1979

Catfish Cage Culture in a South Dakota Power Plant Cooling Reservoir

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CATFISH CAGE CULTURE IN A SOUTH DAKOTA POWER PLANT COOLING RESERVOIR

BY

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A thesis submitted
in partial fulfillment of the requirements
for the degree, Master of Science, Major
in Wildlife and Fisheries Sciences
Fisheries Option
South Dakota State University
1979

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This thesis is approved as a creditable and independent investigation by a candidate for the degree, Master of Science, and is acceptable for meeting the thesis requirements for this degree. Acceptance of this thesis does not imply that the conclusions reached by the candidate are necessarily the conclusions of the major department.

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CATFISH CAGE CULTURE IN A SOUTH DAKOTA POWER PLANT COOLING RESERVOIR

Abstract

Gary P. Wheeler

Studies were conducted to evaluate the Big Stone Power Plant cooling reservoir in northeastern South Dakota as a site for cage culturing channel catfish (Ictalurus punctatus) for market and sport fishery stocking. Temperatures suitable for catfish culture (21-32 C) were present in the reservoir from mid-March through mid-September 1978 and from mid-October through 4 November 1978, the end of the study period. Mean values of chemical parameters analyzed included dissolved oxygen - 8.8 mg/l, total available chlorine - 0.13 mg/l, pH - 8.6, specific conductance - 2228 micromhos/cm, total hardness - 1128 mg/l as $CaCO_3$, calcium hardness - 570 mg/l as $CaCO_3$, and alkalinity - 136 mg/l as $CaCO_3$. Values for all chemical parameters analyzed were found to be within the range of suitability for catfish culture.

Channel catfish 2.2 g in weight and 59 mm total length were cage cultured in the cooling reservoir at densisties of 300 fish per m^3 and 500 fish per m^3 to determine the optimum stocking density. After 31 days fish stocked at 300 per m^3 averaged 2.4 g and 60 mm while fish stocked at 500 per m^3 averaged 2.8 g and 63 mm. There were no significant differences in length or weight ($P > 0.1$) between the 2 treatments. The optimum stocking density appeared to be at least 500 fish per m^3.

Beginning in May 1978 channel catfish 5.7 g in weight and 88 mm total length were cage cultured in the cooling reservoir to determine if a sinking feed could suitably replace the more expensive floating feed normally used in cage culture. After 147 days of culture fish fed floating feed averaged 109 g and 232 mm with feed conversion and survival rates of 1.46 and 89.7%. Fish fed sinking feed averaged 76 g and 211 mm total length with feed conversion and survival rates of 2.21 and 87.1%. Floating feed was judged superior to sinking feed for cage culturing channel catfish larger than 110 mm total length since fish fed floating feed showed significantly greater increases in weight and length ($P < 0.05$) and better feed conversion ($P < 0.05$) than fish fed sinking feed. However, sinking feed produced growth equal to floating feed when fingerlings averaged less than 110 mm total length.

Channel catfish averaging 2.3 g and 65 mm total length were cultured to determine the most efficient food among 4 types tested. The feed type, mean weight, length, and percent survival after 36 days of culture were as follows: floating pelleted feed, 3.1 g, 66 mm, 91%; sinking powder, 3.5 g, 69 mm, 93%; sinking pelleted feed, 2.7 g, 64 mm, 93%; and sinking granules, 2.8 g, 70 mm, 96%. There were no significant differences among the 4 feeding treatments with respect to weight, length, or number of surviving fish ($P > 0.1$). In both of the 2 preceding experiments channel catfish fingerlings smaller than 110 mm total length grew as rapidly on a sinking feed diet as on a comparable floating feed diet. Consequently a savings in feed costs may be realized by feeding a sinking feed to channel catfish fingerlings smaller than 110 mm in place of the conventional floating feed.

Based upon temperature, water chemistry, and catfish growth data, it appears feasible to cage culture channel catfish in the Big Stone Power Plant cooling reservoir from April through October. Catfish fingerlings stocked in April at 150 mm total length should reach marketable size (0.45 kg) in 1 growing season.

TABLE OF CONTENTS

LIST OF TABLES

Table Page

LIST OF FIGURES

Figure		Page

APPENDIX TABLES

APPENDIX FIGURES

Figure | Page

INTRODUCTION

The channel catfish *(Ictalurus punctatus)* is regarded as both an excellent sport and food fish in the United States. In a recent survey of Iowa fishermen, channel catfish were surpassed in popularity only by bullheads *(Ictalurus* spp.) and crappies *(Pomoxis* spp.) (Mitzner Middendorf 1975). The many catfish catchout ponds in the Midwest and South (Baur et al. 1976) and the rapid expansion of the catfish farming industry further testify to its popularity.

Channel catfish fingerlings (51-76 mm total length) are stocked for sport fishing in South Dakota at the end of their first growing season. Fingerlings stocked at this length may have satisfactory survival rates in new or renovated impoundments but have low survival rates in lakes with established predator populations (Mitzner and Middendorf 1975). To avoid predation by adult largemouth bass *(Micropterus salmoides)*, channel catfish fingerlings should weigh at least 75 g or range from 212 to 242 mm total length at stocking (Krummrich and Heidinger 1973). Currently there are no culture facilities in South Dakota available for growing catfish fingerlings larger than 76 mm total length.

Commercial catfish production is currently limited in the northern United States by cool water tempratures and a short growing season. Channel catfish feed sparingly at temperatures below 21 C, and a growing season of 180-200 days is desirable for producing edible-size fish (Lewis 1972). The growing season for channel catfish in Nebraska is about 90 days (Feit and Schainost 1975). Temperature data indicates an even shorter season in South Dakota (Unkenholz and Nickum 1971; Gengerke et al. 1972).

Thermal aquaculture, the growing of fish in heated waters (e.g. thermal effluent from electric generating plants), may provide a means for rapidly growing channel catfish in northern waters to an edible size or to a suitable size for sport fishery stocking. The thermal discharge of a single 500-1000 MW power plant has the capacity to provide hundreds of thousands of liters of water per minute which could be used in maintaining optimal temperatures for year-round aquaculture (Yee 1972). Currently about 227 trillion liters of water per year, roughly 15% of the total flow of U.S. rivers and streams, are used for cooling purposes by steam electric power plants (Lauer et al. 1975). If current predictions hold true, electrical demands will more than double by the year 2000 (more than 600 new power plants will be built), and the thermal effluent from power generation could equal twice the annual flow of the Mississippi, St. Lawrence, Columbia, Rio Grande, and Colorado Rivers (Anonymous 1977, 1978). By using this heated water in aquaculture, new economic opportunities and a substantial new source of animal protein may be developed (Anonymous 1970).

Although thermal aquaculture is currently in the developmental stage, over 40 demonstration or commercial projects have been conducted (Peterson and Seo 1977); and as many as 15 species of fish have been cultured in thermal effluents (Sylvester 1975). Channel catfish have been grown in thermal effluents at several locations. A successful commercial cage culture operation has existed in the thermal effluent waters of Lake Colorado City, Texas since 1969 (Collins 1970; Anonymous

1972; Heffernan 1974). Channel catfish raised in the heated effluent of the Tennessee Gallatin Steam Plant grew 12 to 15 times faster than the control group raised in unheated river water (Upchurch 1971). Catfish were successfully cage cultured in thermal effluents in Missouri (Chen 1976) and Texas (Pennington 1977), but in both states water temperatures in summer were too warm and in winter too cool for optimum catfish growth.

In 1977 and 1978 I evaluated the Big Stone Power Plant cooling reservoir as a site for channel catfish cage culture. This evaluation consisted of a year-round study of the reservoir's thermal and chemical characteristics and a series of cage culture experiments. Channel catfish were initially cage cultured to determine the most economical stocking density for 51-76 mm fingerlings. Other experiments were conducted to determine if a sinking feed could suitably replace the more expensive floating feed normally used in channel catfish cage culture and to choose the most efficient food among 4 types tested in culturing 51-76 mm channel catfish fingerlings.

STUDY AREA

The Big Stone Power Plant and cooling reservoir is located in Grant County, South Dakota, 3.2 km west of Big Stone City. The cooling reservoir was completed in 1972 by constructing a baffle dike and an encompassing levee, riprapping the dike and levee, and pumping water into the reservoir from nearby Big Stone Lake, a long narrow lake on the South Dakota-Minnesota border. Big Stone Plant, a coal-fired 440 MW steam electric generating facility, became operational in 1975. It has the capacity of circulating water from the cooling pond through its main condensor at a rate of 509.7 m^3/min.

The cooling reservoir has a surface area of 145 ha, maximum depth of 10 m, and mean depth of 2.6 m at a water level of 341.1 m above mean sea level (msl) (Fig. 1). The cooling reservoir water level fluctuated from a high of 342.2 m to a low of 340.4 m above msl during the study period. As water evaporated from the cooling reservoir make-up water was pumped in from Big Stone Lake. The cooling reservoir is located at a slightly higher elevation than the surrounding land and as a result was frequently subject to severe wave action.

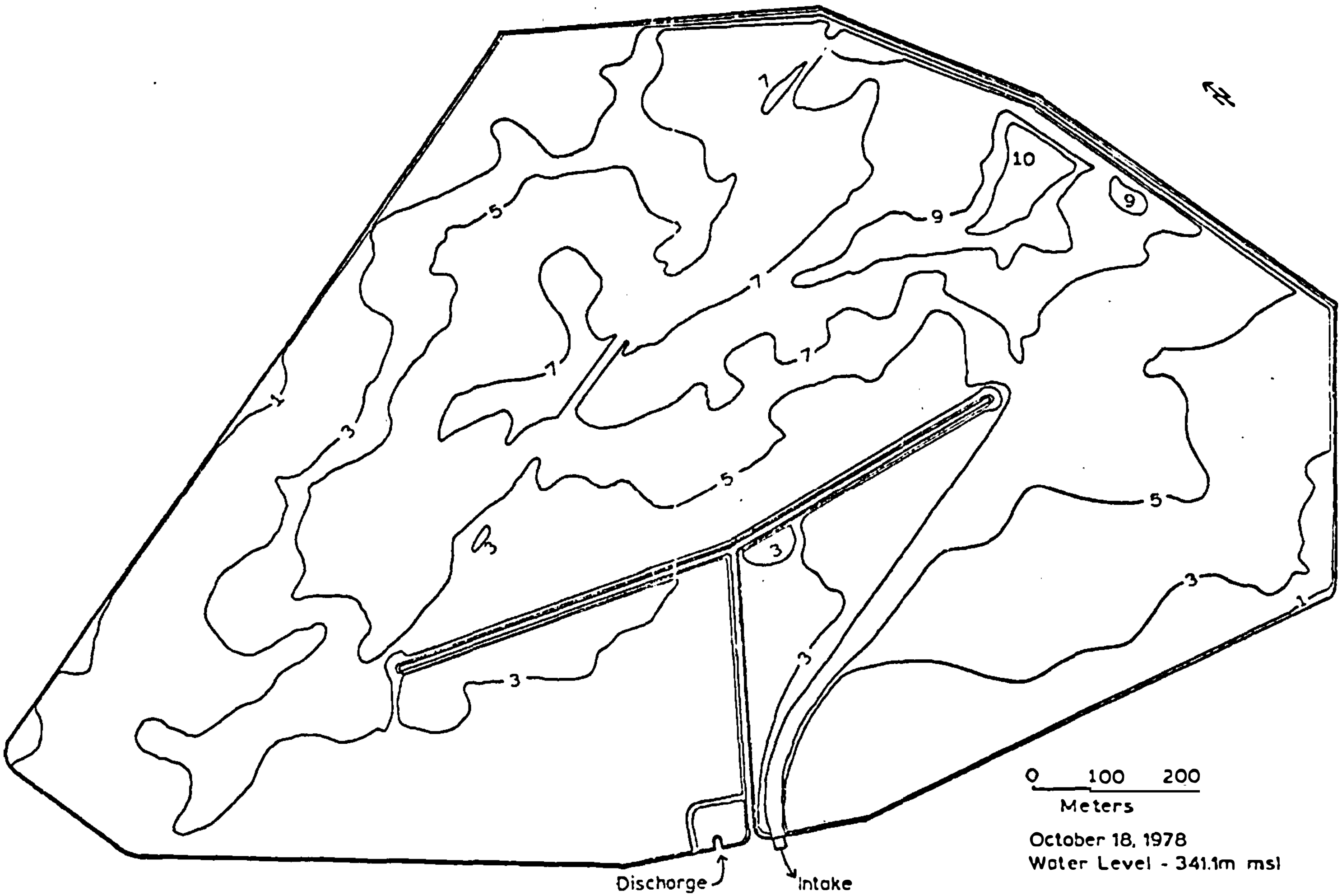

Fig. 1. Big Stone Power Plant cooling reservoir, South Dakota, with depth contours shown at a water level of 341.1 m above mean sea level.

