstract

The goal of this study was to demonstrate the feasibility of using triploid Ctenopharyngodon idella (grass carp) to control Hydrilla verticillata in the Waste Heat Treatment Facility (WHTF) in Lake Anna, Virginia. The four objectives were to determine: the frequency of occurrences of grass carp over hydrilla; the proportions of hydrilla to other aquatic macrophytes in the guts of grass carp; effects of physical and chemical factors on movement of grass carp; and a theoretical stocking rate of grass carp for the WHTF. Frequency of occurrence of grass carp over hydrilla was calculated to be 84% and correlated with impoundment size. The proportion of hydrilla in the guts of two adult triploid grass carp captured from Lake Anna averaged 88%. Physical and chemical factors had no significant effects on movements of triploid grass carp. There were no statistical correlations between fish movement and final location to water chemistry and presence/absence of hydrilla and other macrophytes. A theoretical stocking rate of grass carp to control the approximate biomass of hydrilla in the WHTF was calculated to be 6,134 fish. This theoretical stocking rate is consistent with the stocking rate employed by the Department of Game and Inland Fisheries of seven fish per acre of infestation or approximately 6,800 grass carp to control hydrilla in the WHTF in Lake Anna, Virginia.

Introduction

Lake Anna is a 5261 hectare reservoir in the York River basin in central Virginia constructed by Virginia Power to supply cooling water for the North Anna Power Station (Fig. 1) . Once-through cooling water is withdrawn from the mid-portion of the lake and discharged into the Waste Heat Treatment Facility (WHTF), a 1376 hectare portion of Lake Anna separated from the lake proper by earthen dikes. The WHTF consists of three bodies of water designated as Lagoon I (nearest the Power Station), II, and III (farthest from the Power Station) that are interconnected by canals. Mixing between the WHTF and the lake proper occurs at an underwater weir located at the northeast end of Lagoon III and in the lower portion of the lake adjacent to the dam. Fish pass freely between the two bodies of water at this point. Estimated residence time of water in the WHTF is 14 days (Gribben, 1988). Water quality values in the WHTF are similar to those of the lake with the exception of surface temperatures, which range from 2 to 7 °C warmer than the lake during the summer (Gribben, 1988).

Hydrilla, Hydrilla verticillata, Hydrocharitaceae, an old world tropical aquatic macrophyte, was introduced into Florida in the 1950's as an aquarium plant (Kay, 1989). It appeared in natural waters in 1958 and since has spread north to the Potomac River drainage in Maryland and west to California. Hydrilla was first reported in Lake Anna in 1987 (Gribben, 1988) and by 1992 inhabited 55% of the available lake (depths less than 15 feet); 8.5% of the lake proper and 57% of the WHTF (Anon, 1991).

The plant reproduces sexually and asexually (fragmentation) enabling it to spread rapidly under suitable temperature and light conditions with a potential negative effect on fish habitat and recreational activities (e.g., boating) in the lake, especially in the WHTF. In temperate regions such as Virginia, hydrilla has a three to four month growing season (Aulbach-Smith and Kozlowski, 1990); however, in the thermally enriched WHTF, water temperatures are sufficiently elevated to extend the growing season for hydrilla as well as other macrophytes.

Various methods (water drawdown, photosynthetic reduction by dyes, mechanical removal, chemical herbicides and grass carp, Ctenopharyngodon idella, Cyprinidae) have been employed to control the growth of hydrilla in the United States (Miley, 1979). Size of the WHTF, operational water needs of the facility, asexual reproduction by fragmentation, and recreational and livestock water uses preclude all methods except C. idella as a mechanism to control hydrilla in the WHTF of Lake Anna. As a result, Virginia Power proposed to use genetically altered triploid grass carp as a biological control for hydrilla in the WHTF of Lake Anna.

The grass carp is native to the Pacific slope of Asia from the Amur River of China and Siberia south to the West River in Southern China and Thailand where it inhabits large streams and rivers (Smith and Shireman, 1983). This species was originally imported to the U.S. in 1963 when it was stocked in rivers and lakes to control unwanted aquatic vegetation (Sanders et al., 1991).

Biological control of hydrilla using triploid grass carp represents a non-labor intensive, less restrictive method when compared to other control methods and would appear to be a desirable approach to controlling the spread of hydrilla in the WHTF. Their potential use as a control mechanism in the WHTF, however, raised questions. For example, would the fish target the infestations of hydrilla in the WHTF, a relatively large body of water? How would the fish react to the elevated temperatures and other physical and chemical parameters of the cooling Lagoons in the WHTF? What would be an appropriate stocking rate of grass carp to control the growth of hydrilla in the WHTF?

In an effort to answer these questions, objectives of this study were to determine the frequency of occurrences of grass carp over hydrilla; the proportions of hydrilla to other aquatic macrophytes in the guts of grass carp; effects of physical and chemical factors on movement of grass carp; and a theoretical stocking rate of grass carp for the WHTF.

Materials and Methods

Sixteen triploid grass carp, designated as Group I, were received 16 July 1992 from Hopper-Stephens Hatcheries, Inc. in Arkansas. Four additional triploid grass carp, designated as Group II, were received 27 August 1992. Average weight and length of the fish were 1.52 Kg and 472 mm, respectively. The fish were shipped in aerated cartons by air to Richmond International Airport, where they were received and then transported by vehicle to the WHTF (elapsed time during shipping was approximately eight hours) and placed in a holding pen (2x3x3 m). The PVC pipe frame of the holding pen was covered with chicken wire and mesh netting. Penned fish were kept in Lagoon II of the WHTF for 24 hours to acclimate to the receiving water temperature. Seven fish of Group I died during the acclimation period. Surviving grass carp were surgically implanted with sonar tags in order to monitor their location and movement during the field study.

Each fish, anaesthetized with MS-222 (brand name Fin Quel) at a concentration of 1 g/l, was prepared for surgery. A 2.5 cm incision was made between the pectoral and pelvic fin to the side of the mid-ventral line. A sonar tag (model CT-82-CR 1/3N) from Sonotronics in Tucson, Arizona was implanted into the body cavity of each fish, after which the incision was sutured with 2-3 stitches of 3.0 surgical thread. Following surgery, Group I fish (implanted first) were placed in the holding pen in the WHTF water for 72 hours for observation of post-surgery mortality. Since no Group I fish died during the post-surgery period, Group II fish were released immediately following surgery.

Each cylindrical sonar tag (length = 2.5 cm, diameter = 1 cm, and weight = 10 g) had a battery life of 10 months. Each had a specific three-digit pulse code for identification of individual fish. The sonar tags, differing from each other by 1 MHz, ranged in frequency from 70-85 MHz. Tag #276, originally implanted in a

Group I fish was later retrieved from the WHTF substrate and implanted into a Group II fish and designated as Fish #276N.

Hydrilla beds, identified on previous surveys conducted by Virginia Power, are present in the WHTF from late May to February. Group I fish were released on a hydrilla bed on the southwest side of Barley's Island in Lagoon II at 1200 hrs on 20 July 1992 (Fig. 2). This site was selected because of the abundance of hydrilla and because it is located in the "middle" of the WHTF where the fish could be influenced in either direction [towards Lagoon I (upstream) or towards Lagoon III (downstream)] by the water quality parameters, especially the temperature gradient that exists in the WHTF (Table 1 and Fig. 2). Group II fish were released on a hydrilla bed at the mouth of Rock Creek in Lagoon III at 1200 hrs on 28 August 1992 (Fig. 3). This site was selected as it is proximal to the lake proper and would give an immediate measure of their potential for migration to the lake (Fig. 3). Both groups were monitored from a boat hourly for the first six hours of the study. Weather permitting, the fish were monitored twice a week initially until the fish settled into a home range and then once a week for the remainder of the study. Total monitoring (21 tracking events for Group I and 9 tracking events for Group II) consisted of 72.5 hours of tracking. Each tracking event lasted between one and eight hours.

