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LOUISIANA POWER & LIGHT COMPANY

ASSESSMENT OF THE EFFECTS OF THERMAL RELEASES ON THE AQUATIC ENVIRONMENT

WATERFORD
STEAM ELECTRIC STATION
UNIT NO. 3

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ASSESSMENT OF THE EFFECTS OF THERMAL RELEASES ON THE AQUATIC ENVIRONMENT

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I. INTRODUCTION

A. Purpose and Scope

This assessment is submitted in support of Louisiana Power & Light Company's application for a National Pollutant Discharge Elimination System Permit, filed pursuant to 40 CFR 125 with the U S Environmental Protection Agency, Region VI, on October 18, 1978. In order to facilitate review of this application, this document has been prepared in accordance with the guidelines developed by the U S Environmental Protection Agency, pursuant to 40 CFR 122. This is based upon an evaluation of the design of the discharge facility and the nature of the Mississippi River near Waterford.

The primary source of site-specific data and analyses utilized in the determination of thermal impacts on the river is the Waterford 3 Operating License Stage Environmental Report (OLER). This report, and its detailed supporting data base, forms the basis of this demonstration. However, for the purposes of this document, it was considered necessary to only reproduce that biological and hydrothermal data from the OLER that would adequately demonstrate the low impact of thermal discharges from Waterford 3. As appropriate, additional analysis methodologies, additional data, etc. are cross-referenced in this document to the OLER.

The scope of work included:

1. A brief description of pertinent systems at Waterford 3 contributing to this discharge,

2. A master ecosystem rationale highlighting key points indicative of the low potential impact of Waterford 3 thermal discharges,

3. Biotic category rationales supporting the master ecosystem rationale and keyed to decision criteria for low potential impact detailed in the EPA guidance manual.

B. PLANT DESCRIPTION

Waterford 3 is located at River Mile 129.6 on the west bank (right descending) of the Mississippi River. This location is approximately one-half mile downstream from Waterford 1 and 2 (882 MWe fossil-fueled) and is almost directly across river from the Little Gypsy Generating Station (1229 MWe fossil-fueled). Figure 1 presents a location map of the project area.

The gross electrical output of this nuclear-fueled unit for the rated power level is 1202 MWe. Makeup water for all systems, with the exception of the Potable and Sanitary Water System and the service Water System, is the Mississippi River. Potable water and service water are obtained from the St Charles Parish Water Works.

The main condenser Circulating Water System, the Turbine Closed Cooling Water System and the Steam Generator Blowdown System heat exchangers all operate in the once-through (open cycle) mode. For these once-through systems, evaporative losses are assumed to be negligible. Spent cooling water from these systems, along with certain plant process wastewaters, are combined and discharged to the Mississippi River in the Circulating Water System Discharge. The water is discharge to the river utlizing a surface discharge through a canal which is tapered to provide improved dispersion of the spent cooling water during lower river flows. Chlorine (used on an intermittant basis as necessary) is added to the circulating water to prevent biological fouling of the condenser tubing.

The Circulating Water System has three operational modes, corresponding to the operation of two, three or four intake water pumps. The requirements for the operation of these pumps are a function of ambient intake water temperatures in the river and plant operating conditions. For the purposes of this document, all analyses assume maximum plant load conditions. Section IV of this document contains information on the operational modes of the intake water pumps. Discharges are expected to range from approximately 622,000 gpm (1386 cfs) to 1,003,000 gpm (2235 cfs), during maximum plant load conditions.

II. MASTER ECOSYSTEM RATIONALE

This section summarizes the basis for the conclusion that the balanced indigenous population of the Mississippi River will not be disrupted by thermal discharges of Waterford 3. This section also briefly discusses the findings, detailed in Section III, concerning the acreage and cross-sectional area affected by the excess temperature of the discharge, as well as the ecological characteristics of the organisms present. These factors indicate that the ecosystem should be considered one of low potential for impact from thermal discharges.

The Mississippi River at Waterford 3 is a turbid water body with little habitat diversity. The productivity of the system is limited by light penetration as well as the stability and habitability of the substrate. The system is considered to be detrital-based, because phytoplankton occur in low densities, averaging approximately 260 cells/cm^3, and are not seen to be the significant energy base that they constitute in more lake-like environments. This is typical of large, southeastern and midwestern rivers. Similarly, the densities of zooplankton and ichthyoplankton are also low. Zooplankton densities in the Mississippi at Waterford 3 range from approximately 400 to 1000 organisms/m^3, and ichthyoplankton densities are all significantly less than 1 organism/m^3.

In the vicinity of Waterford 3, the Mississippi River does not offer good spawning habitat for most fish species, but catfish and shad may take some advantage of this area for such purposes. Nevertheless, it is not a unique or critical fish spawning area.

A commercial fishery exists in the Mississippi River for catfish, freshwater drum and river shrimp. From Baton Rouge to the Gulf of Mexico, this fishery took 1.2 million pounds of catfish, 80 thousand pounds of drum, and 4 thousand pounds of river shrimp in 1975. These commercial species do not uniquely occur near Waterford 3, but are present throughout the Mississippi River.

Benthic species of beneficial commercial value do not occur in the river near Waterford. However, the Asiatic clam (Corbicula), one of the dominant benthic organisms in this area and a food for indigenous fish, has been found to be a nuisance species in other parts of the country, forcing economic losses for their control. The Corbicula population is not expected to be significantly affected by the thermal discharges because of the very small area of its habitat which will be influenced.

The species found in the Mississippi River near Waterford 3 do not include any of those listed on the U S Fish and Wildlife Service threatened or endangered species list for 1976.

The thermal characteristics of the Mississippi River ecosystem, as depicted in more detail in Section III, will be affected by the combined discharge plumes of Waterford 1 and 2, Waterford 3, and the Little Gypsy Generating Station. Plumes are shown in Section IV for the combined discharges of these plants during typical low flow and average seasonal flow conditions. The plume configuration and detailed supporting data indicate that, with all generating stations operating, a zone of passage conservatively estimated to exceed 90 percent of the river area will exist in all seasons.

The benthic community near Waterford is relatively sparse. Also, river cross-sectional configuration at Waterford places a very small percentage of this communities' habitat within the area affected by the thermal discharges. It is estimated that a total of one acre of benthic habitat will have contact with water heated greater than 2°C (3.6°F) above ambient conditions.

The relatively small volumes of the river affected indicate that a significant problem from cold shock to fish is unlikely. The small volumes are also estimated on the assumption that the Waterford 1 and 2, Waterford 3 and Little Gypsy Stations are all operating. A simultaneous, abrupt shutdown of all three stations would be necessary to cause significant cold shock. Such an event is very improbable. For example, if Waterford 3 went off-line when ambient river temperatures were a minimum (40°F) and Waterford 1 and 2 and Little Gypsy were already shutdown cold shock would be limited to 3.2 acre-feet.

For the reasons presented above, the balanced indigenous population of the Mississippi River will not be disrupted by the thermal discharge of Waterford 3. This conclusion is substantiated by the following ecosystem characteristics: low productivity, sparse populations, absence of endangered species, the unsuitability and nonuniqueness for fish spawning, and the presence of commercially important species. The combination of these ecological characteristics with the small volume of river to be thermally affected and the lack of potential for significant effects from cold shock demonstrates the low potential for adverse impact from the operation of Waterford 3.

III. BIOTIC CATEGORY RATIONALES

The following section utilizes the data which was collected from the Mississippi River near Waterford 3 by the Waterford 3 Environmental Surveillance Program. This program was conducted from 1973 through 1976 to predict the expected biological impacts from the thermal discharges of Waterford 3.

The sampling stations utilized during the Environmental Surveillance Program were selected to analyze the various types of habitat existing in the Mississippi near Waterford. Station locations included shallow water - low current velocity areas and deep water - fast current velocity areas. Control stations were also established in these habitat types. Figure 2 presents the location of the sampling stations.

The discussion below is divided into six sections, describing six biotic categories:

- phytoplankton
- habitat formers
- zooplankton and meroplankton
- shellfish and macroinvertebrates
- fish and;
- vertebrate wildlife

Section 2.2.2.1 of the Waterford 3 Environmental Report - Operating License Stage presents a more detailed discussion of the aquatic ecology of the lower Mississippi River near Waterford.

In each section data are compared to the decision criteria for impact potential as detailed in the United States Environmental Protection Agency's Section 316(a) Guidance Manual, dated May 3, 1977[2].

A. PHYTOPLANKTON

In the lower Mississippi River, turbidity, turbulence and suspended solids limit the productivity of the primary producers (eg, phytoplankton). High river suspended solids concentrations (Figure 3) and turbidity limit light

pentration to very shallow depths. Also,shallow areas of suitable substrate for benthic (attached) algae production are rare. Therefore, production of "tychoplankton", or algae which find their way into the plankton community by sloughing off of various substrates on which they grow, is limited. The system may be considered a detrital-based one, typical of large, commercially-travelled rivers such as the Mississippi. Recent data support the fact that primary productivity is very low, with values of between 0 - 47.6 mg carbon/ hr/m^3 being measured in the river near Waterford between August 1977, and April 1978[3]. Most measurements were near zero.

During the period 1973 through 1976, phytoplankton densities measured in the Environmental Surveillance Program ranged from 24.6 to 1,446.8 $cells/cm^3$ in the Mississippi River near Waterford. The mean (average) and median (50th percentile) densities were 260 and 150 $cells/cm^3$, respectively[1]. These densities can be compared to those found in lakes, where phytoplankton usually occur in much higher densities and consequently make a more significant contribution to the food web than in rivers. For example, phytoplankton densities typically range from 500-8000 $cells/cm^3$ in some lakes which have been studied[4,5].

It is also noted that a maximum seasonal average of only 6.6 percent of the cross-section will be heated $2^{o}C$ ($3.6^{o}F$) or more above ambient (during fall) by the combined discharges from Waterford 1 and 2, Waterford 3 and Little Gypsy. It is estimated that an organism entrained into the Waterford 1 and 2 plume along the Waterford 3 plume to the $2^{o}C$ ΔT isotherm would be subject to these excess temperatures for approximately one hour. Therefore, this low percentage of the river affected by the heated discharge, as well as the short duration of the exposure of phytoplankton to the discharge, are not expected to cause any change to the phytoplankton community. Blue-green algae (Cyanophyta) a group containing many nuisance species, are also not expected to increase above their present, low proportions in the phytoplankton community. Table 1 presents the measured densities of cyanophyta in the Mississippi River near Waterford.

1. Decision Criteria

It is felt that the phytoplankton category should be considered one of low potential impact because:

1. A shift towards nuisance species of phytoplankton is not likely to occur;
2. There is little likelihood that the discharge will alter the indigenous community from a detrital to a phytoplankton based system; and
3. Appreciable harm to the balanced indigenous population is not likely to occur as a result of phytoplankton community changes caused by the heated discharge.

B. HABITAT FORMERS

Habitat formers are defined as "....any assemblage of plants and/or animals characterized by a relatively sessile life stage with aggregated distribution and functioning as:

1. A living and/or formerly living substrate for the attachment of epibiota (eg, a coral);
2. Either a direct or indirect food source for the production of shellfish, fish and wildlife (eg, Elodea);
3. A biological mechanism for the stabilization and modification of sediments, contributing to the development of soil (eg, salt cord grass).
4. A nutrient cycling path or trap (eg, a marsh); or
5. Species sites for spawning and providing nursery, feeding, and cover areas for fish and shellfish"[2].

The Mississippi River in the vicinity of Waterford 3 was found, during the Environmental Surveillance Program, to be devoid of habitat formers[1,6].

C. ZOOPLANKTON AND MEROPLANKTON

The Environmental Protection Agency states that "areas of low potential impact for zooplankton and meroplankton are defined as those characterized by low concentrations of commercially important species, rare and endangered speices, and/or those forms that are important components of the food web or where the thermal discharge will affect a relatively small proportion of the receiving water body" [2].

1. Zooplankton

None of the species of zooplankton collected in the Mississippi River near Waterford (Table 2) are commercially important, threatened or endangered[7]. It is also believed that zooplankton are of limited importance in the food web.

Table 3 presents the average densities of all zooplankton sampled near Waterford 3.

Average densities of the dominant taxa sampled from 1973 through 1976 are shown in Table 4. Rotifers, usually numerically dominant in river systems, were poorly represented in samples of zooplankton taken near the Waterford site. In view of the large number of rotifers sampled elsewhere in the Lower Mississippi River[8], and the small mesh-sized net normally required to sample members of this phylum[9], it is suspected that the densities found during the Environmental Surveillance Program were biased downwards because of the relatively large mesh-size (0.243 mm) utilized.

Nevertheless, the 0.243 mm mesh size is well suited for sampling zooplankton large enough to serve as prey for many juvenile and adult fish. Galbraith[10] found that yellow perch and rainbow trout usually fed on zooplankton larger than 1.3 mm. Lyaklnovich et al[11] found that similarly sized zooplankton were preferred by carp. Also, Vineyard et al found that bluegill sunfish responded towards daphnids ranging from 0.75mm to 3.75 mm, with a preference exhibited for the larger sizes[12]. Allan[13] reported that yellow perch were most interested in prey 1.3 mm or larger, and least interested in prey less than 0.5mm; comparable values for rainbow trout were 1.6mm and 0.9mm. Alewives, which are planktivores, showed most and least interest, respectively, in zooplankton 0.7mm and 0.2mm in length. Thus, the above findings suggest that estimates of zooplankton abundance presented in this document (Table 4) although biased, because of sampling equipment, provide a measure of the potential contribution of zooplankton as forage for the fish community near Waterford.

The significance of this contribution can be assessed by comparing the densities of large zooplankton in the Mississippi River to densities reported for other ecosystems. The zooplankton densities measured during the Environmental Surveillance Program ranged from about 200 to $4000/m^3$ (Tables 3 and 4). Zooplankton are generally regarded to be an important component of quiet water systems. Crustacean zooplankton were reported to range between 2000 and $2400/m^3$, 2000 and $55,000/m^3$, 2000 and $200,000/m^3$ in Lakes Huron, Ontario and Erie, respectively[(14)]. In a survey of 340 lakes and ponds in the Canadian Rockies, Anderson[(15)] found that the mean density of crustacean zooplankton in the "sparsely populated" water bodies to be $28,000/m^3$ and the mean of "densely populated" water bodies to be $170,500/m^3$. The densities of cladocerans and calanoid copepods sampled by Lane[(16)] in Gull Lake, Michigan; Cranberry Lake, New York; and Lake George, New York were 6,000 to $13,000/m^3$, 20,000 to $26,000/m^3$ and $15,000/m^3$, respectively.

Combining the above data with thermal tolerance information presented in the Waterford 3 Environmental Report - Operating License Stage[(1)], impact to the zooplankton community should appear negligible. In summer, for example, when ambient temperatures are highest, (84.3°F), the 5.6°C (10°F) Δ T isotherm only affects 2.2 percent of the cross-sectional area of the river (combined discharges of Waterford 1, 2, and 3, and Little Gypsy). The zone of potentially lethal temperatures should occupy a much smaller percentage of the river. and travel times through the portions of Waterford 1, 2, and 3 plumes experiencing such temperatures are expected to be less than one hour.

2. Meroplankton

In the Mississippi River, fish, shellfish, and the macroinvertebrate *Macrobrachium ohione* (river shrimp) have meroplanktonic life stages. These life stages form the meroplankton community. These are considered in the appropriate sections (Sections III.D and III.E). However, it will be shown that the Waterford portion of the Mississippi River is of no special significance to support of their population.

3. Decision Criteria

For reasons given above, in this section, and considering that an average of only 6.6 percent of the river cross-section is heated more than 2°C (3.6°F)

by all Waterford 1 and 2, Waterford 3 and the Little Gypsy discharges during the hot season, it is suggested that the zooplankton/meroplankton be considered one of low potential impact. This conclusion is based on the following:

1. Changes in the zooplankton and meroplankton community in the river at Waterford 3 that may be caused by the heated discharge will not result in appreciable harm to the balanced indigenous fish and shellfish population.
2. The heated discharge is not likely to alter the standing crop or relative abundance, with respect to natural population fluctuations in the far-field study area from those values typical of the receiving water body segment prior to plant operation.
3. The thermal plume does not constitute a lethal barrier to the free movement (drift) of zooplankton and meroplankton.

D. SHELLFISH/MACROINVERTEBRATES

1. Threatened, Endangered or Commercial Species

The taxa of shellfish/macroinvertebrates found in samples from the Mississippi River near Waterford are given in Table 5. None of the taxa are considered to be threatened or endangered[7]. Only two taxa, river shrimp (*Macrobrachium ohione*) and blue crab (*Callinectes sapidus*) have the potential to be commercially important[17,18,19]. However, the occurrence of blue crab is marginal near Waterford. Numbers of this species are extremely low, and the Waterford area is distant from water with a salinity sufficiently high for spawning of this species[20].

River shrimp is found in higher numbers. Spawning of river shrimp takes place near the Waterford site. Both females "in berry" and decapod larvae, probably river shrimp, were observed during the 1972-1976 sampling program[1].

However, the occurrence of river shrimp near the Waterford site is not unique. The species occurs as far upstream as St Louis, Missouri[21]. Another study of the lower Mississippi River at a location 400 miles away also found evidence of spawning activity[22]. River shrimp does not appear to require any specialized spawning habitat, but seems to be capable of spawning in any and all habitats in which it occurs. Commercial landings of river shrimp are largely restricted to the Mississippi and Atchafalya Rivers[23]. In 1971, 900 pounds of river shrimp (worth $297) were taken in commercial catches from the lower Mississippi River between the river mouth and Baton Rouge. By 1975, 4200 pounds valued at $2940, were taken[17]. As

these statistics represent the total catch along 230 river miles, the commercial fishing effort is low, and it would seem that the market for this species is not substantial. This is supported by Viosca[23] who states that M ohione is being replaced as a food item by larger sea shrimp and M acanthurus. River shrimp may be marketed as bait, but statistics on this market are not presently available.

To summarize, the Mississippi River near the Waterford site is not unique in terms of macroinvertebrate habitat. Because the Waterford 3 discharge will affect only a small portion of the habitat for river shrimp, no effect on this commercial shellfishery is expected.

2. Importance of Shellfish/Macroinvertebrates

A simple indication of the potential importance of the benthic community to the ecosystem is provided by determining its standing crop. A measure of standing crop is ash-free dry weight - ie, that weight which represents living biomass, exclusive of such material as shells. The Environmental Protection Agency[2] suggests a value of 1 gm ash-free dry weight per square meter of benthic substrate as one decision criteria for benthic low impact potential. At Waterford, recent data (Table 6) indicate that this value was exceeded at Station AC (Figure 2) in February 1978 (due to patches of Corbicula), Stations A_t and B_c in April 1978 (due to sludge worms or Tubificid abundance), and Station B_t in August-September 1977 (due to Corbicula abundance). These exceedences are not considered to be of ecological significance because of the types of organisms present and the general instability of their habitat. Absence of organisms from Station B_t in February and April 1978 suggest that spring flood conditions and scouring washed the organisms away. Also, station B_t is the only Station within the Waterford 3 discharge plume, and it should only experience temperature rises of less than 2.78°C (5°F) (compare Figure 2 with Figures 4-7).

Corbiculà is often considered a nuisance species [24,25,26], but it does serve as a food for fish. Corbicula is frequently found in the stomachs of blue catfish, freshwater drum, sturgeon, and redear sunfish[24]. Several of these fish species are commonly found in the Mississippi River. However, there is little chance that the benthic community will be affected significantly by the Waterford 3 plume.

During the typical low flow (200,000 cfs), the 2°C (3.6°F) isotherm of the Waterford 1 and 2 thermal plume extends 3 ft (1m) below the surface of the river and contacts up to 2062 m^2 (approximately 1/2 acre) of river bottom. The addition of Waterford 3 will not increase this exposure. During average spring and winter flow conditions, the addition of Waterford 3 will increase the area of the bottom contacted by the 2°C (3.6°F) isotherm by approximately 1 acre. Corbicula is very resistant to high temperatures. When acclimated to 30°C (86°F) the incipient lethal limit (i.e. concentration at which 50% of the population can live for an indefinite period) was found to be 34°C (93.2°F) for long-term exposures, while 43°C (109.4°F) was required to kill 50 percent of the test organisms in 30 minutes[25]. On the basis of this information, little or no impact to the benthic community and no impact to the dominant organism, Corbicula , is foreseen.

3. Decision Criteria

The decision criteria for low potential impact on the shellfish/macroinvertebrate cateogry may be summarized as follows:

1. Although shellfish/macroinvertebrate species of existing or potential value do occur at the site (river shrimp), their distribution is wide and there is no evidence to predict that the Waterford discharge will harm their population.
2. Shellfish/macroinvertebrates (Corbicula) may serve as food for finfish. However, these organisms are not expected to be affected by Waterford 3 thermal discharge because little of the plume will impinge on the river bottom.
3. Threatened or endangered species of shellfish/macroinvertebrates do not occur at the site..
4. In certain instances, the standing crop of Corbicula or sludge worms exceeded 1 gm ash-free dry weight per square meter; however, this is considered insignificant for two reasons: (a) the apparent washout of Corbicula in 1978 at a station where it was abundant the prior fall is indicative of the instability of this community, and (b) the thermal plume should affect only a small part of the river bottom (nearshore) at Waterford.
5. The site probably serves as a spawning and/or nursery area for Corbicula and river shrimp, but is certainly not in a unique area. Further, little of the habitat is significantly affected by the plume.

E. FISH

1. Threatened, Endangered, Sport and Commercial Species

The species of fish collected in the vicinity of the Waterford site are listed in Table 7. None of these species are listed by the Fish and Wildlife Service(7) as threatened or endangered. Several species however have some commercial value. Between Baton Rouge and the river mouth, 80,300 lbs of freshwater drum, worth $11,763, 1,198,400 lbs of blue and channel catfish ($401,000) and 16,200 lbs of carp ($944) were taken by commercial fisherman during 1975(17). Those fish of

commercial importance found at the Waterford site are not likely to be affected by the thermal discharge from Waterford 3. As described in the Macroinvertebrate/Shellfish section, the thermal plume is restricted to a relatively shallow surface layer in the river. Since the commercial species are primarily bottom feeders[27,28], temperature effects are expected to be minimal. Furthermore, the two primary commercial taxa, catfish and freshwater drum, have high thermal tolerances.

Sport fishing in the lower Mississippi River is not common[6]. This is probably a result of the industrial development of the river bank and heavy commercial river traffic, which tend to make small boat operations hazardous. Also the generally low productivity of the Mississippi River would probably make sport fishing unattractive from the viewpoint of catch per unit effort.

2. Fish Spawning and Nursery Potential

The Mississippi River at Waterford does not provide habitat suitable for spawning of many fish species. It lacks the riffle areas preferred for spawning by many catfish (Ictalurids)and most suckers (Catastomids), the shallow backwaters and flooded areas preferred by pikes (Esocids) and some of the shads (Clupeidas)and sunfishes (Centrarchids),and the vegetated areas preferred by other sunfishes and perch (Percidas)[27,28,29,30]. To the extent that sheltered locations are available (including cans, snags, etc), a limited number of catfish may spawn near Waterford. Other species that may be capable of spawning in this portion of the river include freshwater drum, gizzard shad, threadfin shad, river carpsucker and skipjack herring[27,29,31]. However, the spawning habitat appears not to be optimal even for these species. This is supported by the low densities

of ichthyoplankton taken during the Environmental Surveillance Program (Tables 8 and 9).

Some fish larvae sampled during the Environmental Surveillance Program must have been produced upstream of Waterford 3, since the habitat at Waterford does not meet their spawning requirements (e.g. sunfishes and pikes). Most of these washed out eggs and larvae are not adapted to the turbid, turbulent, high velocity river conditions and few would be expected to survive, regardless of the Waterford and/or Little Gypsy thermal plumes. However, increased mortality of bouyant freshwater drum eggs, especially during the summer months, might occur. In view of the low numbers of eggs and larvae collected in the river and the high fecundity of drum (approximately 200,000 to 350,000 eggs per female[27], no significant reduction in the number of adults is expected.

With the exception of freshwater drum, the eggs of those species expected to spawn near the Waterford site are demersal and/or adhesive. Because of the buoyant character of the thermal plume, most should not be exposed to large increases in water temperature.

Juvenile stages of certain species will occur at Waterford 3. In the monitoring program, a number of small fish were taken during 1973-1976 (Table 10). The proportion of these fish which were juveniles is dependent upon the individual species growth rate and their size at time of maturation. For example, the majority of bay anchovy taken were probably mature, as the maximum length reported for this species is 100 mm[32]. On the other hand, the channel catfish that were less than 100 mm were probably young-of-the-year because the average total length of

this species at the beginning of its second year of life has been reported to be 102 mm[29].

The dominant small fish (Table 10) were the blue catfish, gizzard shad, threadfin shad and freshwater drum. Some reported lengths at Age I for these species, respectively, 119-150 mm[29], 130mm (average)[29], 102-130mm[29] and 130mm (total length)[27]. Based on these values, it would appear that many of the small fish of these species were young-of-the-year. These same species dominate the fish community throughout their life cycles. The discharges from Waterford 3 are not expected to alter the structure of this community or the success of any given species.

Predictions of low potential impact to the adult fish community resulting from exposure to the Waterford 3 plume are based on the fecundity, breeding habits and thermal tolerances of generally nonunique character of the Mississippi River near Waterford.

Fecundity (eggs/female) along with such parameters as growth rate, longevity, age at first spawning, etc., is related to a species success in exploiting and coping with its environment. The high fecundity of freshwater drum has previously been mentioned. Gizzard shad are even more fecund, with Age II females containing an average 378,958 eggs and Age VI females containing an average 215,331 eggs per female[29]. In addition, some females spawn during their first year of life.

On the average, threadfin shad spawn at younger ages and consequently contain fewer eggs (6,700-12,400 per 102mm female). Members of this species frequently spawn when less than a year old, thereby decreasing the chances of death before reproducing. Two peaks of spawning activity usually occur each year[29], increasing the chances of favorable conditions for survival at the time of spawning.

Catfish are less fecund. A fourteen ounce catfish was reported to contain 3100 eggs, a four pound catfish 8000 eggs, 18 inch catfish from 6000 to 8000 eggs, and a 660mm individual contained 34,500[27,34]. Although catfish fecundity is low compared to the clupeids, catfish ensure a higher survival of eggs and larval fish by spawning in, and subsequently guarding a protected nest. The longevity of catfish also helps compensate for low fecundity by allowing an individual to spawn many times.

Thus, the dominant species (catfish, shad, drum) are well adapted to variations and stresses of the Mississippi River. The species which appear to use the river near Waterford 3 as a nursery exhibit high thermal tolerances. Threadfin shad embryos can survive long-term exposures to 34°C (93.2°F)[35]. Catfish can tolerate temperatures up to 38°C (100.4°F) and can survive temperatures up to 36°C (96.8°F) for long periods of time[27,36]. The optimum temperature for freshwater drum is 29.0-31.0°C (84.2-87.8°F). The lethal threshold for gizzard shad is 36°C (96.8°F) when acclimated at 30°C (86°F)[36]. In actuality, about 1 percent of the cross-sectional area of the river would experience temperatures above 35°C (95°F) during the hot, low flow period in fall. It is expected that most fish would avoid such an area.

3. Zone of Passage

The predicted extent of the combined thermal plumes from the Little Gypsy, Waterford 1 and 2, and Waterford 3 steam electric stations under average seasonal flow conditions are given in Figures 4-7. The predicted thermal plume during typical low flow conditions before and after the addition of Waterford 3, is approximated in Figures 8-11. The cross-sectional profile (Figure 12) indicates that zone of passage will exist under the plume (ΔT 2^{o}C) across most of the river width. This zone of passage will average 93.9 percent of the river cross-section during all four seasons. The zone of passage is smallest during typical low flow conditions but it still allows passage through more than 90 percent of the river cross-sectional area. These values are well within the guidelines provided by EPA[35] of a 67 percent cross-sectional area zone of passage.

4. Potential for Cold Shock

Cold shock is a physiological response (perhaps death) to a sudden decrease in water temperature. During the period 1951-1969, the lowest average monthly Mississippi River water temperature at the Nine-mile Point Generating Station (25.6 miles downstream of the Waterford 3 site) was 8^{o}C (46^{o}F). This occurred during January and February. A minimum temperature of 5^{o}C (41^{o}F) was reported for January, and 4.5^{o}C (40^{o}F) for February[1]. To estimate the potential for cold shock, the graph shown in Figure 12 was utilized. According to this graph, a ΔT of 10^{o}C (18^{o}F) over 5C^{o} ambient (41^{o}F) or a ΔT of 15^{o}C (27^{o}F) over 10^{o}C ambient (50^{o}F) should not cause cold shock. During winter operating conditions, Waterford 3 will create a plume with a volume of 3964 m^3 (3.2 acre-feet) inside the 10^{o}C (18^{o}F) ΔT isotherm. The resulting temperature would then be at least 15^{o}C, or

59^{o}F, in that area. If an unscheduled shutdown were to occur on a day when ambient river temperatures were at their lowest, and if the temperature decrease during shutdown within the 10^{o}C (18^{o}F) plume was rapid, and the other generating units were shutdown, the more sensitive fish within the Waterford 3 plume could experience cold shock. The simultaneous occurence of these conditions is very unlikely.

5. Decision Criteria

Summarizing the above information, it may be concluded that:

1. Although some commercial and sport fish occur in the area, their presence is not unique to the area and their importance as a resource is not significant.
2. No special spawning habitat is provided at Waterford 3 and only small portions of the water column are affected by the thermal plume. Therefore, the Waterford 3 discharge should not significantly affect the fish respective populations.
3. The thermal plume (enclosed by the 2^{o}C (3.6^{o}F) ΔT isotherm) occupies only a small portion of the typical low flow water column.
4. Under most circumstances the Waterford 3 discharge will not cause fish to become vulnerable to cold shock. In the event that conditions were conducive to cold shock, an estimated 3.2 acre-feet could be involved.
5. Threatened or endangered species were not found to be present, and therefore cannot be affected by the thermal plume.

F. VERTEBRATE WILDLIFE

The zone of potential impact from the discharge of Waterford 3 to vertebrate wildlife originates in the discharge area. It extends downstream variable distances, depending upon the configuration of the plume. The wildlife habitat which could be impacted is restricted to a narrow band of land between the levee and the river.

The Waterford site is considered to be a low potential impact area for vertebrate wildlife for the following reasons:

1. The narrow configuration of the limited area available as habitat which may be affected precludes the presence of major concentrations of wildlife species.

2. No unique wildlife concentrations occur on the river shoreline in the site area.

3. The habitat and surrounding environment are highly stressed at the present time.

4. The normal potential impacts to the semi-aquatic vertebrates associated with once-through thermal systems, such as cold shock, should not measurably affect other vertebrates in this climate.

The Waterford 3 Environmental Report - Operating License Stage[1] identifies no major wildlife resources along the river at the site. The stressed industralized environment already limits aquatic food resources to such wildlife groups as fish-eating ducks, watersnakes, etc. Additionally, the river is swift, deep, and generally turbid at the site and therefore not conducive to wildlife usage. A heronry exists off-site, upstream of the discharge. However, the Mississippi River receiving waters in the vicinity of the Waterford site are not preferred heron feeding habitat. Also, the heronry would be active only during the warmer months in late spring and summer. No known rare and endangered species would be measurably impacted by the cooling system. The relatively warm climate in the site area would minimize potential cold shock of possible bank dwelling vertebrates such as muskrats (Ondatra zibethia) and nutria (Myocaster copypus).

IV. ENGINEERING AND HYDROLOGIC DATA

A. ENGINEERING DATA

The Circulating Water System (CWS) provides once-through (open-cycle) cooling water for the main condenser, the Turbine Closed Cooling Water System heat exchangers and the Steam Generator Blowdown System Heat exchangers. The water supply source for the CWS is Mississippi River Water.

Cooling water is transported by pumps located at the intake structure through the main condenser and the heat exchangers and is then returned to the river through a discharge structure. Figures 14 and 15 present a plan drawing of this system and a schematic drawing of the discharge structure, respectively. The CWS operates with either two, three or four intake pumps in use. The number of intake pumps in use at a given time is a function of the ambient water temperatures and the plant load condition. As the intake water temperatures decrease, the heat transfer efficiences across the main condenser (which requires approximately 97% of the CWS design flow) increase. This requires smaller quantities of cooling water to condense the turbine exhaust steam for reuse in the power production cycle. Table 11 presents monthly ranges of ambient Mississippi River (intake) water temperatures. Table 12 summarizes the anticipated annual operation of the intake pumps as dictated by the CWS requirements. The design CWS discharge flow amounts to approximately 97 percent of the design Waterford 3 discharge.

Facilities will be available to add chlorine to the CWS cooling water if needed to control fouling by biological growth. However, experience at the Little Gypsy and the Waterford 1 and 2 generating stations has indicated that the heavy silt content of the Mississippi River tends to cause a continuous scour in the condenser tubes which can control fouling from nuisance organisms.

As a result, no routine chlorination is expected to be needed for the main condenser cooling water. When chlorine is utilized, the free available chlorine at the condenser outlet will be controlled to restrict the concentration from 0.2 to 0.5 ppm and will not be discharged for more than 2 hours per day. The anticipated chlorine requirements are estimated to be sixteen pounds per million gallons of CWS water at a free available chlorine concentration of 0.2 ppm and an available chlorine content of seventy percent in the reagent added.

The travel times after heat addition in the CWS are a function of both the number of intake pumps in operation and the river stage (i.e. at high river water levels, the travel time through the discharge structure and discharge canal is longer). The travel times after heat addition in the CWS are a maximum at average high river water level(AHWL) conditions and are 330, 393, 352 seconds for the four, three and two pump modes, respectively.

Figure 16 presents a schematic diagram of water use at Waterford 3. Plant process wastewaters consisting of primary water treatment plant filter flush wastes and treated wastewaters from both the Waste Management System and the Boron Management System are combined and discharged with the CWS discharges. The primary water treatment plant filter flush water quality is essentially the same as Mississippi River water with increased concentrations of river suspended solids. The design average daily discharge quantity of this wastewater is 180,000 gpd. Radioactive wastewaters are typically treated in either the Waste Management System or the Boron Management System. The treated effluents from these systems average approximately 4000 gpd. Treated effluent concentrations of radioactive substances in these discharges will conform with the limits listed in Table 3 of the Waterford 3 NPDES permit application. These wastewater streams comprise the remaining 3 percent of the Waterford 3 discharge. Figure 16 presents a schematic diagram of water use at Waterford 3.

B. HYDROLOGIC INFORMATION

Spent cooling waters from the operation of Waterford 3 are discharged to the Mississippi River. Monthly average Mississippi River flows, measured at Tarbert Landing (River Mile 306.3) and Red River Landing (River Mile 302.4), varied between 105,000 cfs and 1,470,000 cfs during the period of 1942 to 1976. These stations were chosen because there are no major tributaries below these points and the flows are characteristic of the lower reach of the river (and the Waterford 3 site), except for flood flows. The seasonal average flows at the site are estimated at 580,000, 650,000, 280,000 and 240,000 cfs for the winter, spring, summer and fall seasons, respectively. Each season consists of three consecutive months starting in January.