MATERIALS AND METHODS

Physicochemical Evaluation

Reservoir temperatures were recorded from August 1977 to November 1978. Maximum-minimum thermometers were positioned 0.5 m below the surface at 35 sites in August 1977. Maximum-minimum temperatures and ambient surface and bottom temperatures at each site were recorded weekly during August, September, and October 1977. During the winter period, November 1977-January 1978, reservoir temperatures were recorded once per month.

Beginning in February 1978 ambient reservoir temperatures at 21 sampling sites were recorded weekly at a depth of 0.5 m and at 1 m intervals from surface to bottom. In May 1978 maximum-minimum thermometers were placed at sampling sites in the reservoir at a depth of 0.5 m and monitored weekly until November 1978.

A surface water sample and a bottom water sample were taken monthly near the plant discharge, at mid-reservoir, and near the plant intake. Water quality parameters analyzed included dissolved oxygen, total chlorine, pH, and specific conductance. Total hardness, calcium hardness, and alkalinity were determined once every 3 months. Dissolved oxygen was determined using the azide modification of the Winkler method (Lind 1974). Specific conductance was measured with a YSI (Yellow Springs Instrument Company) Model 33 S-C-T meter and corrected to a standard 18 C using a correction factor of 2.5% per degree centigrade.

Stocking Density Evaluation

In mid-August 1977, 8 cages were placed in the cooling reservoir near the plant intake. Cages were constructed of 6.4 mm mesh tarred nylon netting secured to a frame composed of 2 steel hoops, 1 of which was bolted to a 9.5 mm thick plywood cover. Cages were cylindrical in shape 1.21 m in diameter and 1.09 m deep and encompassed 1.25 m^3 of water. Floatation was provided by a tire innertube placed inside each cage. A feeding ring 0.58 m in diameter and 0.46 m deep constructed of 3.2 mm mesh plastic netting was attached to each cage lid to confine the feed. A 0.36 by 0.20 m hole in each lid covered with 12.7 mm mesh plastic netting allowed feed to be poured into the cages.

On 23 August 1977 channel catfish fingerlings from Gavins Point National Fish Hatchery were stocked in the cages at densities of 300 and 500 fish per m^3 (375 and 625 fish per cage). Each stocking density was replicated with 4 cages of fish. Catfish fingerlings averaged 2.2 g and 59 mm total length at stocking.

Beginning 24 August 1977 catfish were fed Purina Catfish Cage Chow (Purina Company, St. Louis, Missouri) 3.2 mm pellets at 6% of body weight once per day 5 days per week. On 22 September 1978, 10% of the fish in each cage were weighed and measured. Growth data was analyzed using a one-way analysis of variance.

Diet Evaluations

Two diet evaluation experiments were conducted during the 1978 growing season. On 21 May 1978, 14 cages were placed in the cooling reservoir near the southeastern shore. Cages were joined in strings of 4 and 5 using polyethylene rope with 1 end tied to a fence post on the shoreline, and the other end anchored in the pond (Fig. 2). Cages were constructed of 51 by 51 mm wooden frames enclosed by 12.7 mm mesh plastic netting. Frames were painted with Texaco Netcoat to retard waterlogging. Lids were made of 9.5 mm exterior plywood. A 0.31 by 0.25 m hole in each lid covered with 12.7 mm plastic netting allowed feed to be poured into the cages. Styrofoam was placed at the ends of each cage to provide floatation. Cages measured 0.84 by 0.84 by 1.02 m deep and encompassed 0.71 m^3 of water. A 0.46 m diameter and 0.56 m deep cylindrical feeding ring made of 3.2 mm mesh plastic netting was attached to the lid of each cage in which floating feed was fed (Fig. 3). In each cage where sinking feed was fed, a 0.39 m diameter and 0.10 m deep cylindrical galvanized livestock watering pan painted with Texaco Netcoat was suspended by 6.4 mm threaded rods 0.42 m beneath the cage lid (0.30 m below the water's surface) (Fig. 3). This pan served to catch the sinking feed, allowing the fish to swim up and eat the feed out of the pan.

Catfish fingerlings obtained from Willow Lake Fish Hatchery, Hastings, Nebraska were stocked into the cages at a density of 176 fish per m^3 (148 fish per cage). Feeding was begun on 25 May with the fingerlings averaging 5.7 g and 88 mm total length. Two nutritionally complete feeds, Purina Catfish Cage Chow, a floating feed, and Glencoe Enriched Grower Pellets (Glencoe Mills, Inc., Glencoe Minnesota), a sinking feed, were tested. These feeds were as nutritionally similar as

Fig. 2. Cages positioned for channel catfish (Ictalurus punctatus) floating and sinking feed diet evaluation, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Fig. 3. Cages used in channel catfish (Ictalurus punctatus) floating and sinking feed diet evaluation, Big Stone Power Plant cooling reservoir, South Dakota, 1978: (A) floating feed cage; (B) sinking feed cage.

Table 1. Proximate analysis of food fed to caged channel catfish (Ictalurus punctatus) in floating and sirking feed diet evaluation, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

	Purina Catfish Cage Chow (Floating)	Glencoe Enriched Grower Pellets (Sinking)
Crude protein (%)	36	38
Crude fat (%)	4	6
Crude fiber (%)	6	5
Animal protein (%)	10	17.5
Metabolizable energy (kcal/kg)	2552	2694

could be obtained (Table 1). Each feeding treatment was replicated with 7 cages of fish.

The catfish were fed 3.2 mm pellets twice per day on weekdays and once on weekends until 26 September and then fed once each weekday. Fish were fed from a boat by pouring an identical weight of sinking or floating feed through the access hole in each cage lid. The feeding rate was determined by the amount of feed consumed by the fish within 30 minutes after feeding (Table 2). The amount of food fed was adjusted at 2 week intervals based upon the estimated growth of the fish; however, feeding was adjusted each week in September as food consumption declined.

Growth was monitored each month by measuring and weighing 15 randomly selected fish from each cage. On 18 October, 15 fish from each cage were measured and all surviving fish were counted and weighed. Analysis of variance using a 2 X 7 X 5 factorial arrangement of treatments was used to test the growth data. One-way analysis of variance was used to test feed conversion and survival data.

In September 1978, 24 additional cages were placed in the cooling reservoir near the southeastern shore in the manner described in the previous experiment. Cages were constructed of 51 by 51 mm wooden frames enclosed by 6.4 mm mesh plastic netting. Frames were painted with Texaco Netcoat to retard waterlogging. Styrofoam was placed at the ends of each frame to provide floatation. Frames were built with 2 cages per frame. A sheet of 6.4 mm mesh plastic netting separated the 2 cages in each frame and prevented fish interchange (Fig. 4). Cages measured 0.57 by 0.76 by 1.02 m deep and encompassed 0.44 m^3 of water.

Table 2. Feeding rate of caged channel catfish (*Ictalurus punctatus*) in floating and sinking feed diet evaluation, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Date	Feeding Rate (% body weight per feeding)
25 May - 21 June	10.0
22 June - 27 July	3.0
28 july - 21 August	3.5
22 August - 27 August	2.0
28 August - 8 September	2.5
9 September - 12 September	2.25
13 September - 15 September	2.0
16 September - 25 September	1.75
26 September - 18 October	1.0

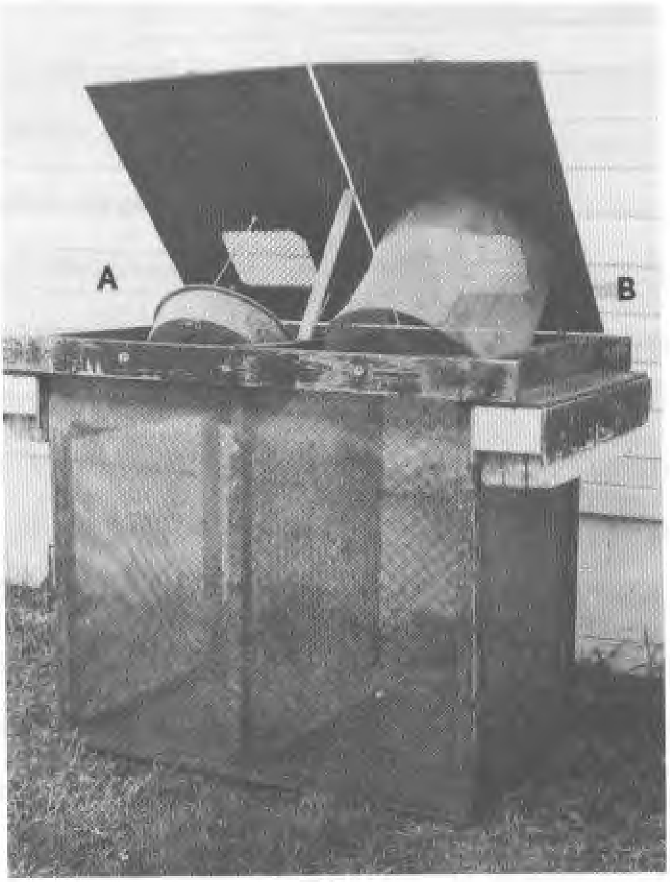

Fig. 4. Cages used in evaluating 4 feeds for culturing fingerling channel catfish (Ictalurus punctatus), Big Stone Power Plant cooling reservoir, South Dakota, 1978: (A) sinking feed cage; (B) floating feed cage.

Cage lids were constructed with feeding access holes and feeding rings or feed pans as described in the previous experiment.

Catfish fingerlings obtained from Gavins Point National Fish Hatchery were stocked into the cages at a density of 409 fish per m^3 (180 fish per cage). Feeding was begun on 13 September with fingerlings averaging 2.3 g and 65 mm total length. Four nutritionally complete feeds were evaluated, Purina Catfish Cage Chow, 3.2 mm floating pellets; ground Purina Catfish Cage Chow, a sinking powder; Glencoe Enriched Grower Pellets, 3.2 mm sinking pellets; and Glencoe Enriched Fry Granules, sinking #3 granules. Each feeding treatment was replicated with 6 cages of fish.

Catfish were fed by boat 5% of body weight twice daily and once on weekends. On 16 September this was reduced to 2% of body weight, and beginning 26 September fish were fed once each weekday. The experiment was terminated 18 October 1978. All surviving fish were counted and weighed and 20 fish from each cage were measured. Survival and growth data were analyzed using a one-way analysis of variance.

RESULTS AND DISCUSSION

Physicochemical Evaluation

Reservoir temperatures varied from a maximum of 43 C to a minimum of 0 C during the study period. Temperatures were warmest at the plant discharge and typically exceeded the intake water temperature by 11-13 C. Reservoir temperatures at a depth of 0.5 m fluctuated an average of 8 C during weekly sampling periods. Temperature data for the study period are presented in 2 types of figures. One type of figure depicts temperatures at a depth of 0.5 m througnout the entire reservoir. Other figures show temperature profiles from the plant discharge to intake along the transect line shown in Appendix Fig. 1.

In this study water temperatures from 21 to 32 C were considered suitable for channel catfish culture since channel catfish feed sparingly at temperatures less than 21 C (Lewis 1972), and temperatures over 32 C may cause stress (Bulow 1967; Kilambi et al. 1971). During August 1977, the beginning of the sampling period, temperatures suitable for catfish culture were present in a large portion of the reservoir (Appendix Fig. 2). Turnover occurred in the reservoir within a few days after the plant was shut down 4 September 1977 for annual maintenance. By 10 September reservoir temperatures had fallen below the 21 C minimum for suitable catfish growth (Appendix Fig. 3). Temperatures remained too cool for satisfactory catfish growth throughout the fall and winter months, October 1977-mid-March 1978 (Appendix Figs. 4-7). As much as half of the reservoir was ice-covered during January 1978 (Appendix Fig.