The fish were monitored for location and net movement by tracking the signal from the sonar tag with a hydrophone and a battery-operated Ultrasonic

Sonotronics receiver (frequency range 69-120 MHz). The hydrophone was mounted to the gunnels of a 4.3 m Boston Whaler boat. Tracking was conducted by listening for sonar signals at the specific range of frequencies of the tags along the shoreline and in coves of each Lagoon.

The range of the hydrophone varied with the weather conditions. On an optimum day (clear skies, no wind) the range of the hydrophone was 700-1000 m. Increased wave action and rain decreased the range of the hydrophone. The hydrophone was unidirectional (i.e., the signal source could be determined by the signal strength). The direction of the strongest (loudest) signal was, therefore, in the direction of the fish.

When an individual fish was detected, its precise location was determined by triangulation of directional plots from two different areas. The location was marked on a map of the corresponding Lagoon in which the fish was found. The net movement (distance and direction from the initial release site) of the fish was then determined by using a scaled map, ruler, and protractor. Characteristics of the substrate (i.e., presence/absence of hydrilla and other aquatic macrophytes) were determined by direct field observation.

Water quality (temperature (°C), dissolved oxygen (mg/l), and pH) was measured with a Hydrolab (Surveyor 3 Display Logger and Water Multiprobe) at the approximate location of each fish on every survey. Since grass carp have been reported to remain near the substrate (Smith and Shireman, 1983), parameters were measured at the substrate. Additional water temperatures, recorded by in-situ Endeco thermal recording devices located throughout the WHTF, were obtained from Virginia Power (Table 1).

The guts of two formerly introduced triploid grass carp, collected during a routine rotenone study in Lake Anna, Virginia on 12 August 1992, were examined for food content. The gut (from the base of the esophagus to the anus) of each fish was excised and stored in 10% formalin. Identifiable gut contents were divided according to vegetation [i.e. hydrilla, Southern naiad (Najas guadalupensis) and unidentifiable species]. The contents were dried in an oven at 38 °C for 24 hours, and weighed on a balance to determine total dry weight (gms).

Pearson correlation coefficient (Anon, 1985) was used to test the hypothesis that final location of fish was correlated with date, water quality (temperature, dissolved oxygen, and pH), and the presence/absence of hydrilla and other macrophytes (Appendix). For the analyses, a fish's final location was expressed as degrees (0-360°, East = 0°) and the distance traveled (m) from the release point.

The total biomass of hydrilla in the WHTF was determined by using a square template (1m x 1m), made with 2x4 lumber. It was placed at random locations in a hydrilla bed in the WHTF where all of the rooted hydrilla within the square was removed by pulling it out of the substrate. This was performed at three different sites in the WHTF. The hydrilla from each site was dried in a desiccating oven and weighed. These values were used to calculate an average biomass of hydrilla in one square meter (0.34 Kg/m^2). The total area of hydrilla infestation is 394.44 hectares (Anon, 1991). The following formula was used to calculate total biomass of hydrilla:

Total biomass of hydrilla in WHTF (Kg) = (total area of hydrilla infestation in hectares) x (average weight (Kg) of hydrilla per hectare).

A theoretical stocking rate of triploid grass carp was determined using a model based on the consumption rate of hydrilla by grass carp (Miller, 1984). The model predicts the biomass of hydrilla consumed monthly by grass carp using the equation CB=RWNT presented in Table 7.

Results

Six of the 13 triploid grass carp released (46%) were found consistently throughout the survey [(91 days); (Fishes #249, 267, 285, 348, 357, 366)]. These fish showed a common movement pattern (Fig. 4) as each dispersed from the initial release site and established a new home range, remaining there throughout the study. The average distances traveled from release sites for Group I and Group II were 576.6 m (s.d., 395.7) and 914.2 m (s.d., 861.9), respectively. The average times that lapsed between release and establishing a new home range were 10.2 days (s.d., 19.9) for Group I and 15.0 days (s.d., 12.2) for Group II (Tables 2 and 3). Four fish (#258, 339, 375, 384) were not contacted again after day 1. Three fish lost their tags (Fishes #276, 276N, 294). Fish #276 (Group I fish) lost its tag between days

10 and 16. Fish #276N and 294 (Group II fish) lost their tags between days 1 and 13.

The average occurrence of fish observed over hydrilla was 84%. Group I fish were over hydrilla an average 89.9% (s.d., 17.4) (Table 2); Group II fish were over hydrilla an average 71.0% (s.d., 34.0) (Table 3). Fish #348, over hydrilla less than 50% of the contacts, accounted for the lower percentage in Group II (Table 3).

Gut contents of each of the two triploid grass carp, collected during a rotenone study in Lake Anna, Virginia on 12 August 1992, consisted primarily of hydrilla (88% of the identifiable material). One fish had 10% Southern naiad and 2% of an unidentified plant material; the other had 12% Southern naiad (Table 4).

The Pearson correlation coefficient analyses indicated that fish movement and final location were not significantly correlated to date, water quality parameters, and presence/absence of hydrilla and other aquatic vegetation (Tables 5 and 6; Appendix). The stocking rate model from Miller (1984) was used to calculate the number of triploid grass carp needed to control hydrilla in the WHTF (Table 7). The calculated theoretical stocking rate for the WHTF is 6,134 fish (Table 7). The stocking rate recommended for the WHTF determined by the Virginia Department of Game and Inland Fisheries was approximately 6,800 (J. Bateman, pers. comm., 1993). Based on the Virginia Power aerial survey in 1992, the approximate area of hydrilla infestation in the WHTF was 394.44 hectares. Total biomass of hydrilla in the WHTF was 1,341,096 Kg (0.34 Kg/m^2 x 394.44 hectares).

Discussion

Movement and feeding of grass carp in the WHTF did not appear to be adversely affected by the trauma of surgery and the presence of implanted sonar tags. In studies where the same technique of implanting sonar tags has been used, fish showed behaviors in feeding and movement comparable to those in the present study (Bain and Webb, 1988; Miller, 1984, Chappelear et al., 1991; Bain et al., 1990).

Of the 13 fish in the study, four (31%) were not found after day one. These fish likely experienced tag failure, were consumed, died, or migrated out of the study area. According to Brent Mabbott (pers. comm., 1992), a biologist for the Montana Power Company, an average of 30% of tagged grass carp are lost due to one or more of these factors during tracking exercises. Probably, the tags recovered from the substrate in the WHTF were expelled from the body cavities of live fish.

Average frequency of occurrence of grass carp over hydrilla (84%) in the WHTF can be correlated with impoundment size. For example, Chappelear et al. (1991) and Bain et al. (1990), who also used sonar tags, found that grass carp were located consistently over hydrilla beds (66% and 43%, respectively) in Lake Marion, South Carolina (6500 ha) and in Guntersville Reservoir (27,479 ha) in northeastern Alabama, respectively. Using my data (84%; 1376 ha) and those of Chappelear et al. (1991) and Bain et al. (1990) correlation analysis indicated that the percent of grass carp over hydrilla is negatively correlated (-0.9404) with impoundment size.

This suggests that the use of grass carp to control hydrilla growth may be more effective in smaller impoundments.