For the purposes of the analyses performed in this study, a typical low flow in the Mississippi River at Waterford is assumed to be 200,000 cfs. The probability of occurrence of flows less than 200,000 cfs (for all months) implies both an annual recurrence interval of about 6.7 years, and a flow which is exceeded approximately 85 percent of the time. Figure 17 presents a plot of the mean Mississippi River discharge versus the percent of time equaled or exceeded.

Current speeds can be expected to fluctuate as the flow and stage in the river changes. Long-term information on current velocity at the Waterford 3 site is not presently available. However, long-term stage and discharge information is available from the records of the Corps of Engineers, New Orleans District; and from these data, cross-sectional averaged velocities (i.e. current speed) can be determined for the river at the Waterford Site. Section 2.4.3.4.1 of the Operating License Stage Environmental Report presents the methodology used to calculate these currents at the Waterford Site. Based on these calculations, the 39 year average and minimum current speeds are 2.3 and 1.1 fps, respectively. These values represent cross-sectional averaged velocities. The actual velocity distribution is controlled by the channel geometry, and, can be expected to vary

greatly along the cross-section. The following briefly summarizes the current velocities for the four average seasonal flows and the typical low flow condition:

Flow Condition	River Flow (1000 cfs)	River Site Stage (ft)	Current Speed (fps)
Winter	580	10.4	3.1
Spring	650	11.8	3.4
Summer	280	4.0	1.6
Fall	240	3.0	1.4
Typical Low Flow	205	2.3	1.2

Thermal stratification, for depths up to 30 feet in the vicinity of discharge, does not appear to occur. Table 11 presents the range of ambient monthly river temperatures which occur at the Waterford 3 site.

Since the bed of the lower Mississippi River is below sea level, salt water from the Gulf of Mexico intrudes as a wedge under the freshwater discharge. The extent of the saline front upstream of the river mouth, as well as the depth of the top of the wedge, is highly dependent on river flow volume and duration. The saline front generally does not extend above New Orleans. However, in two instances of relatively long duration of low flow (less than 100,000 cfs), the front was found to extend up to River Mile 115 and beyond.

For observations made since 1929, the maximum salt water intrusion occured in October 1939, when the wedge was detected at River Mile 120. Flow during the period was slightly less than 100,000 cfs for several days. The wedge also passed the Kenner Hump (RM 115) during October 1940. During 1953-54 and 1956, the wedge encroached to the Kenner Hump, but did not go beyond it as flow slightly exceeded 100,000 cfs. Future intrusions of the wedge should be limited by flow control on the river. Since Waterford 3 is located at River Mile 129.4, there is not expected to be any interactions between the plant discharge and the saline wedge.

C. DISCHARGE OUTFALL CONFIGURATION AND OPERATION

The discharge at Waterford 3 consists of two components: a discharge structure and a discharge canal. Figure 15 presents a drawing containing the dimensions of both the discharge structure and canal. The discharge structure consists of a concrete seal well with outer dimensions approximately 52 feet by 45 feet. Cooling water leaves the seal well by overflowing about 95 feet of weirs placed on three of the four sides of the discharge structure. The elevation of the weir crests (highest point) can be adjusted to correspond to the fluctuations of river water levels. High water levels in the river cause river water to back up into the discharge canal, and as the water level increases, can eventually submerge the discharge structure. The height of discharged water above the weirs at full design flow (caused by high water levels in the Mississippi River) is about 3.4 feet. Elevation of the weir crests is adjustable between elevations 6.0 feet MSL and 11.0 feet MSL. The discharge structure design selected is typically of those presently in use at other LP&L plants on the Mississippi River.

A sheet pile formed discharge canal conveys water from the discharge structure to the river. The bottom portion of the canal at the river face is at elevation - 5.0 feet MSL. At the shore end, the discharge canal is 81 feet wide. The width is constant over the first 81 feet of canal length. From this point, the canal width contracts symmetrically over a distance of about 95 feet, to a width of 50 feet at the river end. The discharge canal is concrete lined to prevent erosion. The top of the canal sheet pile is at elevation 15.0 feet MSL where the canal is 81 feet wide and at elevation 10.0 feet MSL where the canal is contracting. At the river face of the discharge canal, there is a single rectangular opening for the discharge of water to the river.

Velocities of the discharge flow are affected by the rate of discharge flow and the seasonal variations in river stage. The following data present the average discharge velocities for the average seasonal conditions and the typical low flow condition:

CWS Flow Condition	Average Discharge Flow (cfs)	River Stage (ft)	Average Discharge Velocity (fps)
Average Winter	1384	10.4	1.8
Average Spring	2114	11.8	1.9
Average Summer	2235	4.0	5.0
Average Fall	1831	3.0	4.6
Typical Low Flow [1]	2235	2.3	6.1

[1] For the purpose of this study, the maximum expected discharge flow is assumed to occur during the typical low flow period.

D. PLUME PREDICTION METHODOLOGY

To establish the existing thermal characteristics of the river, thermal distributions resulting from operation of Waterford 1 and 2 and Little Gypsy were estimated under typical low and seasonal average river flow conditions. Because of the availability of field measurements at typical low flow conditions, as well as the complexity of the flow regime near the Waterford site, it was determined to be appropriate and accurate to base the low flow thermal predictions for the existing plants on the field measurements. The Edinger and Polk farfield mathematical model (see Appendix A for model description) was utilized for the existing plants to estimate the thermal distributions under the seasonal average river flow conditions.

Thermal plume predictions for Waterford 3 under typical low flow conditions (200,000 cfs) were based on the Prych-Davis-Shirazi (PDS) nearfield jet model (see Appendix A for model description). Both the Edinger and Polk and PSD models were employed to estimate Waterford 3 thermal effects under the four seasonal average flow conditions. When the Waterford 3 discharge

will act as a srong surface jet (river flows less than 300,000-350,000 cfs), the PDS model was applied; at higher flows, the jet will be weak and therefore the Edinger and Polk model was used. Rationales for model selection and a discussion of procedures used to calibrate the models can be found in Appendix A.

Because of the complexities involved in prediction of thermal effects occurring at the river bend, steps were taken to develop a modeling approach that would yield representative, though conservative, results. For example, all plants were assumed operating at full load, the models were calibrated against the largest plumes observed; and surface cooling was neglected.

Figures 4 through 12 present the results of the thermal predictions. The major features of the predictions are the following:

(a) Under typical low flow conditions, the cross-sectional area occupied by the 5°F isotherm is only 4.2 percent of the river cross-section.

(b) Based on the seasonal average, the combined thermal effect of all discharges (i.e. Waterford 1 and 2, and Waterford 3 and Little Gypsy) is a minimum level during the spring season and reaches a maximum during summer and fall.

(c) During both winter and spring seasons, when river discharges are high, dispersion of the thermal plumes is expected to be dominated by the ambient river flow. Therefore, plume distributions on either side of the river would remain separated from each other. The Little Gypsy thermal plume, being in a relatively broad and quiescent flow field located behind a river bend, displays the largest plume dimensions. The thermal plume at Waterford 3 in contrast, takes a narrow and lengthy shape. This is caused primarily by the swiftly moving river flow.

(d) For river flows less than about 300,000 cfs, plume dispersion at Waterford 1 and 2 and Little Gypsy is still expected to be dominated by river flow. The momentum effect in the near-field of the Little Gypsy discharge, however, is expected to be more pronounced than at higher flows.

(e) The Waterford 3 discharge at river flows less than 300,000 cfs is expected to exhibit surface jet characteristics. As such, the dilution of the discharged warm water with the cooler ambient river water is expected to be increased because of an increased rate of jet entrainment of the cooler water into the discharged water. The jet momentum, however, is also expected to transport the thermal discharge across the river channel and cause it to merge with the Little Gypsy and Waterford 1 and 2 plumes. The Waterford 3 discharge is not expected to have any contact with river bottom areas, except in the immediate area of the discharge.

(f) The maximum plume dimensions of the combined thermal field during typical low flow conditions shown in Figure 9 are summarized below:

MAXIMUM PLUME

Dimensions	5^{o}F Isotherm	10^{o}F Isotherm
Cross-Sectional Area	4.2%	1.1%
Cross-stream Extent	full river width (1800 ft)	1100 ft
Longitudinal Extent	7200 ft	2700 ft

(g) Comparison of results between low flow and average flow conditions must consider that estimates for the existing discharges for low flow conditions are based on survey data, while predictive models were utilized for average flow conditions. Because the predictive models are more conservative than estimates based on survey data, some predictions of the combined field thermal plume distribution show slightly greater effects for average flows than the corresponding low flow conditions.

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TABLES

TABLE 1

CONTRIBUTION OF CYANOPHYTA TO THE PHYTOPLANKTON COMMUNITY

Year	Month	Number of Cyanophytes (per 5 liters)	Total Phytoplankton (per 5 liters)	Cyanophytes (%)
1973	Jun	0	136,000	0
	Jul	0	289,000	0
	Aug	25,500	1,045,500	2
	Sep	8,500	3,672,000	0
	Oct	0	297,500	0
	Nov	0	263,500	0
	Dec	0	170,000	0
1974	Feb	0	204,000	0
	Mar	0	255,000	0
	Apr	0	229,500	0
	May	0	144,500	0
	Jun	1,000	1,154,071	0
	Aug	1,200	2,397,085	0
1975	Feb	4,000	2,506,003	0
	Apr	1,200	1,189,642	0
	Oct	23,007	283,753	8
	Nov	0	122,704	0
	Dec	7,669	299,082	3
1976	Jan	0	761,744	0
	Feb	0	598,182	0
	Mar	0	812,871	0
	Apr	0	7,234,078	0
	May	0	1,602,740	0
	Jun	7,685	2,633,497	0.5
	Jul	7,685	2,200,946	0.4
	Aug	30,676	3,044,593	1
	Sep	38,425	812,893	5

Source: Louisiana Power & Light Company, Environmental Report - Operating License Stage, Waterford Steam Electric Station, Unit 3. 1978.

TABLE 2

TAXA OF ZOOPLANKTON COLLECTED FROM 1973-1976 NEAR WATERFORD

Coelenterata

Hydrozoa

Nematoda

Rotifera

Brachionus
Keratella
Asplanchna
Platyias quadricornis

Arthropoda

Daphnia longiremis
Daphnia magna
Ceriodaphnia reticulata
Moina brachiata
Bosmina longirostris
Bosmina coregoni
Alona sp
Alonella rostrata
Alonopsis sp
Camptocercus branchyurum
Leptodora kindtii
Ostracoda
Eurytemora affinis
Diaptomus pallidus
Diaptomus siciloides
Diaptomus stagnalis
Cyclops bicuspidatus
Cyclops vernalis
Harpacticoida
Decapoda
Amphipoda

Source: Louisiana Power & Light Company, Environmental Report - Operating License Stage, Waterford Steam Electric Station, Unit 3. 1978.

TABLE 3

AVERAGE ZOOPLANKTON DENSITIES*, NUMBER PER M^3, BY STATION BY DATE IN SAMPLES COLLECTED IN THE VICINITY OF WATERFORD 3

YEAR	DATE	STATION Ac	At	Bc	Bt	Btl	Average Density
I	73 JUN 08**	2151.734	1580.130	1803.907	2005.236	2679.522	2044.10
	73 JUL 17	126.281	140.528	97.441	214.526	158.607	147.47
	73 AUG 22**	62.817	99.730	73.826	295.303	272.853	160.90
	73 SEP 28	647.594	1385.887	1944.685	2087.479	1901.405	1593.41
	73 OCT 25**	210.468	77.352	460.079	336.389	223.060	261.46
	73 NOV 30	201.474	314.514	239.250	221.261	248.244	244.94
	73 DEC 19	250.441	229.720	314.981	225.287	252.158	254.51
	74 FEB 13	980.525	744.519	701.260	873.192	459.180	751.73
	74 MAR 27	1475.952	1528.514	1384.779	1806.556	1448.072	1528.77
	74 APR 20	478.675	227.956	319.404	391.012	488.194	381.04
	74 APR 23	1181.860	1284.395	1576.604	1214.239	1118.899	1275.19
	74 MAY 17	3890.018	1991.789	743.248	3291.852	2133.284	2410.03
Average Year I		971.487	800.420	804.96	1080.194	948.623	
II	74 JUN 04	282.044	229.545	223.501	225.018	150.570	222.13
	74 JUN 24	95.196	100.219	148.189	79.112	77.409	100.02
	74 AUG 22	1727.880	4398.961	2395.663	7689.520	928.038	3428.01
	74 NOV 13	483.673	1189.501	508.609	7873.902	2774.520	2566.04
	75 FEB 26	756.809	247.172	399.953	416.015	825.766	529.14
	75 APR 23**	100.409	263.693	160.395	439.766	214.347	235.72
	75 AUG 08	268.163	168.986	297.409	443.718	380.032	311.66
Average Year II		530.596	942.582	590.531	2452.436	764.383	
III	75 OCT 30	123.350	52.613	436.986	314.618	38.785	193.27
	75 NOV 20	62.821	83.003	44.854	20.066	75.966	57.34
	75 DEC 22	32.400	108.214	59.537	28.711	208.136	87.40
	76 JAN 30	5.173	18.819	5.151	9.339	3.593	8.41
	76 FEB 26	.000	5.505	1.033	3.156	1.746	2.28
	76 MAR 25	327.820	233.666	402.086	407.337	7.238	275.62
	76 APR 29**	19.055	132.969	109.459	83.841	141.732	97.41
	76 MAY 27	113.404	225.532	197.259	153.344	182.504	174.40
	76 JUN 24	68.690	150.226	157.960	103.963	150.243	126.21
	76 JUL 29	225.149	69.174	632.122	925.233	504.507	471.23
	76 SEP 10	1434.406	527.145	1985.596	1571.616	1297.066	1363.16
	76 SEP 26	622.113	528.958	792.617	706.768	951.573	720.40
Average Year III		252.865	177.985	402.055	360.666	296.921	

* Densities do not include exoskeletons or fish larvae.
** Sampled on more than one sampling day

Source: Louisiana Power & Light Company, Environmental Report – Operating License Stage, Waterford Steam Electric Station, Unit 3. 1978.

TABLE 4

AVERAGE NUMBER OF DOMINANT* ZOOPLANKTON (PER M^3)
FOR ALL DEPTHS AT ALL STATIONS
FOR SAMPLING YEARS INDICATED**

Taxa	Density (Numbers per m^3) 1973-1974	1974-1975	1975-1976
Cladocera			
Daphnia sp	88	31	10
Bosmina longirostris	121	59	65
Moina brachiata	0	0	65
Ceriodaphnia	32	35	2
Diaphanosoma	0	7	2
Copepoda			
Calanoida	305	362	25.5
Cyclopoida	369	579	141.3
Decopoda	4	3	0
All Zooplankton	975	1,034	317

* Dominant was defined as 10% or more of the zooplankton community on any sampling date.

** Computed with data from Louisiana Power & Light Company (1978)[2].

TABLE 5

(Sheet 1 of 2)

LIST OF MACROINVERTEBRATES AND SHELLFISH
TAXA 1973 to 1976

Coelenterata

Hydrozoa

Hydra sp

Platyhelminthes

Turbellaria

Dugesia trigena
Stenostromum sp

Annelida

Clitellata

Branchiura sowerby
Limnodrilus arvix
Limnodrilus maumeensis

Hirudinea

Erpobdella punctata

Arthropoda

Insecta

Chiromidae
Culcidae
Anisoptera
Hymenoptera
Dermaptera
Ephemeroptera
Corixidae
Coleoptera
Trichoptera

Crustacea

Gammarus sp
Callinectes sapidus
Macrobrachium ohione
Isopoda

Source: Louisiana Power & Light Company, Environmental Report - Operating License Stage, Waterford Steam Electric Station, Unit 3. 1978.

TABLE 5

LIST OF MACROINVERTEBRATES AND SHELLFISH (Sheet 2 of 2)

TAXA 1973 to 1976

Mollusca

Gastropoda

Viviparus intertextus
Amnicola sp
Goniobasis sp
Pleuricera sp
Parapholyx sp
Physa sp
Lymnaea sp
Gyraulus sp
Cochliopa sp

Bivalvia

Corbicula manilensis
Musculium sp
Pisidium sp

TABLE 6 (Sheet 1 of 4)

ASH-FREE DRY WEIGHT (g/m^2) OF BENTHIC MACROINVERTEBRATES AT WATERFORD 3*

Date: August, 1977 Replicate No.

Station	Organism	1	2	3	4		Average
Ac	Corbicula	0	2.48	0.67	0.50		0.91
	Chironomids	0.01	0	0.04	0		0.01
	Coleoptera	0	0	0	0		0
						Sum	0.92
At	Corbicula	0.11	0	0	0		0.03
	Tubificids	0	0.02	0	0		0
	Gyraulis	0.01	0	0	0		0
						Sum	0.03
Bc	Corbicula	0	0	0	0		0
	Tubificids	0.01	0.02	0.15	0		0.05
	Nematodes	0	0.01	0	0		0
						Sum	0.05
Bt	Corbicula	21.08	0.01	5.95	12.01		9.76
	Chironomids	0	0	0	0.01		0
	Gyraulis	0	0	0	0.01		0
						Sum	9.76
Bt_1	No Specimens						

*Collected with a Smith-McIntire Grab Sampler.

Source: Louisiana Power & Light Company, Environmental Report - Operating License Stage, Waterford Steam Electric Station, Unit 3. 1978.

TABLE 6 (Sheet 2 of 4)

ASH-FREE DRY WEIGHT (g/m^2) OF BENTHIC MACROINVERTEBRATES AT WATERFORD 3

Date: September, 1977 Replicate No.

Station	Organism	1	2	3	4		Average
Ac	Corbicula	0.29	0.39	0	0		0.17
	Odonata	0	2.60	0	0		0.65
						Sum	0.82
At	Chironomids	0	0	0.01	0.01		0.01
	Ephemeroptera	0.04	2.22	0.06	1.20		0.88
	Tubificids	0.06	0	0.07	0		0.03
	Odonata	0	0.15	0	0		0.04
						Sum	0.96
Bc	Chironomids	0.01	0.02	0	0		0.01
	Ephemeroptera	0	0	0	0		0
						Sum	0.01
Bt	Corbicula	16.90	13.95	2.67	4.89		9.60
						Sum	9.60
Bt_1		No Specimens					

TABLE 6 (Sheet 3 of 4)

ASH-FREE DRY WEIGHT (g/m^2) OF BENTHIC MACROINVERTEBRATES AT WATERFORD 3

Date: February, 1978

Station	Organism	Replicate No. 1	2	3	4		Average
Ac	Corbicula	1.02	4.08	0	4.74		2.46
						Sum	2.46
At	Tubificids	0	0.18	0.54	0		0.18
	Odonata	0	0	0.11	0		.03
						Sum	0.21
Bc	Tubificids	0	0	0.18	0.26		0.11
						Sum	0.11
Bt	River Shrimp	0	0	0	0.81		0.20
						Sum	0.20
Bt_1	Odonata	0	0	0	0.09		0.02
						Sum	0.02

TABLE 6 (Sheet 4 of 4)

ASH-FREE DRY WEIGHT (g/m^2) OF BENTHIC MACROINVERTEBRATES AT WATERFORD 3

Date: April, 1978

Replicate No.

Station	Organism	1	2	3	4		Average
Ac			No Specimens				
At	Corbicula	0.14	0	0	0.63		0.19
	Tubificids	1.03	1.11	1.37	0.68		1.05
						Sum	1.24
Bc	Tubificids	2.68	3.26	0.43	3.39		2.44
	Chironomids	0.01	0	0.01	0		0
						Sum	2.44
Bt	Tubificids	0.13	0	0.43	0		0.14
	Chironomids	0.01	0	0	0		0
	River Shrimp	2.04	0	0	0		0.51
						Sum	0.65
Bt_1	Tubificids	0	1.35	0	0.49		0.46
						Sum	0.46

TABLE 7

(Sheet 1 of 4)

SPECIES OF FISH COLLECTED IN THE VICINITY OF THE PROPOSED WATERFORD 3 APRIL 1973 - SEPTEMBER 1976

Acipenseriformes

Acipenseridae

Scaphirhynchus albus (Pallid Sturgeon)
Scaphirhynchus platorynchus (Shovelnose Sturgeon)

Polyodonitidae

Polyodon spathula (Paddlefish)

Semionotiformes

Lepisosteidae

Lepisosteus oculatus (Spotted Gar)
Lepisosteus osseus (Longnose Gar)
Lepisosteus platostomus (Shortnose Gar)
Lepisosteus spatula (Alligator Gar)

Amiiformes

Amiidae

Amia calva (Bowfin)

Elopiformes

Elopidae

Elops saurus (Lady Fish)

Anguilliformes

Anguillidae

Anguilla rostrata(American Eel)

Clupeiformes

Clupeidae

Alosa chrysochloris (Skipjack Herring)
Brevoortia patronus (Gulf Menhaden)
Dorosoma cepedianum (Gizzard Shad)
Dorosoma petenense (Threadfin Shad)

Source: Louisiana Power & Light Company, *Environmental Report - Operating License Stage, Waterford Steam Electric Station, Unit 3.* 1978.

TABLE 7

(Sheet 2 of 4)

SPECIES OF FISH COLLECTED IN THE VICINITY
OF THE PROPOSED WATERFORD 3
APRIL 1973 - SEPTEMBER 1976

Engraulidae

Anchoa mitchilli (Bay Anchovy)

Osteoglossiformes

Hiodontidae

Hiodon alosoides (Goldeye)
Hiodon tergisus (Mooneye)

Cypriniformes

Cyprinidae

Cyprinus carpio (Carp)
Hybognathus nuchalis (Silvery Minnow)
Hybopsis aestivalis (Speckled Chub)
Hybopsis amblops (Bigeye Chub)
Hybopsis storeriana (Silver Chub)
Notemigonus crysoleucas (Golden Shiner)
Notropis atherinoides (Emerald Shiner)
Notropis blennius (River Shiner)
Notropis emiliae (Pugnose Minnow)
Notropis fumeus (Ribbon Shiner)
Notropis shumardi (Silverband Shiner)
Notropis venustus (Blacktail Shiner)
Pimephales vigilax (Bullhead Minnow)

Catostomidae

Carpiodes carpio (River Carpsucker)
Carpiodes cyprinus (Quillback)
Ictiobus bubalus (Smallmouth Buffalo)
Ictiobus cyprinellus (Bigmouth Buffalo)

Siluriformes

Ictaluridae

Ictalurus furcatus (Blue Catfish)
Ictalurus melas (Black Bullhead)
Ictalurus natalis (Yellow Bullhead)
Ictalurus nebulosus (Brown Bullhead)
Ictalurus punctatus (Channel Catfish)
Pylodictis olivaris (Flathead Catfish)

TABLE 7

(Sheet 3 of 4)

SPECIES OF FISH COLLECTED IN THE VICINITY
OF THE PROPOSED WATERFORD 3
APRIL 1973 - SEPTEMBER 1976

Atheriniformes

Poeciliidae

Gambusia affinis (Mosquito Fish)

Atherinidae

Menidia audens (Mississippi Silverside)

Perciformes

Percichthyidae

Morone chrysops (White Bass)
Morone mississippiensis (Yellow Bass)
Morone saxatilis (Striped Bass)

Centrarchidae

Elassoma zonatum (Banded Pygmy Sunfish)
Lepomis cyanellus (Green Sunfish)
Lepomis gulosus (Warmouth)
Lepmis macrochirus (Bluegill)
Lepomis megalotis (Longear Sunfish)
Lepomis microlophus (Redear Sunfish)
Micropterus punctulatus (Spotted Bass)
Micropterus salmoides (Largemough Bass)
Pomoxis annularis (White Crappie)
Pomoxis nigromaculatus (Black Crappie)

Percidae

Percina sciera (Dusky Darter)
Stizostedion canadense (Sauger)

Sciaenidae

Aplodinotus grunniens (Freshwater Drum)

Mugilidae

Mugil cephalus (Striped Mullet)

TABLE 7

(Sheet 4 of 4)

SPECIES OF FISH COLLECTED IN THE VICINITY
OF THE PROPOSED WATERFORD 3
APRIL 1973 - SEPTEMBER 1976

Pleuronectiformes

Bothidae

Paralichthys lethostigma (Southern Flounder)

Soleidae

Trinectes maculatus

TABLE 8

AVERAGE ICHTHYOPLANKTON ORGANISMS PER M^3 BY FAMILY AND MONTH IN SAMPLES COLLECTED DURING THE WATERFORD STEAM ELECTRIC STATION SURVEY (OCTOBER 1975 - SEPTEMBER 1976) (YEAR III)

	Family						
Date	Unidentifiable	Centrarchidae	Clupeidae	Cyprinidae	Esocidae	Ictaluridae	Sciaenidae
Nov 13 74	-	-	.019	-	-	-	-
Feb 26 75	-	-	-	-	-	-	-
Apr 24 75	-	-	-	.002	-	-	-
Aug 8 75	-	.015	.005	.004	-	.004	-
Oct 30 75	-	-	-	-	-	-	-
Nov 20 75	-	-	-	-	-	-	-
Dec 22 75	-	-	-	-	-	-	-
Jan 30 76	-	-	-	-	-	-	-
Feb 26 76	-	-	-	-	-	-	-
Mar 25 76	-	-	.002	.008	-	-	-
Apr 30 76	.004	.008	-	.005	.002	.002	.003
May 27 76	.003	.007	-	.012	-	-	-
Jun 08 76	.002	.003	.065	-	-	-	.029
Jun 24 76	-	.002	-	-	-	-	-
Jul 7 76	-	-	.004	-	-	-	.012
Jul 29 76	.003	-	-	-	-	-	-
Aug 12 76	-	-	-	-	-	-	.003
Sep 10 76	-	-	-	-	-	-	-
Sep 27 76	-	-	-	-	-	-	-

Source: Louisiana Power & Light Company, Environmental Report - Operating License Stage, Waterford Steam Electric Station, Unit 3. 1978.

TABLE 9

AVERAGE NUMBERS OF ICHTHYOPLANKTON PER M^3

COLLECTED IN THE WATERFORD VICINITY

STATION / DATE	AC	AT	BC	BT	BT1	AVG
74 NOV 13	.000	.122	.000	.000	.000	.024
75 FEB 26	.000	.000	.000	.000	.000	.000
75 APR 24	.000	.000	.000	.000	.010	.002
75 AUG 08	.000	.000	.005	.054	.077	.027
75 OCT 30	.000	.000	.000	.000	.000	.000
75 NOV 20	.000	.000	.000	.000	.000	.000
75 DEC 22	.000	.000	.000	.000	.000	.000
76 JAN 30*	.000	.000	.000	.000	.000	.000
76 FEB 26	.000	.000	.000	.000	.000	.000
76 MAR 25	.000	.010	.009	.023	.004	.009
76 APR 30*	.000	.081	.007	.026	.015	.026
76 MAY 27	.020	.009	.069	.000	.007	.021
76 JUN 08	.127	.176	.030	.139	.058	.106
76 JUN 24	.000	.000	.000	.000	.008	.002
76 JUL 07	.003	.034	.013	.017	.017	.017
76 JUL 29	.000	.000	.000	.011	.000	.002
76 AUG 12	.000	.000	.006	.000	.007	.003
76 SEP 10	.000	.000	.000	.000	.000	.000
76 SEP 27	.000	.000	.000	.000	.000	.000

*SAMPLES COLLECTED OVER TWO SAMPLING DAYS

Source: Louisiana Power & Light Company, Environmental Report - Operating License Stage, Waterford Steam Electric Station, Unit 3. 1978.

TABLE 10

SMALL FISH* IN THE MISSISSIPPI RIVER

Species	Number**
Bay Anchovy	A
Bigeye Chub	P
Black Bullhead	P
Black Crappie	P
Blacktail Shiner	P
Blue Catfish	D
Bluegill	A
Bullhead Minnow	P
Carp	P
Channel Catfish	A
Emerald Shiner	P
Freshwater Drum	D
Gizzard Shad	D
Golden Shiner	P
Goldeye	P
Green Sunfish	P
Gulf Menhaden	A
Hogchoker	P
Immature Sucker	P
Longear Sunfish	P
Mississippi Silversides	P
Mooneye	P
Mosquitofish	P
Pugnose Minnow	P
Pygmy Sunfish	P
Ribbon Shiner	P
River Carpsucker	P
River Shiner	P
Shovelnose Sturgeon	P
Silver Chub	P
Silverband Shiner	P
Silvery Minnow	P
Skipjack Herring	A
Smallmouth Buffalo	P
Speckled Chub	P
Spotted Bass	P
Striped Bass	P
Striped Mullet	A
Threadfin Shad	D
Warmouth	P
White Bass	P
White Crappie	P
Yellow Bass	P
Yellow Bullhead	P

NOTES: * Less than 100 mm in length ** A - Abundant
D - Dominant
P - Present

TABLE 11

MONTHLY WATER TEMPERATURE DATA FROM THE MISSISSIPPI RIVER NEAR WESTWEGO, LOUISIANA*
(1951-1969)

Month	Temperature (°F) Maximum	Minimum	Mean
January	50	41	46
February	50	40	46
March	56	46	51
April	63	57	59
May	78	67	71
June	83	77	79
July	87	81	84
August	90	81	86
September	87	76	83
October	78	71	74
November	71	57	63
December	57	47	52

* Measurements taken at Ninemile Point Generating Station, 25.6 miles downstream from Waterford 3.

Source: Louisiana Power & Light Company, Environmental Report Operating License Stage, Waterford Steam Electric Station, Unit 3, 1978.

TABLE 12

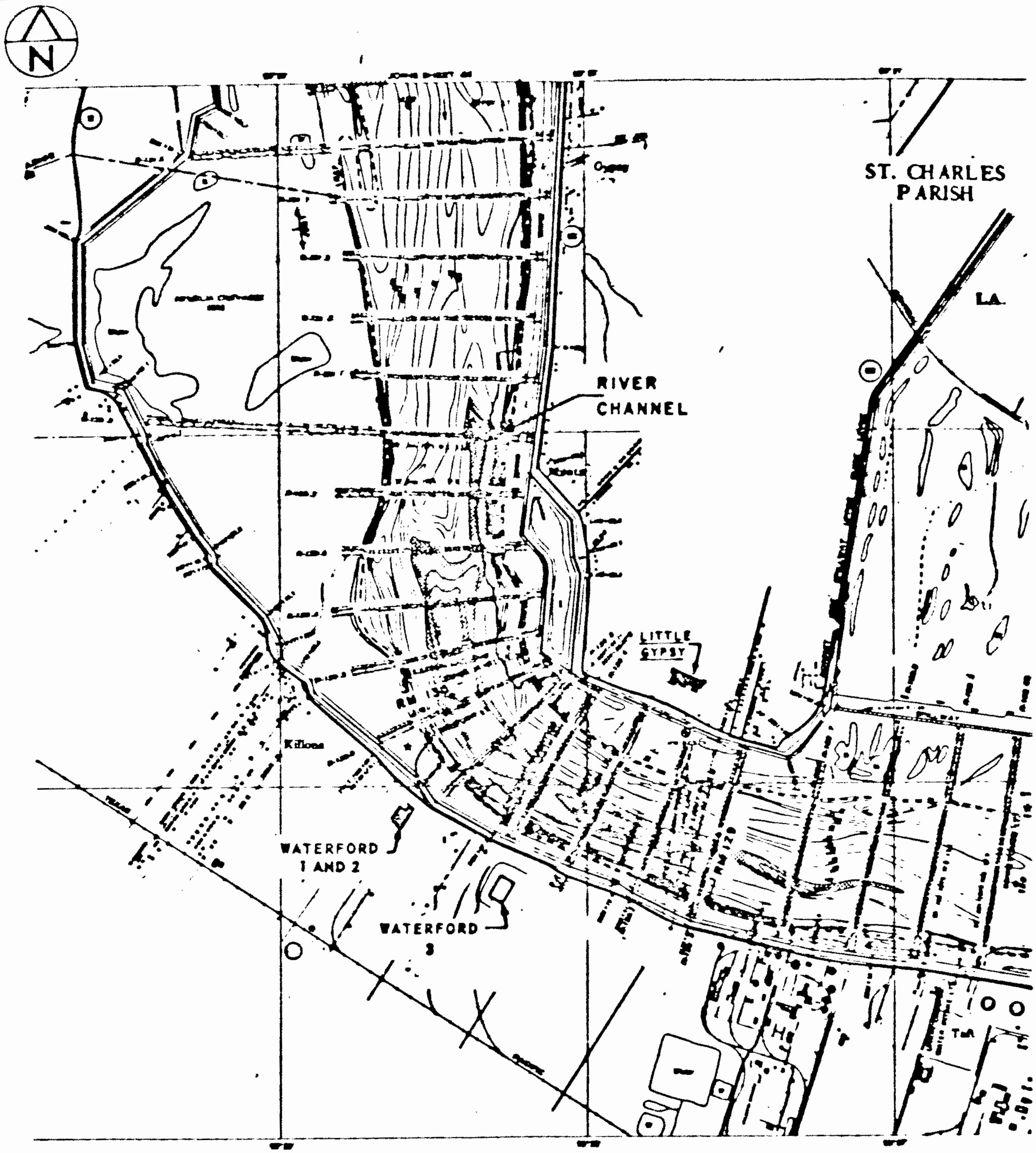
SUMMARY OF COOLING WATER SYSTEM OPERATIONAL MODES

Number of Intake Pumps In Operation	Range of Ambient Intake Water Temperatures[1] (°F)	Months with Average Intake Temperature In Range	Annual % of Time In Use[2]	CWS Design Flow (1000 GPM)	Average Discharge Temperature Increase (°F)
2	< 55	December to March	30	622	26.0
3	55-70	April, May, October, November	25	843	19.2
4	> 70	June to September	34	1,003	16.1

(1) See Figure for range of monthly ambient Mississippi River water temperatures.

(2) Waterford 3 shutdown estimated at eleven percent per year.