5), and heated effluent was discharged at the plant intake (as well as at the plant discharge) to keep it free of ice (Appendix Figs. 5-7). Surface water temperatures in the plant discharge area became suitable for catfish culture about mid-March 1978 (Appendix Figs. 8-9), but during May the discharge area became too warm for catfish culture (Appendix Figs. 9-10). Temperatures in the southern portion of the cooling reservoir remained suitable for catfish culture throughout the summer months, May-August 1978 (Appendix Figs. 9-17). Turnover occurred in the reservoir within a few days after the plant was shut down 2 September 1978 for annual maintenance, but reservoir temperatures remained suitable for catfish culture until mid-September when they fell below 21 C (Appendix Fig. 18). After the plant was returned to service on 6 October 1978, water temperatures in the discharge area again became suitable for catfish culture and remained so through 4 November, the end of the study period (Appendix Figs. 19-20).

Wind speed and direction affected the depth and shape of the effluent plume and a change in wind direction caused rapid changes in reservoir temperatures. For example, on 20 June 1978 during a 32 km/hr northwest wind, the effluent was restrained on the west side of the baffle dike with the thermocline at a depth of about 3 m (Figs. 5-6). On 21 June during calm conditions the effluent spread across the reservoir in a thin layer and thus resulted in bringing the thermocline to the 1-2 m level in the discharge region and raising the surface temperature from 26 to 34 C in the western part of the reservoir (Figs. 7-8).

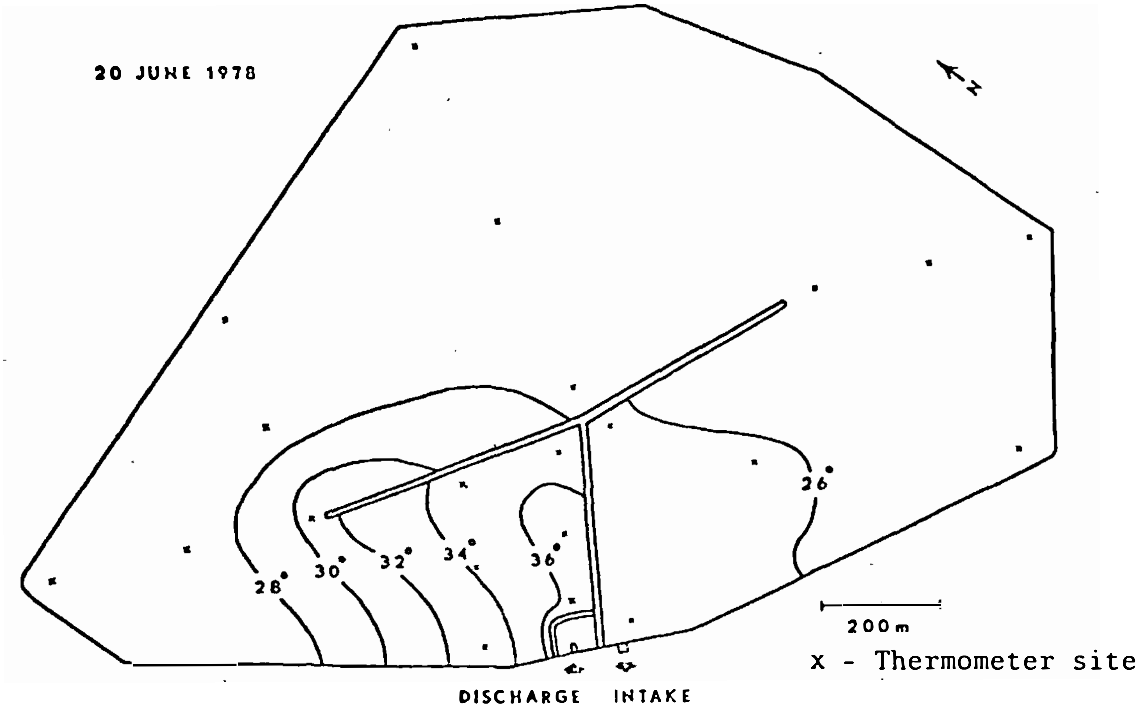

Fig. 5. Temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 20 June 1978, during 32 km/hr northwest winds.

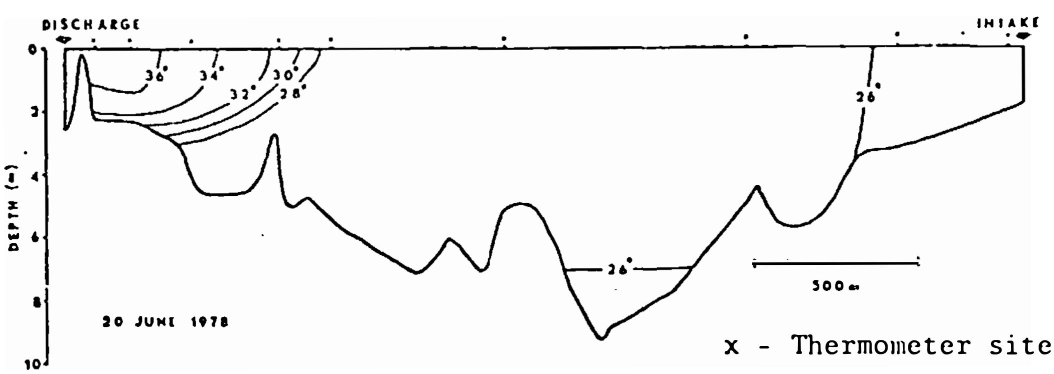

Fig. 6. Temperature profile (C) of the Big Stone Power Plant cooling reservoir, South Dakota, 20 June 1978, during 32 km/hr northwest winds.

ACKNOWLEDGEMENTS

My sincere thanks go to Dr. Richard Applegate for his help and encouragement and his faith in me throughout the study and to Dr. Charles Scalet for inspiring me to enter the fisheries profession. Drs. Robert Benda and W. Lee Tucker aided in the statistical analysis of the data and in reviewing the manuscript. Special thanks to Robert Johnson, Nay Thomas, James Snyder, and the Otter Tail Power Co. for providing access to the cooling reservoir, personnel to feed the fish, and information abou. plant operations.

Lastly a thank you to my many friends who aided in the field work for this project, D. Hogue, W. Kruckenberg, and all of my fellow graduate students. I could not have done it without your help.

Financial assistance was provided by South Dakota National Marine Fisheries Project 1-131-R through the South Dakota Cooperative Fisheries Research Unit[1], South Dakota State University, Brookings, South Dakota.

[1]Cooperating agents: South Dakota Department of Game, Fish and Parks, South Dakota State University, and United States Fish and Wildlife Service.

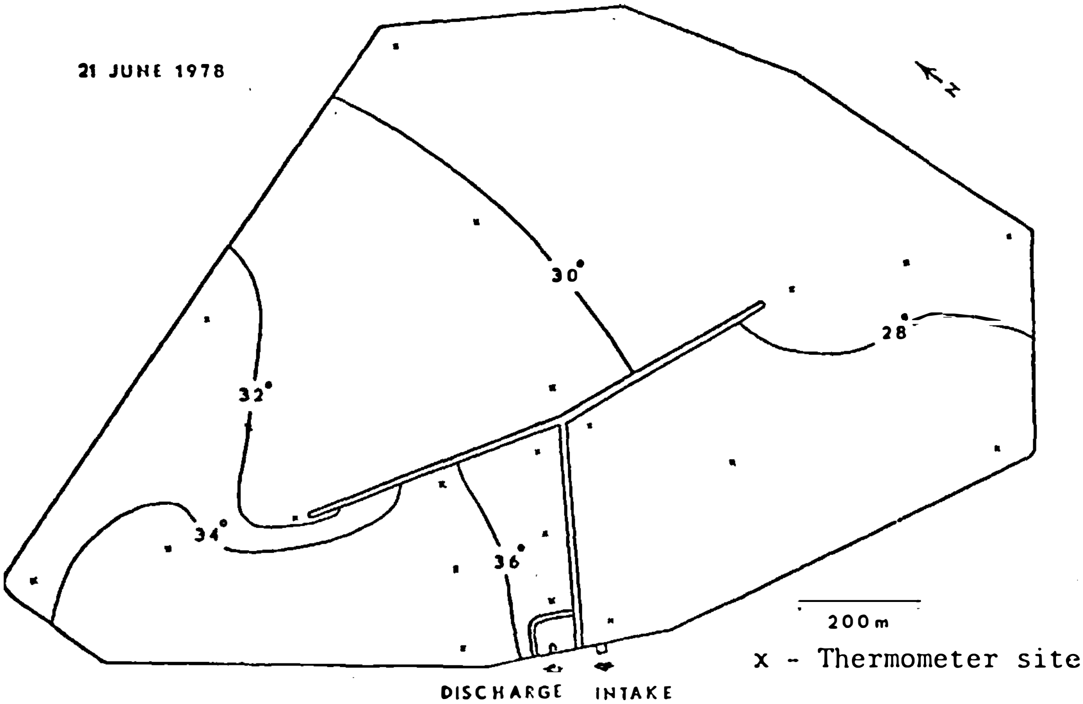

Fig. 7. Temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, 21 June 1978, during calm conditions.

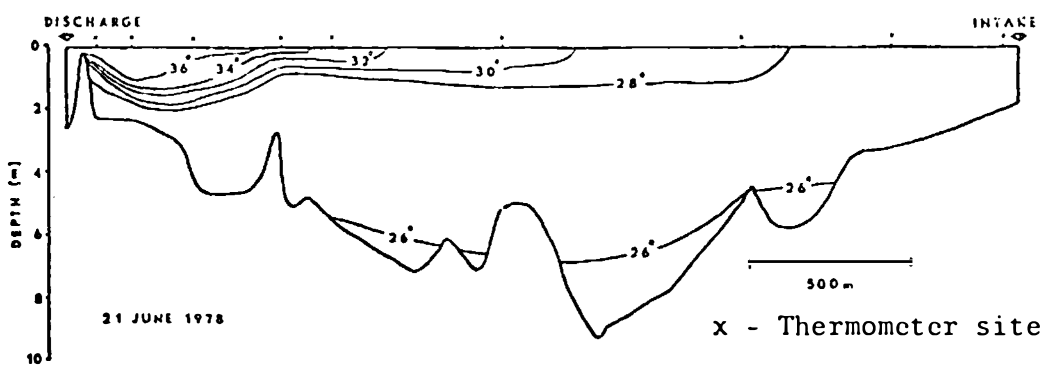

Fig. 8. Temperature profile (C) of the Big Stone Power Plant cooling reservoir, 21 June 1978, during calm conditions.

Although surface temperatures were at times suitable for channel catfish during the winter months, temperature profile data indicated that it was not feasible to overwinter caged fish or to culture catfish in the plant discharge area during March since a plant shutdown and resultant reservoir turnover could cause a rapid temperature drop of over 15 C (Appendix Figs. 5-9). Water temperatures were not suitable for catfish culture in any one area of the reservoir during the entire growing season. Reservoir temperatures indicated that if channel catfish were reared from April to November, cages should be placed along the western arm of the baffle dike on the discharge side and stocked with fingerling catfish in the first part of April. About mid-May cages should be moved to the southeastern shore of the reservoir and should remain there throughout the summer. In mid-September, after the plant has been shut down for maintenance, cages should be returned to their original location on the discharge side of the dike for the remainder of the growing season.

Chemical analysis indicated the cooling reservoir was suitable for channel catfish cage culture (Appendix Tables 1-3). It has been recommended that a dissolved oxygen level of 5 mg/l and pH of 5.0 to 9.0 be maintained in catfish culture operations (Glude 1978). The average cooling reservoir dissolved oxygen level, 8.8 mg/l, and pH, 8.6, satisfied these criteria. Although specific conductance and total hardness in the cooling reservoir were high (2228 micromhos/cm and 1128 mg/l as $CaCO_3$ respectively), Perry (1970) successfully raised channel catfish in ponds with a specific conductance and hardness as high as 23,000 micromhos/cm and 1480 mg/l as $CaCO_3$. Calcium hardness and alkalinity in the cooling reservoir averaged 570 and 136 mg/l as $CaCO_3$. Total available chlorine averaged 0.13 mg/l. On 1 September 1978, 0.37-0.60 mg/l total available chlorine was found in reservoir water samples. Nash (1974) stated that levels as high as 0.3 mg/l cannot be tolerated in aquaculture facilities longer than 2-3 days. However, there was no observed stress among caged catfish or wild fish in the reservoir and chlorine concentrations on all other sampling days were below the 0.3 mg/l level.

Stocking Density Evaluation

On 22 September 1977 after 31 days of cage culture the mean weight and total length of catfish stocked at 300 fish per m^3 were 2.4 g and 60 mm. Catfish stocked at 500 fish per m^3 averaged 2.8 g and 63 mm total length. There were no significant differences in weight ($P > 0.1$) (Table 3) or length ($P > 0.1$) (Table 4) between the 2 treatments.