Movements of fish were random from initial release sites to other hydrilla beds identified during and at the end of the study period. These results are comparable to those reported by Bain et al. (1990), who found that there were no directional trends in movement of grass carp in Guntersville Reservoir. The greatest distance traveled by a single grass carp in the present study was 2.2 Km. This distance agrees with the average distance traveled by grass carp in other studies: 2.2 Km reported by Bain et al. (1990) and 0.65 Km/day for a 90 day study reported by Chappelear et al. (1991).

Neither movement, distance traveled, nor final destination were statistically ($p>0.05$) associated with variations in water temperature, D.O., and pH, even though water temperatures in much of the WHTF during the summer are routinely at the preferred temperature of 35 °C by grass carp (Galloway and Kilambi, 1991). Frequently the temperatures range from 30-35 °C, values at which grass carp are most active (Galloway and Kilambi, 1991; Smith and Shireman, 1983). Unlike the net movement of grass carp away from low dissolved oxygen levels reported by Chappelear et al. (1991), there were no movements that could be attributed to variations in dissolved oxygen concentrations.

Hydrilla is an excellent food source for grass carp due to the soft nature of the plant and its high ash content (Rottman, 1977). Smith and Shireman (1983), Miller (1984), and Sanders et al. (1991) report that grass carp prefer hydrilla over other aquatic macrophytes as a food source. About 88% of the identifiable gut contents of two triploid grass carp collected in a rotenone study in Lake Anna was hydrilla. Small sample size and the absence of data related to proportions of hydrilla to other aquatic macrophytes in the lake preclude conclusions on food preference in the present study; however, grass carp occurring over hydrilla beds 84% of the time in the WHTF, were observed feeding on hydrilla.

My theoretical stocking rate of triploid grass carp (6,134), needed to control hydrilla in the WHTF, agrees with the stocking rate recommended by the Virginia Department of Game and Inland Fisheries of seven grass carp per acre to control hydrilla infestations, or 6,800 fish for the area of hydrilla in the WHTF. As an outcome of the results of grass carp distributional patterns, and a proposed stocking rate of 6,317 (=calculated stocking rate of 6,134 + three percent (183) for natural mortality) in the present investigation, the Virginia Department of Game and Inland Fisheries approved release of 6,300 triploid grass carp in June, 1994 to control hydrilla in the WHTF. Based on this information, Virginia Power released 6,185 triploid grass carp into the WHTF (J. Bateman, pers. comm., 1995), and will evaluate the effectiveness of the stocking rate by measuring the changes in total area of hydrilla infestation with aerial surveys.

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Table 1. Mean (minimum - maximum) temperature (°C) of the Waste Heat Treatment Facility of Lake Anna monitored by fixed Endeco recorders from June - October, 1992.

Month	Lagoon I	Lagoon II	Lagoon III
June	31.5 (31.2 - 31.7)	29.3 (28.7 - 29.9)	27.9 (27.5 - 28.4)
July	36.0 (35.7 - 36.3)	33.4 (32.9 - 34.0)	31.8 (31.4 - 32.3)
August	35.0 (34.6 - 35.3)	32.4 (32.0 - 33.0)	30.7 (30.3 - 31.1)
September	33.4 (33.2 - 33.7)	30.9 (30.4 - 31.4)	29.0 (28.7 - 29.4)
October	27.2 (26.9 - 28.4)	24.6 (24.2 - 25.0)	22.6 (22.4 - 22.9)

Table 2. Percent of sampling trips that Ctenopharyngodon idella in Group I were located over Hydrilla verticillata and total distance traveled from initial release site in the Waste Heat Treatment Facility in Lake Anna, Virginia from July - October, 1992.

Fish	No. of Sampling Events	Trips Found	Trips Over Hydrilla	% Trips Over Hydrilla	Total Distance Traveled (m)	Days To Final Dest.
249	21	13	13	100	1100	8
258	21	6	6	100	700	3
267	21	16	16	100	925	0.3
276	21	8	8	100	575	3
285	21	13	12	92	107	66
339	21	3	2	67	1000	0.3
357	21	16	8	50	708	3
366	21	16	16	100	58	8
375	21	4	4	100	17	0.2
AVG	■	■	■	89.9	576.6	10.2
SD	■	■	■	17.4	395.7	19.9

-total distance traveled calculated using scaled a map and ruler.
-final destination defined as when a fish stayed in a circular area with a diameter of 100m.

Table 3. Percent of sampling trips that Ctenopharyngodon idella in Group II were located over Hydrilla verticillata and total distance traveled from initial release site in the Waste Heat Treatment Facility in Lake Anna, Virginia from July - October, 1992.

Fish	No. of Sampling Events	Trips Found	Trips Over Hydrilla	% Trips Over Hydrilla	Total Distance Traveled (m)	Days To Final Dest.
276N	9	3	3	100	22	13
294	9	3	2	67	1135	13
348	9	6	1	17	2225	34
384	9	2	2	100	275	0.08
AVG	■	■	■	71	914.2	15.0
SD	■	■	■	34	861.9	12.2

-total distance traveled calculated using a scaled map and ruler.
-final destination defined as when a fish stayed in a circular area with a diameter of 100m.

Table 4. Percent of gut contents (dry weight/item, gm) of two Ctenopharyngodon idella collected from Lake Anna, Virginia, 12 August 1992.

Fish		Gut Analysis		
No.	Weight(kg)/ Length(mm)	Item	Dry Weight (gms)	% Gut Contents
1	7.8/702	H. verticillata	3.6	88
		N. guadalupensis	0.4	10
		Unidentified	0.1	2
2	7.4/686	H. verticillata	4.3	88
		N. guadalupensis	0.6	12
		Unidentified	0.0	0

Table 5. Average temperature, °C (± s.d and range), dissolved oxygen (mg/l), and pH at sites where Group I and Group II Ctenopharyngodon idella were located in the Waste Heat Treatment Facility in Lake Anna, Virginia from July - October, 1992.

Group #	Fish #	TEMP (°C)	D.O. (mg/l)	pH
I	249	33.3 ± 1.2 (31.24-35.2)	7.45 ± 0.65 (6.34-8.53)	7.46 ± 0.33 (7.05-8.32)
	267	32.7 ± 1.9 (28.5-35.2)	7.4 ± 0.5 (6.7-8.5)	7.52 ± 0.31 (7.26-8.32)
	276	33.7 ± 1.04 (30.7-34.9)	7.5 ± 0.76 (6.3-8.5)	7.64 ± 0.34 (7.32-8.32)
	258	34.1 ± 1.05 (32.6-35.2)	7.6 ± 0.81 (6.3-8.5)	7.76 ± 0.34 (7.28-8.32)
	285	32.4 ± 2.4 (26-35.2)	7.2 ± 0.66 (6.3-8.5)	7.51 ± 0.30 (7.28-8.32)
	357	32.3 ± 2.54 (26.2-35.2)	7.34 ± 0.6 (6.5-8.5)	7.43 ± 0.32 (7.1-8.32)
	366	32.7 ± 2.24 (26-35.2)	7.33 ± 0.62 (6.6-8.5)	7.53 ± 0.30 (7.15-8.32)
	375	34.6 ± 0.42 (34.1-34.9)	8.14 ± 0.35 (7.9-8.5	7.96 ± 0.34 (7.64-8.32)
	339	35.1 ± 0.17 (34.9-35.2)	8.1 ± 0.42 (7.7-8.5)	7.88 ± 0.38 (7.62-8.32)
II	294	31.05 ± 0.35 (30.8-31.3)	7.85 ± 0.07 (7.8-7.9)	7.15 ± 0.07 (7.1-7.2)
	276N	31.0 ± 0.42 (30.7-31.3)	7.85 ± 0.07 (7.8-7.9)	7.1 ± 0.0 (7.1-7.1)
	384	31.2 ± 0.14 (31.1-31.3)	7.9 (0.00) (7.9-7.9)	7.1 ± 0.0 (7.1-7.1)
	348	28.05 ± 3.5 (24.2-31.3)	7.6 ± 0.49 (6.9-8.0)	7.15 ± 0.06 (7.1-7.23)

Table 6. Results of Pearson Correlation Coefficient tests for movement and final location of *Ctenopharyngodon idella* in the Waste Heat Treatment Facility in Lake Anna, Virginia from July - October, 1992.