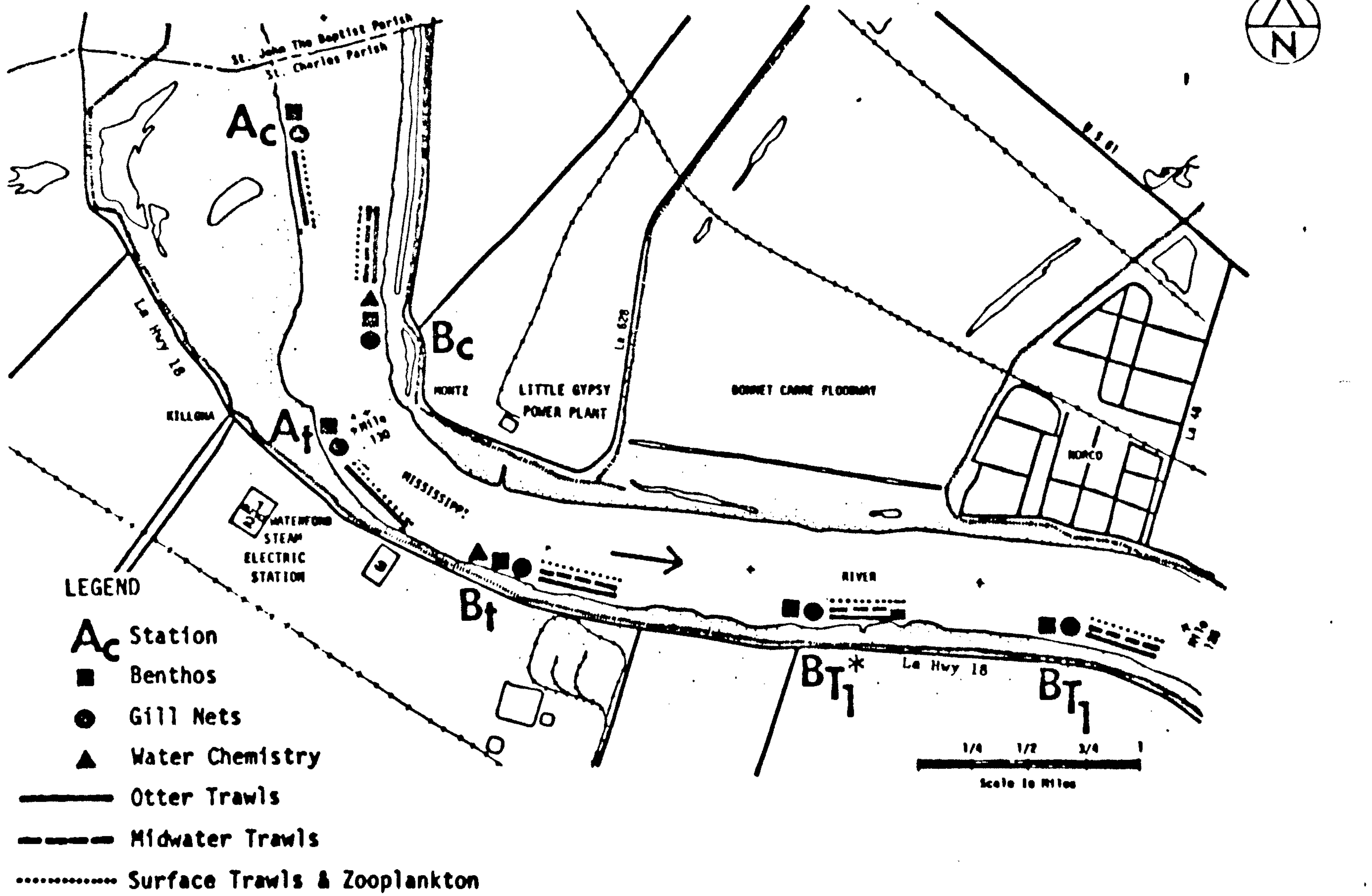
FIGURES



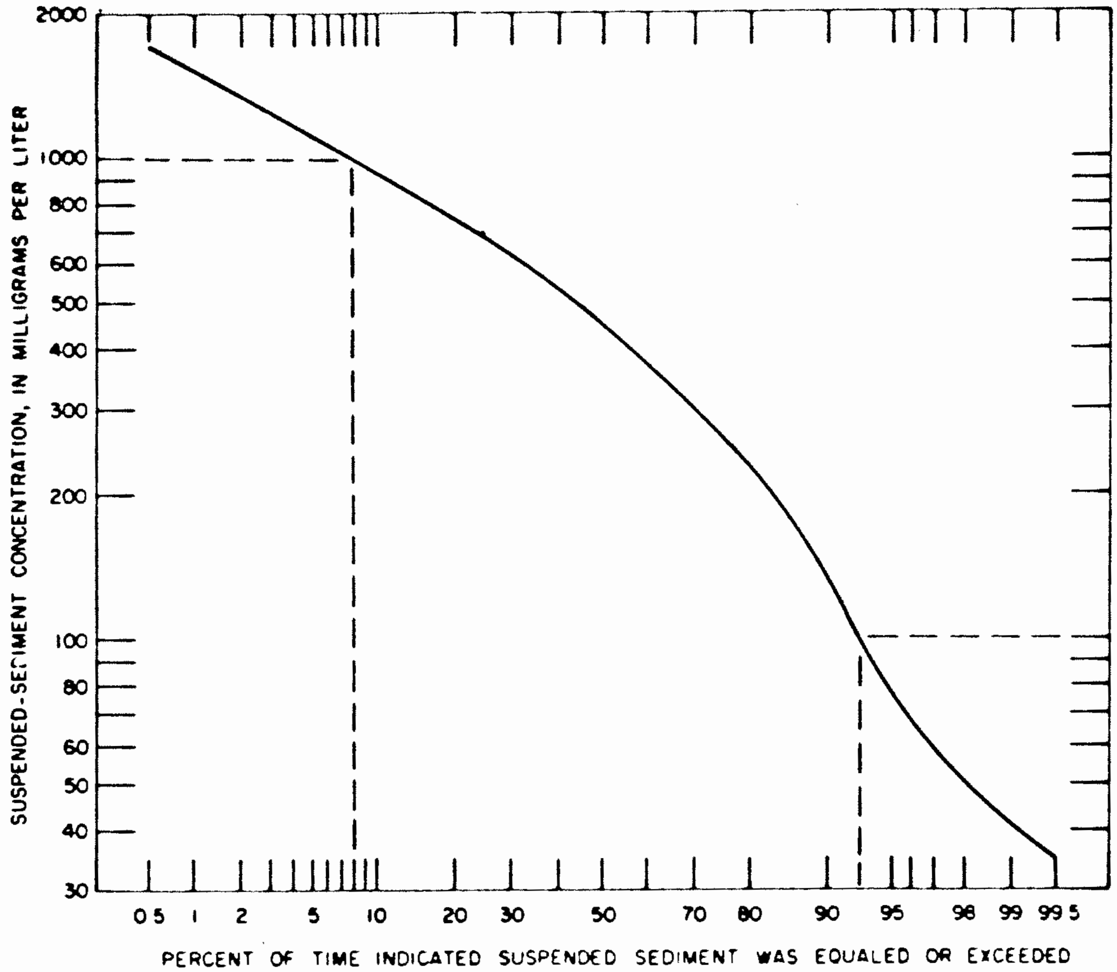
NOTE: SHADED AREA REPRESENTS
DEPTHS GREATER THAN 100 ft

SOURCE: US ARMY CORPS OF ENGINEERS, NEW ORLEANS, LA. "MISSISSIPPI RIVER HYDROGRAPHIC SURVEY – [illegible] TO 1975 – BLACK HAWK, LA TO HEAD OF PASSES, LA" 1976.

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	MISSISSIPPI RIVER DEPTH CONTOURS AT WATERFORD	Figure 1



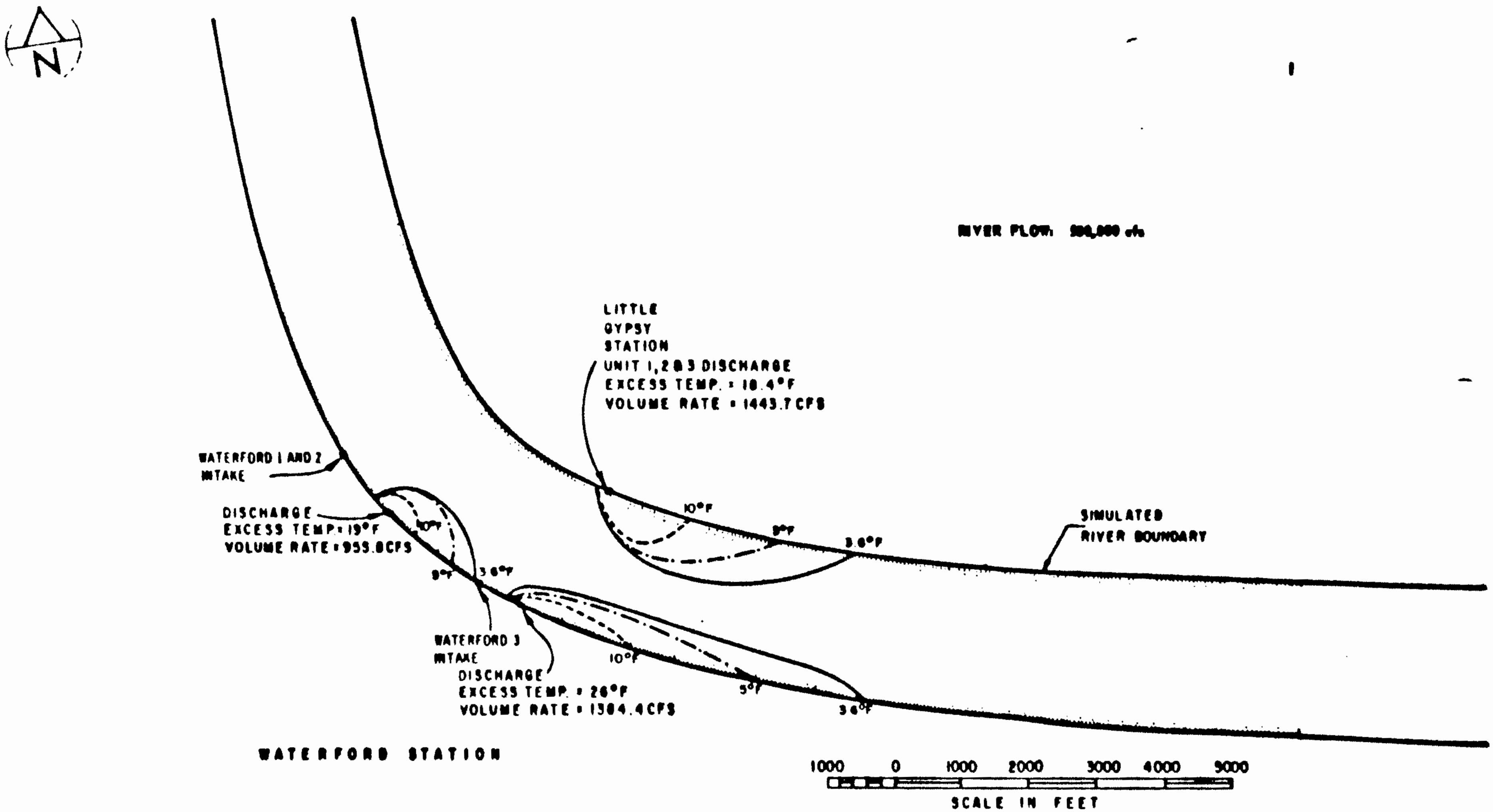
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	SAMPLING AREAS IN THE MISSISSIPPI RIVER NEAR WATERFORD 3	Figure 2



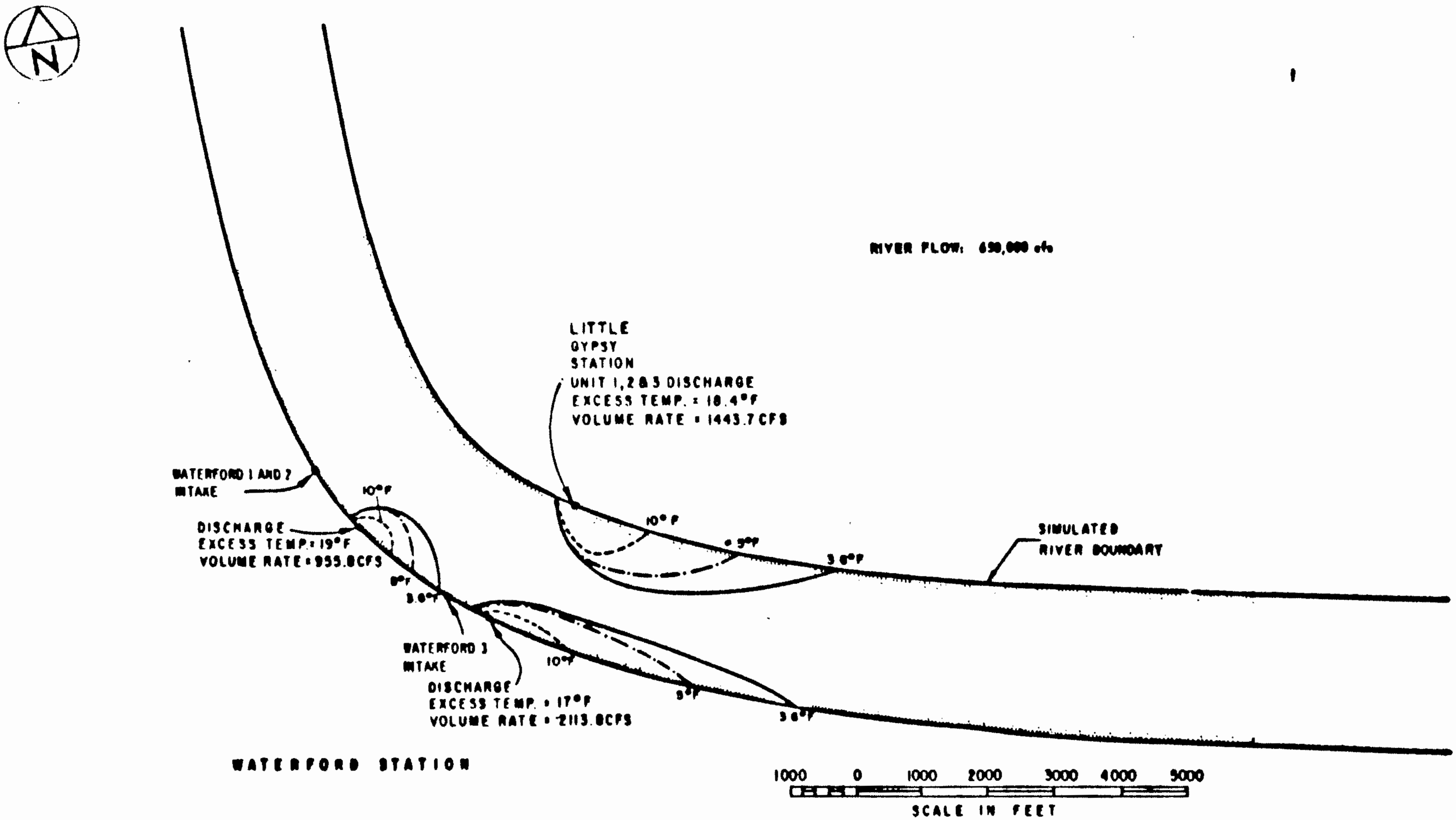
SOURCE: SMITH, A. B. CHANNEL SEDIMENTATION AND DREDGING PROBLEMS, MISSISSIPPI RIVER AND LOUISIANA GULF COAST ACCESS CHANNELS. PROCEEDINGS OF THE FEDERAL INTER-AGENCY SEDIMENTATION CONFERENCE.

U.S. DEPT. OF AGRICULTURE MISC. PUBLICATION 970, pp 618-626, 1963

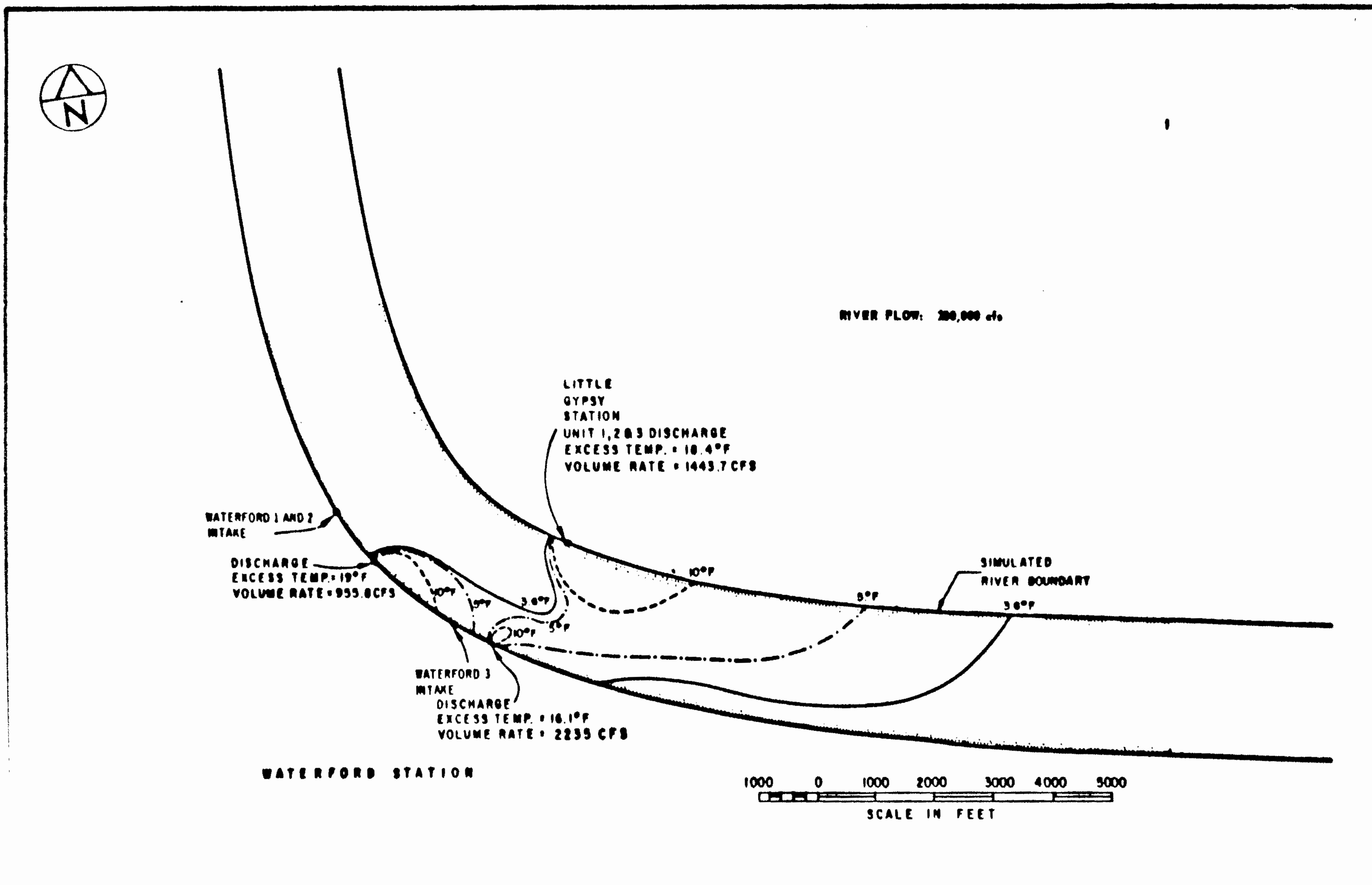
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	DURATION CURVE OF SUSPENDED-SEDIMENT CONCENTRATION MISSISSIPPI RIVER AT RED RIVER LANDING, LA., 1949-63	Figure 3



LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	PREDICTED EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – AVERAGE WINTER RIVER FLOW CONDITION	Figure 4



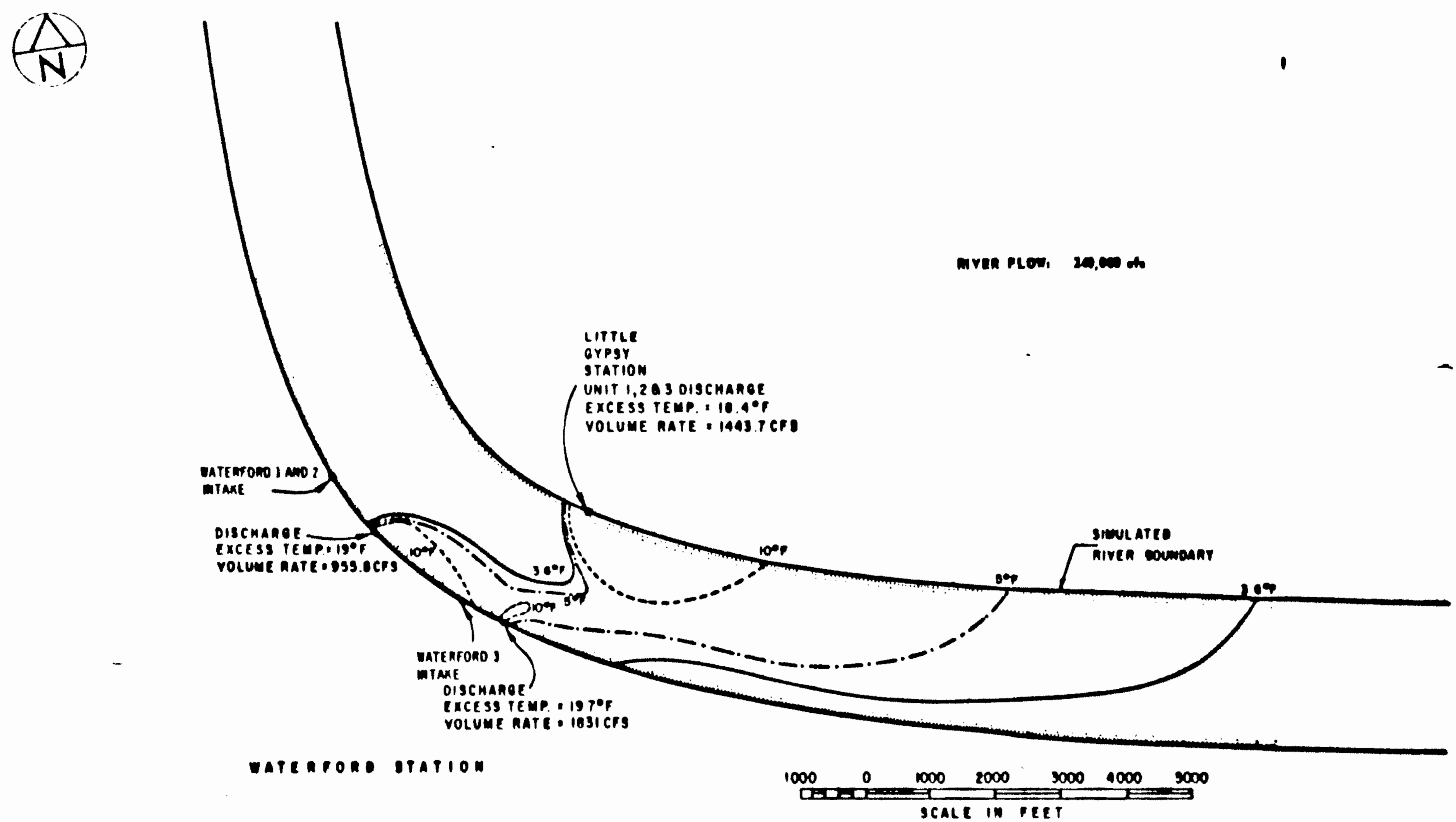
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	PREDICTED EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – AVERAGE SPRING RIVER FLOW CONDITION	Figure 5



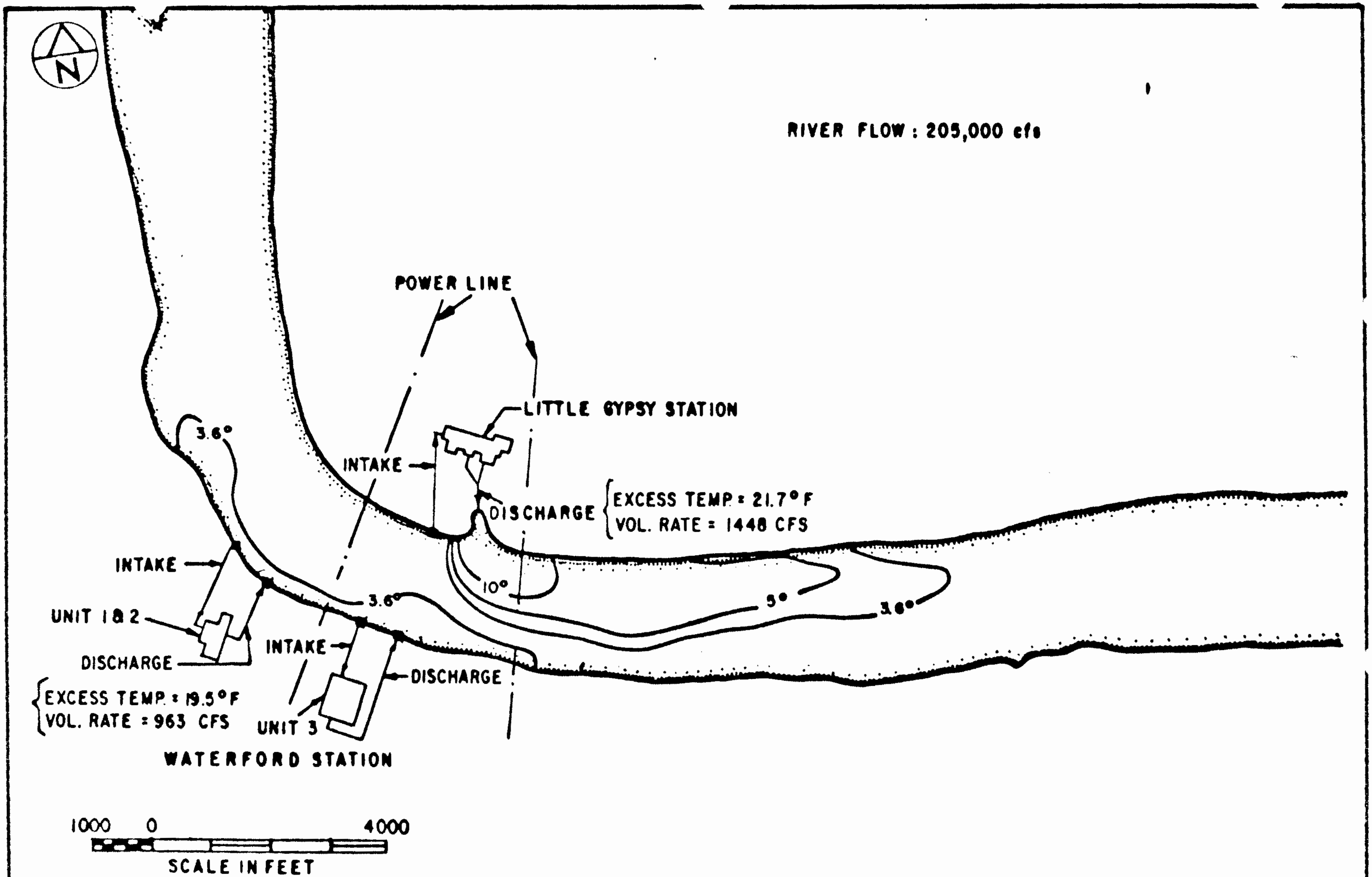
LOUISIANA
POWER & LIGHT CO.
Waterford Steam
Electric Station

PREDICTED EXCESS ISOTHERMS (°F) AT THE SURFACE
COMBINED FIELD – AVERAGE SUMMER RIVER FLOW CONDITION

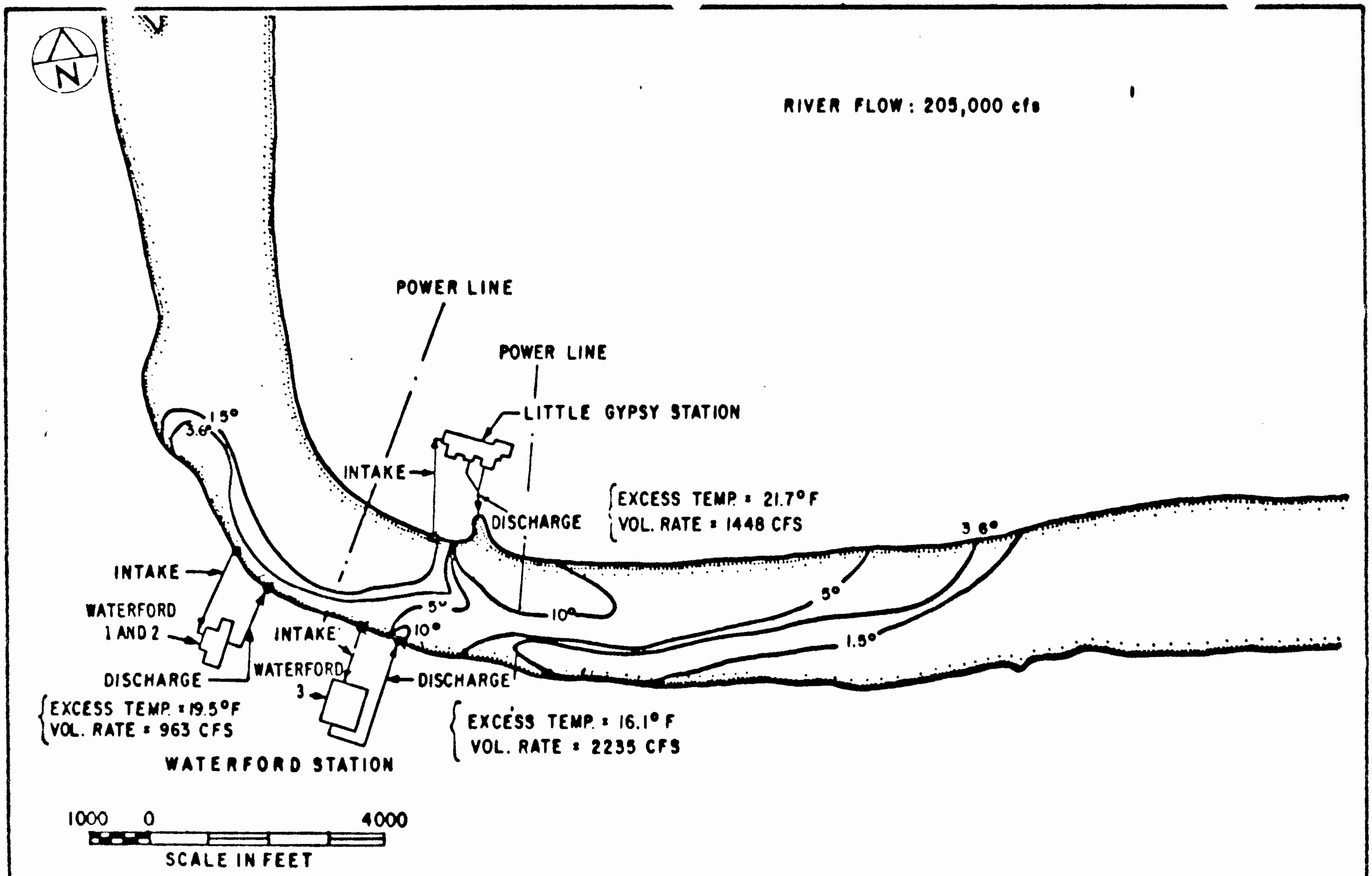
Figure
6



LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	PREDICTED EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – AVERAGE FALL RIVER FLOW CONDITION	Figure 7



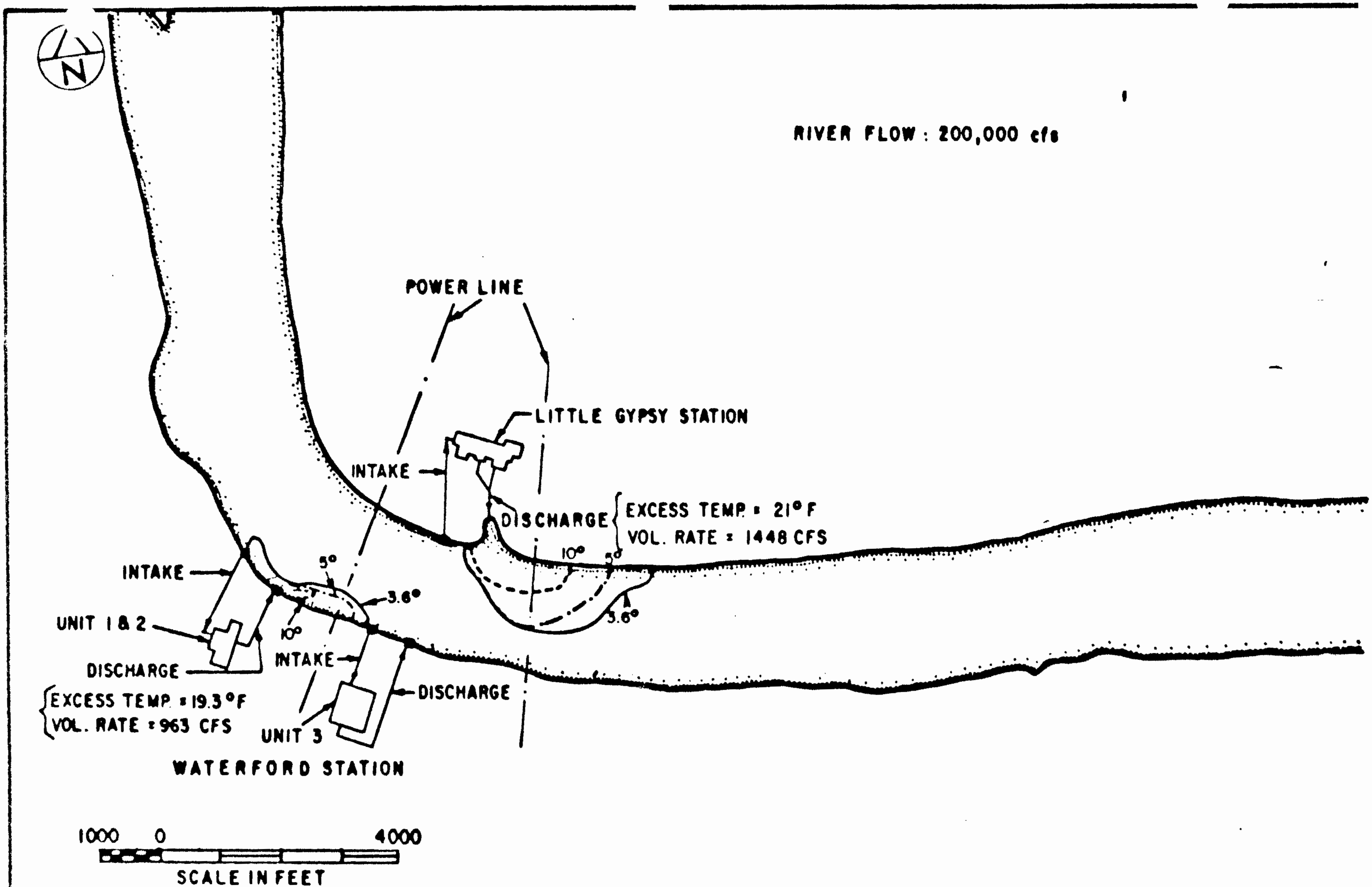
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	EXCESS ISOTHERMS (°F) AT THE SURFACE BEFORE WATERFORD 3 DISCHARGE – SEPTEMBER 9, 1976 LOW FLOW CONDITION	Figure 8