Optimum stocking density is defined as the largest number of fish that can be efficiently raised in a given volume (Schmittou 1969). Since fish stocked at 500 per m^3 grew as rapidly as fish stocked at 300 per m^3, the optimum stocking density for channel catfish 2.2-2.8 g in weight appeared to be at least 500 fish per m^3. The true optimum stocking density may have been much higher since there was no indication of slowed growth among fish stocked at 500 per m^3. Other studies have demonstrated optimum stocking densities from 400 (Hess 1976) to 500 (Schmittou 1969) fish per m^3 in growing channel catfish from 5 g to 376 g.

Table 3. Analysis of variance of weights of caged channel catfish <u>(Ictalurus punctatus)</u> stocked at 300 fish per m^3 and 500 fish per m^3 for 31 days, Big Stone Power Plant cooling reservoir, South Dakota, 1977.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	1	0.24	0.94
Within	6	0.26	

Table 4. Analysis of variance of lengths of caged channel catfish <u>(Ictalurus punctatus)</u> stocked at 300 fish per m^3 and 500 fish per m^3 for 31 days, Big Stone Power Plant cooling reservoir, South Dakota, 1977.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	1	16.47	0.86
Within	6	19.18	

Growth was poor in this experiment with only a 21% increase in weight (both treatments combined) during the feeding period. Under optimum conditions channel catfish may double their weight each month (Gray 1969). Optimum growth temperatures for channel catfish occur in the 25 to 30 C range (West 1966; Bulow 1967; Shrable et al. 1969; Andrews et al. 1972; Andrews and Stickney 1972; Chen 1976); however, during the feeding period the mean temperature was only 22 C. Cool water temperatures therefore probably restricted growth. Growth may have been improved by feeding the fish more than once per day. Andrews and Page (1975) found channel catfish grew significantly faster when fed 2 times per day than when fed once per day; since growth was dependent upon food intake which in turn is limited by stomach capacity.

Diet Evaluations

On 18 October 1978 after 147 days of cage culture, the average weight, length, feed conversion, and survival rate of channel catfish fed floating feed were 109 g, 232 mm, 1.46, and 89.7% respectively. Catfish fed sinking feed showed an average weight, length, feed conversion, and survival rate of 76 g, 211 mm, 2.21, and 87.1%. Floating feed was superior to sinking feed for use in catfish cage culture since fish fed floating feed showed significantly greater increases in weight ($P < 0.05$) (Table 5) and length ($P < 0.05$) (Table 6) than fish fed sinking feed. The feed conversion rate was also better ($P < 0.05$) (Table 7) among fish fed floating feed than among fish fed sinking feed. There were no significant differences in the number of surviving fish between the 2

Table 5. Analysis of variance of weights of caged channel catfish (*Ictalurus punctatus*) fed floating or sinking feed for 147 days, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	1	6173.91	67.89*
Replication	6	51.03	
Treatment X Replication	6	90.94	
Month	4	21552.94	726.38*
Treatment X Month	4	969.97	15.08*
Replication X Month	24	29.67	
Treatment X Replication X Month	24	64.31	

*Significant at .05 level of probability.

Table 6. Analysis of variance of lengths of caged channel catfish (*Ictalurus punctatus*) fed floating or sinking feed for 147 days, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	1	2523.60	24.58*
Replication	6	160.04	
Treatment X Replication	6	102.68	
Month	4	33438.25	982.12*
Treatment X Month	4	250.56	5.12*
Replication X Month	24	34.05	
Treatment X Replication X Month	24	48.95	

*Significant at .05 level of probability.

Table 7. Analysis of variance of feed conversion rates of caged channel catfish (*Ictalurus punctatus*) fed floating or sinking feed for 147 days, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	1	2.10	76.36*
Within	12	0.003	

*Significant at .05 level of probability.

Table 8. Analysis of variance of number of survivors of caged channel catfish (*Ictalurus punctatus*) fed floating or sonking feed for 147 days, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	1	52.07	1.22
Within	12	42.69	

Table 9. Analysis of variance of weights of caged channel catfish (*Ictalurus punctatus*) fed floating or sinking feed after 28 days of growth, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	1	1.64	2.19
Within	12	0.75	

Table 10. Analysis of variance of weights of caged channel catfish (*Ictalurus punctatus*) fed floating or sinking feed after 57 days of growth, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	1	92.57	18.47*
Within	12	5.01	

*Significant at .05 level of probability.

feeding treatments ($P > 0.1$) (Table 8).

The catfish readily accepted either the floating or sinking feed, and after the initial month ot the study there was no difference in weight between the 2 groups ($P > 0.1$) (Table 9). However from the second month of growth until the end of the study, fish fed floating feed were significantly larger than fish fed sinking feed ($P < 0.05$) (Table 10). Under optimum conditions channel catfish double their weight each month (Gray 1969). In this study the growth or catfish fed floating feed was excellent since the fish more than doubled their weight each month during the period 25 May-22 September. Also their feed conversion rate, 1.46, was better than the notional average of 1.90 (Adrian and McCoy 1971).

The average daily feeding rate in this experiment (7.6% of body weight) was higher than that of most other studies (e.g. 1.5-4.0% (Schmittou 1969); 2.0-3.0% (Lewis 1971); 3.0% (Douglass and Lackey 1974)). However, fingerlings in this study were stocked at a smaller size than those cultured in other studies, and in accordance with common culture practices these smaller fingerlings were initially fed a higher percentage of body weight. The excellent feed conversion rate shown by fish fed floating feed as compared with the national average indicated the feeding rate was not excessive.

Wind as well as cool water temperatures may have contributed to the slow growth of fish during the last month of the study. Strong northerly winds formed waves that washed feed out of the cages. Wave action may also have diminished the feeding response of the fish.

The fish in this experiment did not reach the minimum size desirable for human consumption (340 g). Marketable size was not achieved because large fingerlings (150 mm) normally used for cage culture are not readily available in northern areas until the middle of their second growing season. Also, fingerlings were stocked in the cooling reservoir too late in the year to take advantage of the full growing season. By examining temperature data from the cooling reservoir and the growth and feed conversion rates of the fish (fed floating feed) in this study, it appears possible to cage culture channel catfish in the cooling reservoir from fingerling (150 mm) to marketable size in 1 growing season. Cages would need to be moved at least once during the growing season to take advantage of suitable water temperatures.

Production costs for cage culturing channel catfish in this study, \$5.86 per kg, (Table 11) seem high when compared to other recent studies, e.g. \$2.97 per kg (Feit and Schainost 1975), \$1.83 per kg (Hess 1976). This was due partly to inflation and partly to the high cost of feed and fingerlings in South Dakota as compared with costs in traditional catfish farming areas. Production costs could be substantially reduced in a commercial venture by increasing the stocking density, purchasing feed in bulk, and utilizing cages which amortize at a lower rate. The stocking density in this study (176 fish per m^3) was purposely kept low due to budgetary constraints; however, Schmittou (1969) cultured channel catfish at densities of up to 500 fish per m^3 with no decrease in growth. Assuming a stocking density of 500 fish per m^3, a cage life of 3 years, a cost of \$0.25 per fingerling, a survival rate of 90%, and a feed cost

Table 11. Production costs (labor excluded) of channel catfish (Ictalurus punctatus) cage culture experiment, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

	Floating Feed	Sinking Feed
Cages (7)	$322.07	$317.52
Fish (1036 at $0.18 each)	$186.48	$186.48
Feed	$ 81.44 (137.8 kg at $0.59 per kg)	$ 63.8[illegible] (137.8 kg at $0.46 per kg)
Total	$589.99	$567.82
Number of fish harvested	929	902
Cost per fish	$ 0.64	$ 0.63
Cost per kg of fish	$ 5.86	$ 8.31
Estimated lifetime of cages (years)	3	3
Cost per fish over lifetime of cages	$ 0.40	$ 0.39

and feed conversion rate identical to this study ($0.59 per kg and 1.46), market-sized (0.45 kg) catfish could be produced in the cooling reservoir at a cost of $1.63 per kg excluding labor costs.

The feed type, mean weight, length, and percent survival for channel catfish fed 4 types of feed for 36 days were as follows: floating pelleted feed, 3.1 g, 66 mm, 91%; sinking powder, 3.5 g, 69 mm, 93%; sinking pelleted feed, 2.7 g, 64 mm, 93%; and sinking granules, 2.8 g, 70 mm, 96% (Table 12). There were no significant differences among the feeding treatments with respect to weight, length, or number of surviving fish ($P > 0.1$) (Tables 13-15).

The results of this experiment indicate that small (65-70 mm) caged channel catfish fingerlings grow equally well on floating or sinking feed. In this situation a less expensive sinking feed could be fed for an initial month or more before switching to a more expensive floating feed with no loss in growth and some savings in feed cost. The previous diet evaluation substantiates these findings since there was no difference in growth for the first month between fish 88-110 mm fed sinking or floating feed.

In summary, the Big Stone Power Plant cooling reservoir was found chemically suitable for channel catfish culture and provided a long enough growing season for 150 mm fingerlings to reach marketable size in 1 growing season when stocked in April. Cage culture of catfish fingerlings for sport fishery stocking would also be possible during the April-October period. Culture cages would need to be moved across the reservoir at least once and possibly twice during the growing season to take

Table 12. Growth and survival data for caged channel catfish (*Ictalurus punctatus*) fed 4 types of feed for 36 days, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

	Feed Type			
	Floating Pellets	Sinking Powder	Sinking Pellets	Sinking Granules
Weight (g)	3.1	3.5	2.7	2.8
Length (mm)	66	69	64	70
Mean number of Survivors	164	167	167	173
Survival rate (%)	91	93	93	96

Table 13. Analysis of variance of weights of caged channel catfish (*Ictalurus punctatus*) fed 4 types of feed for 36 days, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	3	0.81	1.35
Within	20	0.60	

Table 14. Analysis of variance of lengths of caged channel catfish (*Ictalurus punctatus*) fed 4 types of feed for 36 days, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	3	37.72	1.81
Within	20	20.89	

Table 15. Analysis of variance of number of surviving caged channel catfish (*Ictalurus punctatus*) fed 4 types of feed for 36 days, Big Stone Power Plant cooling reservoir, South Dakota, 1978.

Source of Variation	Degrees of Freedom	Mean Square	F
Treatment	3	87.26	0.48
Within	20	180.49	

advantage of suitable water temperatures.

The optimum stocking density for cage culturing 2.2-2.8 g (59-62 mm) channel catfish appeared to be at least 500 fish per m^3. Catfish cage cultured in the reservoir and fed a floating pelleted feed showed an excellent feed conversion and growth rate but did not reach marketable size due to their small size at stocking and the late time of year at which they were stocked. Floating feed was found superior to sinking feed for use in cage culturing fingerlings larger than 110 mm total length; however, sinking feed produced growth equal to the more expensive floating feed in cage culturing catfish fingerlings less than 110 mm total length. There was no difference in growth or survival among channel catfish fingerlings stocked at 65 mm total length and fed 4 types of feed for 37 days. A less expensive sinking feed may therefore be used in place of floating feed in culturing small catfish fingerlings (less than 110 mm total length) for a month or more with no decrease in growth rate.

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APPENDIX

Appendix Table 1. Water chemistry data, Big Stone Power Plant cooling reservoir, South Dakota, 10 August-28 November 1977.

		10 August 1977			2 September 1977			14 October 1977			28 November 1977		
	Depth[a]	Sample Site[b]											
		D	M	I	D	M	I	D	M	I	D	M	I
Temperature (C)	S	33.8	30.6	27.8	31.7	30.2		8.9	8.9	9.2	10.0	6.1	6.0
	B	30.2	28.7	31.0	27.9	27.7		8.9	8.9	9.2	7.2	5.1	4.8
Total Chlorine (mg/l)	S	0.10	0.08	0.05	0.17	0.17		0.24	0.15	0.08			
	B	0.13	0.08	0.03	0.12	0.24		0.20	0.09	0.09			
pH	S	7.7	8.4	8.4	7.4	8.5		8.6	8.8	8.9			
	B	7.8	7.8	8.6	7.5	7.5		8.6	8.[illegible]	8.9			
Specific Conductance (micromhos/cm)	S							2591	2629	2673	2108	2039	2085
	B							2591	2635	2673	2089	2067	2275
Total Hardness (mg/l as $CaCO_3$)	S	1300	1240	1300									
	B	1300	1250	1300									
Calcium Hardness (mg/l as $CaCO_3$)	S	720	640	600									
	B	520	740	540									
Alkalinity (mg/l as $CaCO_3$)	S	130	105	115									
	B	170	110	105									

[a]S - surface, B - bottom.
[b]D - discharge area, M - mid-reservoir, I - intake area.