CORRELATION ANALYSIS

Pearson Correlation Coefficients / Prob > |R| under Ho: Rho=0
/ Number of Observations

	DATE	DISTANCE	DIRECTION	HYDRILLA	TEMPERATURE	D.O.	pH	VEGETATION
DATE	1.00000 0.0001 99	0.43669 0.9526 99	0.07752 0.0001 99	-0.39885 0.0006 51	-0.44299 0.0 108	-0.00605 0.0001 108	-0.49578 0.4252 108	0.39562 0.0001 108
DISTANCE		1.00000 0.0 108	0.27067 0.0046 108	-0.43258 0.0001 108	-0.18017 0.0743 99	-0.16107 0.1112 99	-0.40845 0.0001 99	0.52366 0.0004 51
DIRECTION			1.00000 0.0 108	0.18318 0.0578 108	-0.05095 0.6165 99	-0.07530 0.4588 99	-0.20811 0.0387 99	0.14258 0.2551 51
HYDRILLA				1.00000 0.0 108	0.14595 0.1495 99	0.13281 0.1900 99	0.28350 0.0045 99	. 51
TEMPERATURE					1.00000 0.0 99	0.37837 0.0001 99	0.34345 0.0005 99	-0.10035 0.6421 49
D.O.						1.00000 0.0 99	0.38126 0.0001 99	-0.09901 0.0021 49
pH							1.00000 0.0 99	-0.24415 0.1152 49
VEGETATION								1.00000 0.0 51

Table 7. Calculation of theoretical stocking rate for <u>Ctenopharyngodon idella</u> using model by Miller (1984).

$$CB = R\ W\ N\ T$$

where:

CB = consumed biomass of hydrilla, lb/day
R = the daily ration of each fish calculated as the product of three factors:
- R_t = effect of water temperature on the daily ration
- R_w = effect of weight of the grass carp on the daily ration
- R_s = seasonal changes in the daily ration

W = mean weight of each fish, lb
N = number of fish
T^* = time, days (the growing period of hydrilla)

Values for R_t, R_w, and R_s were obtained from graphs presented in the model by Miller (1984).

The equation is:

$$(1{,}341{,}096 \text{ Kg} \times 2.2 \text{ lbs/Kg}) = [(0.6)(1.0)(1.0)] \times [(1.52 \text{ Kg})(2.2 \text{ lbs/Kg})] \times N \times 240 \text{ days}$$

$$2{,}950{,}411.2 \text{ lbs} = 0.6 \times 3.34 \text{ lbs} \times N \times 240 \text{ days}$$

$$2{,}950{,}411.2 \text{ lbs} = 480.96 \text{ lbs days} \times N$$

$$N = 2{,}950{,}411.2 \text{ lbs} / 480.96 \text{ lbs days}$$

$$N = 6{,}134 \text{ fish days}$$

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* - time for control of hydrilla during growing season in the WHTF = 240 days (Anon, 1991)

Figure 1. Location of the Waste Heat Treatment Facility in Lake Anna, Virginia.