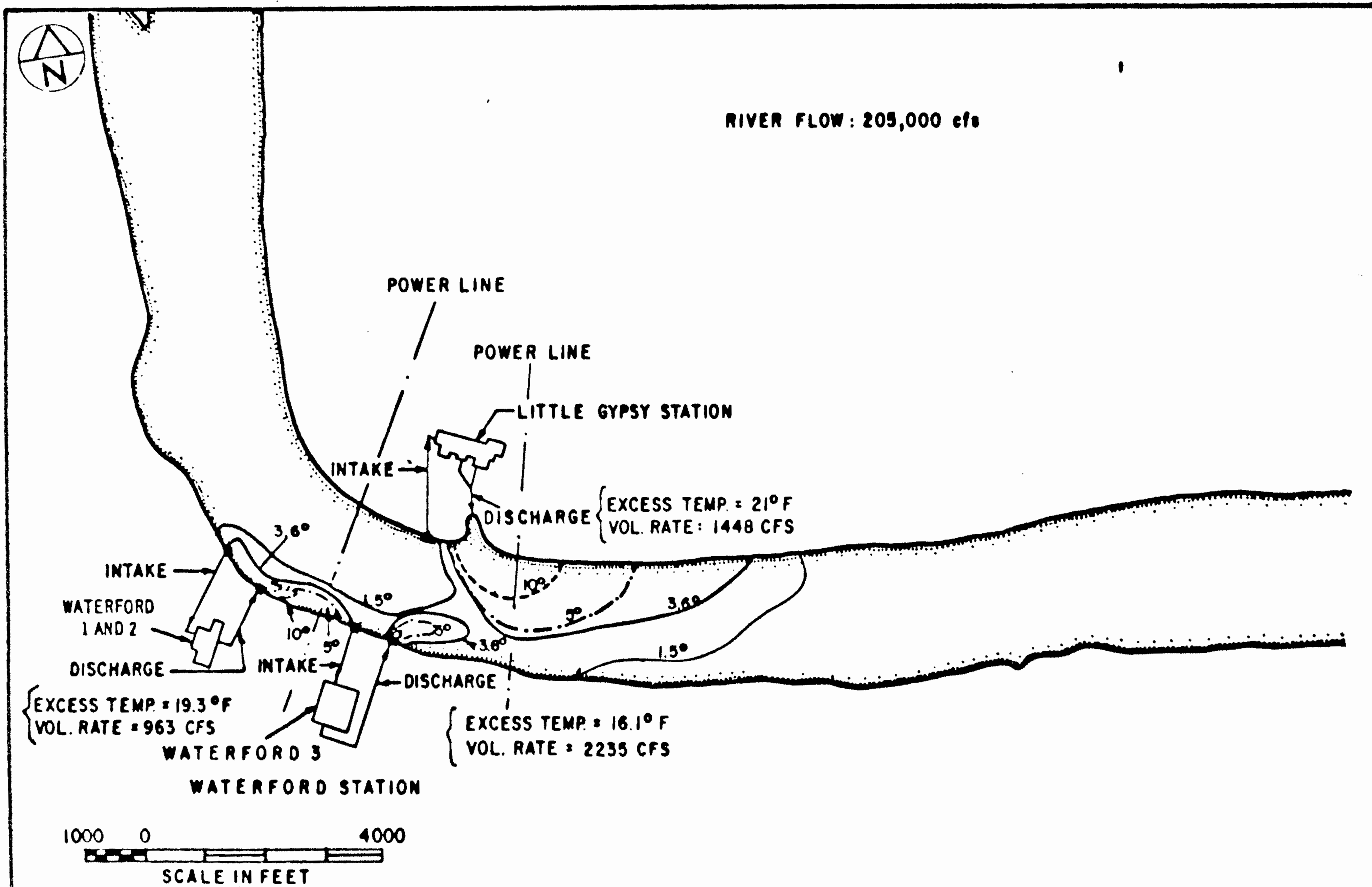
LOUISIANA POWER & LIGHT CO.
Waterford Steam Electric Station

EXCESS ISOTHERMS (°F) AT THE SURFACE
COMBINED FIELD – SEPTEMBER 9, 1976 LOW FLOW CONDITION

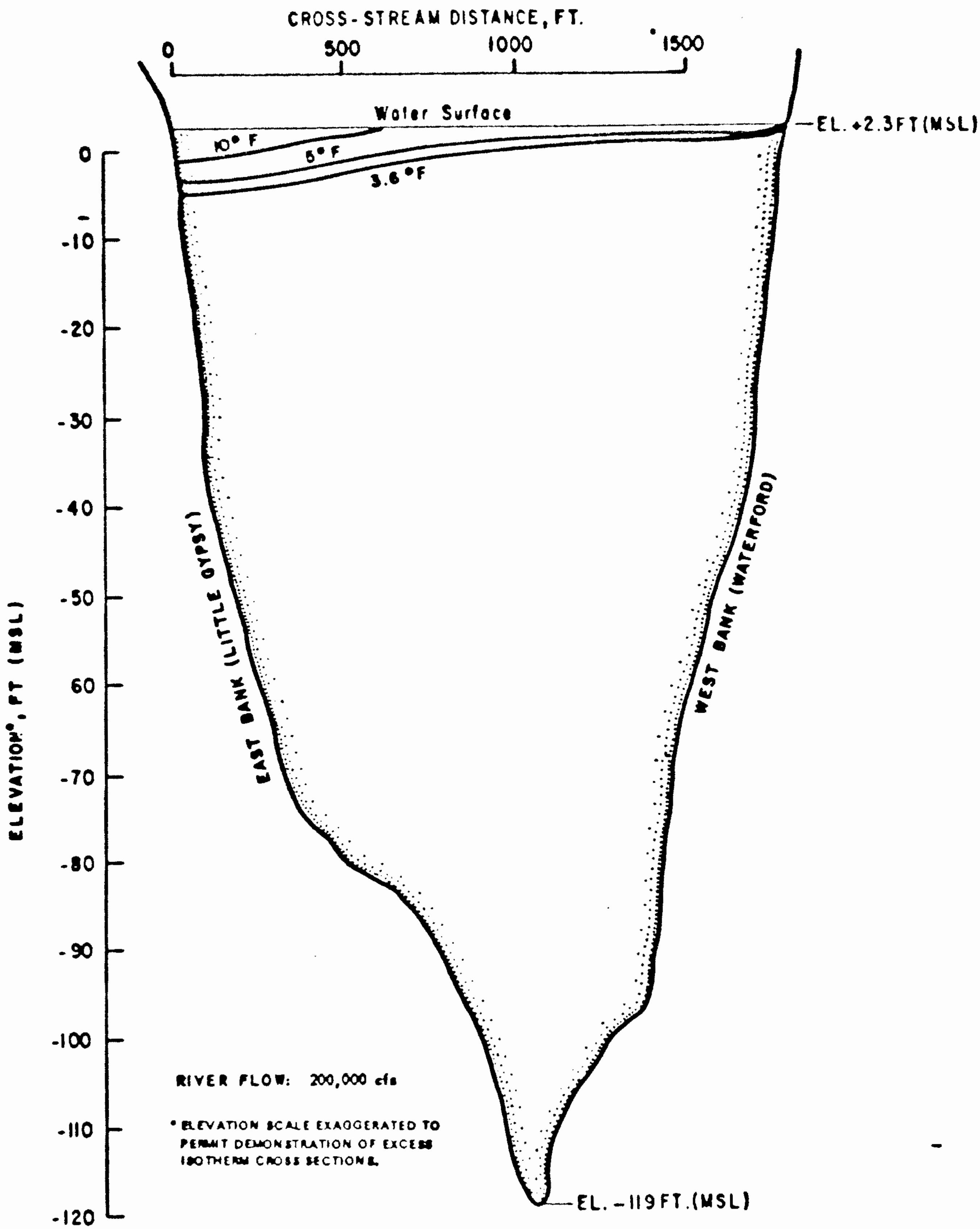
Figure 9



LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	EXCESS ISOTHERMS (°F) AT THE SURFACE BEFORE WATERFORD 3 DISCHARGE - SEPTEMBER 10, 1976 LOW FLOW CONDITION	Figure 10

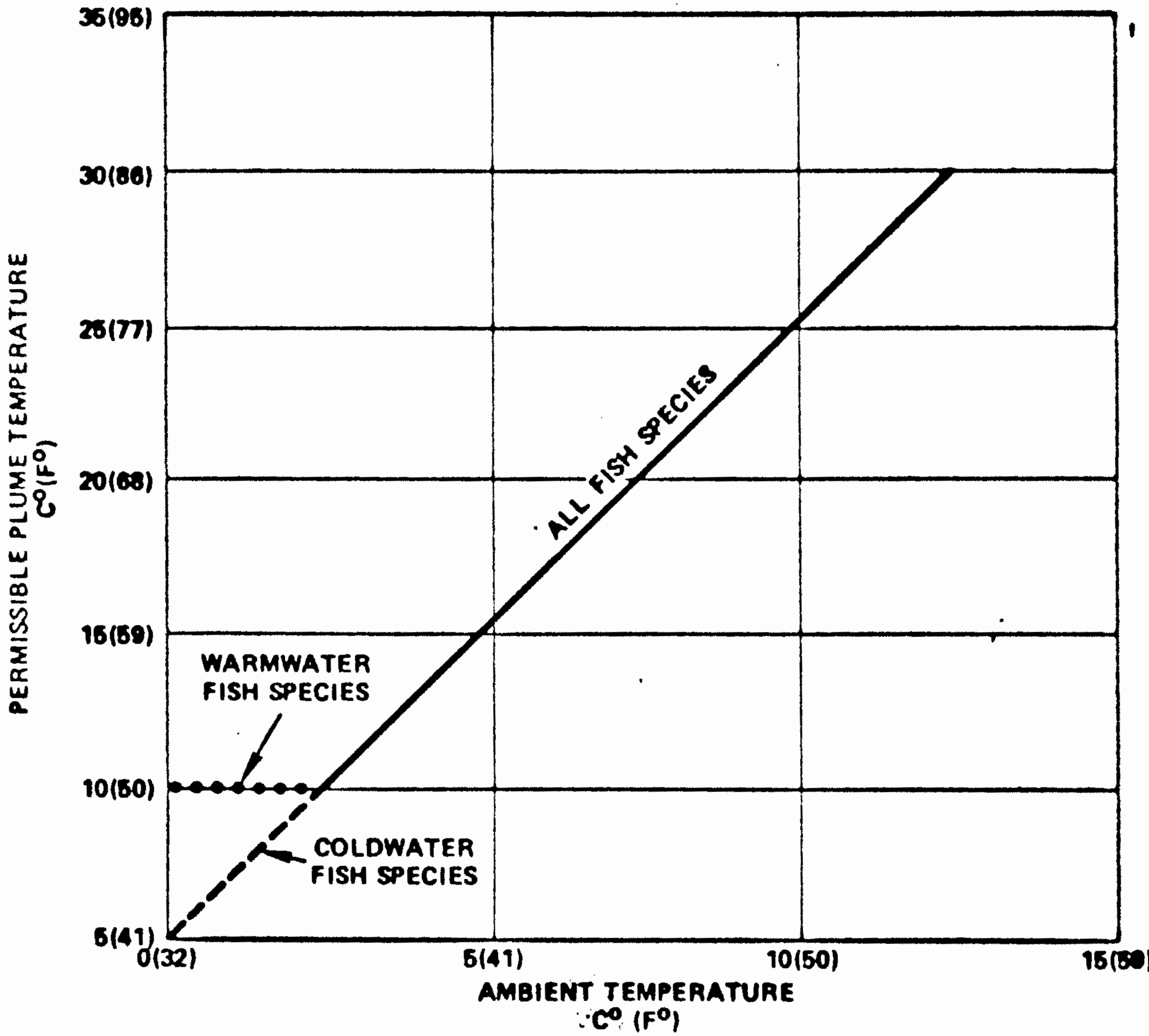


LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – SEPTEMBER 10, 1976 LOW FLOW CONDITION	Figure 11



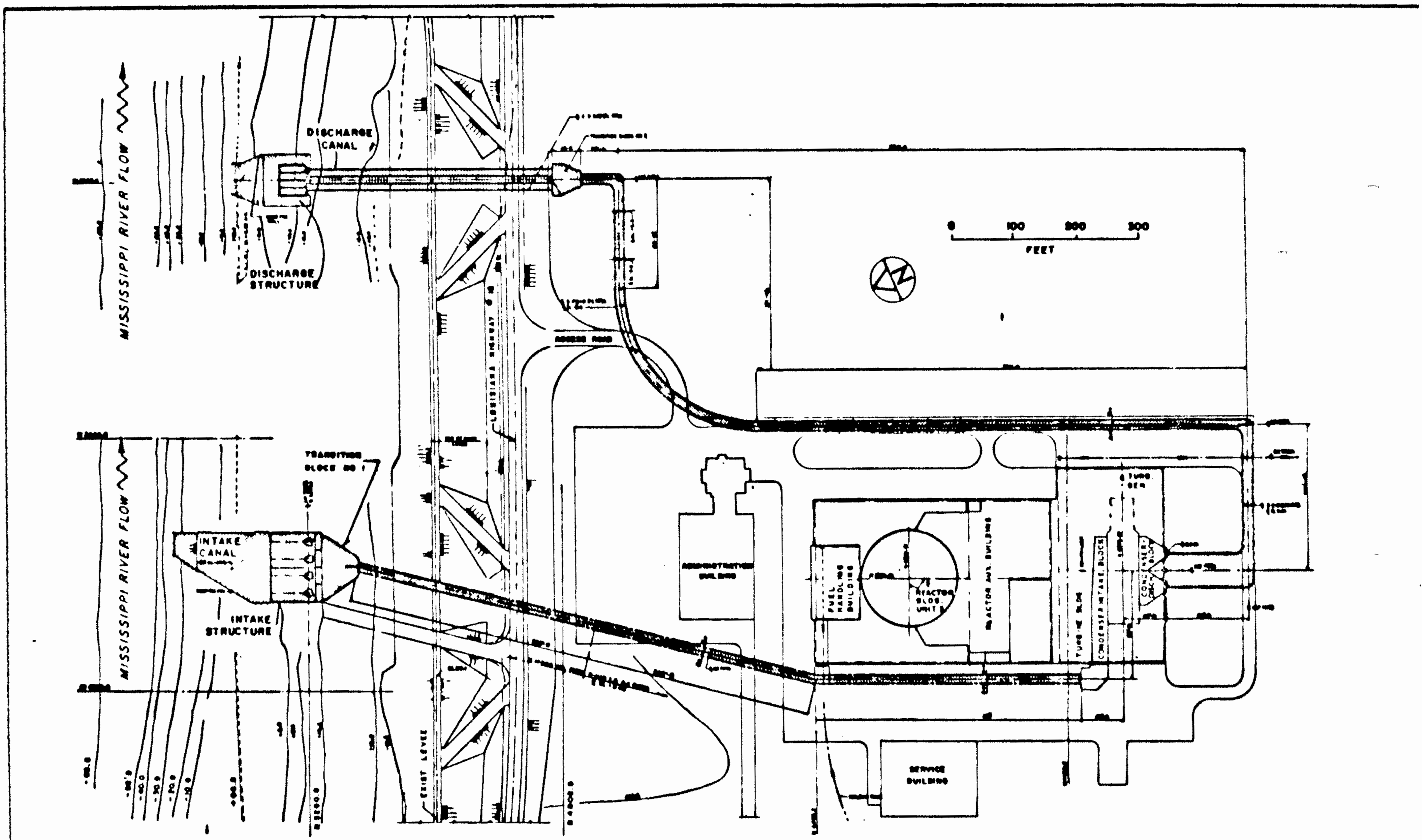
SOURCE: RIVER CROSS SECTION CONSTRUCTED FROM CONTOUR MAP FROM US ARMY CORPS OF ENGINEERS, NEW ORLEANS, LA. "MISSISSIPPI RIVER HYDROGRAPHIC SURVEY - 1973 TO 1975 - BLACK HAWK, LA. TO HEAD OF PASSES, LA." 1976.

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	COMBINED THERMAL PLUME CROSS-SECTION AT LITTLE GYPSY FOR TYPICAL LOW FLOW CONDITIONS	Figure 12

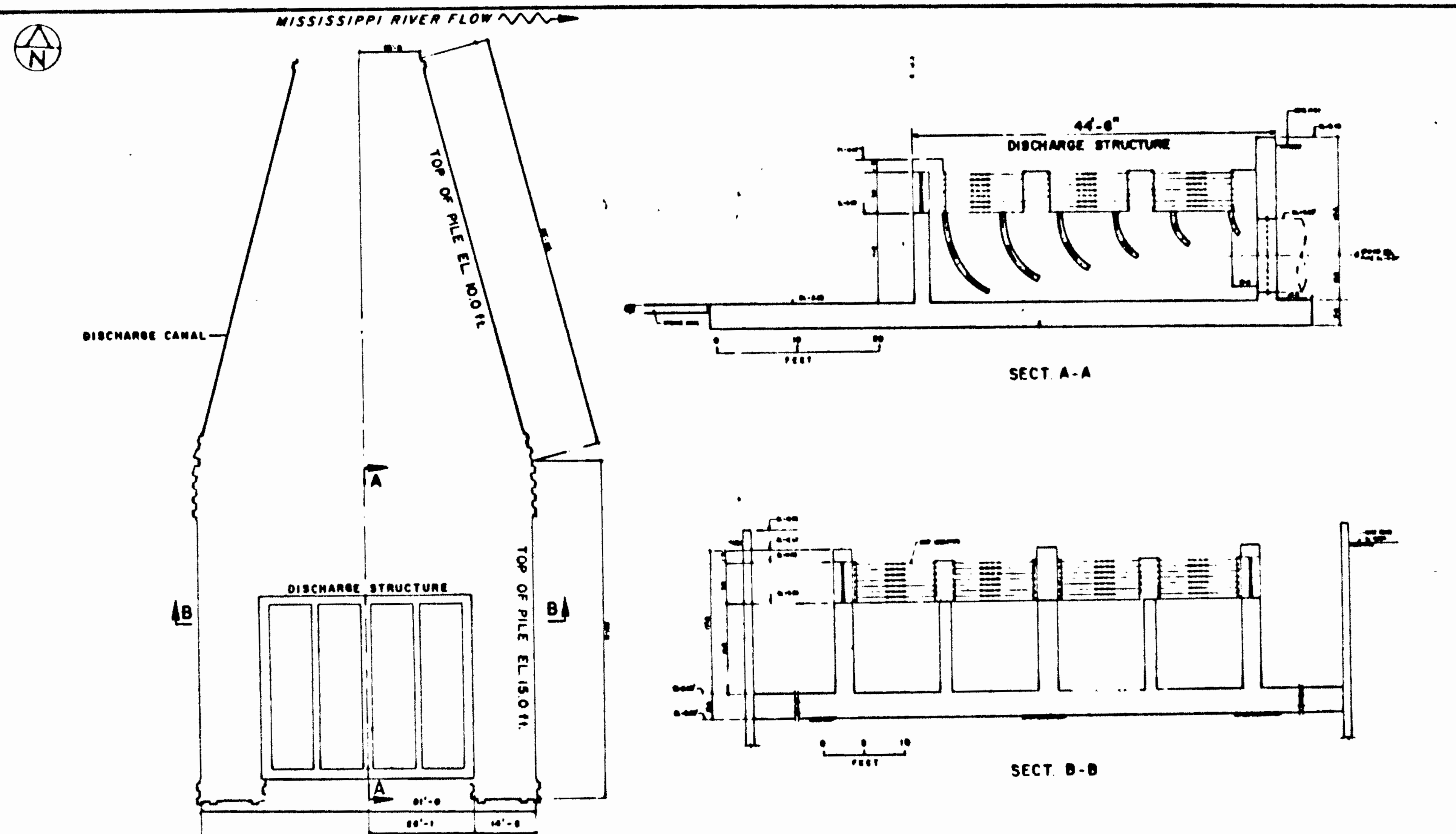


SOURCE: US ENVIRONMENTAL PROTECTION AGENCY.
QUALITY CRITERIA FOR WATER – 1976

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	ALLOWABLE THERMAL PLUME TEMPERATURES FOR THE MINIMIZATION OF COLD SHOCK IN THE EVENT OF PLANT SHUTDOWN	Figure 13



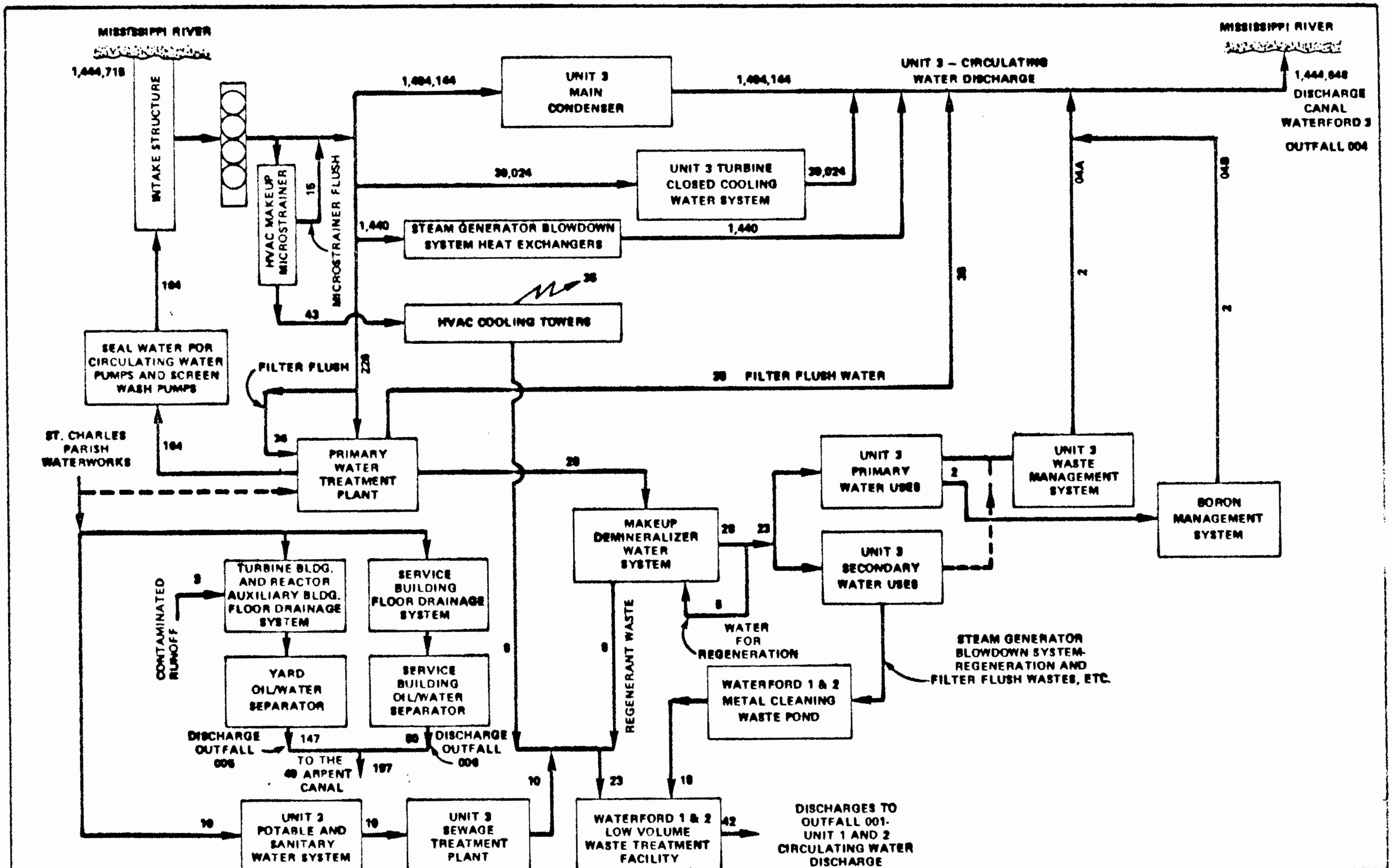
LOUISIANA POWER & LIGHT Co. Waterford Steam Electric Station	CIRCULATING WATER SYSTEM GENERAL PLAN	FIGURE 14



PLAN (NOT TO SCALE)

DISCHARGE STRUCTURE

LOUISIANA POWER & LIGHT Co. Waterford Steam Electric Station	CIRCULATING WATER SYSTEM DISCHARGE STRUCTURE AND CANAL	FIGURE 15



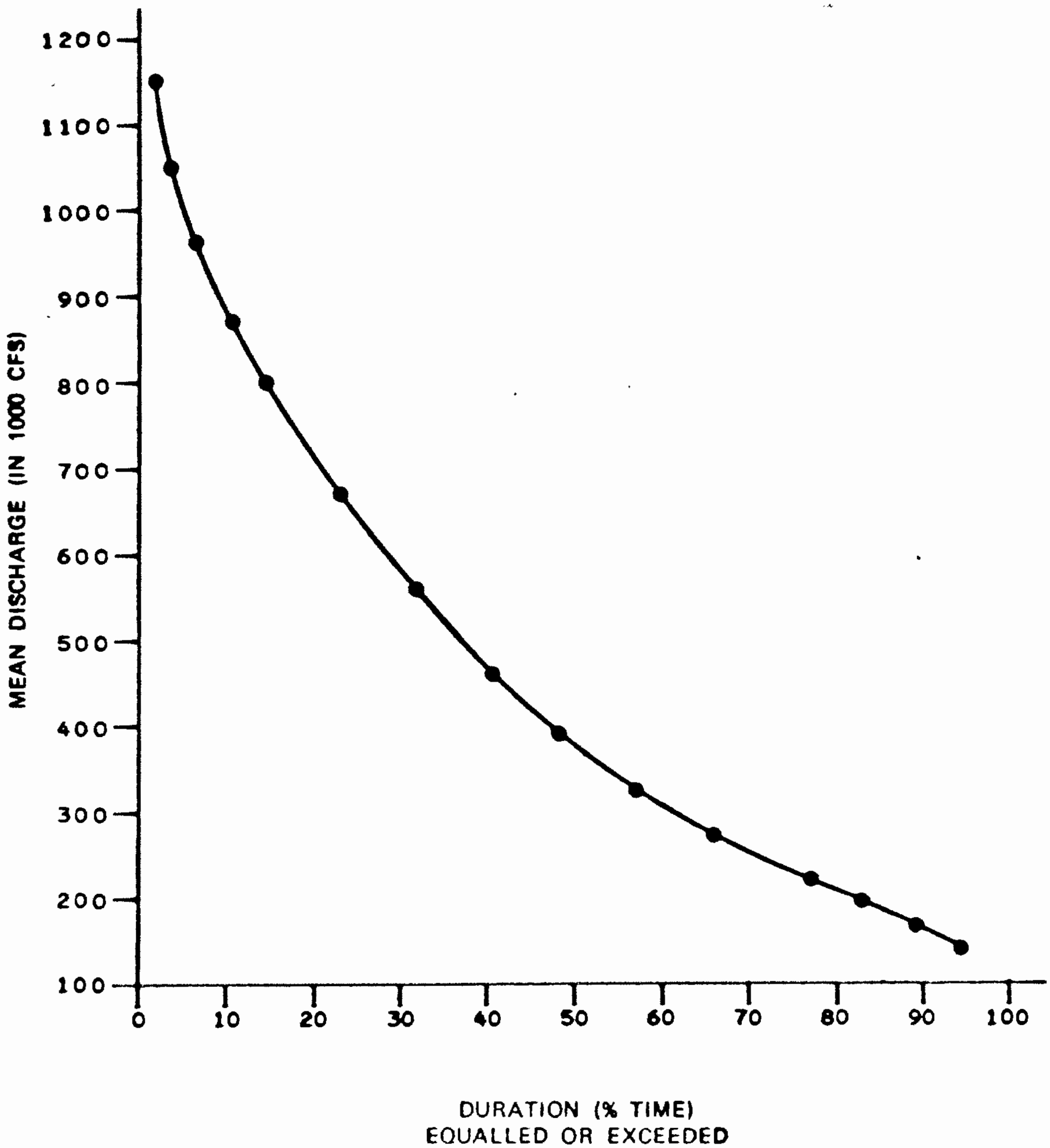
NOTES:
1. FLOWS IN THOUSAND GALLONS PER DAY.
2. PRIMARY WATER USE SYSTEMS ARE THOSE SYSTEMS WHERE WATER COMES IN DIRECT CONTACT WITH POTENTIAL SOURCES OF RADIOACTIVITY.
3. SECONDARY WATER USE SYSTEMS ARE THOSE SYSTEMS WHERE THE WATER DOES NOT COME IN DIRECT CONTACT WITH ANY POTENTIAL SOURCES OF RADIOACTIVITY.
4. WASTE MANAGEMENT SYSTEM TREATS LIQUID RADIOACTIVE WASTES.
5. FIRE STORAGE AND THE ASSOCIATED SYSTEM DEMANDS NOT SHOWN.

LOUISIANA POWER & LIGHT CO.
Waterford Steam Electric Station

SCHEMATIC OF WATER FLOW, WATERFORD UNIT 3

FIGURE 16

NOTE:
COMBINED DATA FROM TARBERT LANDING AND RED RIVER LANDING 1930-1975.



SOURCE
UNPUBLISHED PRELIMINARY DATA - SUBJECT TO REVISION
U.S. GEOLOGICAL SURVEYS BATON ROUGE LA [illegible]

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	MISSISSIPPI RIVER FLOW DURATION CURVE	Figure 17

Draft

LOUISIANA POWER & LIGHT COMPANY

APPENDIX A

WATERFORD 3 - HYDROTHERMAL STUDY

WATERFORD
STEAM ELECTRIC STATION
UNIT NO. 3

JANUARY 1979

APPENDIX A

WATERFORD 3 HYDROTHERMAL STUDY

TABLE OF CONTENTS

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1.0 SUMMARY

1.1 INTRODUCTION - PURPOSE AND SCOPE

In 1973 an analysis of the thermal plume distribution in the Mississippi River resulting from heated water released by the Waterford 1, 2 and 3 and Little Gypsy Steam Electric Generating Stations was conducted for the Construction Permit Environmental Report. This analysis was based upon mathematical models available at that time and field data obtained in surveys performed during the period 1970-1973. Since 1973, results of the hydrothermal field program, which is part of the Waterford 3 Preoperational Monitoring Program, have become available. Consequently, Louisiana Power & Light Company authorized Ebasco Services Incorporated to re-evaluate the Waterford 3 thermal plume predictions in light of the more detailed hydrothermal data base and recent advances in thermal field predictive techniques. In addition, Dr. B.A. Benedict, formerly of Tulane University (New Orleans, Louisiana) and presently of University of South Carolina (Columbia, South Carolina), was consulted during the preparation of this report.

This report discusses the methodology used to select an appropriate modeling approach, describes the models utilized and presents the results of thermal plume distribution predictions of the combined Waterford 3, Waterford 1 and 2 and Little Gypsy circulating water discharges. General descriptions of Waterford 3 and the surrounding environment can be found in ER Sections 2.1 and 3.4.

1.2 RESULTS AND CONCLUSIONS

a) Methods for thermal predictions were developed under low river flow conditions and seasonal average river flow conditions. For the low river flow case, field measurements at Little Gypsy and Waterford 1 and 2 were utilized as representative of the effects of these plants at low flow (approximately 200 kcfs). The Prych-Davis-Shirazi (PDS) model[8] was used to predict the Waterford 3 thermal distribution during low flow.

b) The Edinger and Polk model[9] which is a farfield model, was employed for the Waterford 1 and 2 and Little Gypsy discharges during seasonal average flow conditions. The PDS model, a nearfield surface jet-type model, was used at Waterford 3 when the discharge behavior was jetlike; otherwise, the Edinger and Polk model was applied.

c) Comparison of the model results with field data indicated that model selections give conservative estimates of the combined thermal plume extents.

d) An analysis of available field data suggests that interaction of the existing Waterford 1 and 2 and Little Gypsy plumes is limited; flow along the river channel appears to prevent significant mixing of the two plumes.

e) Recirculation between intake and discharge of Waterford 1 and 2 is not significant, and will not affect the farfield thermal plume distribution. However, recirculation between the Waterford 1 and 2 discharge and Waterford 3 intake will occur, and was taken into account by the modeling approach utilized.

f) The combined thermal distribution was predicted for average river flow during each season and for a typical low river flow condition (200 kcfs). The results are presented in pictorial form on Figures A-12 to A-15, and Figures A-16 and A-17, respectively.

g) The maximum plume dimensions of the combined thermal field during low flow conditions are summarized below:

Maximum Plume Dimensions	5^{o}F Isotherm	10^{o}F Isotherm
Cross-sectional Area	4.2%	1.1%
Cross-stream Extent	full river width (1800 ft)	1100 ft
Longitudinal Extent (ft)	7200 ft	2700 ft

Dimensions of the combined thermal distribution at seasonal average flow conditions are presented in Table A-11.

h) A comparison of the study results with predictions made for the Construction Permit Environmental Report shows that there are differences in plume configuration. In effect, the revised modeling results show a slightly smaller cross-sectional area affected, but with a larger surface plume.

2.0 DESCRIPTION OF THE MISSISSIPPI RIVER AT WATERFORD

This section reviews the existing hydrodynamic and hydrothermal conditions in the Mississippi River in the vicinity of the Waterford site.

2.1 DESCRIPTION OF THE EXISTING FLOW FIELD

2.1.1 FLOW FREQUENCY ANALYSIS

An analysis of Mississippi River flow conditions was made utilizing flow data taken by the Corps of Engineers at Red River and Tarbert Landings over a 35 year period (1942-1976). Figure A-1 presents a statistical analysis of river flow based on monthly averaged flows grouped by season. For this study, winter, spring, summer and fall were defined by three month periods starting with January.

Seasonal average flow rates were previously obtained from Corps of Engineers data over a 40 year period (1936-1975). They were obtained by utilizing the median value for each season. The results are:

Winter:	580 kcfs
Spring:	650 kcfs
Summer:	280 kcfs
Fall :	240 kcfs

A river flow of approximately 200 kcfs was taken to be a typical low river flow condition for predictive purposes. This is consistent with the studies conducted for the Construction Permit Environmental Report. The probability of occurrence for flows less than 200 kcfs (for all months) implies an annual recurrence interval of about 6.7 years. On a seasonal basis, flows less than 200 kcfs would be expected to occur most frequently during summer and fall, when the recurrence interval is 4 years.

2.1.2 STREAMLINE ANALYSIS

Figure A-2 shows a contour map drawn by the Corps of Engineers[15] using 1973-1975 hydrographic survey data. The shaded area indicates where the river bottom elevation exceeds -100 ft MSL. This indicates that over a long period of time, bed material has been transported downstream along the river channel where maximum bottom shear stress exists. Also, since higher river discharges per unit width were empirically observed[22] to be located along the deeper portion of the river, it is expected that a major fraction of the river flow follows the river channel. This flow starts near the Little Gypsy (east) shore upstream of the river bend and bears to the Waterford (west) shore as it moves around the bend.