Appendix Table 2. Water chemistry data, Big Stone Power Plant cooling reservoir, South Dakota, 25 February-27 June 1978.

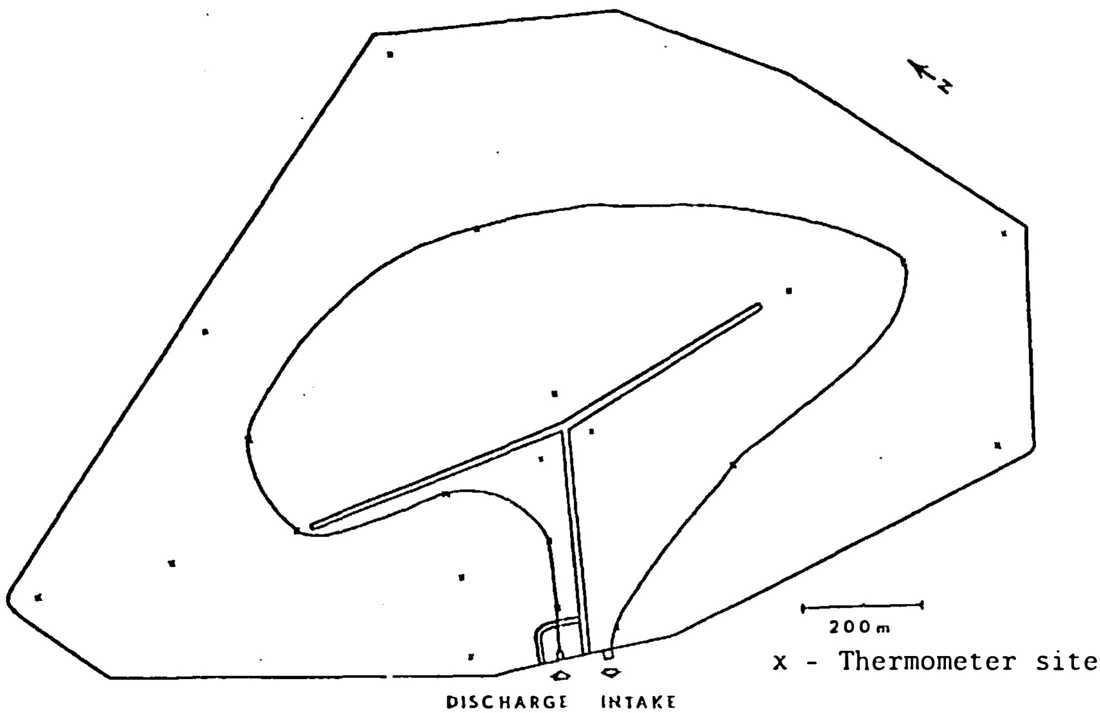
	Depth[a]	25 February 1978			24 March 1978			21 April 1978			25 May 1978			27 June 1978		
		Sample Site[b]														
		D	M	I	D	M	I	D	M	I	D	M	I	D	M	I
Temperature	S	4.0	6.0	6.0	35.3	14.1	13.7	31.0	13.3	12.5	37.7	28.7	26.7	41.1	31.1	29.1
(°C)	B	4.0	6.0	6.0	35.0	13.1	13.7	26.0	11.5	12.0	37.2	21.3	23.0	38.9	25.4	28.2
Dissolved Oxygen	S	11.9	11.6	11.8	9.5	9.8	9.9	10.7	12.1	12.1	7.0	7.6	7.3	8.1	8.3	8.5
(mg/l)	B	13.0	11.7	11.6	9.4	9.6	9.9	10.9	10.1	11.8	7.1	4.6	5.2	7.9	1.1	8.2
Total Chlorine	S	0.06	0.06	0.03	0.15	0.17	0.19	0.07	0.05	0.08	0.10	0.10	0.09	0.21	0.13	0.08
(mg/l)	B	0.00	0.07	0.03	0.10	0.11	0.11	0.08	0.06	0.10	0.10	0.09	0.10	0.27	0.12	0.13
pH	S	8.4	8.4	8.8	8.8	8.8	8.8	8.9	8.9	9.0	8.5	8.7	8.7	8.8	8.8	8.7
	B	8.5	8.6	8.6	8.7	8.8	8.8	8.8	8.9	8.9	8.6	8.4	8.5	8.8	8.7	8.7
Specific	S	2091	2138	2152	2009	2230	2224	1770	1977	1856	1749	1892	1910	1770	1988	1968
Conductance	B	2091	2138	2152	2009	2262	2246	1609	1820	1867	1741	2061	1947	1770	1981	1989
(micromhos/cm)																
Total Hardness	S	1090	1050	1065							1000	1000	1000			
(mg/l as $CaCO_3$)	B	1075	1075	1125							1000	1000	1000			
Calcium Hardness	S	575	575	530							480	480	480			
(mg/l as $CaCO_3$)	B	495	600	550							480	480	480			
Alkalinity	S	158	140	143							140	140	140			
(mg/l as $CaCO_3$)	B	159	140	140							140	140	140			

[a] S - surface, B - bottom.
[b] D - discharge area, M - mid-reservoir, I - intake area.

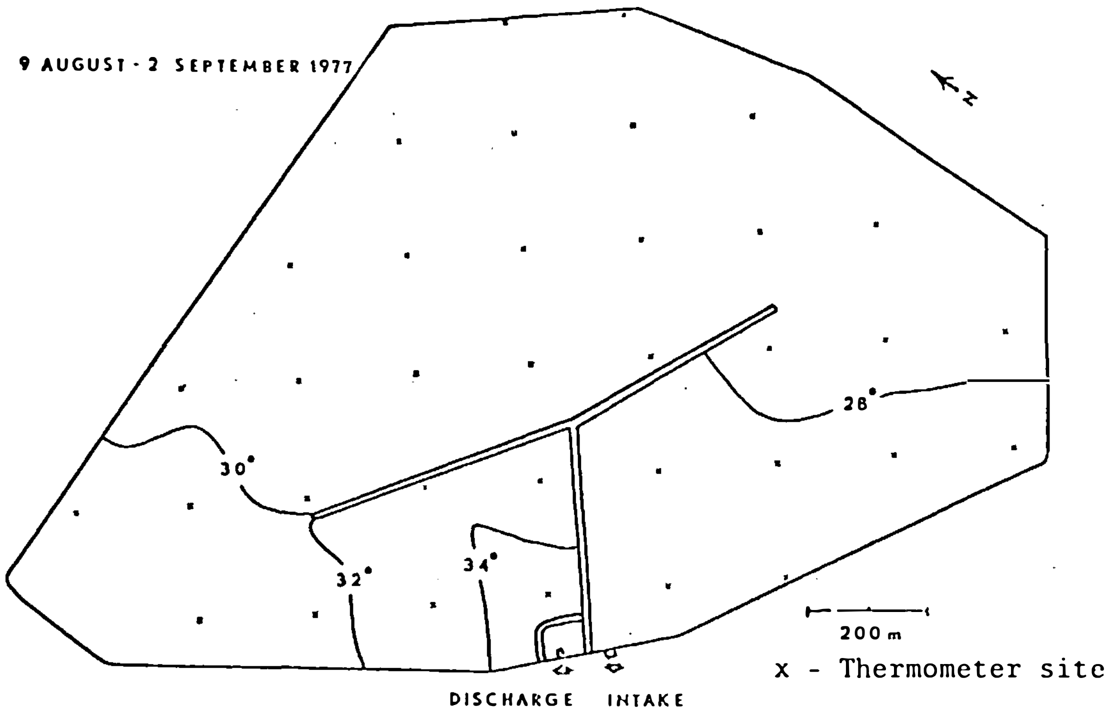
Appendix Table 3. Water chemistry data, Big Stone Power Plant cooling reservoir, South Dakota, 2 August-27 October 1978.

	Depth[a]	2 August 1978			1 September 1978			29 September 1978			27 October 1978		
		Sample Site[b]											
		D	M	I	D	M	I	D	M	I	D	M	I
Temperature	S	41.7	28.8	28.3	39.5	28.8	26.0	15.9	15.9	15.7	30.0	18.0	17.1
(°C)	B	41.5	28.2	28.3	39.0	28.0	25.9	15.9	15.9	15.8	30.1	17.9	17.0
Dissolved Oxygen	S	7.0	6.4	7.2	7.3	7.3	7.6	9.3	9.1	9.2	8.6	8.9	9.4
(mg/l)	B	7.0	5.6	7.2	7.4	7.5	7.3	9.5	8.8	9.1	9.0	8.3	9.6
Total Chlorine	S	0.05	0.12	0.08	0.60	0.43	0.37	0.05	0.04	0.05	0.03	0.06	0.05
(mg/l)	B	0.08	0.15	0.13	0.44	0.57	0.50	0.07	0.02	0.05	0.05	0.02	0.04
pH	S	8.7	8.8	8.9	8.7	8.7	8.7	9.0	9.1	9.1	8.5	8.5	8.9
	B	8.7	8.8	8.9	8.7	8.7	8.7	9.1	9.0	9.1	8.8	8.8	8.8
Specific	S	4116	2435	2250	2037	2214	2229	2401	2391	2350	2325	2450	2556
Conductance	B	4137	2263	2234	2057	2251	2252	2391	2264	2365	2326	2286	2573
(micromhos/cm)													
Total Hardness	S				1150	1150	1150						
(mg/l as $CaCO_3$)	B				1150	1150	1150						
Calcium Hardness	S				620	620	620						
(mg/l as $CaCO_3$)	B				620	620	620						
Alkalinity	S				140	140	140						
(mg/l as $CaCO_3$)	B				140	140	140						

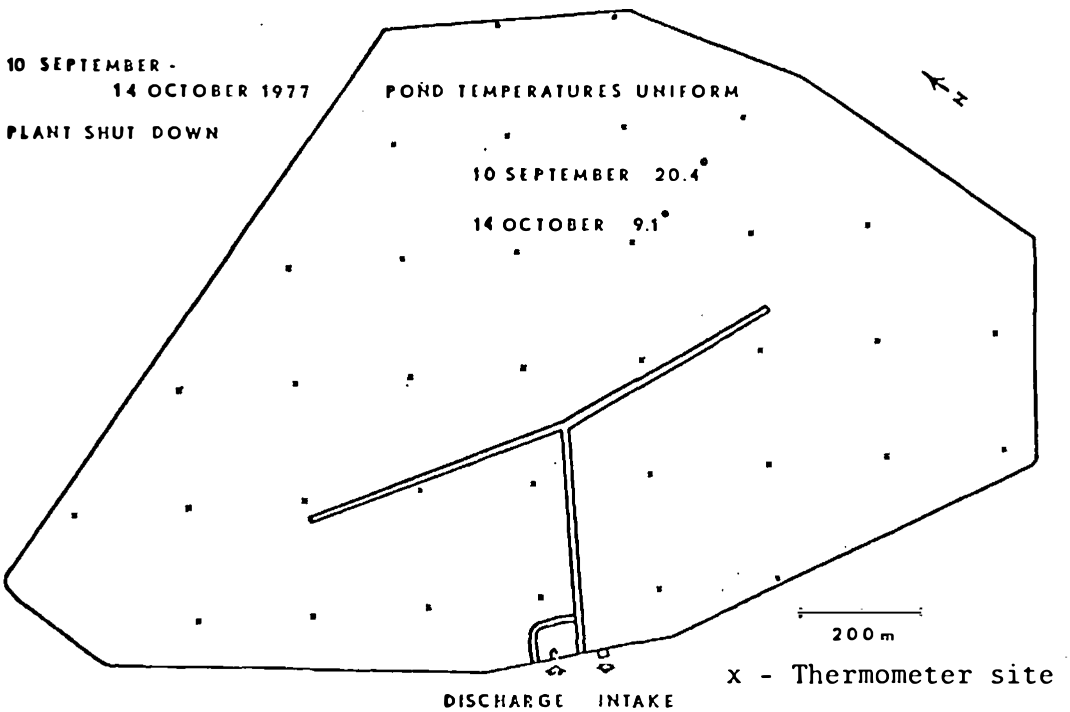
[a]S - surface, B - bottom.
[b]D - discharge area, M - mid-reservoir, I - intake area.