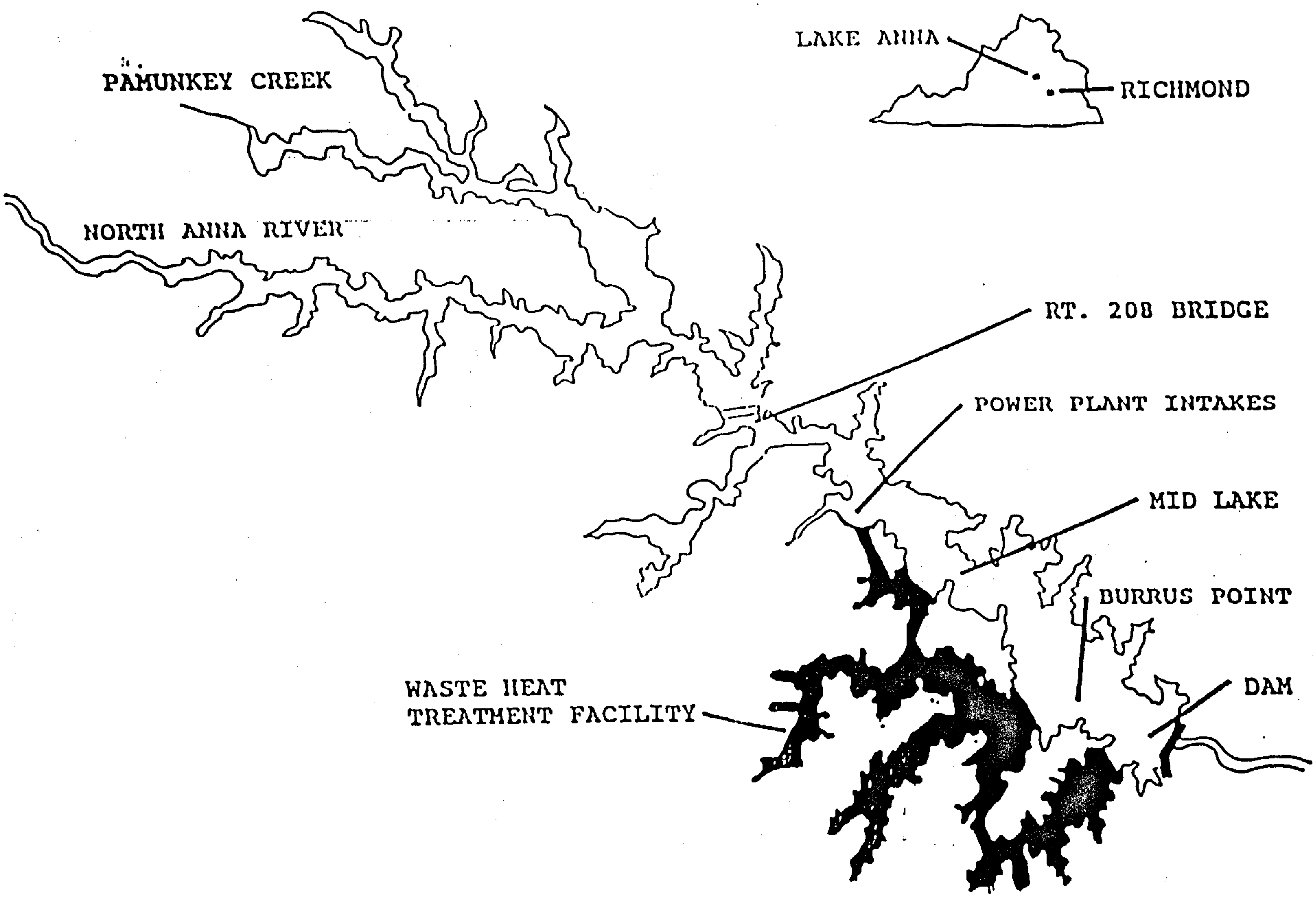
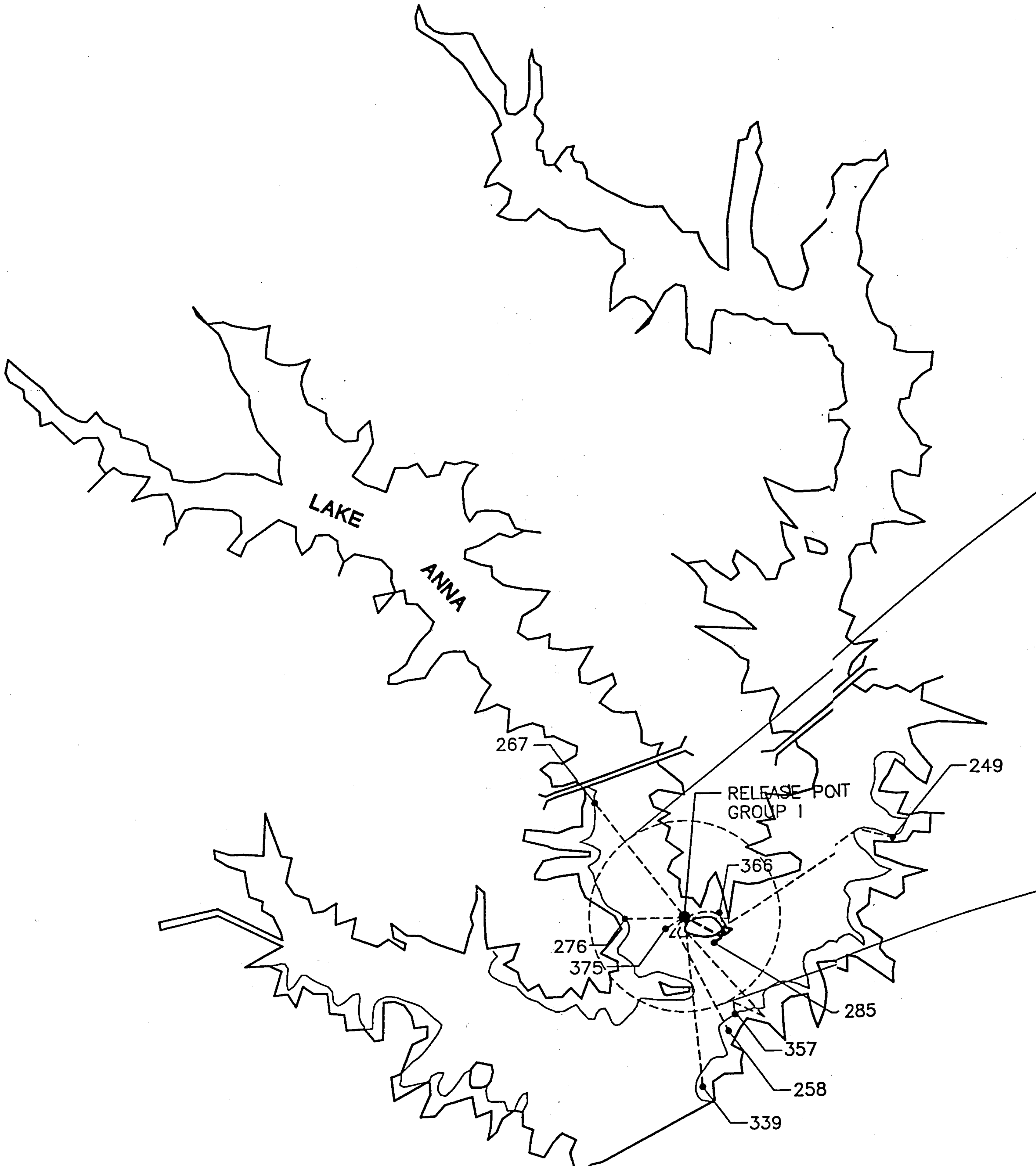