This characteristic flow pattern was confirmed by the three sets of drogue experiments conducted by LP&L. On September 11 and 13, 1976, drogues released upstream of the river bend were tracked around the river bend (Geo-Marine, 1976[7]). Pathlines (or streamlines, assuming steady flow) traced

by drogues released near the river channel are reproduced in Figure A-3. On August 8 and 10, 1977, similar drogue experiments [23] were carried out, and on September 20, 21 and 22, 1977, drogue surveys[24] covering the entire river width were conducted. Streamlines for drogues released near the river channel in these surveys are reproduced in Figure A-4. Both figures confirm the flow characteristic expected from the bottom contour distribution.

The circulating water discharges from both Waterford 1 and 2 and Little Gypsy affect river flow characteristics in a zone bounded by the shoreline and the river channel. These discharge effects are, however, of a secondary nature. Typically, station discharge flow rates are approximately one percent of the river flow. The Waterford 1 and 2 discharge effect on the ambient river flow is expected typically to be the lowest during low flow conditions (200,000 to 350,000 cfs) since the Waterford 1 and 2 discharge is of a vertical drop type. With the exception of the area in the immediate vicinity of the discharge, the perturbations on the natural flow are expected to be minimal.

Under the same ambient conditions, however, the Little Gypsy surface jet discharge (in the offshore direction) not only displaces natural flow streamlines near the surface but also entrains ambient water. Additionally, the flow field is affected by buoyancy spreading due to the thermal content of circulating water discharge. As a result, the surface area affected by the discharge grows as the jet momentum decays. The process continues until the river flow momentum dominates and then washes out the discharge flow effect.

Figures A-5 and A-6 present drogue studies conducted near the Little Gypsy discharge, and Figure A-7 presents the results of a drogue study conducted near Waterford 1 and 2. Streamlines traced by drogues on Figures A-5 through A-7 confirm the flow characteristics described above. The data show that streamlines do not cross the main river channel.

In summary, a major portion of the river flow follows the deep channel, which is close to the Little Gypsy (east) side upstream of the river bend and bears close to the Waterford (west) shore downstream of the river bend. Effects due to circulating water discharges from Little Gypsy and Waterford 1 and 2 are limited to areas on either side of the river channel streamlines. Thus, the flow field can be viewed as being comprised of two nearshore zones and a main channel zone which tend to separate flows past the Waterford site.

2.1.3 BACK EDDY CURRENT AT WATERFORD 1 AND 2

The results of several field studies [2-7, 23, 24] have indicated the presence of a back eddy current in the vicinity of the Waterford 1 and 2 intake and discharge structures. The field studies employed tracer dyes, velocity and temperature measurements, and drogue tracking to delineate and characterize the back eddy phenomenon.

The back eddy current is strongest (always less than 1.0 fps) during periods of low flows and does not exist for river flows exceeding approximately 600,000 cfs. The back eddy appears to vary greatly with wind speed and direction. The eddy characteristics are also very dependent upon shoreline configuration. The west bank undergoes continual change as material is deposited during low flows and eroded at high flows. In addition, the construction effort at the Waterford site has produced significant alterations to the shoreline in the back eddy area.

The area affected by this current extends approximately from the Waterford 1 and 2 outlet structure on the downstream side, to 400 ft offshore of the west bank, and 2000 ft upstream.

2.2 AMBIENT RIVER WATER TEMPERATURES

Monthly average Mississippi River water temperatures from the Ninemile Point Generating Station for the period 1951-69 were presented in the Construction Permit Environmental Report. These data yield average seasonal river temperatures of $47.7^{\circ}F$, $69.7^{\circ}F$, $84.3^{\circ}F$ and $63^{\circ}F$ for winter, spring, summer and fall, respectively. These seasonal average river temperatures were used as input data for the thermal plume predictions (Table A-8).

Additional temperature data measured at the Carrollton Gage were obtained from the Corps of Engineers. The Carrollton Gage is located about one mile downstream of the Ninemile Point Generating Station. Data were analyzed for the period 1961-77. Daily temperatures were ranked within each

season in descending order and a cumulative frequency distribution was prepared. The results, which are shown in Figure A-22, depict the annual frequency of occurrence of the ambient water temperature data.

2.3 REVIEW OF PREVIOUS THERMAL SURVEYS

Since 1970, a hydrothermal field program has been conducted by LP&L to investigate the dispersion characteristics of the Mississippi River in the vicinity of the Waterford site. The field program surveys were conducted before and after operation of Waterford 1 and 2. (Little Gypsy was in operation in each case.) Results of the surveys have been presented in a series of reports[1-7, 23, 24].

The characteristics of thermal plumes surveyed at Waterford 1 and 2 and Little Gypsy are summarized in Table A-1. The following observations can be made:

a) The Waterford 1 and 2 thermal distribution affects a smaller surface area than Little Gypsy discharge. This is partly due to the lower heat release rate and partly to a higher river discharge rate (see Figure A-2) on the Waterford side.

b) The largest surface plume was observed during the September 9, 1976 survey.

The thermal plumes with maximum extent during each survey (using the lowest excess temperature contours reported) are overlayed on Figures A-3 and A-4. Figure A-3 depicts the extent of thermal plumes observed with a river flow of about 200 kcfs. In spite of identical station discharge and river flow conditions existing on both September 9 and 10, 1976, the extent of the combined thermal distribution in the river was much less on September 10. Differences in weather conditions are a possible source of explanation. There was a 6.3 mph southerly wind on September 9, which would have a component in the up-river direction. On September 10, there was a 12.3 mph westerly wind, which would have a large down-river component. This difference in wind speed and direction could have significantly affected plume dispersion, particularly in regions of relatively low river velocity (e.g. offshore of the Little Gypsy discharge canal).

The comparatively small thermal plume observed on November 2, 1974 and depicted in Figure A-3 resulted because both Little Gypsy and Waterford 1 and 2 were not operating at full load during the survey period. The stations were operating at about 68 percent and 26 percent of full load, respectively. This is in contrast to the 97 percent loading condition for both stations on September 9 and 10, 1976.

Figure A-4, which depicts the surface of thermal plumes observed during river flows of about 300 kcfs, shows that the plumes were similar on all three survey days.

2.4 INTERACTION BETWEEN EXISTING FLOW AND THERMAL FIELDS

One feature of the measurements shown in Figures A-3 and A-4 is the similarity in lateral extent of the thermal plumes from both Waterford 1 and 2 and Little Gypsy. A line of demarcation appears to exist near the location of the river channel indicated on Figure A-2. In Figures A-3 and A-4, this line appears to have been traced by a drogue placed near the river channel location upstream of the bend. Along this line of demarcation and within a zone (or corridor) about 200 feet wide, low excess temperatures (lower than 1° to 2°F) persist for some distance downstream before dissipating. It is also along this corridor and downstream of the Little Gypsy discharge, that the Little Gypsy and Waterford 1 and 2 thermal plumes interact. Because a large fraction of the river discharge flows within the main channel, residual heat transported laterally into the corridor from each shoreline is rapidly diluted. Thus, the river channel acts as a heat energy sink by diluting and convecting the heat downstream. This condition restricts the interaction of heated water from the Waterford 1 and 2 and Little Gypsy discharges.

3.0 MODEL SELECTION AND CALIBRATION

3.1 MODEL SELECTION

The model selection process involved a review of existing mathematical models followed by an assessment of their applicability. Because of the complexity of the flow regime and differences between discharge structures, models were evaluated for each station discharge. After appropriate models were selected in a preliminary review, a detailed calibration was performed for each of these models. It should be noted that the temperature distributions for the existing plants during low flow conditions were based on actual measured data; predictive models were applied to tne Waterford 3 discharge and the existing discharges under seasonal average conditions.

3.1.1 MODEL SELECTION FOR EXISTING PLANT DISCHARGES

The following models were evaluated for predicting excess temperature distributions at Waterford 1 and 2 and Little Gypsy:

a) Little Gypsy: Prych/Davis/Shirazi[8,12]

Edinger/Polk[9]

Lau[10] (modified for three-dimensional field)

Prakash[11] (see review by Benedict)

Pritchard 2 Model[12]

b) Waterford 1 and 2:

NRC recommended model[13]

Kuo[14]

Prakash[11]

Edinger/Polk[9]

These models were calibrated, on a preliminary basis, to the field data available from hydrothermal surveys[1-7, 23, 24]. Data from these surveys were also used to determine the approximate behavior of the heated discharge as it passed through the outlet structure. At Waterford 1 and 2, the discharge flowed over a weir crest and down into the river, to approximate a surface point discharge with little horizontal momentum. This condition is in contrast to the Little Gypsy discharge, which exhibited surface jet characteristics near the canal outlet location.

The results of the preliminary calibration analysis indicated that the Edinger and Polk farfield model was the most appropriate model for predicting both the Waterford 1 and 2 and Little Gypsy thermal distributions.

The rationale for selecting the Edinger and Polk model is summarized below:

a) The Edinger and Polk model yielded reasonable solutions in a complex flow regime. The other models investigated either required greater computational effort in return for only marginal improvement in response or could not adequately reproduce field observations.

b) Regarding the Waterford 1 and 2 discharge, no model reviewed satisfactorily estimated the upstream heat transport. Consequently, in predicting seasonal average conditions, all of the heat was assumed to be transported downstream, a procedure which would yield conservative results. As previously stated, temperature distributions during low flow conditions were based on actual measured data, which depict the upstream heat transport.

c) From the preliminary calibration effort, it was concluded that implementation of a suitable nearfield model for the Little Gypsy jet discharge would require considerable additional field data and development effort. Since the primary interest was to include the effects of the Little Gypsy discharge on the Waterford 3 discharge, it was decided to forego development of a detailed nearfield model and utilize a farfield model.

3.1.2 MODEL SELECTION FOR THE WATERFORD 3 DISCHARGE

The Waterford 3 discharge behaves like a surface jet when the river flow is

less than 300-350 kcfs; at higher flows, the jet is weak and the Edinger and Polk model is applicable. In order to model the nearfield region of the Waterford 3 discharge under jet-like conditions, several site specific requirements must be included in the model:

a) Jet entrainment due to vector velocity differences between jet and ambient fluids,

b) Three-dimensional field,

c) Buoyancy effects due to the discharged heat,

d) Dynamic effect of the ambient current (drag and shear effects), and

e) Allowance of ambient momentum entrainment.

The Prych-Davis-Shirazi (PDS) model was selected for the Waterford 3 discharge because it met all of the above requirements and has performed satisfactorily in similar applications.

3.2 DESCRIPTION OF SELECTED MODELS

3.2.1 EDINGER AND POLK MODEL

The Edinger and Polk model gives analytical predictions of an excess temperature field produced by a point source located at a river bank. The heat

source is assumed to release heat continuously at a constant rate into a waterbody with a constant mean velocity, infinite depth and width, and constant lateral and vertical diffusivities. The effect of longitudinal diffusion is assumed small compared to longitudinal convection and no heat is lost to the river bank or atmosphere. A detailed discussion of the solution to the governing equation is presented in Reference 9; a summary description is given in Table A-3.

3.2.2 PRYCH-DAVIS-SHIRAZI MODEL

The PDS model treats the three dimensional surface jet by the integral approach. Using assumed profiles for temperature and velocity along with the entrainment and drag functions, the 3-D equations of mass, momentum and energy conservation are reduced to a set of coupled nonlinear ordinary differential equations that are solved numerically.

In addition to the classical type of entrainment that is due to vector velocity differences between jet and ambient flows, the model allows for entrainment due to ambient turbulence in the mass flux equation. The momentum flux equation is formulated to include bouyancy forces, shear forces between jet and ambient flows, drag force due to cross flow, and entrainment of ambient momentum. The heat flux equation includes heat loss; this term in the equation was ignored for conservatism. The rate of spreading of the jet is expressed as the sum of a non-buoyant and a buoyant component. The form of the buoyant component is derived by considering a moving density front such as exists when oil is spreading over water.

A summary description of the PDS model is given in Table A-3; a detailed discussion of this model can be found in References 8 and 12.

3.3 MODEL CALIBRATION

3.3.1 INTRODUCTION

The two selected models contain several site specific adjustable physical parameters. Before the models are utilized for predicting thermal impacts, the adjustable physical parameters have to be calibrated against site specific thermal measurements obtained under known plant and river discharge conditions. The calibrated parameters can then be translated to other discharge conditions of interest for thermal predictions.

The adjustable parameters are the effective convection velocity (U_e), lateral diffusivity (K_y), the vertical diffusivity (K_z), and the extent of upstream intrusion (L). U_e is an effective velocity at which the discharged water is transported downstream through a non-uniform velocity region. K_y and K_z are coeffecients that account for lateral (cross-stream) and vertical turbulent heat dispersion. L is the distance over which the heat is transported upstream of the Little Gypsy discharge.

Table A-2 depicts the procedure used to obtain model input data required for calibration. Because river flow data were not available at the site, information from both Tarbert Landing and the Carrollton Gage were employed

to construct the site rating curve. River cross-sections were constructed from contour maps published by the Corps of Engineers [15], and river temperatures were obtained from station intake temperature records. Heated discharge temperatures were obtained from plant operating logs; plant discharge type (behavior) and velocity were estimated from site river stage and plant operating data.

3.3.2 CALIBRATION PROCEDURE FOR THE EDINGER AND POLK MODEL

a) General Procedure

As discussed earlier, Little Gypsy and Waterford 1 and 2 thermal plumes interfere only in the limited region along the river channel. In this region both plumes are quickly mixed with water at ambient temperature and transported downstream. For this reason, the Edinger and Polk model was separately calibrated against the thermal plumes at each plant. Interference from other thermal plumes and corridor boundary effect are assumed negligible. Dilution in the corridor is ignored; thus, the model provides a conservative result.

The procedure summarized below was utilized to calibrate the Edinger and Polk model against field data for the Waterford 1 and 2 and Little Gypsy discharges. For conservativeness, the field surveys with the largest surface plumes were utilized to estimate model parameters.

1) For each given isotherm of interest, the observed maximum ex-

tent in the longitudinal, lateral and vertical directions was recorded as x_m, y_m, and z_m, respectively.

2) Based on these values, equivalent diffusivities (K_y, K_z) and the effective convection velocity (u_e) were calculated according to the following expressions:

$$u_e = \frac{\Delta t_o}{\Delta t} \frac{4Q_p}{e \pi y_m z_m}$$

$$K_y = \frac{eu_e}{4} \frac{y_m^2}{x_m}$$

$$K_z = \frac{eu_e}{4} \frac{z_m^2}{x_m}$$

where:

Δt_o	discharge excess temperature (^oF)
Δt	excess temperature in the field (^oF)
p	plant discharge rate (CFS)
e	Napierian base, 2.718

An effective convection velocity, U_e, was used because the discharge momentum tends to change both the apparent diffusivities and the longitudinal convection velocity. In addition, there is a variable ambient velocity field at the river bend. The requirement of a single convection velocity in the Edinger and Polk model necessitated the establishment of an effective convection velocity that can account for the plant discharge momentum effect and the cumulative effects of the variable velocity field on heat dispersion.

3) For each selected t, there is a unique set of parameter values (K_y, K_z, u_e). This indicates the variability in the ambient water characteristics associated with different zones of Δt's. However, the mathematical model allows only a unique set of these values for the entire thermal field of interest. A guideline in selecting a set of these values as calibrated model parameters is to preserve conservatism. A physical parameter that can be used as a guide is the volumetric measure given by:

$$x_m y_m z_m = \left(\frac{\Delta t_o}{\Delta t}\right)^2 \frac{4Q_p^2}{u_e e \pi^2} \frac{1}{\sqrt{K_y K_z}}$$

Conservatism was achieved by maximizing the volumetric extent of a given excess isotherm. The above expression indicates that a set of (K_y, K_z, u_e) giving the minimum value of $u_e \sqrt{K_y K_z}$ is a conservative set.

Before the model is utilized to predict thermal impacts under various plant discharge and ambient conditions, the calibrated diffusivities and effective convection velocities must be translated from the field survey conditions used in the previous steps to a general form applicable to any set of plant and river conditions.

According to Elder[17], diffusivities can be expressed in the functional form:

$$K \sim uH^{5/6}$$

where:

u = river velocity, and

H = river depth averaged.

The proportional constant was obtained from river velocity and river depth observed during a survey and the corresponding diffusivity calibrated under the same conditions. The calibrated effective convection velocity was expressed as a fraction of the average river velocity.

b) Calibration of the Little Gypsy Discharge

1) Estimation of Model Parameters

Field survey data used for calibration were taken on July 31, 1973 [4], November 2, 1974 [5], September 9, 1976 [7], September 10, 1976 [7], August 4, 1977[23], August 5, 1977 [23], and August 9, 1977[23]. The data from September 9, 1976 were used to calibrate the model and estimate model parameters. Data from the remaining surveys were used in comparisons of predicted and observed plume characteristics.

Calibration results using the 1973 data are presented on Figure A-8. It presents a comparison of the predicted lateral locations (y) of surface excess isotherms given by

$$(y)_{z=0} = 2\sqrt{\frac{K_y x}{u_e}}\left[\ln\left(\frac{\Delta t_o}{\Delta t}\;\frac{Q_p}{x\pi\sqrt{K_y K_z}}\right)\right]^{1/2}$$

with those observed as a function of longitudinal distance (x). It is seen that prediction of both the 1.5 and 2.5^{o}F surface excess isotherms is adequate while the prediction for 3.5^{o}F is conservative. Since a major portion of the data in the vertical plane is located in a jet region, which cannot be calibrated by a farfield model, only the observed maximum vertical penetration of a given excess isotherm was incorporated in the calibration

procedure. Calibration results for the 1973 survey data indicate that depth penetration of the isotherms was properly predicted.

The field survey on September 9, 1976, yielded the largest surface plume observed at Little Gypsy. Consequently, these survey data were used to estimate a conservative set of model parameters to be used for predictive purposes.

The result of calibrating the Edinger and Polk model against the largest plume surveyed on September 9, 1976 is presented on Figure A-9. Comparisons are seen to be adequate for 6° and $8^{\circ}F$ but the model predicts conservatively for 10° and $4^{\circ}F$.

As indicated in Figure A-9, longitudinal plume extent includes excursion of heat about 550 ft upstream of the Little Gypsy discharge canal. The extent of this excursion can be explained by a theory of wedge intrusion presented by Polk, Benedict and Parker [16]. According to the theory, an arrested surface density layer is created upstream of the discharge point if the ambient current (u_w) is weak enough. The extent of upstream intrusion (L) can be expressed (see Figure A-10) in terms of the densimetric Froude number at the discharge point, i.e.,

$$F_w = \frac{u_w}{\sqrt{g \frac{\Delta \rho}{\rho_a} H_w}}$$

where:

$\Delta\rho$ = density difference between ambient and discharged water,

ρ_a = density of the ambient water, and

H_w = river depth where the wedge is formed.

On September 9, 1976, the river stage was 2.3 feet, $H_w \sim 25$ feet and $\Delta\rho / \rho_a \sim 0.00389/0.99555$. In order to have $L \sim 550$ feet, u_w is estimated to be about 0.9 fps. Averaged river velocity was about 1.5 fps on this day. Since the wedge intrusion was formed near the river bank and behind the river bend, it is judged that this intrusion was formed against a weak current of about $0.6\ u_a = u_w$.

The estimated model parameters from the Little Gypsy discharge are summarized in Table A-12. For Little Gypsy, Table A-12 shows that the effective downstream convection velocity of the thermal plume (u_e) is lower than the velocity upstream of the wedge intrusion (u_w). The effective downstream convection at the discharge was retarded by the off-shore component of the river convection (generated by the river bend) and the off-shore orientation of the plant discharge.

2) Comparison of Predicted vs Observed Plume Data

Table A-4 shows a comparison between the calibrated model predictions and observed thermal plume characteristics for the September 9 and 10, 1976 surveys. The larger spread in the observed values indicates variability contributed by factors not included in the model, such as wind effects and local hydrodynamic flow conditions. The comparison shows that the model predictions are conservative.

The model was used to predict the thermal plume distributions observed on August 4, 5 and 9, 1977. The predicted surface areas were larger than those observed. However, as might be expected from the field data on Table A-1, predicted cross-sectional areas were smaller than those observed. The observed cross-sectional areas enclosed by a 5^{o}F excess isotherm were as high as 1.45 times that of the predicted values. Comparison of the 1977 field data with that of 1976 indicates that there was unusual vertical penetration and lateral constriction of the Little Gypsy plume in the 1977 survey. This phenomenon might be partially explained by the onshore (towards Little Gypsy) winds setting up an opposing surface current which opposed buoyancy spreading and promoted vertical heat transport.

A general characterization of model behavior was obtained by comparing predicted and observed fractions of river cross-section affected by any given excess isotherm for all of the

available field observations. The ratio of the maximum plume cross-sectional area to the river cross-sectional area is given by the expression:

$$1.84 \frac{\Delta t_o}{\Delta t} \frac{Q_p}{Q_R} = \left[\frac{\left(A_c\right)_m}{A_R} \right]_{predicted}$$

where:

Δt_o = excess temperature at the discharge,

Δt = a given excess temperature,

Q_p = plant discharge rate,

Q_R = river discharge rate,

$\left(A_c\right)_m$ = the maximum plume cross-sectional area enclosed by a Δt, and

A_R = river cross-sectional area.

The predicted ratios were evaluated for all seven hydrothermal surveys spanning the period of 1973 to 1977. For each survey, four excess isotherms (10^o, 5^o, 3.6^o, 1.5^oF) were selected for the analysis. These values were then compared to those

values observed (Table A-1) and the result is presented in Figure A-20. The 45° line in the Figure is the line of perfect prediction. The plot shows that the predictive model estimates cross-sectional areas conservatively in most cases.

c) Calibration of the Waterford 1 and 2 Discharge Plume

1) Estimation of Model Parameters

The Edinger and Polk model was calibrated against plume data from the survey of September 9, 1976. This survey yielded the largest surface thermal plume size of those observed. Figure A-11 shows a pictorial comparison of the predicted (fitted) and observed data. Using identical values for the parameters K_y, K_z and u_e, estimates of isotherm depth penetration indicated similar extents as those observed. The model parameters obtained from this calibration are summarized in Table A-12.

2) Comparison of Predicted vs Observed Values

Table A-5 shows a comparison between the calibrated model predictions and observed thermal plume characteristics for the September 9 and 10, 1976 surveys. The larger spread in the observed values indicates variability contributed by factors not included in the model. The comparison shows that the model predictions are conservative.

3.3.3 RECIRCULATION EFFECTS AT WATERFORD 1 AND 2

Despite the upstream excursion of heat on September 9, 1976, recirculation at the Waterford 1 and 2 intake was observed to be approximately 0.5°F. Combining all available data, the excess temperature at the Waterford 1 and 2 intake could be about on the order of 1°F. The recirculated heat will raise the discharge temperature; the field temperature downstream of the discharge, however, will not necessarily rise.

While the nearfield temperatures will be affected, the farfield temperature will not rise at all. When estimating the farfield temperature, the only parameter of importance at the plant discharge is the rate of heat released downstream. This heat release will not be greater than the heat release rate under a no-recirculation situation. Given a heat release rate of H Btu/hr and a B fraction of discharged heat being recirculated, the heat released downstream into the farfield, H_d Btu/hr, can be computed as

$$H_d = (1-B^n) H$$

where n is the number of the recirculation process. As n approaches infinity, the $H_d \rightarrow H$, because $B < 1$.

This analysis shows that recirculation of the Waterford 1 and 2 discharge back to its intake will not increase the farfield temperature. Consequently, the effect of Waterford 1 and 2 recirculation on the Waterford 3 thermal field will be negligible. Recirculation between the Waterford 1 and 2 discharge and Waterford 3 intake is discussed in Section 4.3.1 of this

Appendix.

3.3.4 PDS MODEL CALIBRATION

No data were available at Waterford 3 or at Little Gypsy (when the velocity ratio of jet to ambient current velocity is higher than 2.5) for calibrating the PDS surface jet model. However, the PDS model has been calibrated by the Environmental Protection Agency against both laboratory and field data.

The ambient turbulent diffusivities required by the model were obtained from dye release data [2]. For all combinations of plant and river discharge conditions investigated, the PDS model was used only for Waterford 3 discharges during average summer, average fall, and typical low flow conditions. The effective convection velocity at Waterford 3 was assumed to be the same as the average river velocity. The estimated model parameters are shown in Table A-12.

4.0 METHODS AND PROCEDURES FOR THERMAL FIELD PREDICTION

4.1 INTRODUCTION

Once the calibrated mathematical models and their translated adjustable parameters were available, the following procedure was employed to obtain predictions of thermal distribution in the Mississippi River at Waterford:

Step 1: Compile the required input data

Step 2: Characterize heat recirculation effects

Step 3: Characterize plume interference effects

Step 4: Utilize the appropriate predictive modeling approach for the specific river conditions under study.

Each of these steps is discussed in the following paragraphs.

4.2 COMPILATION OF REQUIRED INPUT DATA

The input data required for the predictive models were derived from the following sources:

1) River flow frequency analysis (Appendix Section 2.1.1)

2) River water temperature data (Appendix Section 2.2)

3) Plant operational modes and discharge conditions

4) River cross-section profile and rating curves

5) Plant discharge structure designs.

Table A-6 depicts the procedure utilized to determine the model input data.

The sets of input data used to predict the combined Waterford-Little Gypsy thermal field are presented in Tables A-7 and A-8.

4.3 ASSESSMENT OF PLUME RECIRCULATION AND INTERFERENCE EFFECTS

4.3.1 ASSESSMENT OF RECIRCULATION EFFECTS

Assessment of the thermal effects due to operation of Waterford 3, Waterford 1 and 2 and Little Gypsy must consider the effects of recirculation.

Despite the occasional upstream excursion of heat passing the Waterford 1 and 2 intake location, intake temperature measurements have indicated little recirculation. The Waterford 1 and 2 intake is submerged at -26.5 feet (MSL). Similarly, at the Little Gypsy intake (submerged at -11.8 feet), the effect of upstream wedge intrusion of the heated discharge was measured to be negligible. As discussed in Appendix Section 3.3.3, recirculation at Little Gypsy or Waterford 1 and 2 intake is judged to

have negligible effects on the farfield temperature distribution near the Waterford 3 discharge.

At the intake for Waterford 3, however, recirculation from the Waterford 1 and 2 discharge is expected to occur. For a river stage of less than 15 feet, the Waterford 3 intake opening ranges from -1 to -35 feet below MSL (see ER Section 3.4.2.2). For estimating purposes, the Waterford 3 intake is conservatively assumed to withdraw the entire water column above -35 feet elevation. Given a discharge at Waterford 1 and 2, the Edinger and Polk solution at the Waterford 3 intake location can be integrated over the water column of depth d_{3i}, to estimate the Waterford 3 intake excess temperature, Δt_{3i}. The result is:

$$t_{3i} = \frac{Q_p \Delta t_o}{2\sqrt{K_Y K_z \pi}} \quad \frac{1}{X_{3i}} \quad \frac{\operatorname{erf}\left(\sqrt{\frac{u_e}{4x_{3i} K_z}} \; d_{3i}\right)}{\sqrt{\frac{u_e}{4x K_z}} \; d_{3i}}$$

where:

Q_p = plant discharge rate (cfs)

Δt_o = plant discharge excess temperature (^oF)

K_y, K_z = lateral, vertical diffusivities (ft^2/sec)

(the above three: At Waterford 1 and 2)

u_e = effective convection velocity (fps) } **At Waterford 1 and 2**

x_{3i} = distance between Waterford 1 and 2 discharge and Waterford 3 intake = 1700 feet

d_{3i} = (river stage +35) = depth of Waterford 3 intake (feet)

In deriving the above expression, the intake location was assumed to be at the river bank. Because the actual intake location is about 150 feet offshore during low river flow conditions, the above estimate should be conservative.

As a result of the Waterford 1 and 2 discharge, both the Waterford 3 intake and discharge conditions are altered; therefore the estimates of the combined thermal impacts at the Waterford 3 discharge include these recirculation effects (see Appendix Section 4.4).

4.3.2 ASSESSMENT OF PLUME INTERFERENCE EFFECTS

If the Waterford 3 discharge, a surface jet, penetrates across the river channel (or corridor), the discharge plume would be affected by the Little Gypsy discharge plume located near the opposite bank. Therefore, estimates of the combined thermal field impacts include assessment of interference effects from the Little Gypsy discharge (See Appendix Section 4.4).

4.4 MATHEMATICAL FORMULATION FOR COMBINED THERMAL FIELD

This section describes the mathematical treatment used to estimate the combined thermal plume effects from Waterford 1 and 2, Waterford 3, and Little Gypsy. Effects of plume recirculation and interference are included in this formulation.

Through a given point in the thermal field, the total heat transported as a result of operating the three generating plants simultaneously was assumed to be the sum of all heat transported through the same point by the independent operation of each plant. This is expressed by the following equation:

$$u \, \Delta t = u_A \, \Delta t_A + u_B \, \Delta t_B + u_C \, \Delta t_C$$

where:

u = combined longitudinal velocity = $u_R + u_A' + u_B' + u_C'$

u_R = river velocity

u_A', u_B', u_C' = excess longitudinal velocity due to operation of plant A, B and C

$$u_A = u_R + u_A'$$

$$u_B = u_R + u_B'$$

$$u_C = u_R + u_C'$$

Δt = combined excess temperature, and

$\Delta t_A, \Delta t_B, \Delta t_C$ = excess temperatures caused by the thermal discharges at plants A, B and C.

The above expression can be written in terms of the velocity ratio

$$R_A = u_A'/u_R,\ R_B = u_B'/u_R,\ R_C = u_C'/u_R, \text{ i.e.,}$$

$$\Delta t = \left[(1 + R_A)\Delta t_A + (1 + R_B)\,\Delta t_B + (1 + R_C)\,\Delta t_C\right] \Big/ \left[1 + R_A + R_B + R_C\right]$$

For the present application outside of dynamic discharge effect of Waterford 1 and 2 and Little Gypsy, $R_A = R_B = 0$, $R_C = R_{W3}$, $\Delta t_A = \Delta t_{W12}$, $\Delta t_B = \Delta t_{LG}$, and $\Delta t_C = \Delta t_{W3}$. Thus, the Δt expression becomes

$$\Delta t = \frac{\Delta t_{W3} + \Delta t_{W12} + \Delta t_{LG} + R_{W3}\,\Delta t_{W3}}{1 + R_{W3}}$$

R_{W3} is the longitudinal velocity ratio of the Waterford 3 discharge jet to the ambient river flow. It was estimated from the PDS model results.

The thermal plume interference between Waterford 1 and 2 and Little Gypsy was found to be limited within a narrow river channel region of about 200 feet, as discussed in Appendix Section 2.4. Thus, the quantity (Δt_{W12} + Δt_{LG}) can be denoted by Δt_{W12LG} which takes on either the value Δt_{W12} or Δt_{LG} depending on whether the field point of interest is on the Waterford 1 and 2 side or on the Little Gypsy side of the channel, respectively. The combined excess temperature is estimated by the expression

$$\Delta t = \frac{\Delta t_{W12LG} + \Delta t_{W3} + R_{W3}\, \Delta t_{W3}}{1 + R_{W3}}$$

The large volumetric flow along the river channel, which effectively separates the two existing discharge plumes, is expected to reduce excess temperatures as computed above. This additional dilution realized locally at the plume/river channel boundary was ignored.

4.5 THERMAL PREDICTIVE APPROACH

The mathematical formulation in Appendix Section 4.4 was utilized to predict combined thermal effects of all discharges. To use the formula, thermal

impact of each discharge has to be estimated. The following section describes the approach used under the different ambient conditions investigated.

4.5.1 PREDICTIVE APPROACH - LOW RIVER FLOW CONDITIONS

1) Existing Plants: Contributions from Waterford 1 and 2 and Little Gypsy were estimated directly from field survey data of September 9 and 10, 1976, when the river flow was approximately 205 kcfs.

2) Waterford 3: The Waterford 3 plume was estimated using the PDS model since the discharge exhibited jet-like behavior at low river flow.

4.5.2 PREDICTIVE APPROACH - SEASONAL AVERAGE RIVER FLOW CONDITIONS

1) Existing Plants: For all average seasonal conditions, the discharge from Waterford 1 and 2 is a vertical drop type and the Little Gypsy discharge is a weak jet; consequently, the Edinger and Polk model was applied to each plant.

2) Waterford 3: For winter and spring average flow conditions, when the Waterford 3 discharge is a weak jet, the Edinger and Polk model was applied.

For summer and fall average flow conditions, the Waterford 3 discharge acts like a strong jet. Under

these conditions, the PDS model was applied to predict the nearfield thermal distribution. Beyond the model's range (where jet momentum has practically vanished), the Edinger and Polk model was used to estimate farfield excess temperatures.

5.0 RESULTS OF PREDICTIONS

5.1 INTRODUCTION

The results of predicting thermal impacts from heated discharges released by Waterford 1 and 2, Waterford 3, and Little Gypsy operating under average and typical low river flow conditions are presented below. Individual and combined impacts from Waterford 3 and both existing plants were estimated and compared.

5.2 INDIVIDUAL DISCHARGE EFFECTS

In order to assess the impact of each of the three discharges separately, the thermal characteristics of the 5° and 10°F excess temperature isotherms were estimated for the typical low flow condition of approximately 200,000 cfs.

As discussed earlier, the observed thermal characteristics at Little Gypsy and Waterford 1 and 2 discharges can be considered as approximating individual thermal plumes. For the Waterford 3 discharge, the thermal characteristics of the surface jet were estimated by using the PDS model. The

results are separately tabulated on Tables A-9 and A-10 for two excess temperatures, 10^{o}F and 5^{o}F, respectively. Because of a lower rate of heat released to a portion of the river with a high volumetric flow, thermal impacts at Waterford 1 and 2 discharge were limited to lower isotherms and therefore information on the 5 and 10^{o}F isotherms were either missing or incomplete.

Relative contributions to the heat load in the river by Waterford 3, Little Gypsy, and Waterford 1 and 2 were 8.01×10^{9}, 5.9×10^{9}, 4.12×10^{9} Btu/hr, respectively. Despite the highest contribution from Waterford 3, fractions of the river cross-section and surface area affected by Waterford 3 are quite small compared to those of Little Gypsy. This is the result of the efficient jet mixing (with cooler ambient water) provided by the much higher discharge velocity (6 fps) at Waterford 3.

5.3 COMBINED THERMAL EFFECTS OF ALL DISCHARGES

The characteristics of the combined thermal field were predicted by the method detailed in Appendix Section 4.4 and are tabulated on Table A-11. The corresponding surface plumes are depicted on Figures A-12 through A-17.

The following general observations can be made from Table A-11:

1) The predictions are conservative.

2) Seasonally averaged, the combined thermal impact is at a minimum in the spring and approaches a maximum in summer and fall.

3) Comparison of results between low flow and average flow conditions must consider that plume estimates for the existing discharges for low flow conditions were based on survey data and utilized predictive models for average flow conditions.

Figures A-12 through A-15 depict seasonal variations in surface excess temperatures for the combined thermal field assuming (conservatively) full station load throughout the year. The variations in the Waterford 3 discharges, temperature and flow rate are the result of using a different number of circulating water pumps, according to the river temperature (see ER Section 3.4.2.1). The rate of heat discharged, however, is the same for the entire year.