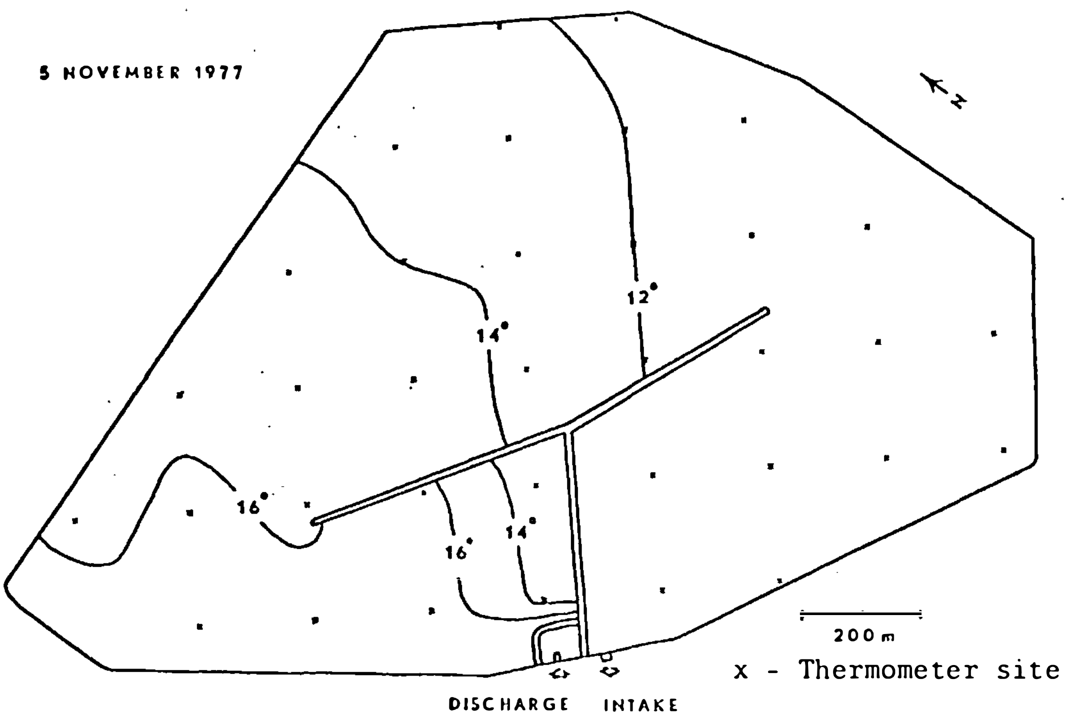
Appendix Fig. 1. Transect line along which reservoir thermal profiles are depicted, Big Stone Power Plant cooling reservoir, South Dakota.



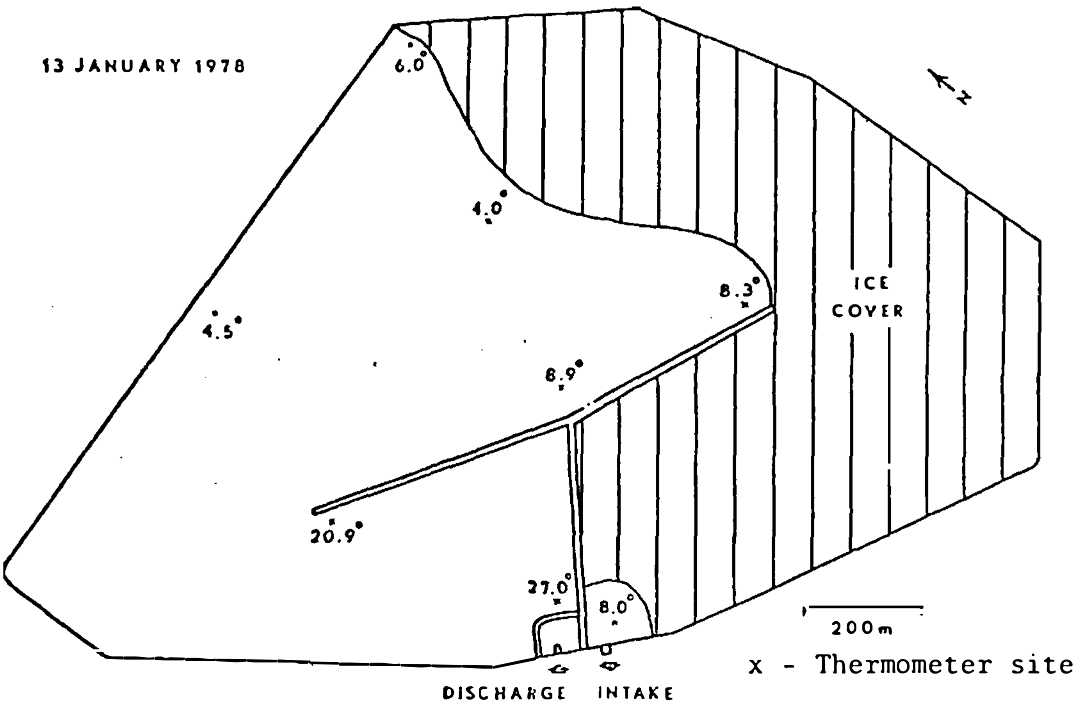
Appendix Fig. 2. Average temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 9 August - 2 September 1977. Temperatures shown are mean values of 4 maximum-minimum readings.



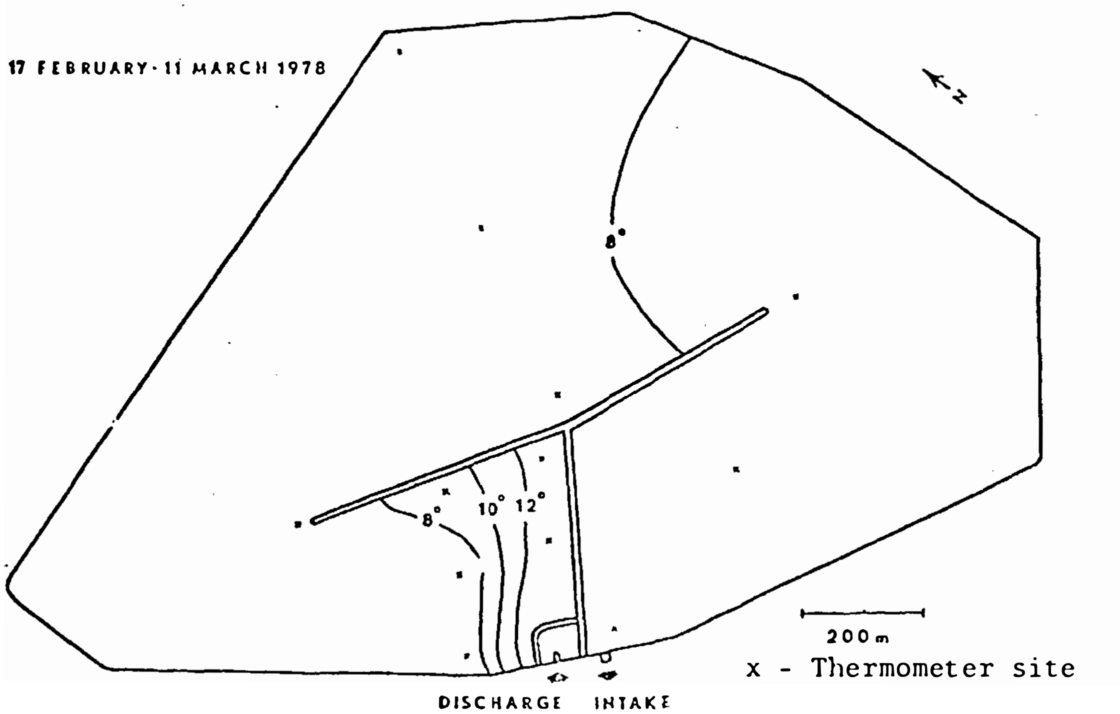
Appendix Fig. 3. Ambient temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 10 September and 14 October 1977, with the power plant shut down.



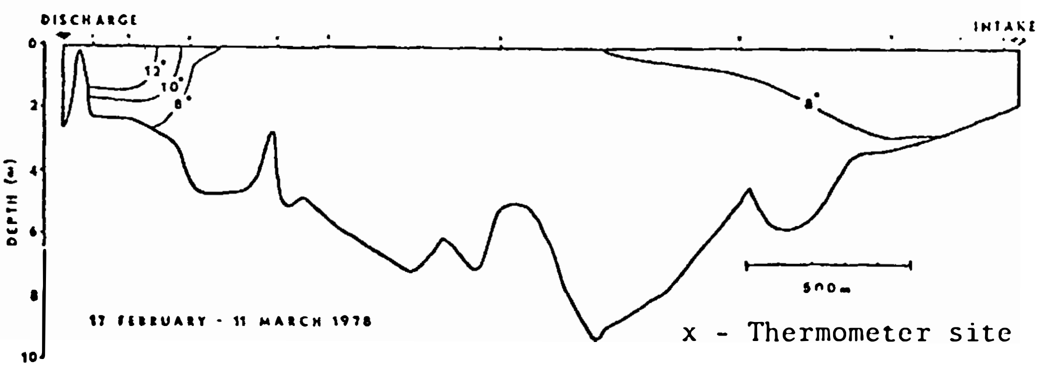
Appendix Fig. 4. Ambient temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 5 November 1977.



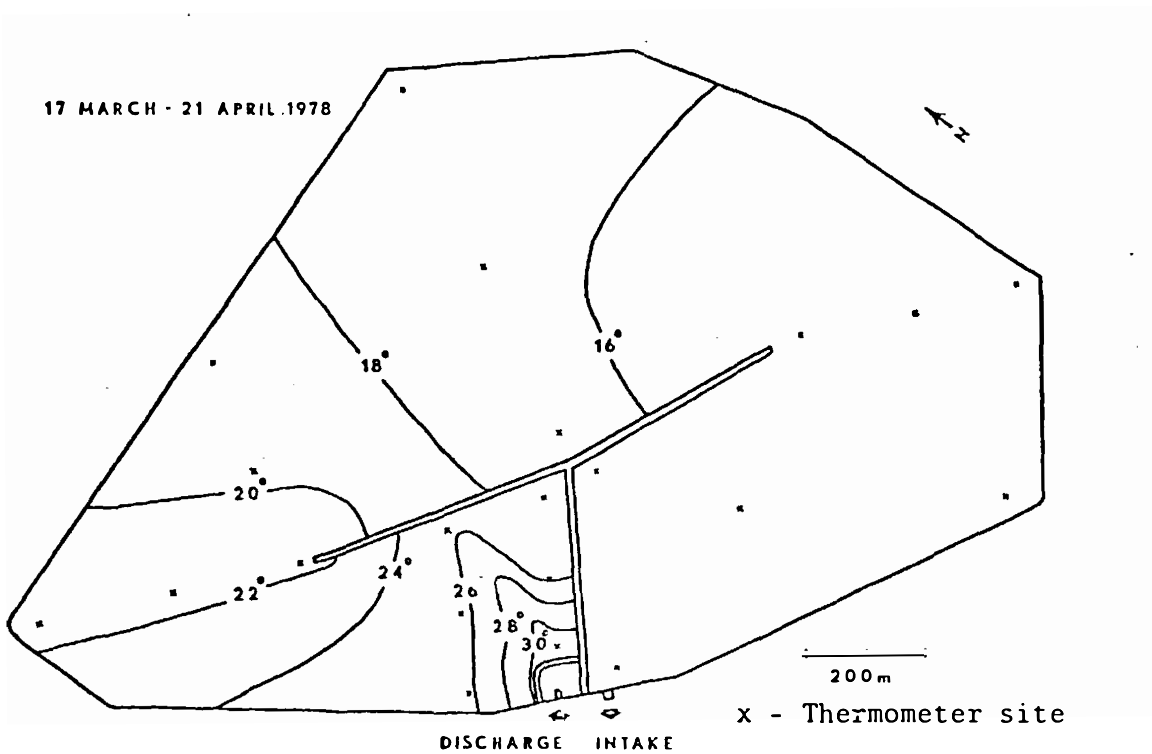
Appendix Fig. 5. Ambient temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 13 January 1978.