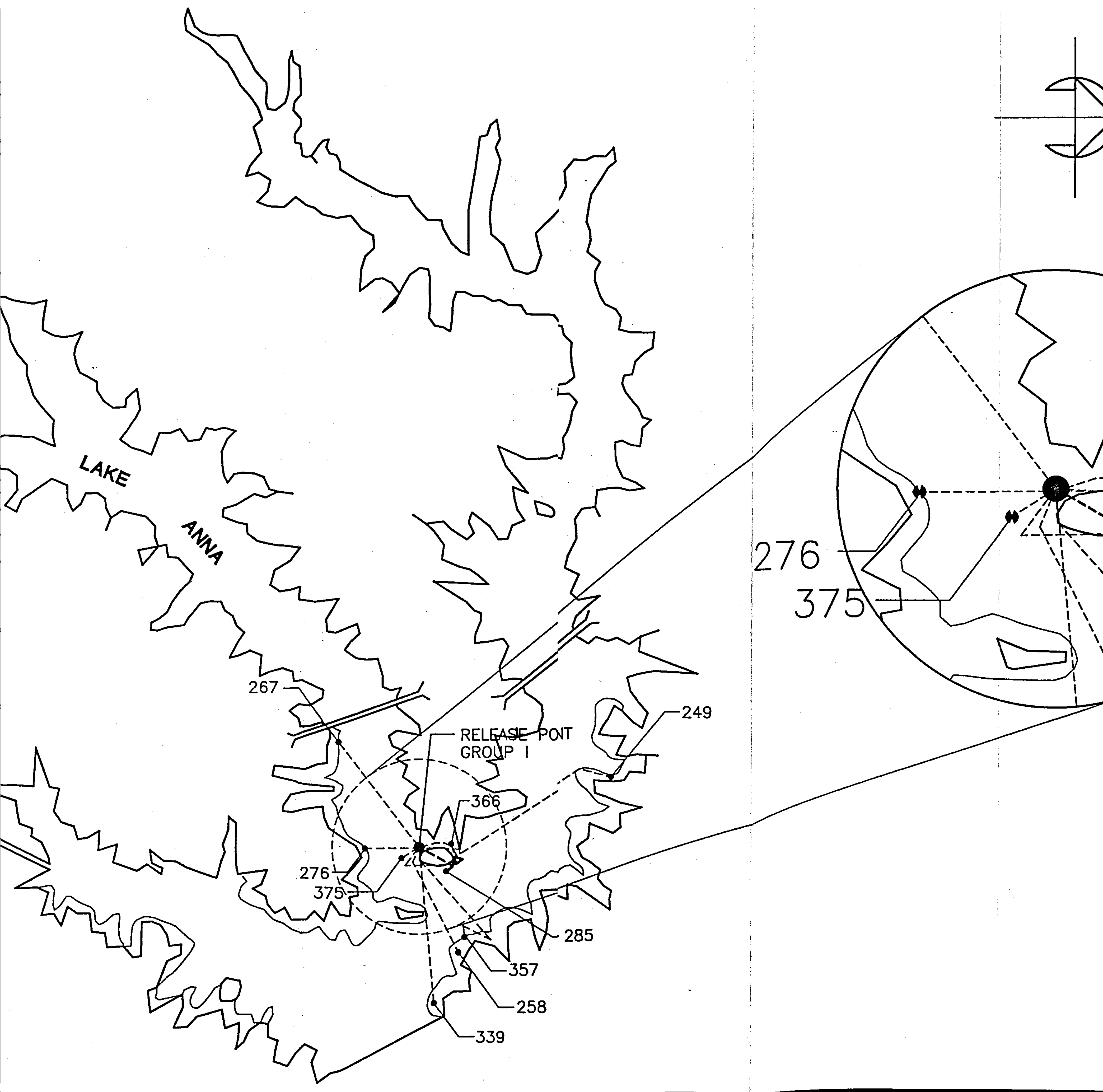
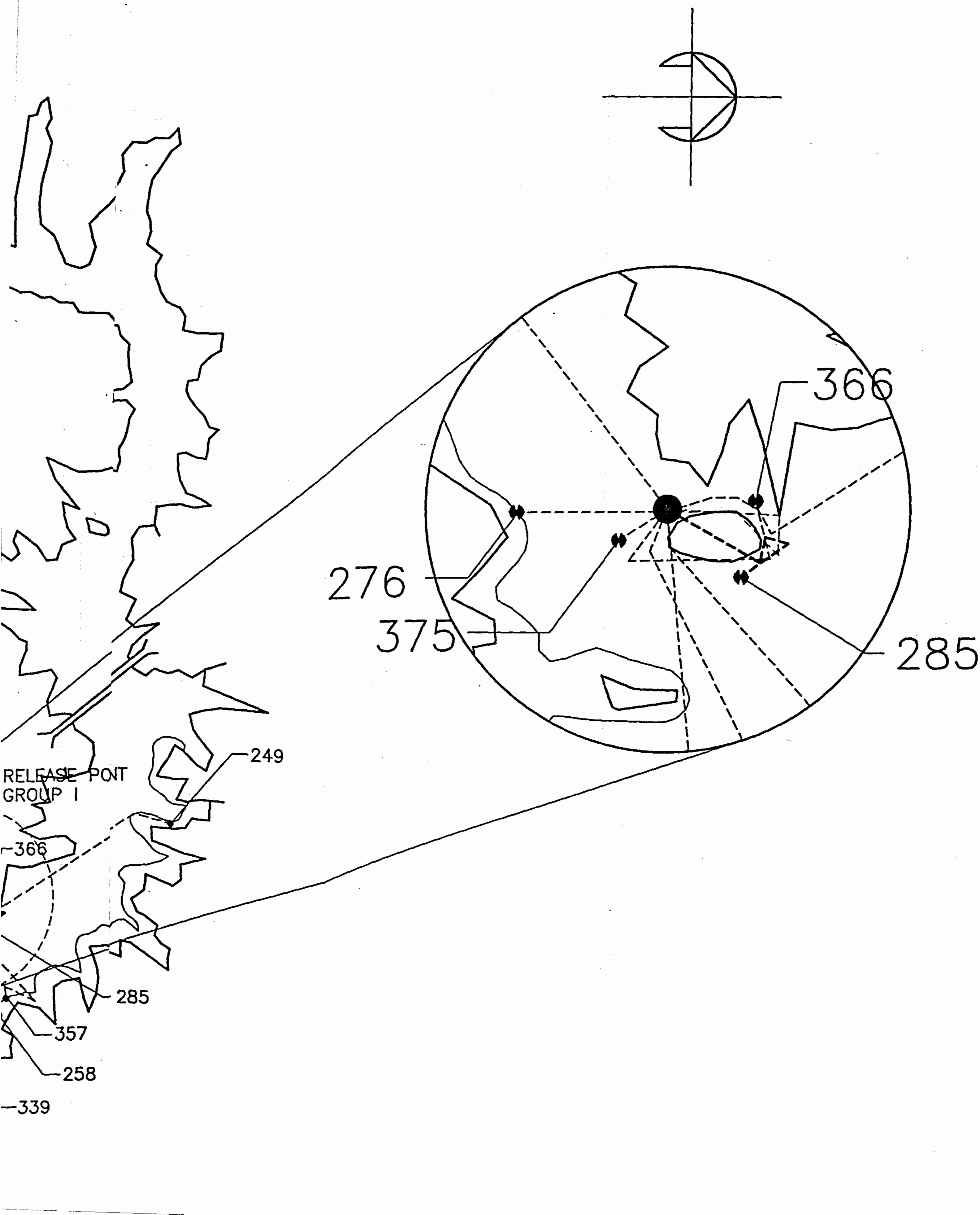