For average winter and spring conditions when river flows are highest, all discharges behave like the non-jet type. Owing to a lower river flow condition, thermal impacts are more extensive for both average summer and fall seasons. Due to the jet-type discharge, the Waterford 3 plume under those conditions is expected to penetrate across the river channel and join with the Little Gypsy thermal plume during these seasons (see Figures A-14 and A-15). However, since the jet-type discharge promotes rapid initial mixing of heated water, the Waterford 3 contribution to the total thermal field is expected to be small during the summer and fall seasons.

Figures A-18 and A-19 depict representative surface isotherms for the

Waterford 1 and 2 and Little Gypsy discharges observed during the 1976 field surveys on September 9 and 10, respectively. These distributions were assumed to be the existing thermal impacts under the typical low river flow conditions. The predicted thermal impacts of the Waterford 3 discharge were added to the existing thermal field to produce the combined surface field shown in Figures A-16 and A-17. A comparison of Figures A-16 through A-19 shows that the extent of the Waterford 3 discharge contribution to the combined thermal field is relatively small.

Figure A-21 depicts a cross-section of the river at the Little Gypsy discharge canal and includes isotherms of excess temperature for the low river flow conditions. As shown, the proportion of the cross-section occupied by isotherms of 5^{o}F or more is small, and the effect is restricted to a shallow surface layer. The cross-sectional distributions for average seasonal conditions display similar features.

5.4 COMPARISON WITH EARLIER PREDICTIONS

Previous thermal predictions at Waterford were performed during preparation of the Construction Permit Environmental Report in 1972-1973, and were based on field data from surveys taken during the period 1970-1973.

Table A-13 shows a comparison of maximum plume dimensions for the combined field obtained from this study and those prepared in 1972 for the Construction Permit Environmental Report (Supplement 3). From the Table, the revised models predict the thermal distribution to be located in a shallower surface

region than before, which results in a smaller river cross-section affected and a larger surface plume.

The differences can be generally ascribed to a revised modeling approach that used recently developed solution techniques, and availability of a larger data base. For the case of Little Gypsy, where plume size differences were largest, the additional field survey data covered a much wider range of river and plant discharge conditions. As a result, it was observed that the Little Gypsy plume behavior was very responsive to changes in river flow rate and meteorological conditions.

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TABLE A-1

CHARACTERISTICS OF THERMAL PLUMES MEASURED IN PREVIOUS SURVEYS
OF THE WATERFORD 1 AND 2 AND LITTLE GYPSY DISCHARGES

		River Conditions			Plant Conditions During Survey		Isotherm Characteristics											
							10° F Isotherm						5° F Isotherm					
Date	Plant	River Flow (cfs)	River Stage (ft)	X-Sectional Area (ft^2)	Discharge Flow (cfs)	Discharge ΔT (°F)	Xmd (ft)	Xmu (ft)	Ym (ft)	X-Sectional Area (ft^2)	% of River X-Section	Surface Area (Ac)	Xmd (ft)	Xmu (ft)	Ym (ft)	X-Sectional Area (ft^2)	% of River X-Section	Surface Area (Ac)
9/28/70	L G	275,000	4.4	14.25×10^4	1,448.2	23.2	870	240	690	N A	N A	11.7	2,340	360	840	N A	N A	43.0
7/31/73	L G	380,000	6.1	14.5×10^4	1,448.2	16.6	700	100	250	350	0.24	1.8	1,350	100	400	1,090	0.75	8.0
11/02/74	L G	210,000	3.0	14.0×10^4	1,285.7	17.0	280	200	400	1,770	1.2	2.4	1,400	230	840	3,450	2.4	7.1
9/09/76	L G	205,000	2.3	14.0×10^4	1,448.2	21.7	1,600	370	800	1,540	1.1	34.8	6,600	420	1,400	4,230	3.0	188.0
9/10/76	L G	200,000	2.2	14.0×10^4	1,448.2	21.0	1,500	350	700	700	0.5	22.8	2,700	450	1,200	2,930	2.1	54.0
8/04/77	L G	260,000	3.4	14.0×10^4	1,451.0	19.7	700	400	820	3,888	2.8	17.4	1,450	420	1,000	7,850	5.6	38.3
8/05/77	L G	260,000	3.4	14.0×10^4	1,451.0	19.8	1,400	330	750	4,000	2.9	26.5	4,560	400	900	8,400	6.0	90.6
8/09/77	L G	270,000	3.5	14.1×10^4	1,451.0	21.5	1,260	800	670	3,100	2.2	23.6	3,800	920	950	4,113	2.9	66.7
11/02/74	W1 and 2	210,000	3.0	14.0×10^4	481.2	16.5	N A	N A	N A	N A	N A	N A	N A	N A	N A	N A	N A	N A
9/09/76	W1 and 2	205,000	2.3	14.0×10^4	962.5	19.5	N A	N A	N A	N A	N A	N A	3,200	2,500	500	N A	N A	N A
9/10/76	W1 and 2	200,000	2.2	14.0×10^4	962.5	19.25	1,000	N A	350	N A	N A	N A	1,500	1,000	400	N A	N A	N A
8/04/77	W1 and 2	260,00	3.4	15.6×10^4	958.0	19.4	900	150	313	313	0.2	3.1	1,160	240	500	625	0.4	9.2
8/05/77	W1 and 2	260,000	3.4	15.6×10^4	958.0	19.2	850	0	250	250	0.2	3.0	1,080	1,060	330	500	0.3	12.9
8/09/77	W1 and 2	270,000	3.5	15.7×10^4	958.0	19.7	890	0	1,625	1,625	1.0	3.6	1,100	1,180	390	488	0.3	13.5

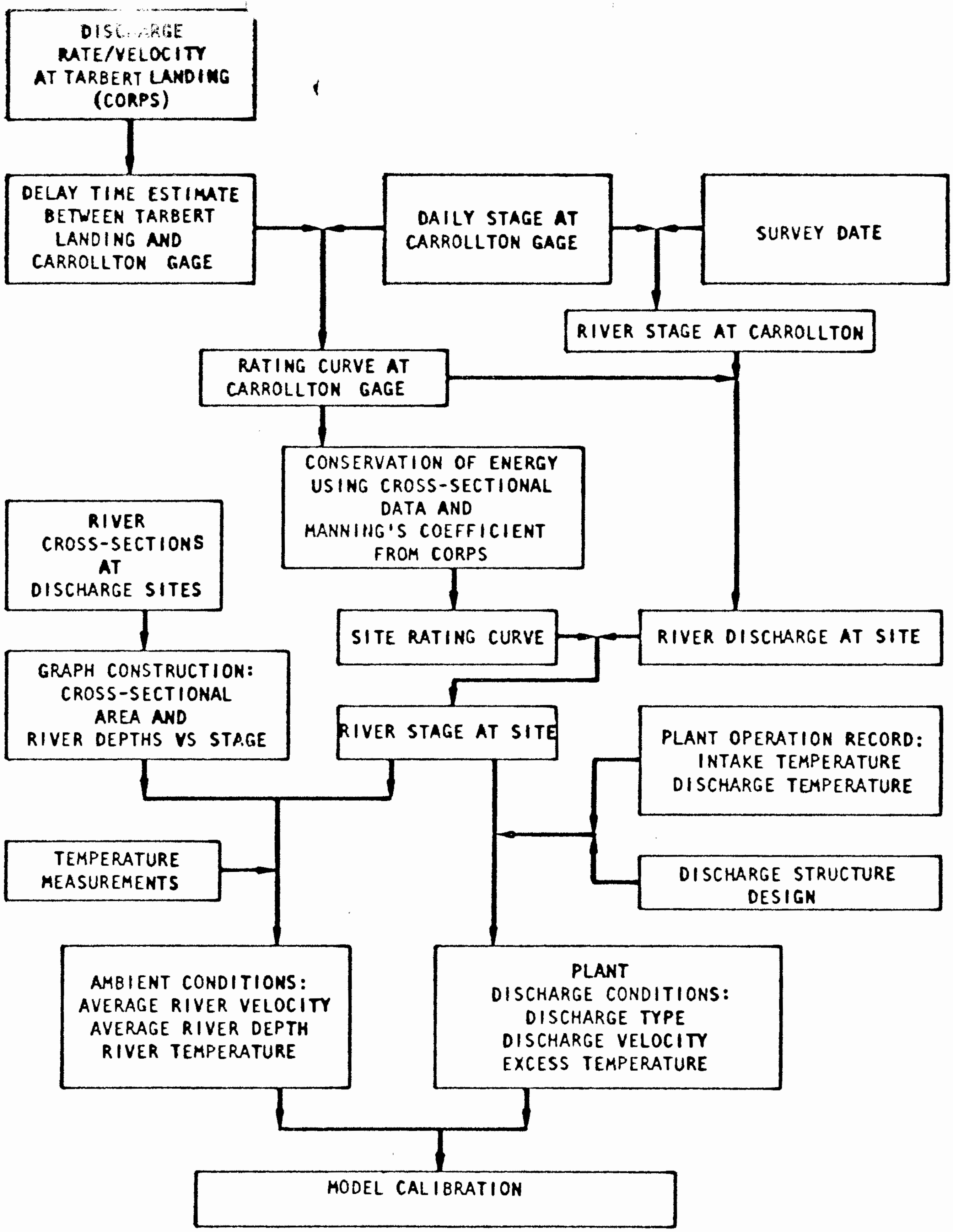
N A - Not Available
L G - Little Gypsy 1, 2 and 3
W1 and 2 - Waterford 1 and 2
Xmd - Downstream Extent
Xmu - Upstream Extent
Ym - Lateral Extent
Ac - Acre

TABLE A-1 (Cont'd)

CHARACTERISTICS OF THERMAL PLUMES MEASURED IN PREVIOUS SURVEYS
OF THE WATERFORD 1 AND 2 AND LITTLE GYPSY DISCHARGES

		Isotherm Characteristics											
		3.6°F Isotherm						1.5 F° Isotherm					
Date	Plant	Xmd (ft)	Xmu (ft)	Ym (ft)	X-Sectional Area (ft^2)	% of River X-Section	Surface Area (Ac)	Xmd (ft)	Xmu (ft)	Ym (ft)	X-Sectional Area (ft^2)	% of River X-Section	Surface Area (Ac)
9/28/70	L G	3,510	450	1,080	N A	N A	83.7	4,560	570	1,860	N A	N A	158.8
7/31/73	L G	2,600	100	850	3,930	2.7	36.7	9,700	200	2,450	7,890	5.4	263.8
11/02/74	L G	3,800	280	1,000	4,320	3.0	22.9	5,230	280	1,040	10,600	7.4	90.6
9/09/76	L G	8,000	550	1,500	4,930	3.5	266.3	N A	N A	N A	N A	N A	N A
9/10/76	L G	3,200	550	1,300	3,770	2.7	70.8	5,200	600	2,000	5,420	3.9	134.3
8/04/77	L G	2,420	470	1,130	8,125	5.8	52.1	3,550	450	1,340	10,025	7.2	81.6
8/05/77	L G	6,500	400	920	9,050	6.5	113.3	N A	490	1,150	11,500	8.2	N A
8/09/77	L G	6,200	910	1,000	4,250	3.0	118.0	N A	1,050	1,130	N A	N A	N A
11/02/74	W1 and 2	N A	N A	N A	N A	N A	N A	1,800	800	440	N A	N A	7.3
9/09/76	W1 and 2	4,900	2,950	800	N A	N A	N A	5,400	5,300	900	2,480	1.7	139.1
9/10/76	W1 and 2	4,000	1,100	500	N A	N A	N A	7,700	1,700	600	5,190	3.6	48.0
8/04/77	W1 and 2	1,280	1,250	520	975	0.6	17.7	1,570	1,420	630	2,700	1.7	27.0
8/05/77	W1 and 2	1,200	1,080	360	1,625	1.0	13.8	4,600	2,040	520	3,350	2.1	59.0
8/09/77	W1 and 2	1,300	1,630	350	1,300	0.8	19.7	1,400	2,220	450	4,575	2.9	29.3

N A - Not available
L G - Little Gypsy 1, 2 and 3
W1 and 2 - Waterford 1 and 2
Xmd - Downstream Extent
Xmu - Upstream Extent
Ym - Lateral Extent
Ac - Acre



LOUISIANA POWER & LIGHT Co. Waterford Steam Electric Station	FLOW DIAGRAM: INPUT DATA COMPUTATIONS FOR MODEL CALIBRATION	TABLE A - 2

TABLE A-3

COMPARISON OF MATHEMATICAL MODEL CHARACTERISTICS

		PDS Model	Edinger/Polk Model
Field		Nearfield	Farfield
Dimensions Included	Longitudinal	Yes	Yes
	Lateral	Yes	Yes
	Vertical	Yes	Yes
Mathematical Approach		Integral	Analytical
Model Assumptions		Steady State	Steady State
		Free Jet	Semi-infinite Medium
		Homogeneous & Uniform Ambient Flow	Homogeneous & Uniform Ambient Flow
		No Wind Effects	Continuous Point Source
Model Verification		Calibrated by EPA Against Laboratory and Field Data	Calibrated with the Site Specific Field Data

TABLE A-4

COMPARISON BETWEEN PREDICTED AND OBSERVED THERMAL PLUME CHARACTERISTICS ON SEPTEMBER 9, 10 OF 1976 - LITTLE GYPSY EDINGER/POLK MODEL

Δt (°F)	y_m (Ft)	x_m (Ft)	A_c (Ft^2)	A_s (Acres)	Predicted/ Observed
5	1536 - 1587	9248 - 9876	7766 - 8024	266 - 294	Predicted
	1200 - 1400	3150 - 7020	2930 - 4230	54 - 188	Observed
10	1086 - 1122	4624 - 4938	3861 - 4077	94 - 104	Predicted
	700 - 800	1850 - 1970	700 - 1540	23 - 35	Observed

y_m: Maximum Lateral Extent

x_m: Maximum Longitudinal Extent

A_c: Maximum Cross-Sectional Area

A_s: Surface Area

TABLE A-5

COMPARISON BETWEEN PREDICTED AND OBSERVED THERMAL PLUME CHARACTERISTICS ON SEPTEMBER 9, 10 OF 1976 - WATERFORD 1 AND 2 EDINGER/POLK MODEL

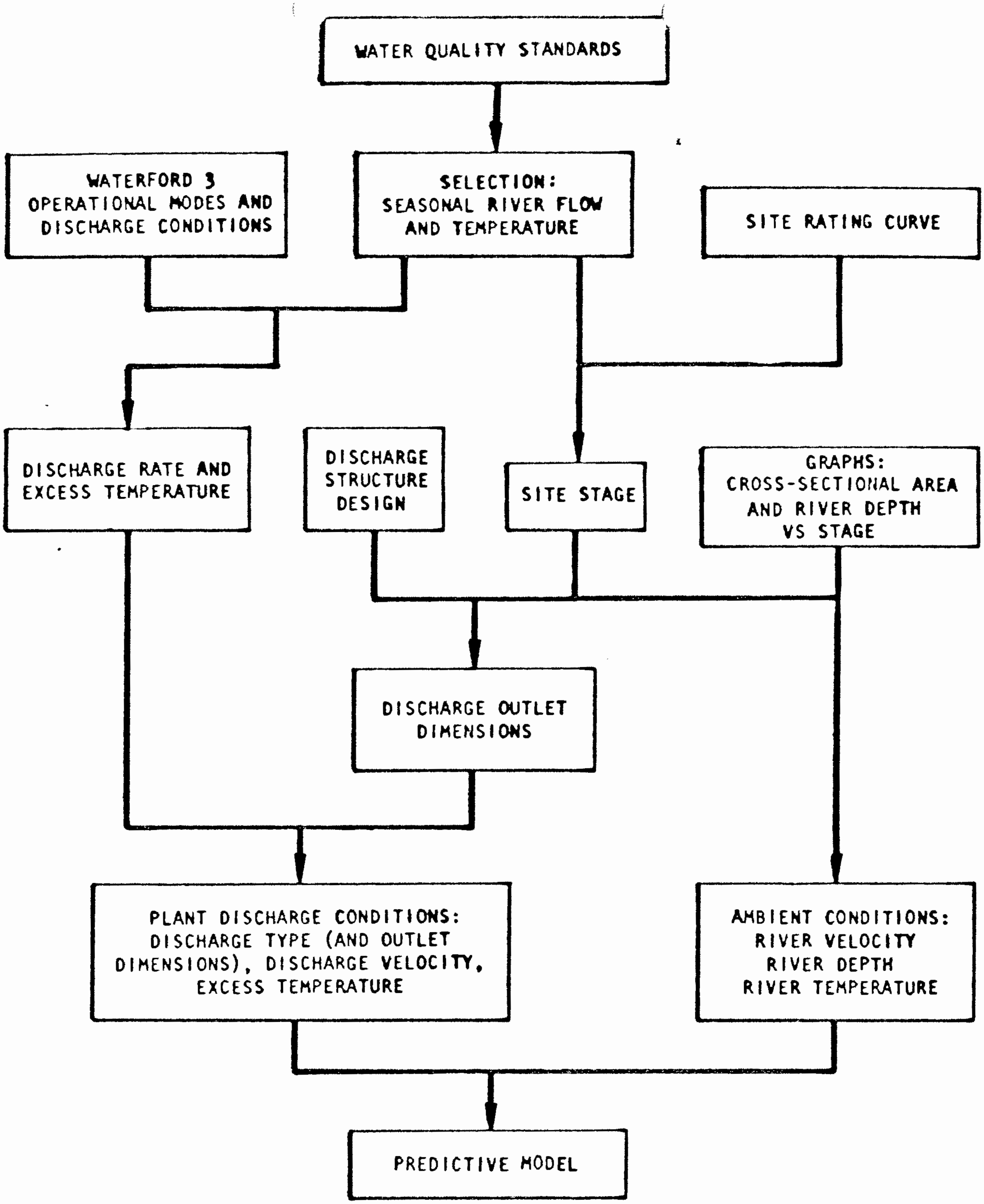
Δt (^oF)	y_m (Ft)	x_m (Ft)	A_c (Ft^2)	A_s (Acres)	Predicted/ Observed
1.5	1,307	10,267	6,608	252	Predicted
	600 - 900	5400 - 7700	2480 - 5190	48 - 139	Observed
5	716	3,080	1,980	41	Predicted
	400 - 500	1500 - 3200	---	---	Observed

y_m: Maximum Lateral Extent

x_m: Maximum Longitudinal Extent

A_c: Maximum Cross-Sectional Area

A_s: Surface Area



LOUISIANA POWER & LIGHT Co.
Waterford Steam Electric Station

FLOW DIAGRAM: INPUT DATA FOR PREDICTION

TABLE A-6

TABLE A-7

INPUT AND EXISTING CONDITIONS FOR THERMAL ANALYSIS
TYPICAL LOW FLOW CONDITIONS OF ABOUT 205,000 CFS

A. River Conditions

River Discharge Rate (cfs)	River Site Stage (Ft)	Average River Temp (^oF)	River X-Sec Area ($10^4 Ft^2$)			River Flow Velo. (fps):V_a		
			LG	W1 and 2	W3	LG	W1 and 2	W3
205,000	2.3	85	14	14.5	17.1	1.5	1.4	1.2

B. Plant Discharge Conditions

Discharge Rate (cfs)			Velocity: V_j (fps)		Velocity Ratio (V_j/V_a)		Outlet Depth (Ft)		Outlet Width (Ft)		Excess Temp (^oF)		
LG	W1 and 2	W3	LG	W3	LG	W3	LG	W3	LG	W3	LG	W1 and 2	W3
1648	963	2235	2.4	6.1	1.6	5.1	8.3	7.3	72.6	50	21.7	19.5	16.1

LG: At Little Gypsy Discharge
W1 and 2: At Waterford 1 and 2 Discharge
W3: At Waterford 3 Discharge

TABLE A-8

INPUT CONDITIONS FOR THERMAL ANALYSIS - AVERAGE FLOW CONDITIONS

A. River Conditions

Season	Average River Discharge Rate (cfs)	Site River Stage (Ft)	Average River Temp* (^{o}F)	River X-Sec Area($10^4 Ft^2$)			River Flow Vel. (fps):V_a		
				LG	W 1 and 2	W3	LG	W 1 and 2	W3
Winter	580,000	10.4	47.7	15.3	17.5	19.0	3.8	3.3	3.1
Spring	650,000	11.8	69.7	15.7	17.8	19.2	4.1	3.7	3.4
Summer	280,000	4.0	84.3	14.2	15.9	17.5	2.0	1.8	1.6
Fall	240,000	3.0	63.0	14.0	15.2	17.2	1.7	1.6	1.4

B. Plant Discharge Conditions

Season	Discharge Rate (cfs)			Velocity: V_j (fps)		Velocity Ratio (V_j/V_a)		Outlet Depth (Ft)		Outlet Width (Ft)		Excess Temp (^{o}F)		
	LG	W 1 and 2	W3	LG	W3	LG	W3	LG	W3	LG	W3	LG	W 1 and 2	W3
Winter	1444	956	1384	1.1	1.8	0.29	0.58	16.4	15.4	81.5	50	18.4	19	26.0
Spring	1444	956	2114	0.9	1.9	0.22	0.57	17.8	16.8	91.6	65	18.4	19	17.0
Summer	1444	956	2235	1.9	5.0	1.0	3.1	10.0	9.0	76.0	50	18.4	19	16.1
Fall	1444	956	1831	2.2	4.6	1.3	3.3	9.0	8.0	74.0	50	18.4	19	19.7

LG: At Little Gypsy Discharge

W 1 and 2 : At Waterford 1 and 2 Discharge

W3: At Waterford 3 Discharge

* Based on temperature data taken at Ninemile Point Generating Station, Westwego, Louisiana, 1951-1969, given in Table 2.4-14.

TABLE A-9

COMPARISON OF INDIVIDUAL THERMAL DISCHARGE IMPACTS - ZONES OF EXCESS TEMPERATURE EXCEEDING $10^{o}F$
TYPICAL LOW RIVER FLOW CONDITIONS OF 200,000 CFS

Survey Date	Longitudinal Spread (ft)			Lateral Spread (ft)			Surface Area (acres)			Maximum X-Section Area (ft^{2})			% of the River X-Section Area		
	L G	W 1&2	W 3	L G	W 1&2	W 3	L G	W 1&2	W 3	L G	W 1&2	W 3	L G	W 1&2	W 3
9/ 9/76	1,970	-	40	800	-	179	34.8	-	0.2	1,540	-	347	1.1	-	0.2
9/10/76	1,850	1,000	38	700	350	177	22.8	-	0.2	700	-	342	0.5	-	0.2

L G - Little Gypsy Discharge

W 1&2 - Waterford 1 and 2 Discharge

W 3 - Waterford 3 Discharge

Note: For Waterford 1 and 2 and Little Gypsy, thermal discharge impacts were extrapolated from field survey data obtained during the typical low flow condition. The PDS model was used for Waterford 3 predictions. No entry indicates little or no excess temperatures exceeding $10^{o}F$.

TABLE A-10

COMPARISON OF INDIVIDUAL THERMAL DISCHARGE IMPACTS - ZONES OF EXCESS TEMPERATURES EXCEEDING 5°F
TYPICAL LOW RIVER FLOW CONDITIONS OF 200,000 CFS

Survey Date	Longitudinal Spread (ft)			Lateral Spread (ft)			Surface Area (acres)			Maximum X-Section Area (ft²)			% of the River X-Section Area		
	L G	W 1&2	W 3	L G	W 1&2	W 3	L G	W 1&2	W 3	L G	W 1&2	W 3	L G	W 1&2	W 3
9/ 9/76	7,020	5,700	325	1,400	500	524	188	-	1.9	4,230	-	1,287	3.0	-	0.8
9/10/76	3,150	2,500	316	1,200	400	525	54	-	1.9	2,930	-	1,277	2.1	-	0.7

L G - Little Gypsy Discharge

W 1&2 - Waterford 1 and 2 Discharge

W 3 - Waterford 3 Discharge

Note: For Waterford 1 and 2 and Little Gypsy, thermal discharge impacts were extrapolated from field survey data obtained during the typical low flow condition. The PDS model was used for Waterford 3 predictions. No entry indicates little or no excess temperatures exceeding 5°F.

TABLE A-11

COMBINED THERMAL IMPACTS OF WATERFORD 1, 2 AND 3 AND LITTLE GYPSY DISCHARGES

	10°F							5°F							3.6°F						
Season	Zm (ft)	Xm (ft)	Ym (ft)	Tm (1,000 sec)	Ac/Ar (%)	Vol (Aft)	As (Ac)	Zm (ft)	Xm (ft)	Ym (ft)	Tm (1,000 sec)	Ac/Ar (%)	Vol (Aft)	As (Ac)	Zm (ft)	Xm (ft)	Ym (ft)	Tm (1,000 sec)	Ac/Ar (%)	Vol (Aft)	As (Ac)
Predicted	Average Seasonal River Flow Conditions (see Table A-8, Appendix A-1, for the Definition)																				
Winter	6.0	1,800	635	2.0	1.5	14.7	28	7.0	4,000	1,000	3.8	3.0	73	87	8.5	5,700	1,400	5.3	4.8	154	137
Spring	3.4	1,900	610	1.8	0.9	12.0	27	4.8	3,400	1,150	4.8	2.2	59	73	5.6	5,000	1,400	5.4	3.4	124	126
Summer	6.8	3,000	870	6.5	2.2	89.0	59	9.9	6,200	1,700	14.0	4.5	472	174	11.1	8,400	Wr	20.3	8.0	1,136	367
Fall	7.1	3,600	1,000	9.7	2.6	132.0	81	9.7	7,600	1,700	20.6	6.6	852	257	11.0	10,800	Wr	31.8	10.0	1,897	459
Survey	Typical Low River Flow Conditions of 200,000 cfs																				
9/9/76	3.0	2,700	1,100	7.7	1.1	<150.0	50	8.0	7,200	Wr	24.0	4.2	<1,752	219	11.0	8,900	Wr	30.0	5.5	3,641	331
9/10/76	2.5	1,850	700	6.0	0.7	<63.0	25	12.0	3,300	1,300	10.0	2.2	<888	74	14.0	5,300	1,400	17.0	2.7	1,694	121

Zm = Maximum vertical spread
Xm = Maximum longitudinal spread
Ym = Maximum lateral spread
Tm = Maximum travel time (a particle drift time through the longest plume length)
Ac = Maximum cross-sectional area for a given excess temperature
Ar = Cross-sectional area of the river at Waterford 3 discharge location
Vol = Volume occupied by excess temperatures higher than that indicated
As = Surface area
Wr = River width (about 2,000 ft for average Summer/Fall seasons and for typical low flow seasons)
Aft = Acre-Ft (equals 43,560 ft^3)
Ac = Acre

TABLE A-12

COEFFICIENT FOR PREDICTIVE MODEL PARAMETERS

A. Diffusivities and Effective Convection Velocities

Lateral Diffusivity = Ky = $a_y\ uH^{5/6}$ (Ft^2/Sec)

Vertical Diffusivity = Kz = $a_z\ uH^{5/6}$ (Ft^2/Sec)

Effective Convection Velocity = $u_e = \beta u$ (FPS)

River Velocity = u (FPS)

River Mean Depth = H (Feet)

Plant	Coefficients a_y	a_z	β
Little Gypsy	0.92	0.00002	0.2
Waterford 1 & 2	1.63	0.00004	0.5
Waterford 3	0.29	0.00010	1.0

B. Upstream Wedge Intrusion at Little Gypsy Discharge

$$\text{Froude Number} = \frac{0.6u}{\sqrt{g\frac{\Delta\rho}{\rho a} Hw}}$$

Hw = Water depth at the Wedge = 25 + (River Stage -2.3) (Ft)

g = Gravity acceleration (Ft/Sec^2)

$\Delta\rho$ = Density difference between discharge and river water (lb/Ft^3)

ρ_a = River Water Density (lb/Ft^3)

L = Wedge length (Figure A-10) (Ft)

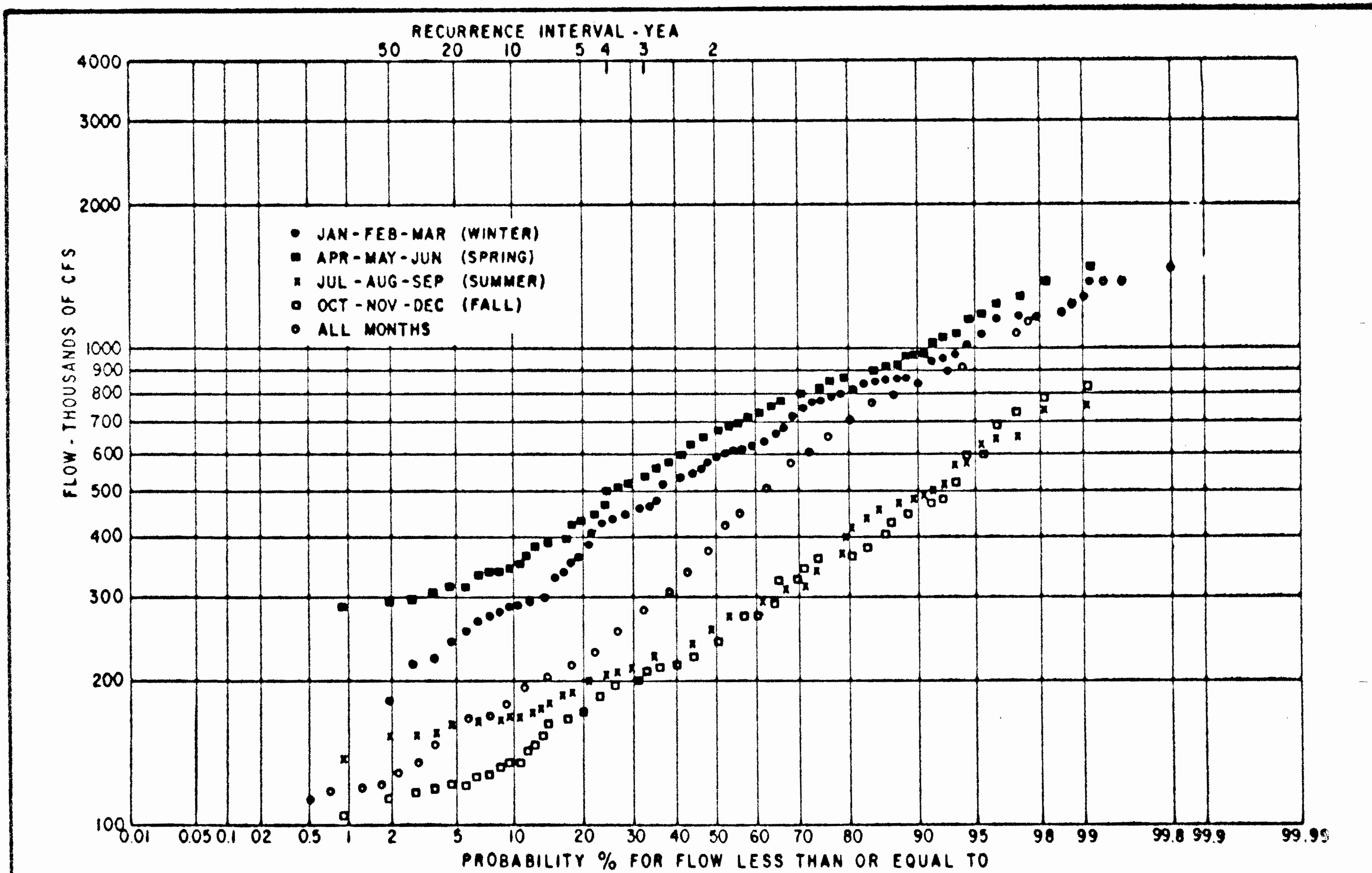
TABLE A-13

COMPARISON OF STUDY RESULTS WITH EARLIER PREDICTIONS
AT LOW RIVER FLOW CONDITIONS

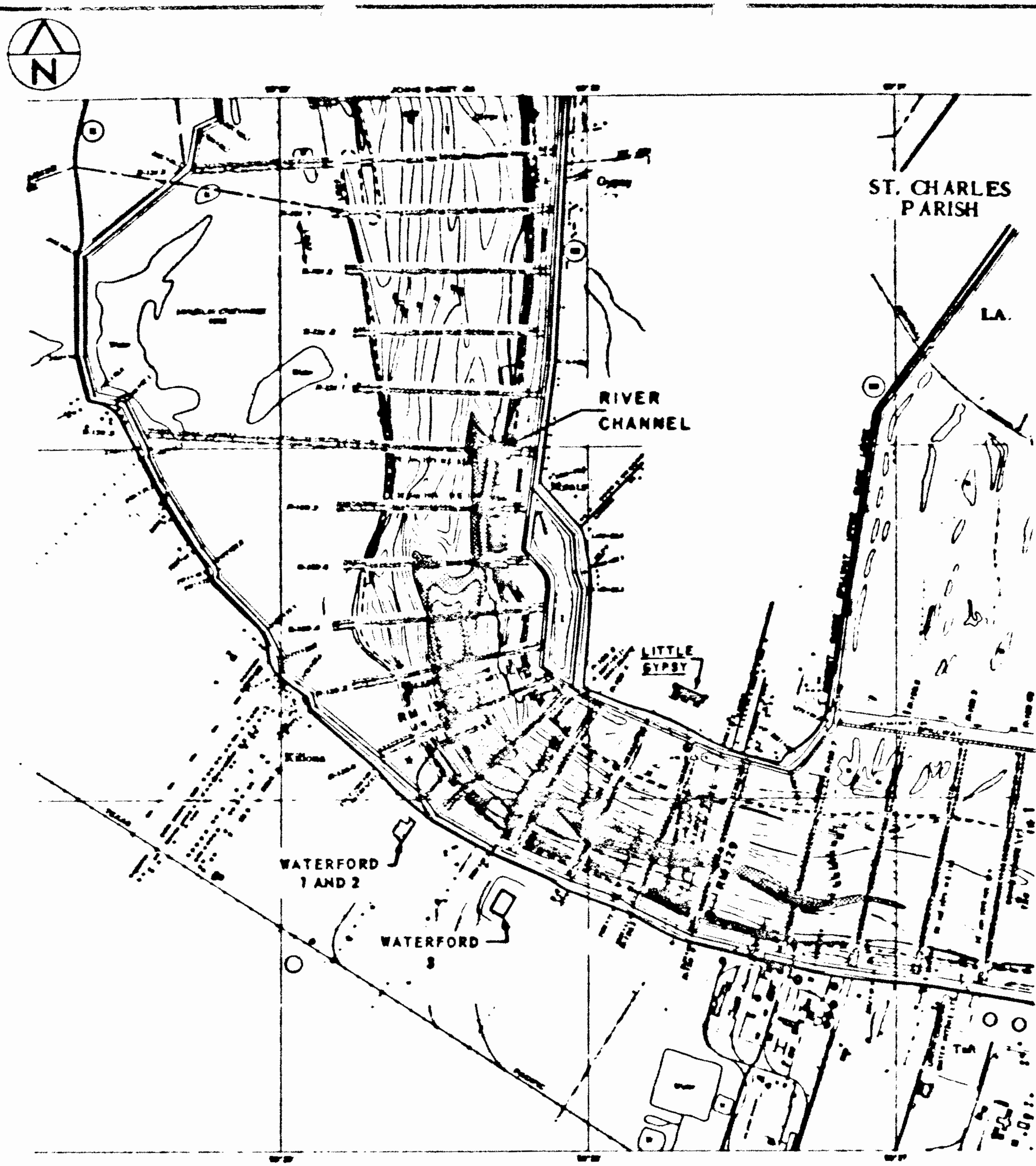
Isotherm of Excess Temperature, °F	Max Cross-Sectional Area Affected, %		Max Lateral Extent, ft		Max Longitudinal Extent, ft	
	OL-ER[1] Study	CP-ER[2] Study	OL-ER Study	CP-ER Study	OL-ER Study	CP-ER Study
5	4.2%	5%	1800	1800	7200	3800
10	1.1%	3%	1100	590	2700	900

[1] Operating License Stage Environmental Report

[2] Construction Permit Stage Environmental Report, Exhibits 22 through 24, Supplement 3, December, 1972.



LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	MISSISSIPPI RIVER FLOW STATISTICS – BASED ON AVERAGE MONTHLY FLOWS FOR PERIOD 1942 THROUGH 1976	Figure A–1

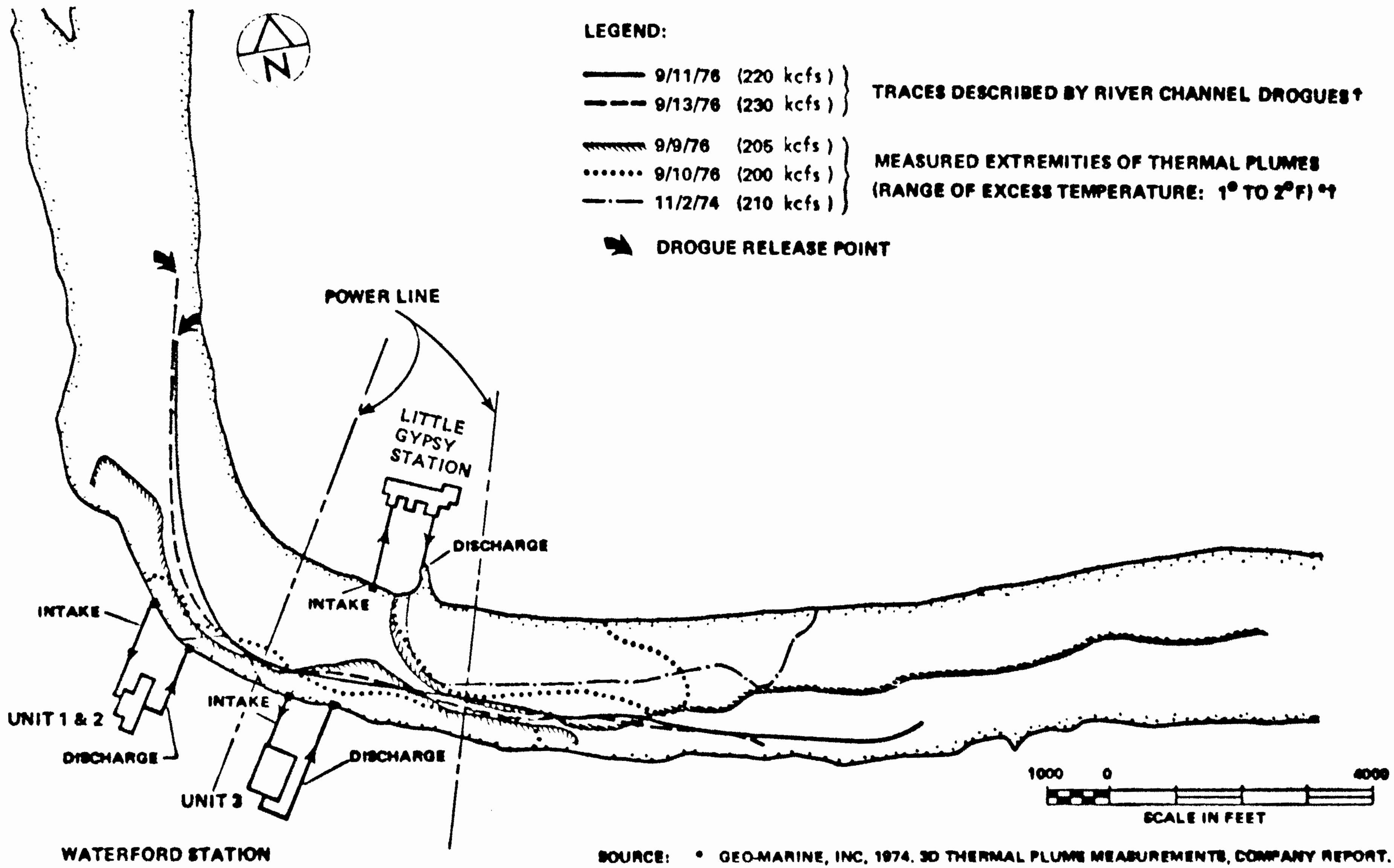


NOTE: SHADED AREA REPRESENTS DEPTHS GREATER THAN 100 ft

SCALE 1:20 000

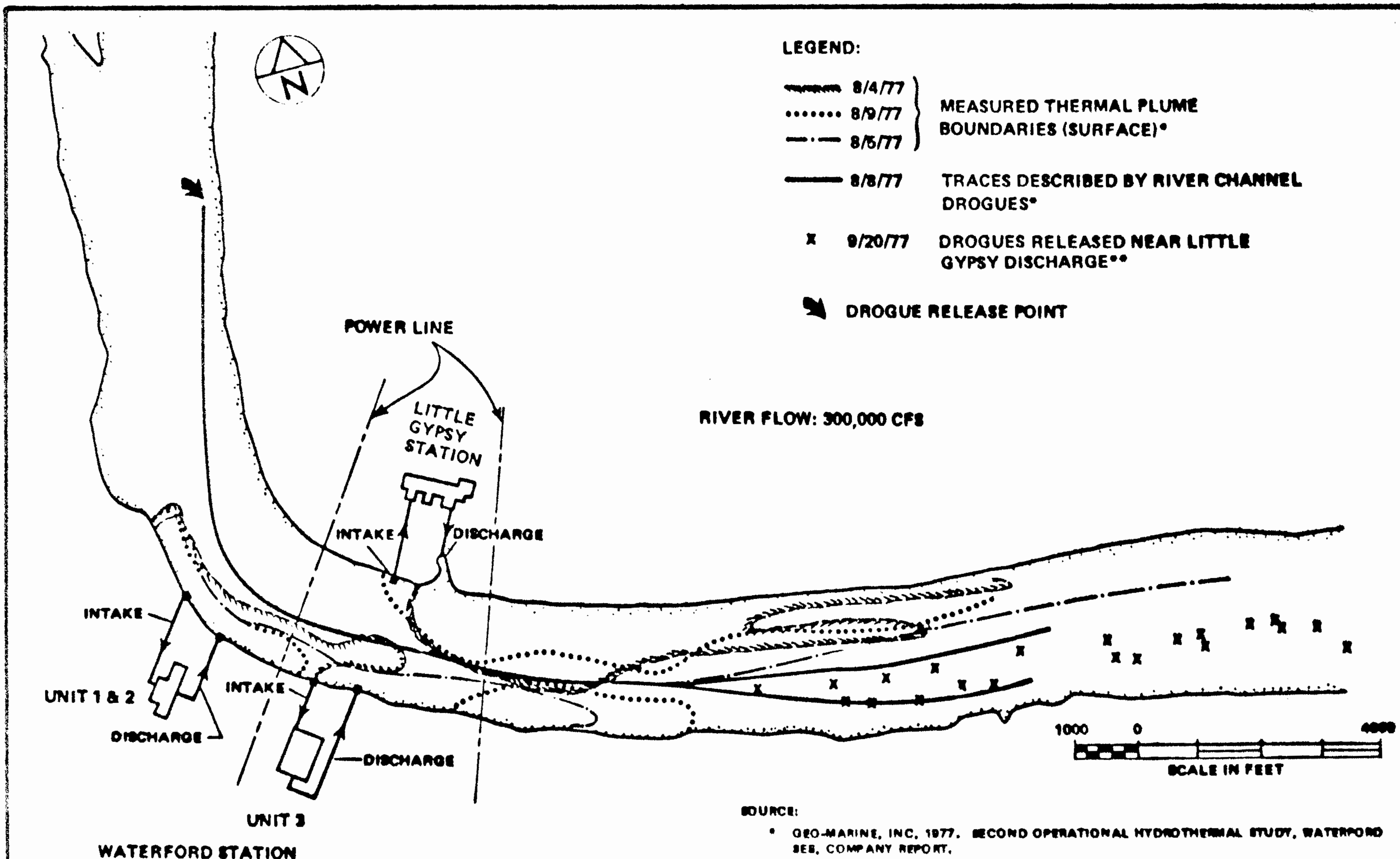
SOURCE: US ARMY CORPS OF ENGINEERS, NEW ORLEANS LA. "MISSISSIPPI RIVER HYDROGRAPHIC SURVEY - 1973 TO 1975 - BLACK HAWK, LA TO HEAD OF PASSES, LA" 1976.

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	MISSISSIPPI RIVER DEPTH CONTOURS AT WATERFORD	Figure A-2



SOURCE: * GEO-MARINE, INC. 1974. 3D THERMAL PLUME MEASUREMENTS, COMPANY REPORT.
† GEO-MARINE, INC. 1976. FIRST OPERATIONAL HYDROTHERMAL STUDY – WATERFORD SES, COMPANY REPORT.

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	SUMMARY OF DROGUE AND PLUME DATA FOR 200 KCFS RIVER DISCHARGE	Figure A-3

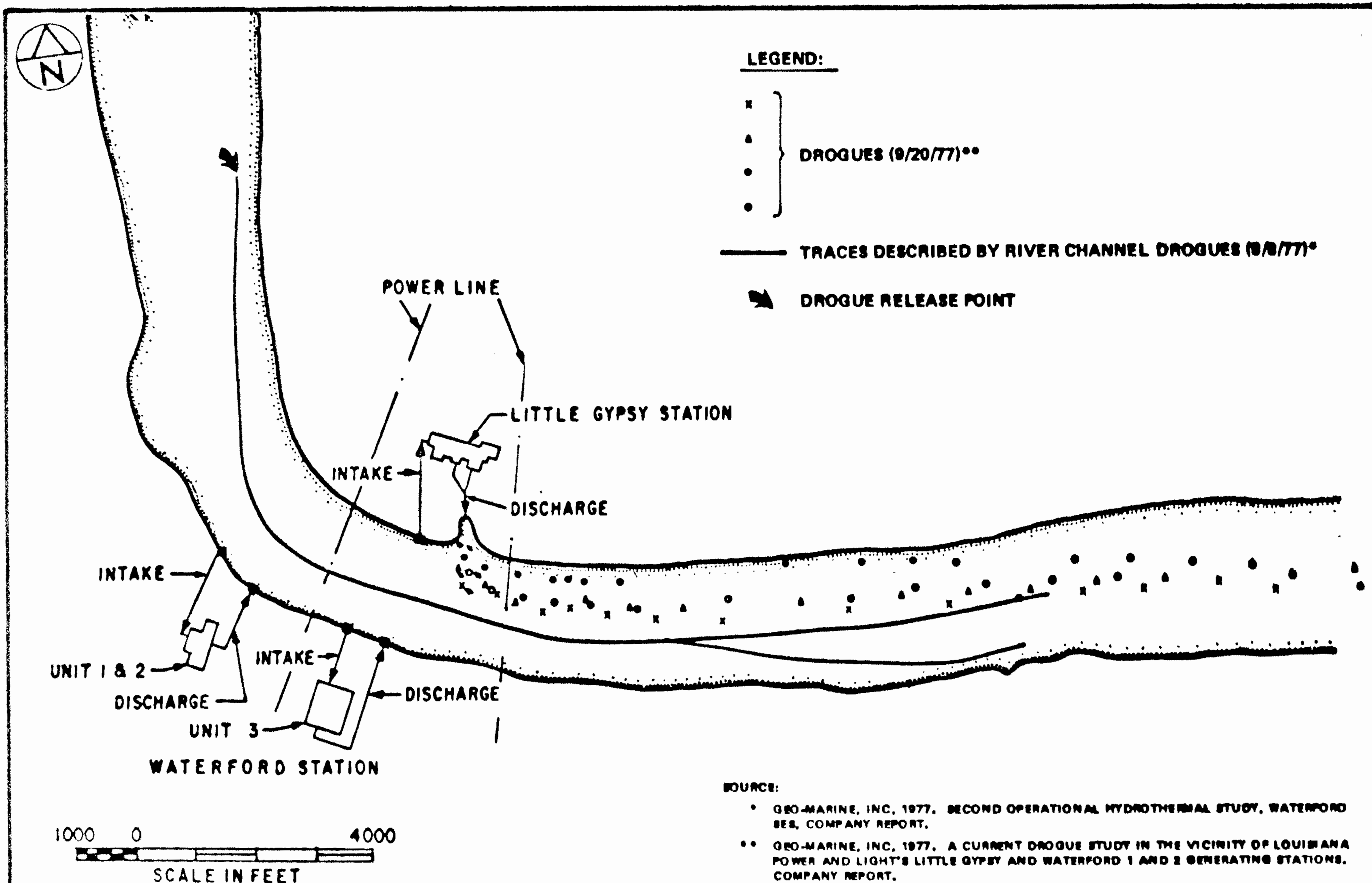


SOURCE:

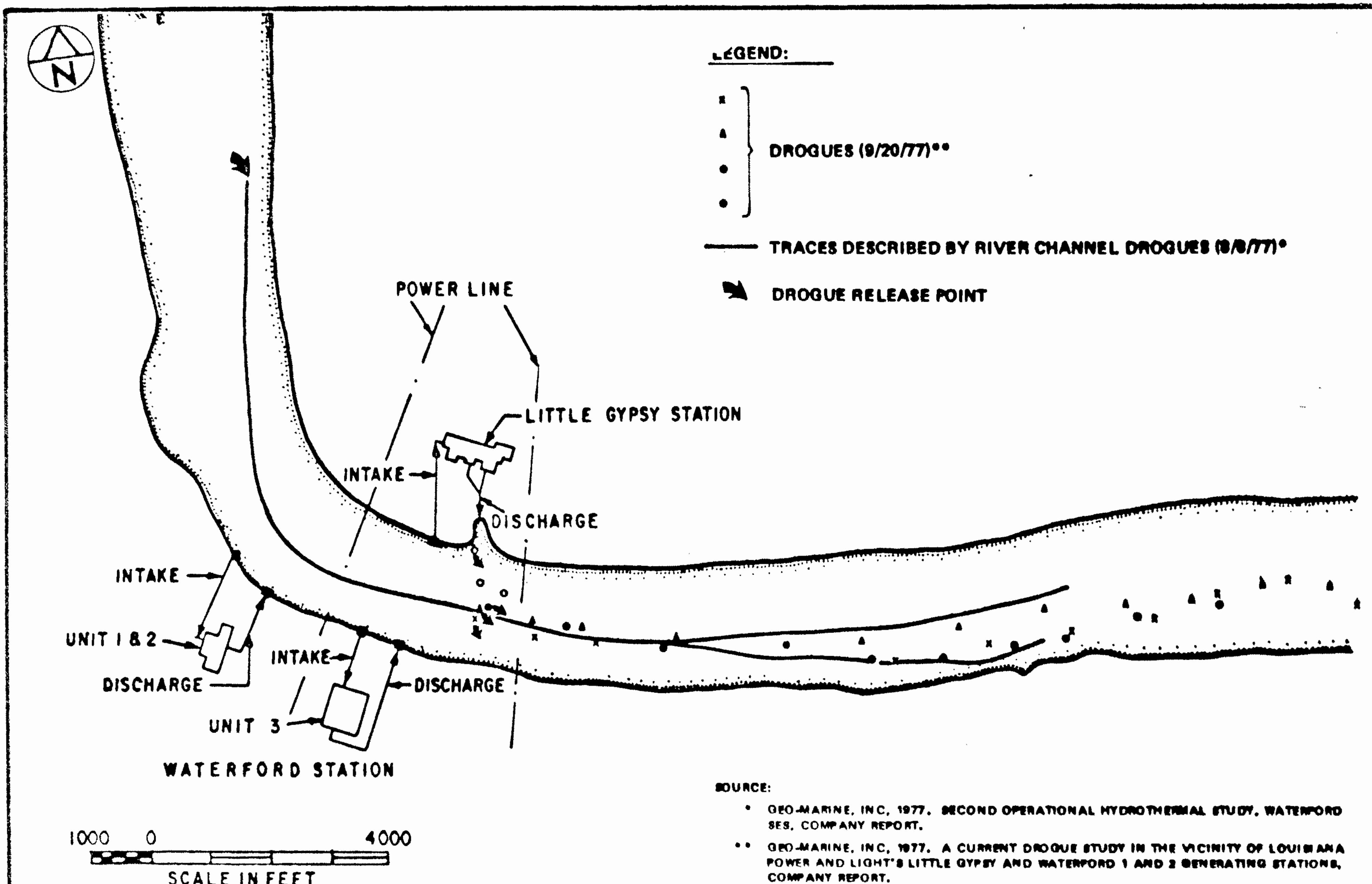
* GEO-MARINE, INC, 1977. SECOND OPERATIONAL HYDROTHERMAL STUDY, WATERFORD SES, COMPANY REPORT.

** GEO-MARINE, INC, 1977. A CURRENT DROGUE STUDY IN THE VICINITY OF LOUISIANA POWER AND LIGHT'S LITTLE GYPSY AND WATERFORD 1 AND 2 GENERATING STATIONS, COMPANY REPORT.

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	SUMMARY OF DROGUE AND PLUME DATA FOR 300 KCFS RIVER DISCHARGE	Figure A-4



LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	DROGUE STUDY RESULT #1 (10:35 – 13:07, SEPTEMBER 20, 1977)	Figure A–5

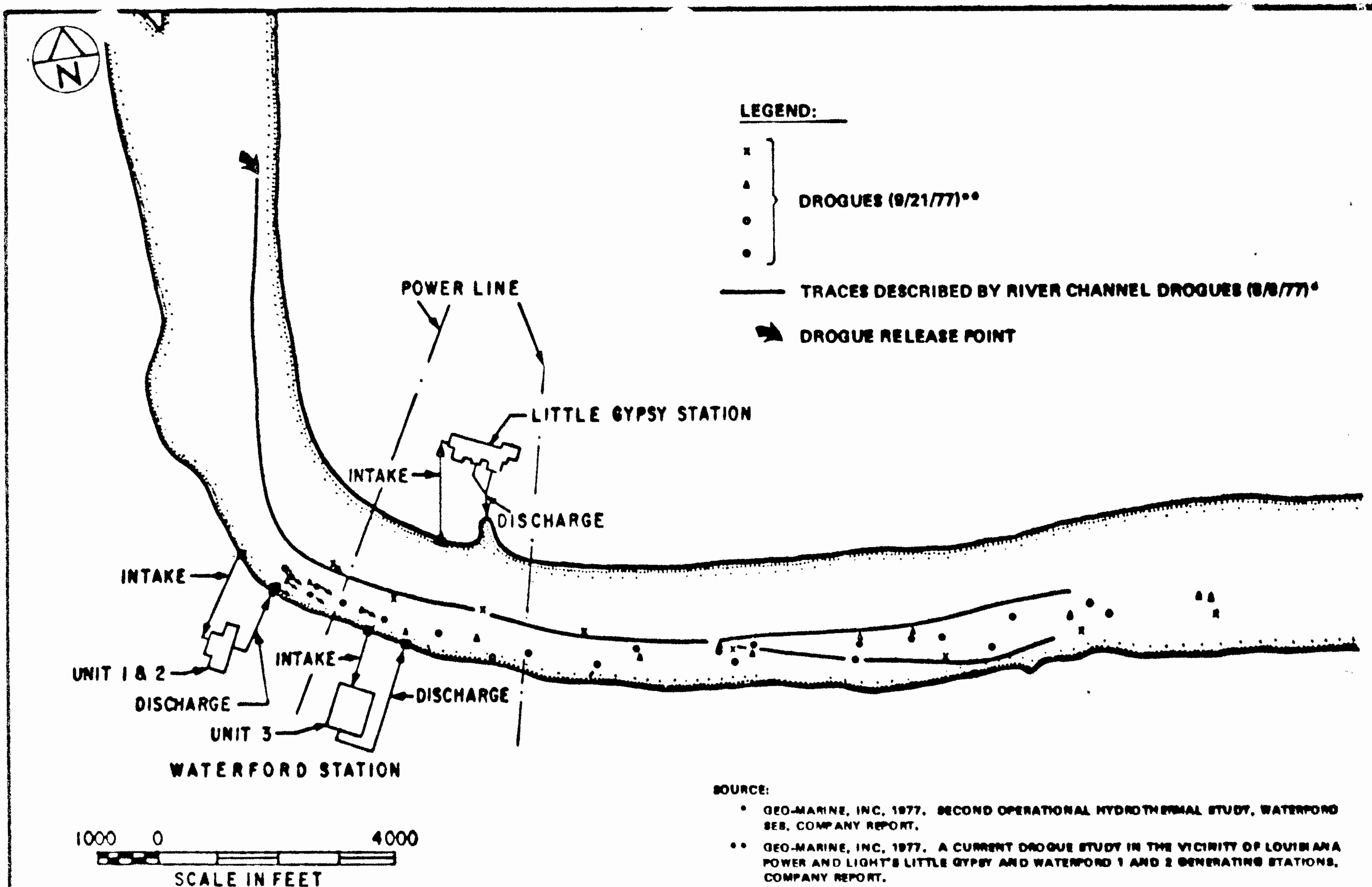


SOURCE:

* GEO-MARINE, INC, 1977. SECOND OPERATIONAL HYDROTHERMAL STUDY, WATERFORD SES. COMPANY REPORT.

** GEO-MARINE, INC, 1977. A CURRENT DROGUE STUDY IN THE VICINITY OF LOUISIANA POWER AND LIGHT'S LITTLE GYPSY AND WATERFORD 1 AND 2 GENERATING STATIONS. COMPANY REPORT.

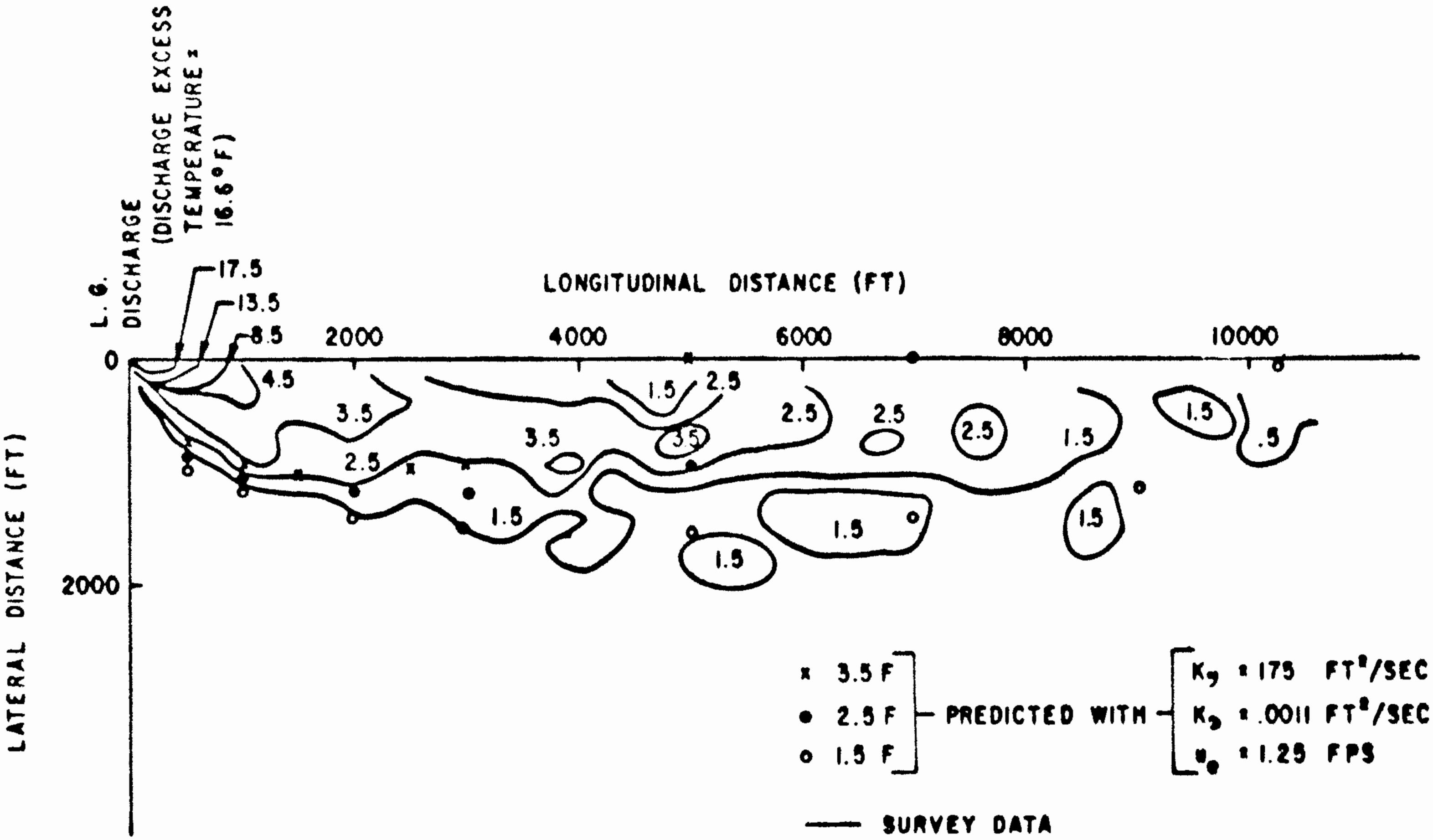
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	DROGUE STUDY RESULT #2 (14:10 – 16:35, SEPTEMBER 20, 1977)	Figure A–6



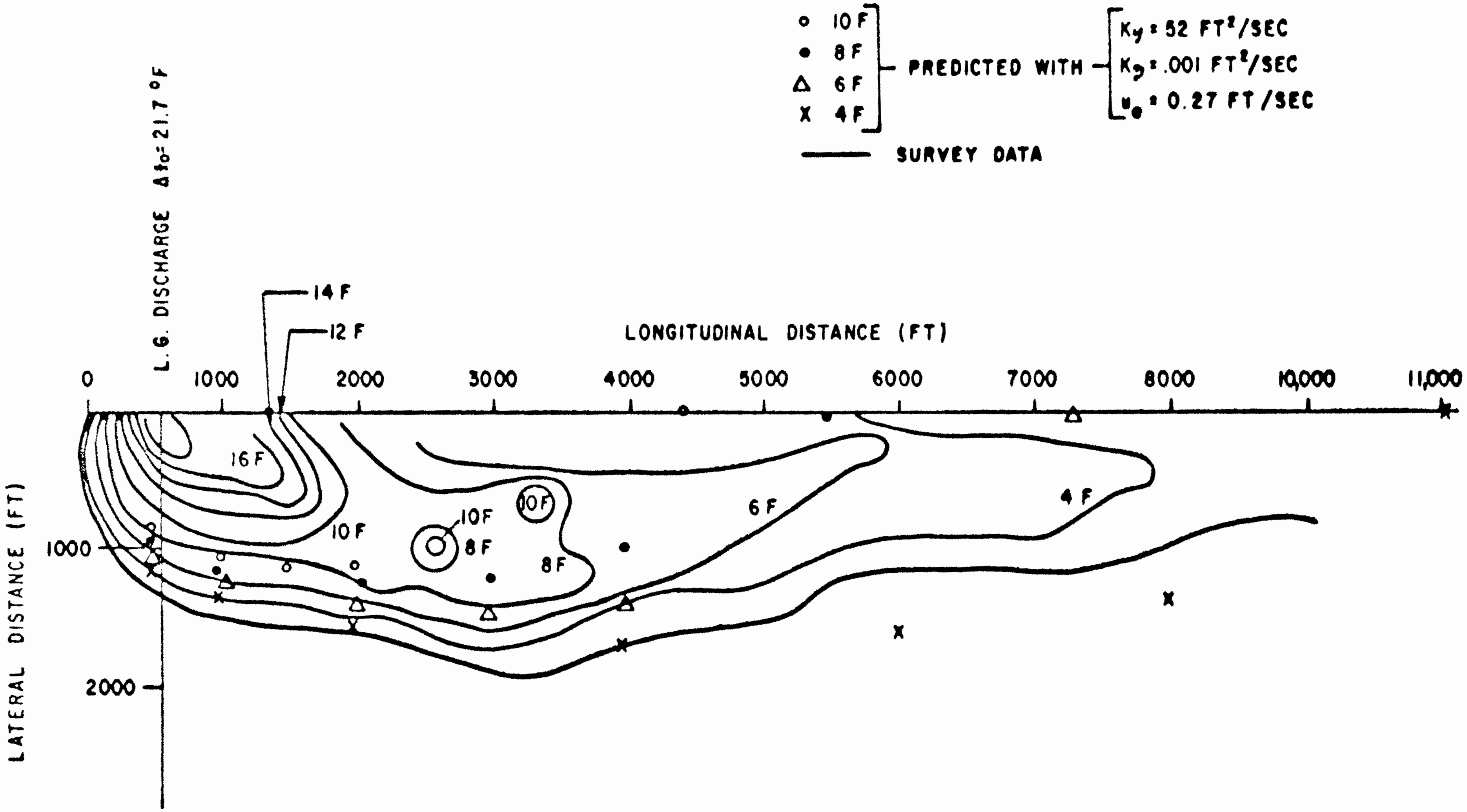
SOURCE:

* * GEO-MARINE, INC. 1977. SECOND OPERATIONAL HYDROTHERMAL STUDY, WATERFORD SES. COMPANY REPORT.
* ** GEO-MARINE, INC. 1977. A CURRENT DROGUE STUDY IN THE VICINITY OF LOUISIANA POWER AND LIGHT'S LITTLE GYPSY AND WATERFORD 1 AND 2 GENERATING STATIONS. COMPANY REPORT.