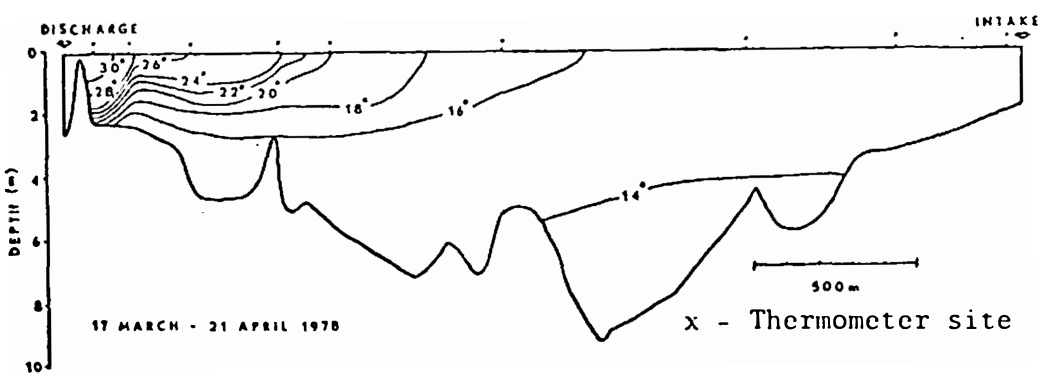
Appendix Fig. 6. Average temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 17 February - 11 March 1978. Temperatures shown are mean values of 4 ambient readings.



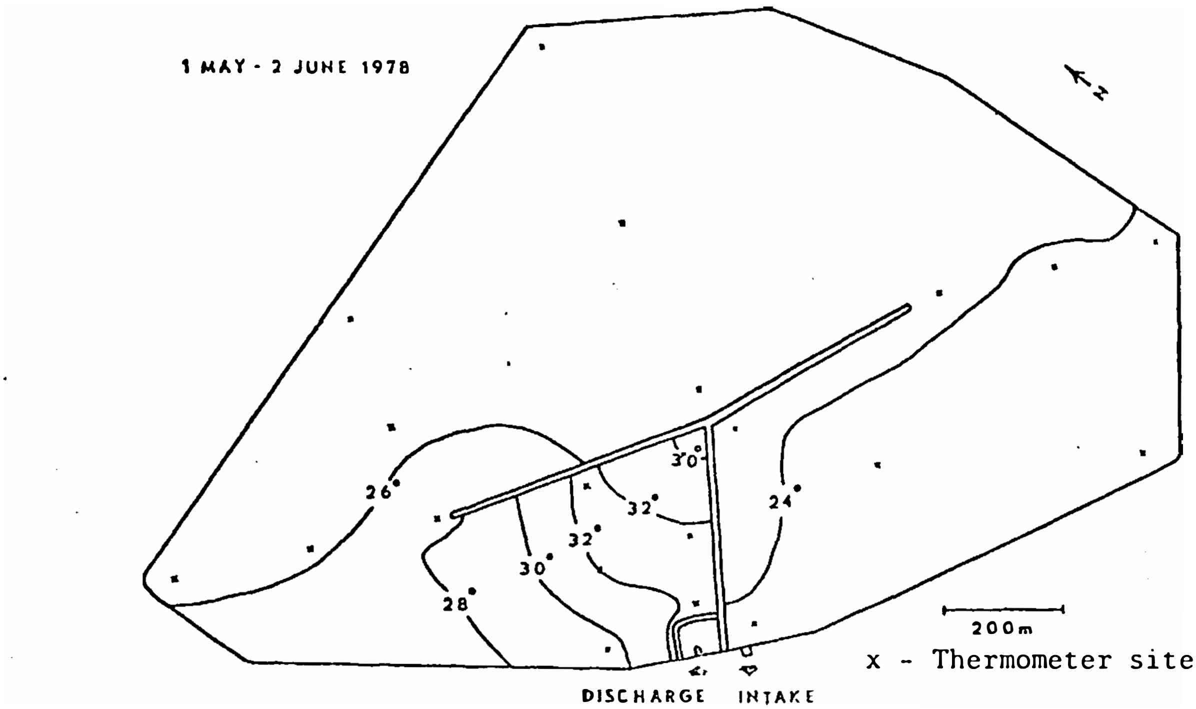
Appendix Fig. 7. Average temperature profile (C) of the Big Stone Power Plant cooling reservoir, 17 February - 11 March 1978. Temperatures shown are mean values of 4 ambient readings.



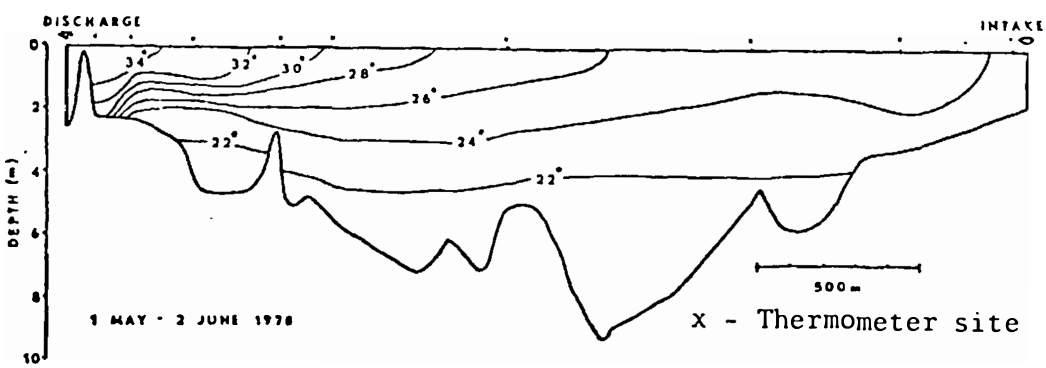
Appendix Fig. 8. Average temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 17 March - 21 April 1978. Temperatures shown are mean values of 6 ambient readings.



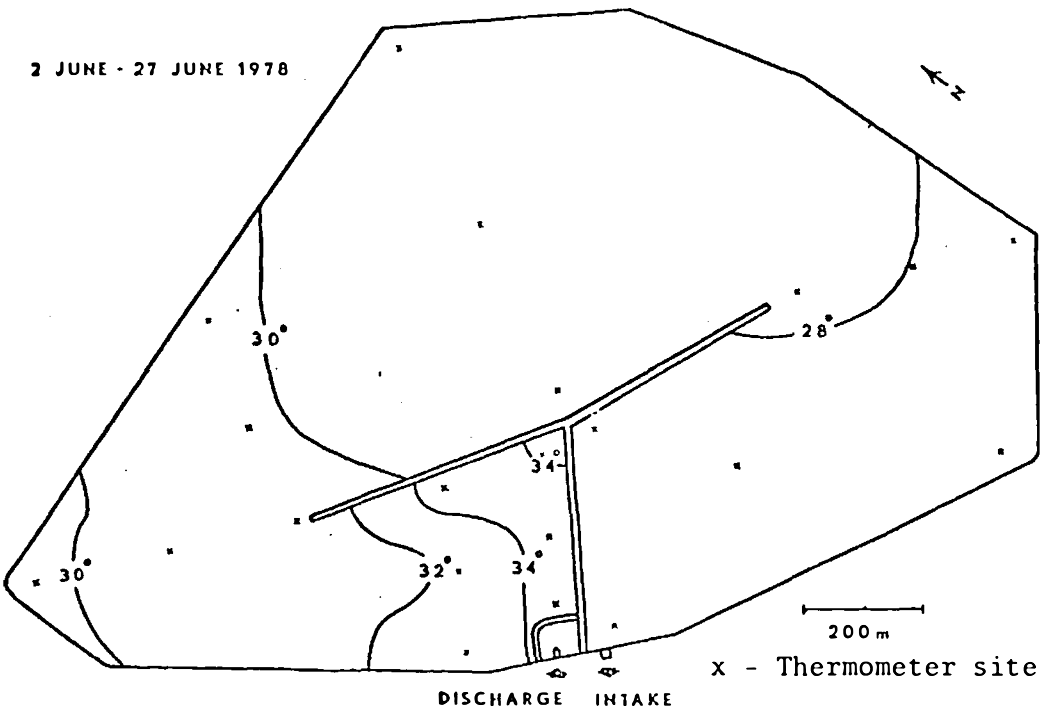
Appendix Fig. 9. Temperature profile (C) of the Big Stone Power Plant cooling reservoir, South Dakota, 17 March - 21 April 1978. Temperatures shown are mean values of 6 ambient readings.



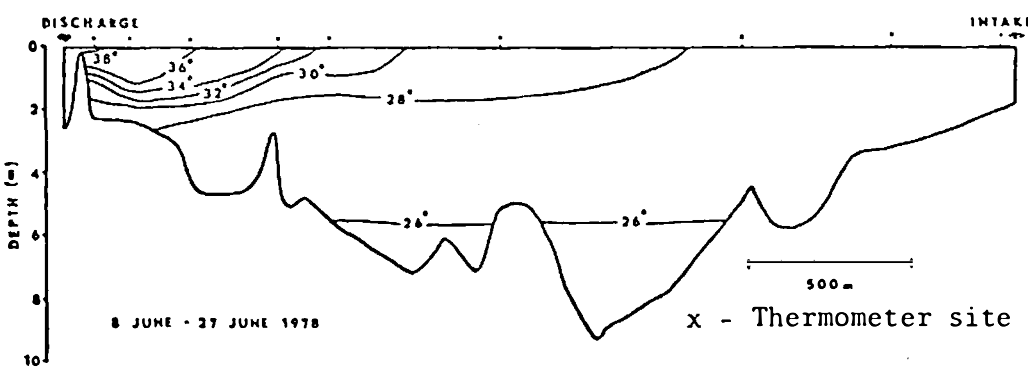
Appendix Fig. 10. Average temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, 1 May - 2 June 1978. Temperatures shown are mean values of 4 maximum-minimum readings.



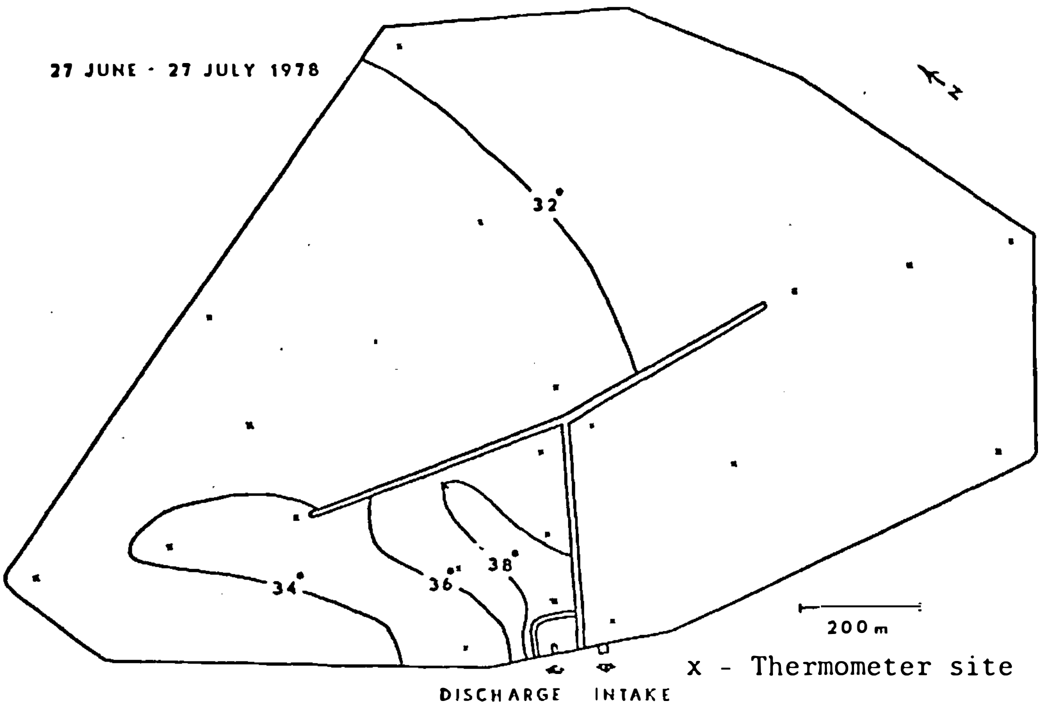
Appendix Fig. 11. Temperature profile (C) of the Big Stone Power Plant cooling reservoir, South Dakota, 1 May - 2 June 1978. Temperatures shown are mean values of 4 ambient readings.