PAMUNKEY CREEK
NORTH ANNA RIVER
LAKE ANNA
RICHMOND
RT. 208 BRIDGE
POWER PLANT INTAKES
MID LAKE
BURRUS POINT
WASTE HEAT
TREATMENT FACILITY
DAM

Figure 2. Movement of Group I Ctenopharyngodon idella (Fish # 249, 258, 267, 276, 285, 339, 357, 366, 375) from the release site in Lagoon II in the Waste Heat Treatment Facility in Lake Anna, Virginia from July - October 1992 (scale 1" = 910m).

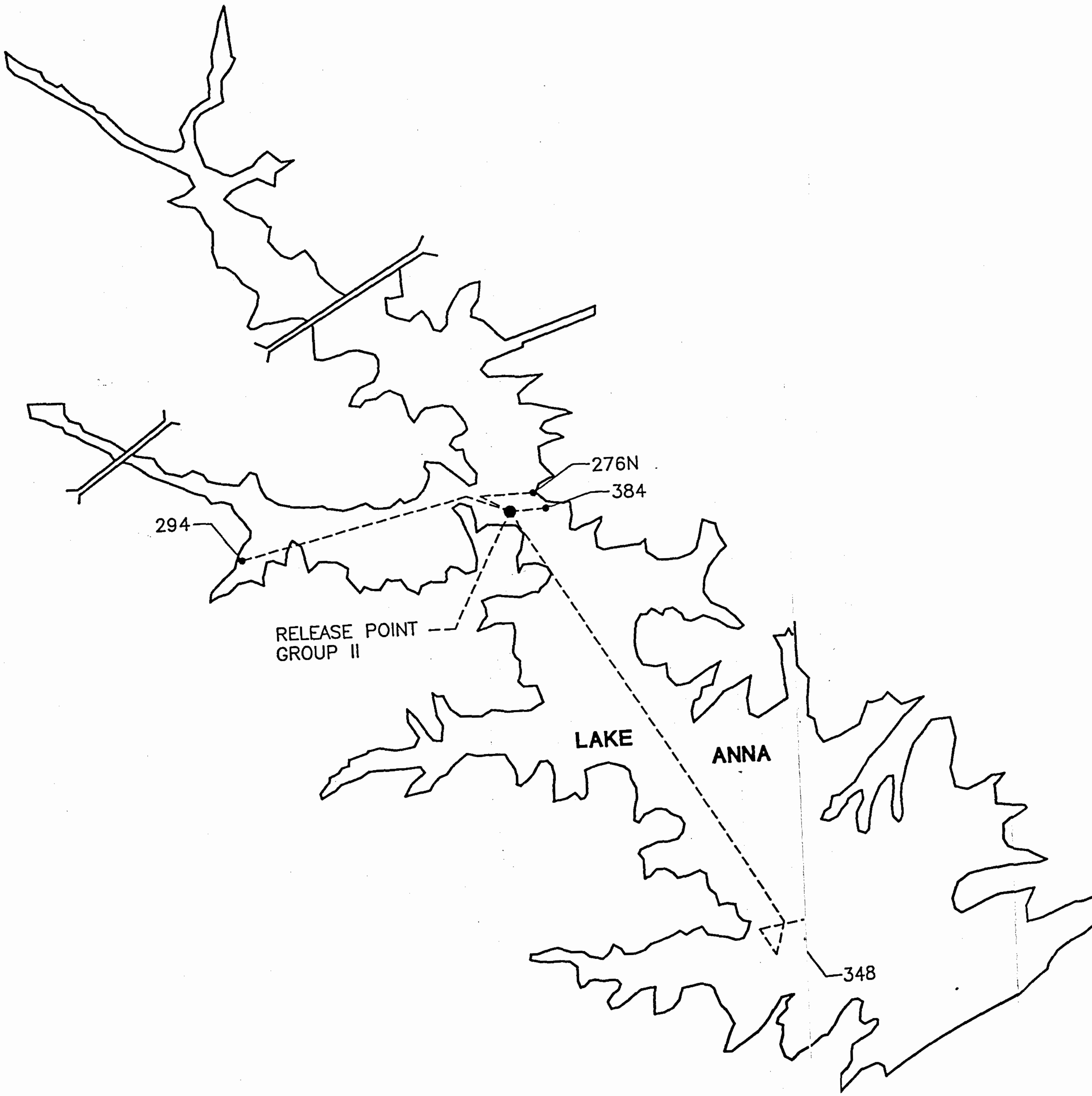

LAKE
ANNA
267
RELEASE POINT
GROUP I
249
366
276
375
285
357
258
339


LAKE
ANNA
267
249
RELEASE POINT
GROUP I
366
276
375
285
357
258
339
276
375



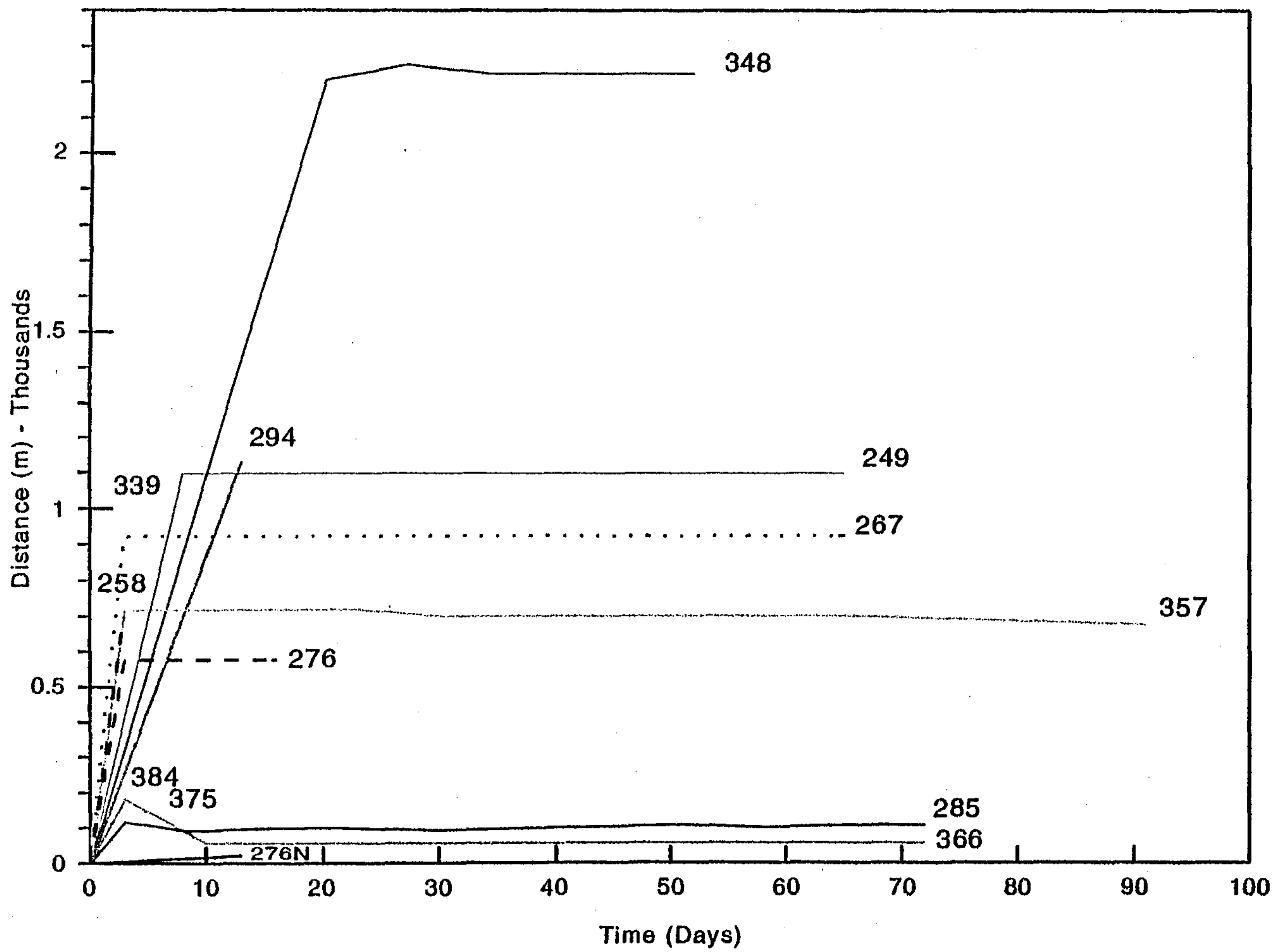
366
276
375
285
249
RELEASE PONT
GROUP I
366
285
357
258
339

Figure 3. Movement of Group II Ctenopharyngodon idella (Fish # 276N, 294, 348, 384) from the release site in Lagoon III in the Waste Heat Treatment Facility in Lake Anna, Virginia from August - October, 1992 (scale 1" = 910m).



276N
384
294
RELEASE POINT
GROUP II
LAKE
ANNA
348

Figure 4. Distance per time (m/days) traveled from initial release site by Ctenopharyngodon idella in the Waste Heat Treatment Facility in Lake Anna, Virginia from August - October, 1992.


348
294
249
339
267
258
357
276
384
375
285
366
276N
Distance (m) - Thousands
0
0.5
1
1.5
2
0
10
20
30
40
50
60
70
80
90
100
Time (Days)

Appendix. Event number, date, fish ID number, time of day, distance from release point(m), direction (degrees; East = O°), presence (1)/absence (0) of Hydrilla verticillata and other aquatic vegetation (1= Najas guadalupensis; 2= Brasenia schreberi; 3= Chara sp.), water temperature (°C), dissolved oxygen (mg/l), and pH recorded for Ctenopharyngodon idella released and tracked in the Waste Heat Treatment Facility of Lake Anna, Virginia from July - October, 1992.