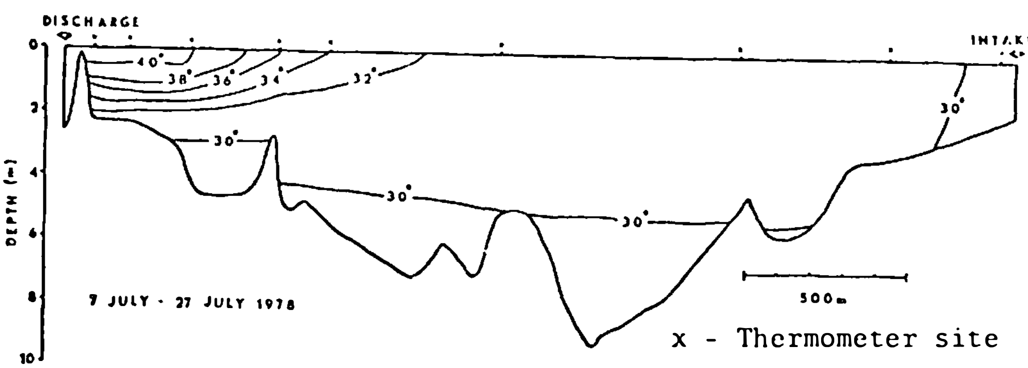
Appendix Fig. 12. Average temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 2 June - 27 June 1978. Temperatures shown are mean values of 4 maximum-minimum readings.



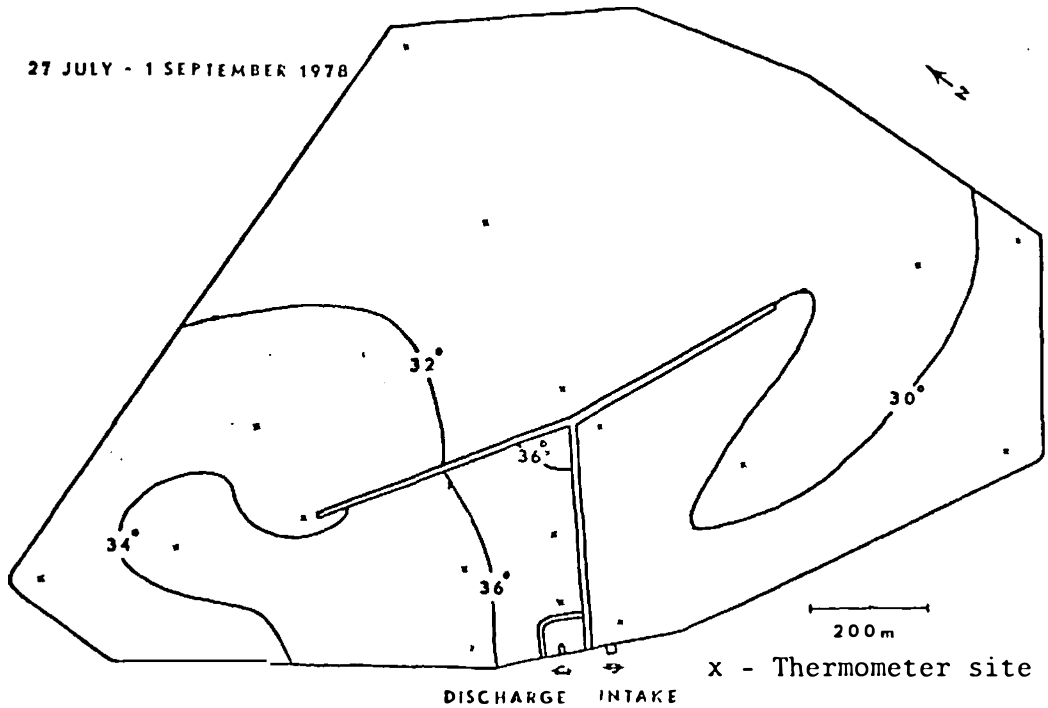
Appendix Fig. 13. Temperature profile (C) of the Big Stone Power Plant cooling reservoir, South Dakota, 8 June - 27 June 1978. Temperatures shown are mean values of 5 ambient readings.



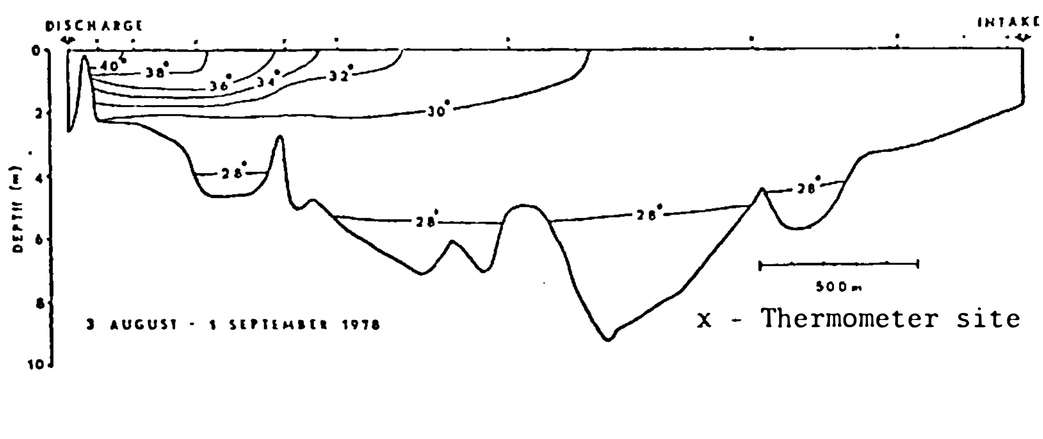
Appendix Fig. 14. Average temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 27 June - 27 July 1978. Temperatures shown are mean values of 4 maximum-minimum readings.



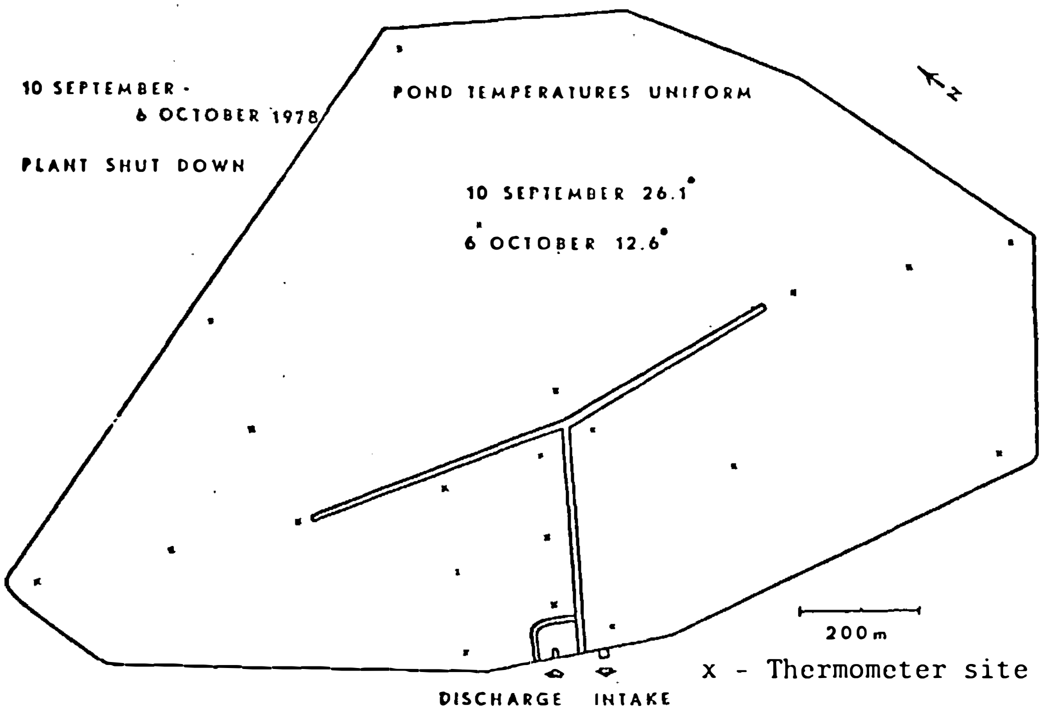
Appendix Fig. 15. Temperature profile (C) of the Big Stone Power Plant cooling reservoir, South Dakota, 7 July - 27 July 1978. Temperatures shown are mean values of 4 ambient readings.



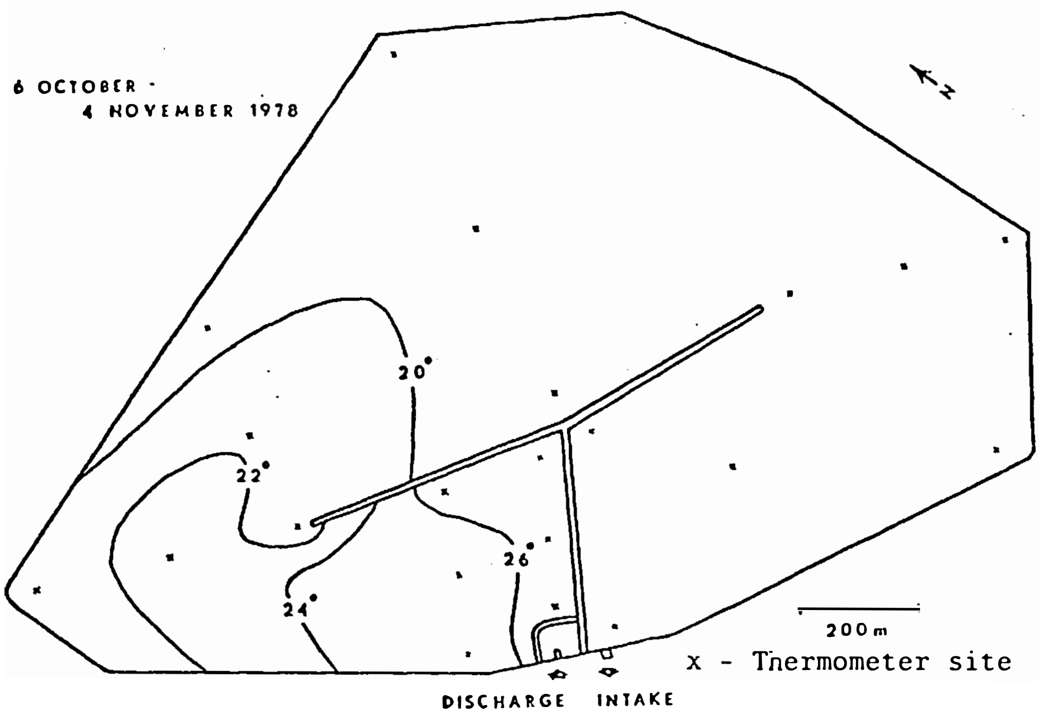
Appendix Fig. 16. Average temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 27 July - 1 September 1978. Temperatures shown are mean values of 5 maximum-minimum readings.



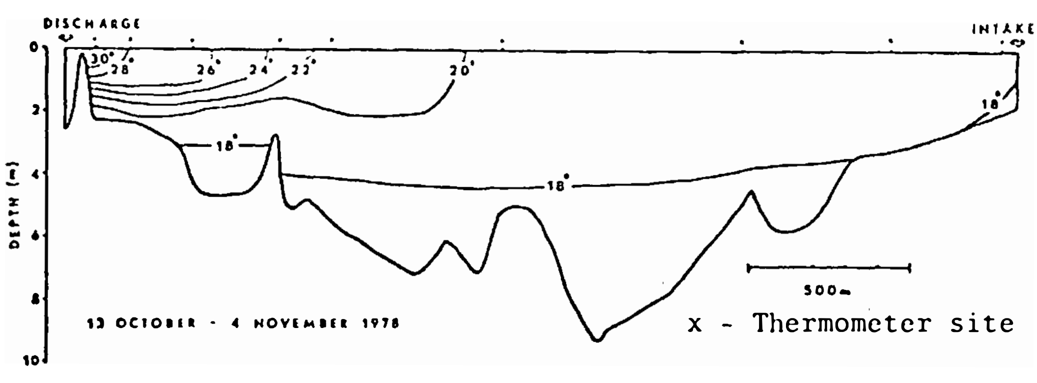
Appendix Fig. 17. Temperature profile (C) of the Big Stone Power Plant cooling reservoir, South Dakota, 3 August - 1 September 1978. Temperatures shown are mean values of 5 ambient readings.



Appendix Fig. 18. Ambient temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 10 September and 6 October 1978, with the plant shut down.



Appendix Fig. 19. Average temperature (C) at 0.5 m depth, Big Stone Power Plant cooling reservoir, South Dakota, 6 October - 4 November 1978. Temperatures shown are mean values of 4 maximum-minimum readings.



Appendix Fig. 20. Temperature profile (C) of the Big Stone Power Plant cooling reservoir, South Dakota, 13 October - 4 November 1978. Temperatures shown are mean values of 4 ambient readings.