Event	Date	Fish ID #	Time of day	Distance (m)	Direction (degrees)	hydrilla	vegetation	Temperature (C)	D.O. (mg/l)	pH
1	072092	249	1200	0	0	1	1	34.91	8.53	8.32
2	072092	249	1310	0	0	1	1	35.20	8.04	7.71
4	072092	249	1630	125	85	1	1	33.22	7.91	7.57
5	072092	249	1830	120	90	1	1	32.60	6.34	7.70
7	072892	249	1515	1100	112	1	0	34.45	7.47	7.64
8	073092	249	1100	1100	112	1	0	34.30	7.10	7.30
9	080692	249	1135	1100	112	1	3	33.40	7.00	7.30
10	081192	249	1010	1100	112	1	3	33.43	6.74	7.27
11	081392	249	1115	1100	112	1	0	33.50	6.92	7.21
12	082092	249	1055	1100	112	1	0	31.24	7.15	7.48
16	091092	249	1045	1100	112	1	0	32.60	7.50	7.40
18	091792	249	1130	1100	112	1	0	32.00	8.10	7.15
19	092492	249	1030	1100	112	1	0	32.10	8.10	7.05
1	072092	258	1200	0	0	1	1	34.91	8.53	8.32
2	072092	258	1310	0	0	1	1	35.20	8.04	7.71
3	072092	258	1415	0	0	1	1	34.83	7.87	7.64
4	072092	258	1600	33	345	1	1	34.15	8.02	7.92
5	072092	258	1825	80	0	1	1	32.60	6.34	7.70
6	072392	258	1020	700	35	1	1	33.16	6.96	7.28
1	072092	267	1200	0	0	1	1	34.91	8.53	8.32
2	072092	267	1310	0	0	1	1	35.20	8.04	7.71
3	072092	267	1415	0	0	1	1	34.83	7.87	7.64
5	072092	267	1920	925	225	1	0	35.10	7.70	7.70
6	072392	267	1345	925	225	1	0	33.42	7.06	7.50
7	072892	267	950	925	225	1	0	32.27	6.95	7.42
8	073092	267	1030	925	225	1	0	32.40	7.10	7.30
9	080692	267	1115	925	225	1	0	32.40	7.10	7.30
10	081192	267	1020	925	225	1	0	32.65	6.72	7.31
11	081392	267	1130	925	225	1	0	32.20	7.10	7.26
12	082092	267	1115	925	225	1	0	30.80	6.94	7.30
15	090392	267	1030	925	225	1	0	.	.	.
16	091092	267	1105	925	225	1	0	32.00	7.70	7.40
17	091292	267	1315	925	225	1	0	.	.	.
18	091792	267	1000	925	225	1	0	30.58	7.59	7.53
19	092492	267	1120	925	225	1	0	28.50	7.45	7.45
1	072092	276	1200	0	0	1	1	34.91	8.53	8.32
2	072092	276	1310	0	0	1	0	35.20	8.04	7.71
4	072092	276	1640	135	270	1	1	33.22	7.91	7.57
5	072092	276	1835	115	270	1	0	32.60	6.34	7.70
6	072390	276	1400	575	270	1	1	33.67	7.25	7.44
7	072892	276	1130	575	270	1	0	32.89	6.78	7.32
8	073092	276	1010	575	270	1	1	33.20	7.40	7.40
9	080692	276T	1540	575	270	1	0	.	.	.
1	082892	276N	1200	0	0	1	1	31.30	7.90	7.10
2	082892	276N	1400	17	230	1	1	30.70	7.80	7.10
4	091092	276T	1130	22	125	1	1	.	.	.
1	072092	285	1200	0	0	1	1	34.91	8.53	8.32
2	072092	285	1310	0	0	1	1	35.20	8.04	7.71
5	072092	285	1830	125	85	1	1	32.60	6.34	7.70
6	072392	285	1000	117	85	1	1	34.08	6.96	7.33
7	072892	285	930	92	45	1	0	32.83	6.66	7.36
8	073092	285	950	92	45	1	0	33.30	7.40	7.40
9	080692	285	1100	100	45	0	1	32.80	6.90	7.30
10	081192	285	930	100	45	1	0	33.15	6.55	7.35
12	082092	285	1050	92	45	1	1	31.50	6.72	7.28
16	091092	285	1015	108	45	1	1	32.10	7.60	7.60
18	091792	285	1045	100	45	1	0	31.37	7.28	7.43
19	092492	285	1000	107	45	1	0	26.00	7.70	7.30
20	100192	285	930	107	45	1	0	.	.	.
1	082892	294	1200	0	0	1	0	31.30	7.90	7.10
2	082892	294	1400	280	260	0	0	30.80	7.80	7.20
4	091092	294T	1215	1135	275	1	2	.	.	.
1	072092	339	1200	0	0	1	1	34.91	8.53	8.32
2	072092	339	1310	0	0	1	1	35.20	8.04	7.71
5	072092	339	1850	1000	5	0	0	35.20	7.70	7.62
1	082892	348	1200	0	0	1	0	31.30	7.90	7.10
2	082892	348	1400	125	25	0	0	31.00	8.00	7.10
6	091792	348	1300	2208	37	0	0	29.24	6.94	7.20
7	092492	348	1230	2250	35	0	0	24.20	7.40	7.10
8	100192	348	1045	2225	35	0	0	.	.	.
9	101992	348	1030	2225	39	0	0	24.50	8.30	7.23
1	072092	357	1200	0	0	1	1	34.91	8.53	8.32
2	072092	357	1310	0	0	1	1	35.20	8.04	7.71
3	072092	357	1430	125	0	1	1	32.60	6.40	7.20
4	072092	357	1630	108	0	1	1	33.22	7.91	7.57
6	072390	357	1020	716	45	0	0	33.16	6.96	7.28
7	072892	357	1445	716	45	1	0	33.82	7.46	7.68
8	073092	357	1050	716	45	1	1	33.70	7.10	7.20
9	080692	357	1125	716	45	1	1	33.10	7.70	7.60
10	081192	357	1000	716	45	0	0	33.52	6.45	7.22
11	071392	357	1045	716	45	1	0	33.00	7.00	7.15
12	082092	357	1045	700	40	0	0	29.38	6.80	7.28
16	091092	357	1035	700	40	0	0	32.60	7.60	7.40
18	091792	357	1115	700	40	0	0	31.62	7.28	7.34
19	092492	357	1050	700	40	0	0	26.20	7.10	7.10
20	100192	357	1015	690	38	0	0	.	.	.
21	101992	357	1100	675	38	0	0	27.80	7.80	7.40
1	072092	366	1200	0	0	1	1	34.91	8.53	8.32
2	072092	366	1310	0	0	1	1	35.20	8.04	7.71
3	072092	366	1415	0	0	1	1	34.83	7.87	7.64
4	072092	366	1600	17	92	1	1	34.15	8.02	7.92
5	072092	366	1820	80	92	1	1	32.60	6.34	7.70
6	072392	366	1000	185	92	1	1	34.08	6.96	7.33
7	072892	366	930	58	92	1	0	32.83	6.66	7.36
8	073092	366	950	58	92	1	1	33.30	7.40	7.40
9	080692	366	1100	58	92	1	1	32.80	6.90	7.30
10	081192	366	930	58	92	1	1	33.15	6.55	7.35
11	081392	366	1015	58	92	1	1	32.80	7.10	7.15
12	082092	366	1050	58	92	1	1	31.03	6.99	7.41
16	091092	366	1015	58	92	1	0	32.10	7.60	7.60
18	091792	366	1050	58	92	1	0	31.37	7.28	7.43
19	092492	366	1000	58	92	1	0	26.00	7.70	7.30
20	100192	366	930	58	92	1	0	.	.	.
1	072092	375	1200	0	0	1	1	34.91	8.53	8.32
3	072092	375	1415	0	0	1	1	34.83	7.87	7.64
4	072092	375	1600	17	280	1	1	34.15	8.02	7.92
1	082892	384	1200	0	0	1	0	31.30	7.90	7.10
2	082892	384	1400	275	93	1	0	31.10	7.90	7.10

Vitae

Paul Matthew Overton, born on March 5, 1968 in Richmond, Virginia, graduated from Henrico High School in June, 1986. He received Bachelor of Science degrees in Biology and Chemistry from the College of William and Mary in May, 1990. He was married to April Green of Richmond, Virginia in February, 1992, and has a son Shane, born in April, 1993. Currently he is employed with Draper Aden Associates, an engineering firm, where he serves as staff biologist in the Environmental Division conducting groundwater and wetland studies.