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	DROGUE STUDY RESULT #3 (15:11 – 17:33, SEPTEMBER 21, 1977)	Figure A–7



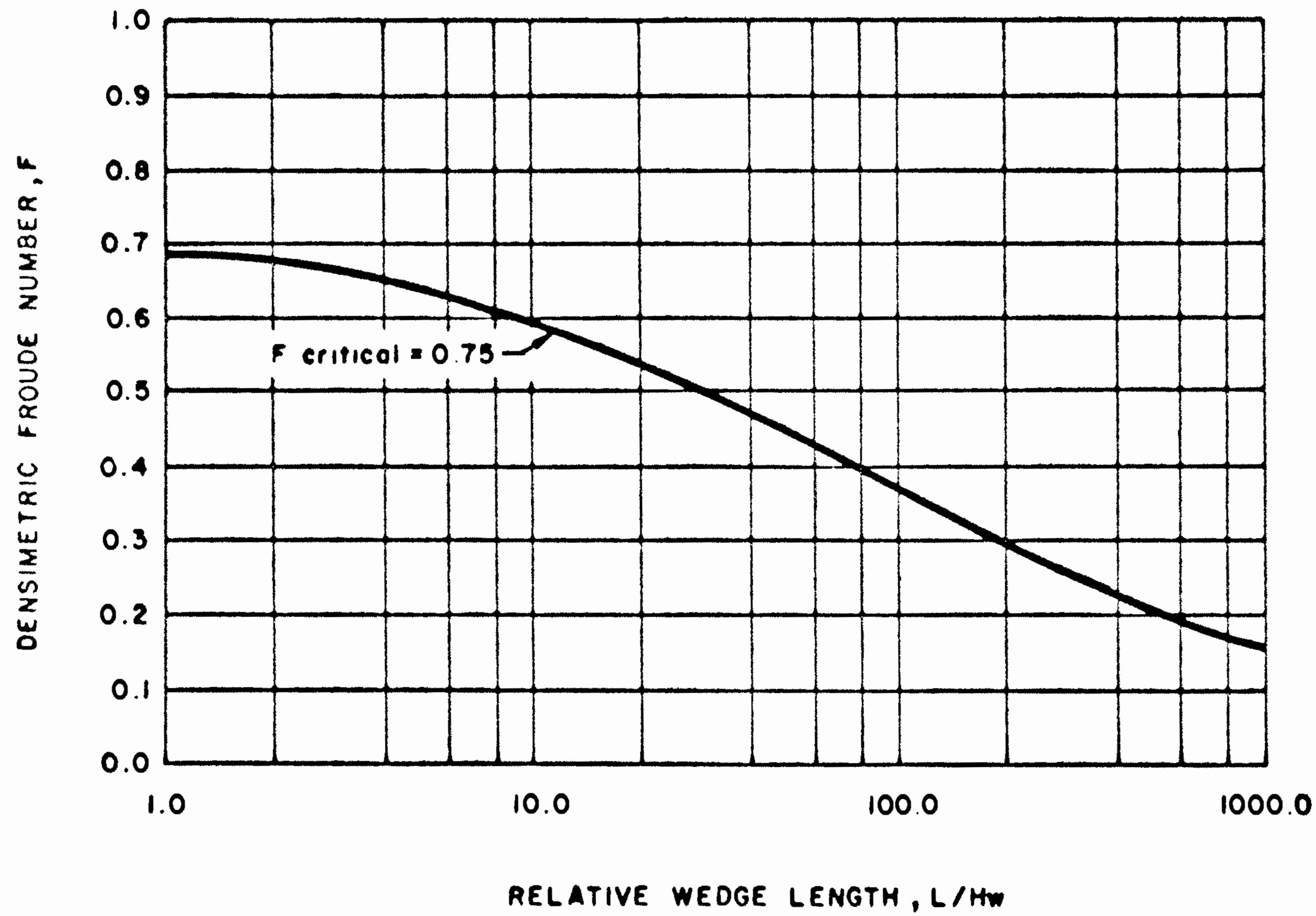
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	COMPARISON OF PREDICTED & OBSERVED (7/31/73) EXCESS SURFACE ISOTHERMS (°F) – LITTLE GYPSY SES	Figure A-8



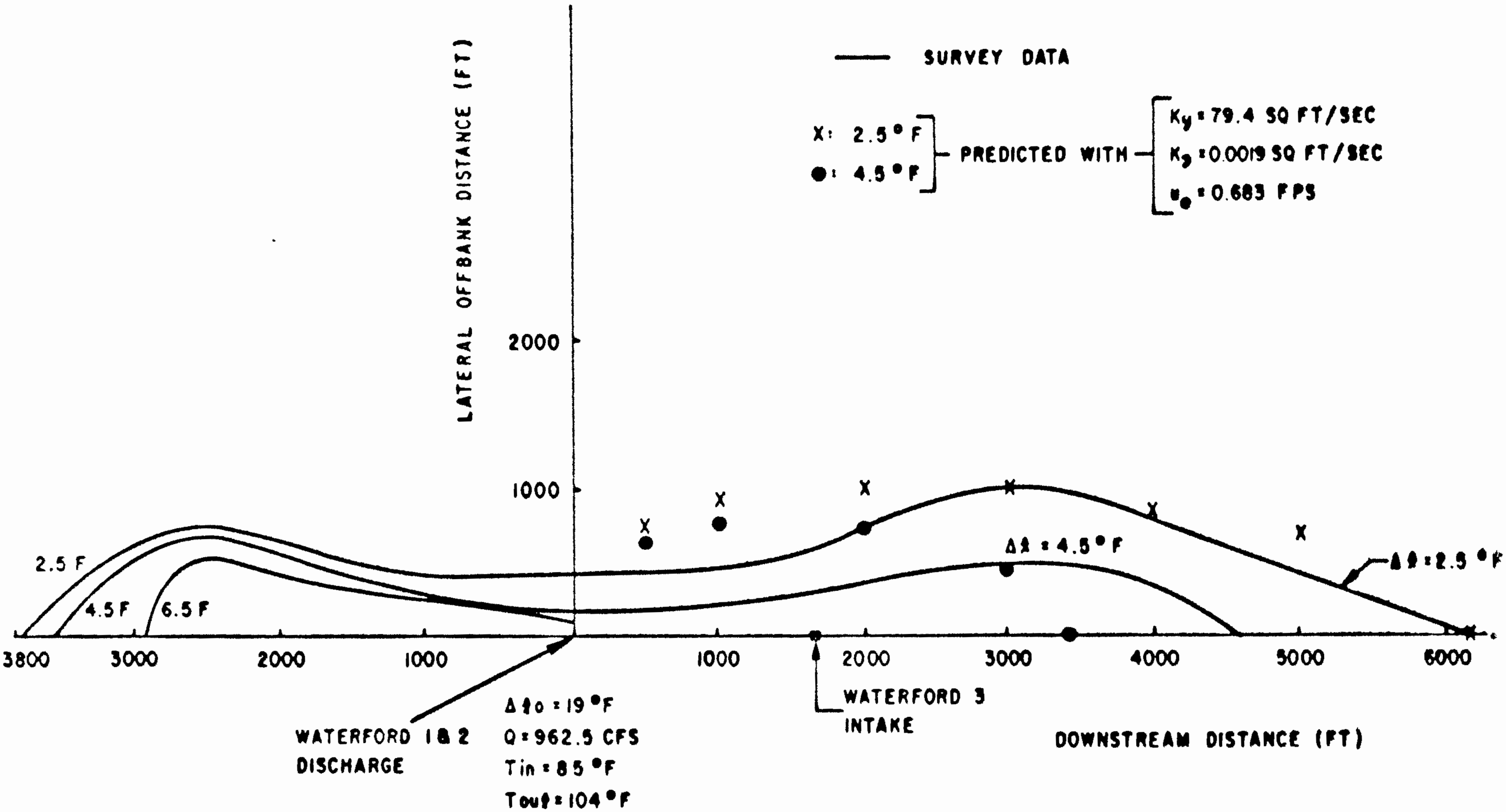
LOUISIANA POWER & LIGHT CO.
Waterford Steam Electric Station

COMPARISON OF PREDICTED & OBSERVED (9/9/76)
EXCESS SURFACE ISOTHERMS (°F) – LITTLE GYPSY SES

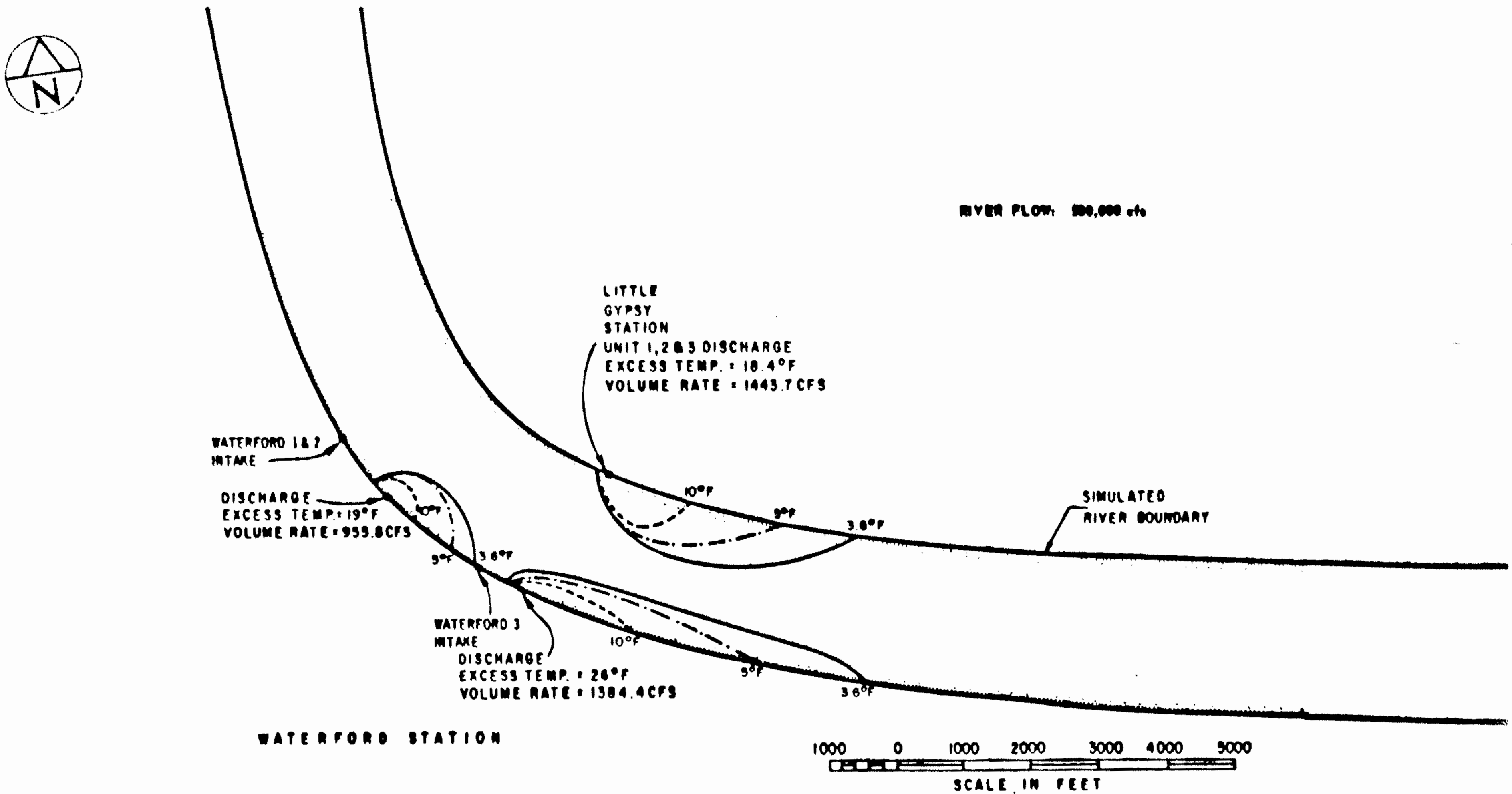
Figure A-9



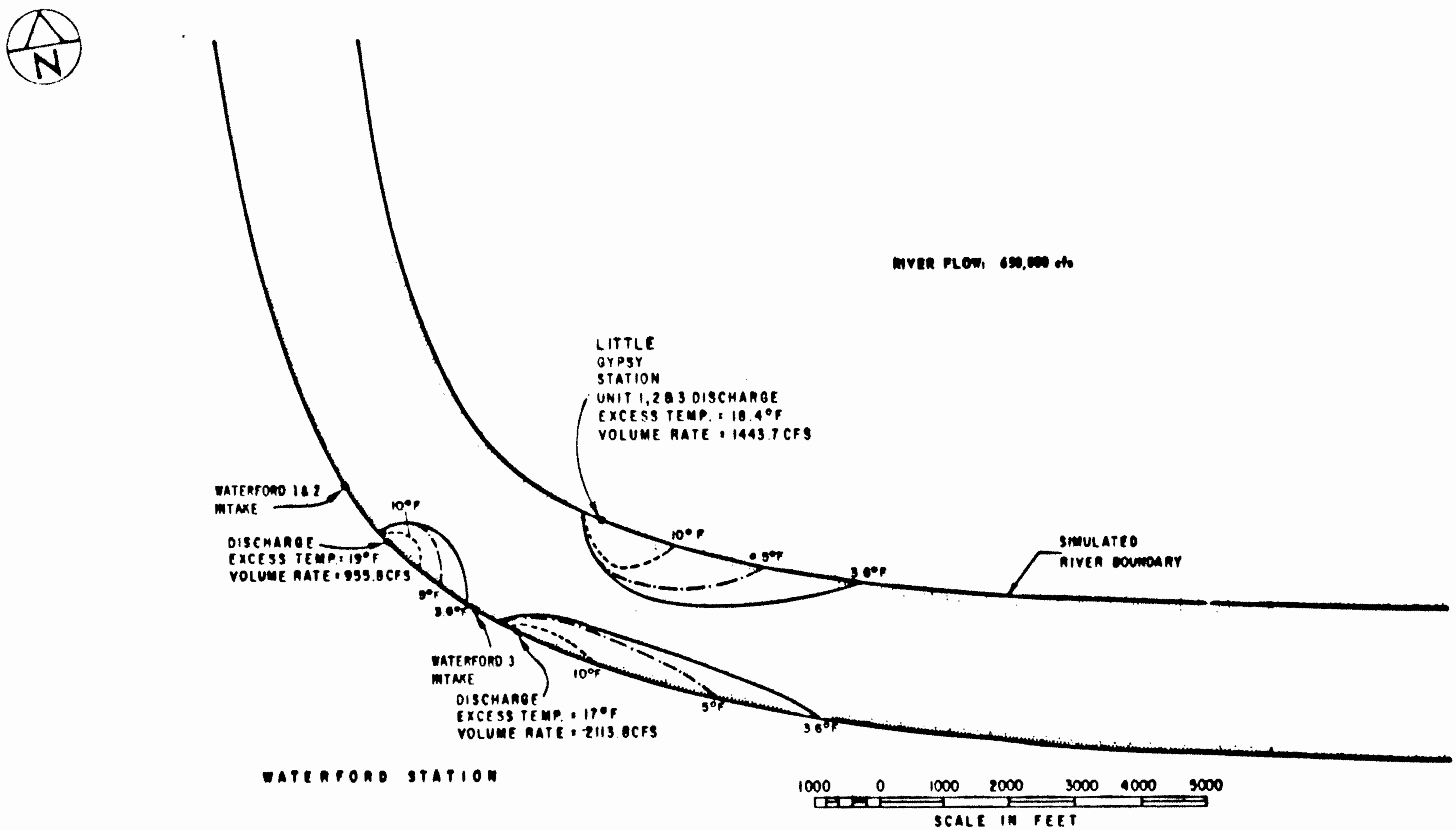
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	VARIATION IN RELATIVE WEDGE LENGTH WITH DENSIMETRIC FROUDE NUMBER	Figure A-10



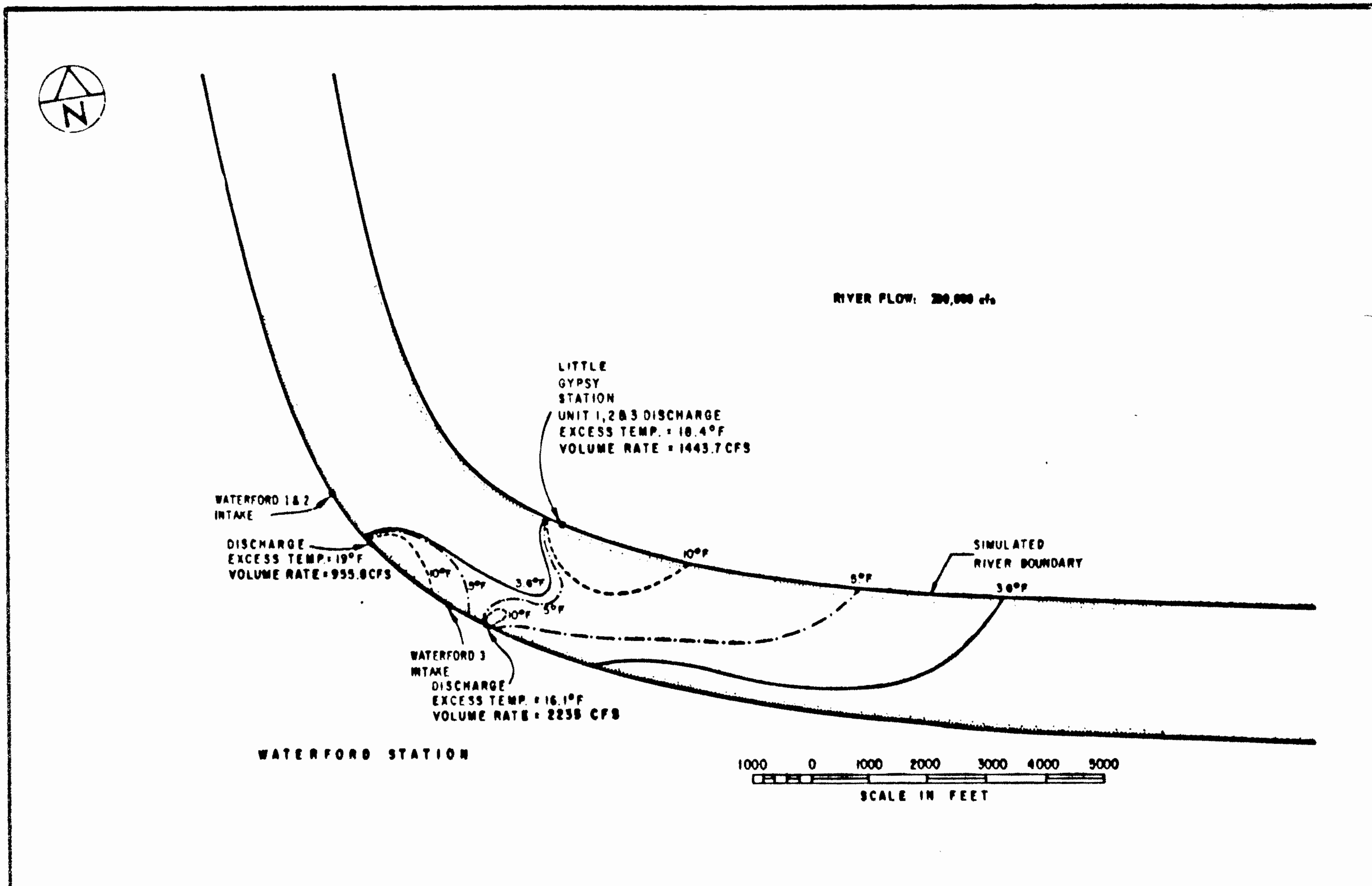
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	COMPARISON OF PREDICTED & OBSERVED (9/9/76) EXCESS SURFACE TEMPERATURE (°F) – WATERFORD 1 & 2	Figure A-11



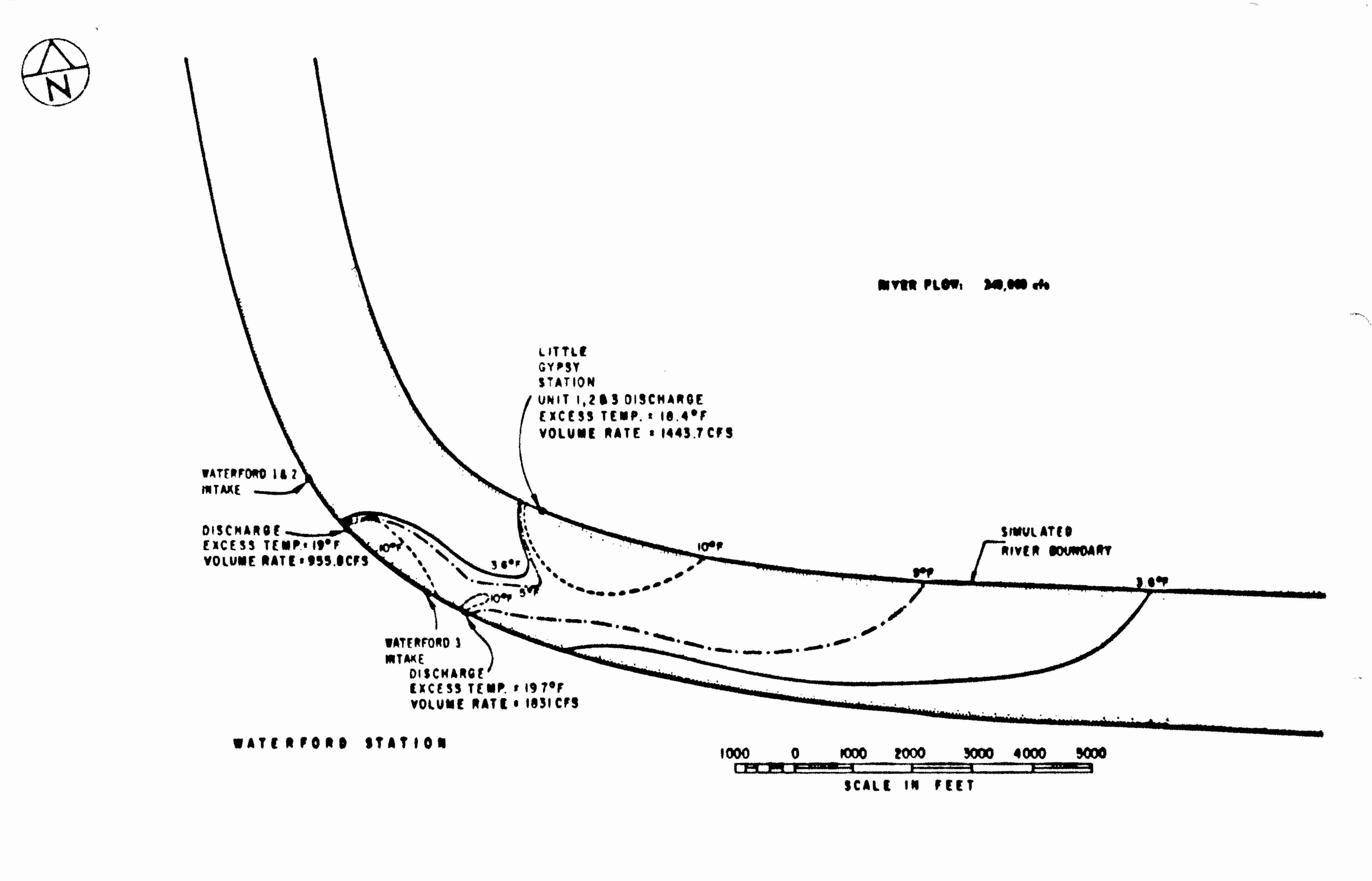
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	PREDICTED EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – AVERAGE WINTER RIVER FLOW CONDITION	Figure A–12



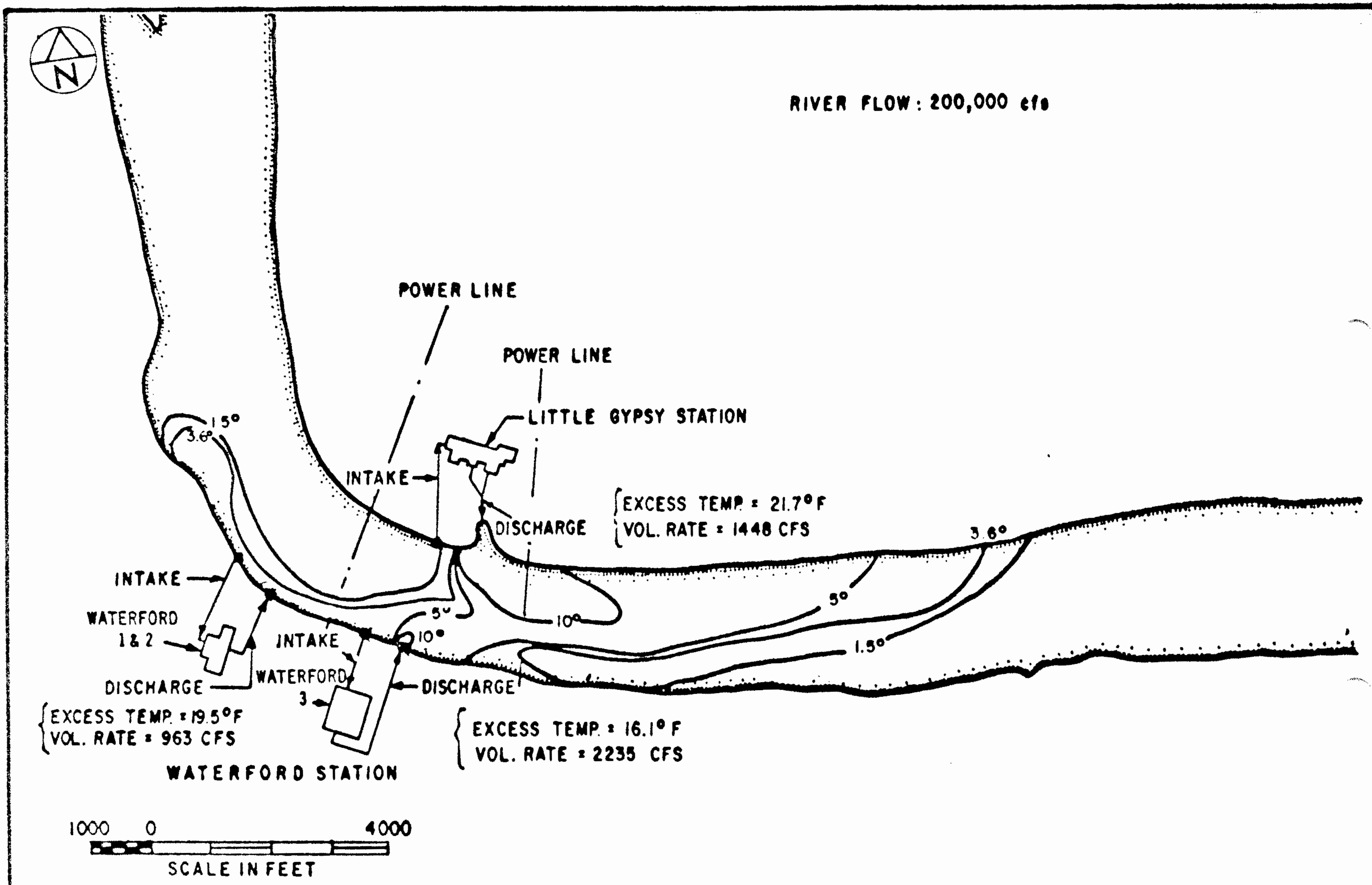
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	PREDICTED EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – AVERAGE SPRING RIVER FLOW CONDITION	Figure A-13



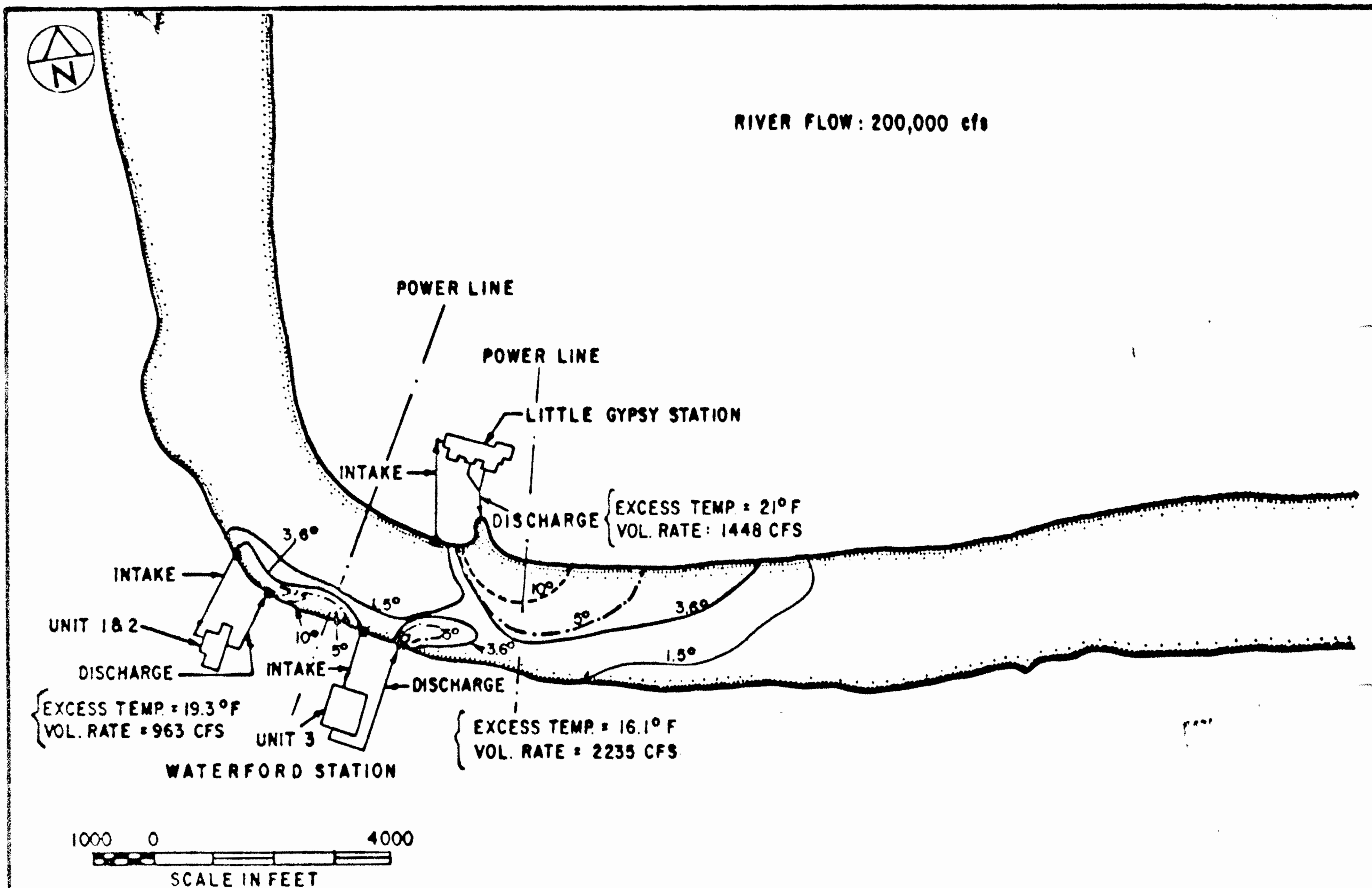
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	PREDICTED EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – AVERAGE SUMMER RIVER FLOW CONDITION	Figure A-14



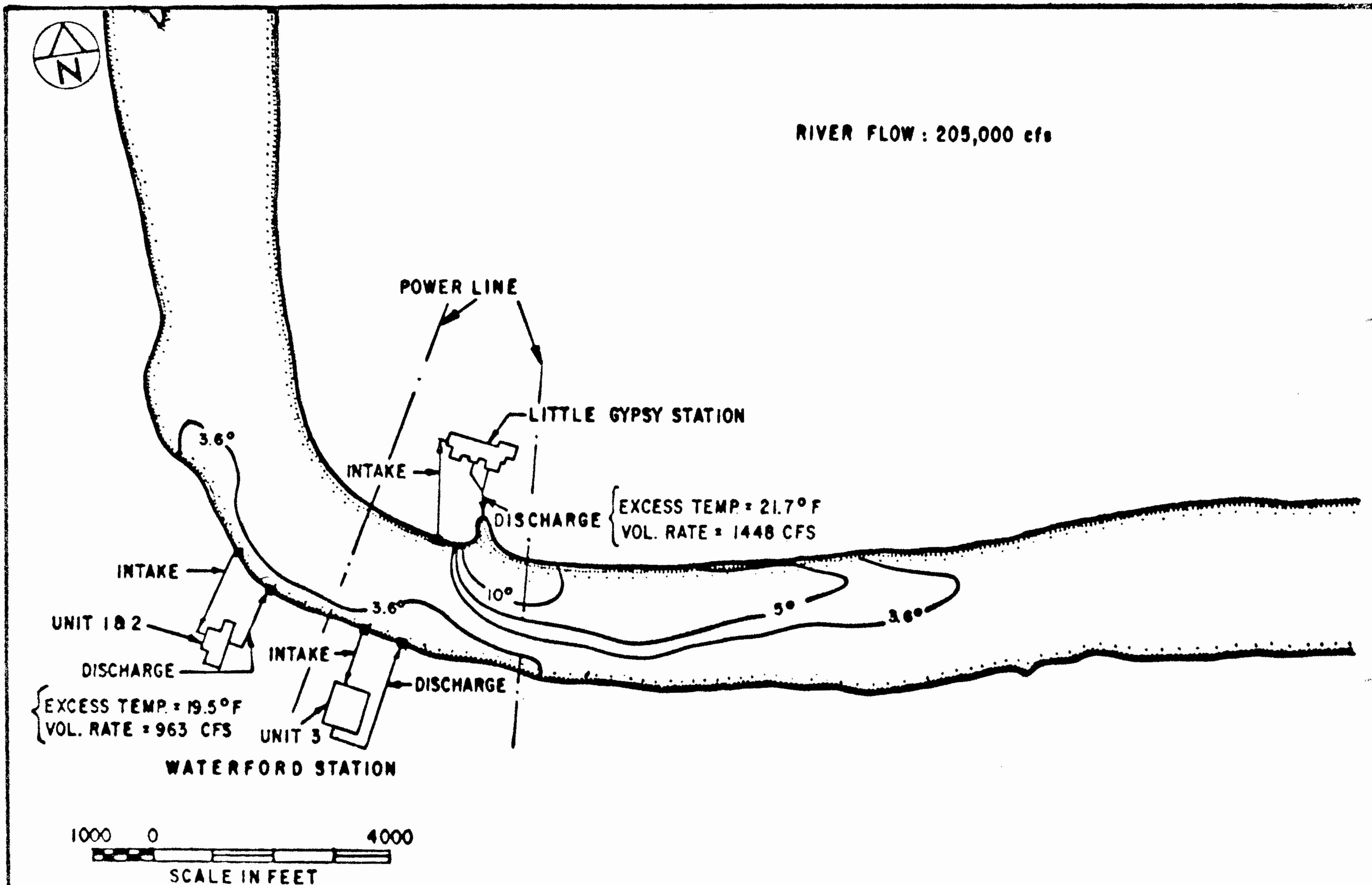
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	PREDICTED EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – AVERAGE FALL RIVER FLOW CONDITION	Figure A–15



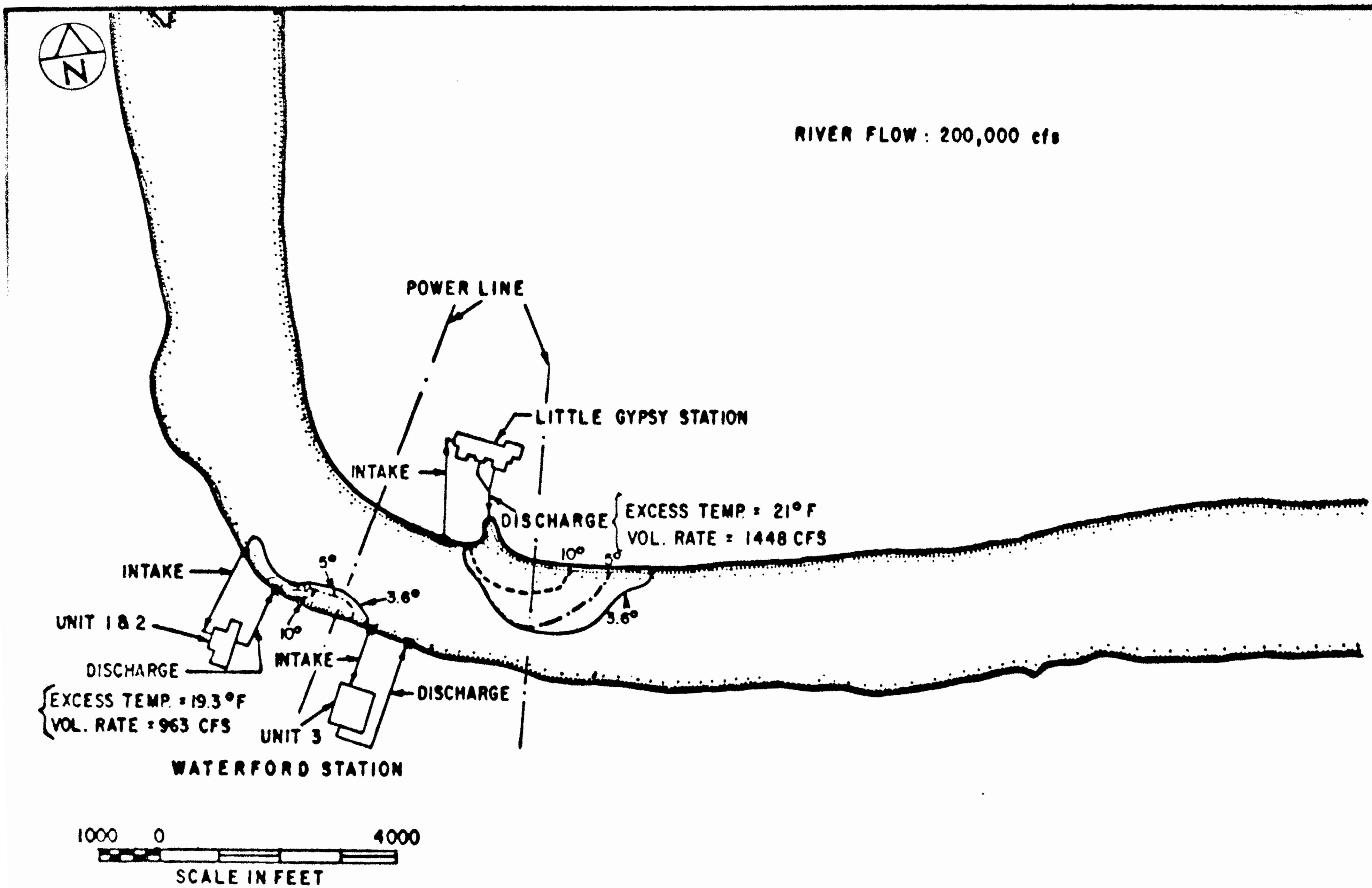
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINED FIELD – SEPTEMBER 9, 1976 LOW FLOW CONDITION	Figure A-16



LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	EXCESS ISOTHERMS (°F) AT THE SURFACE COMBINDED FIELD – SEPTEMBER 10, 1976 LOW FLOW CONDITION	Figure A–17



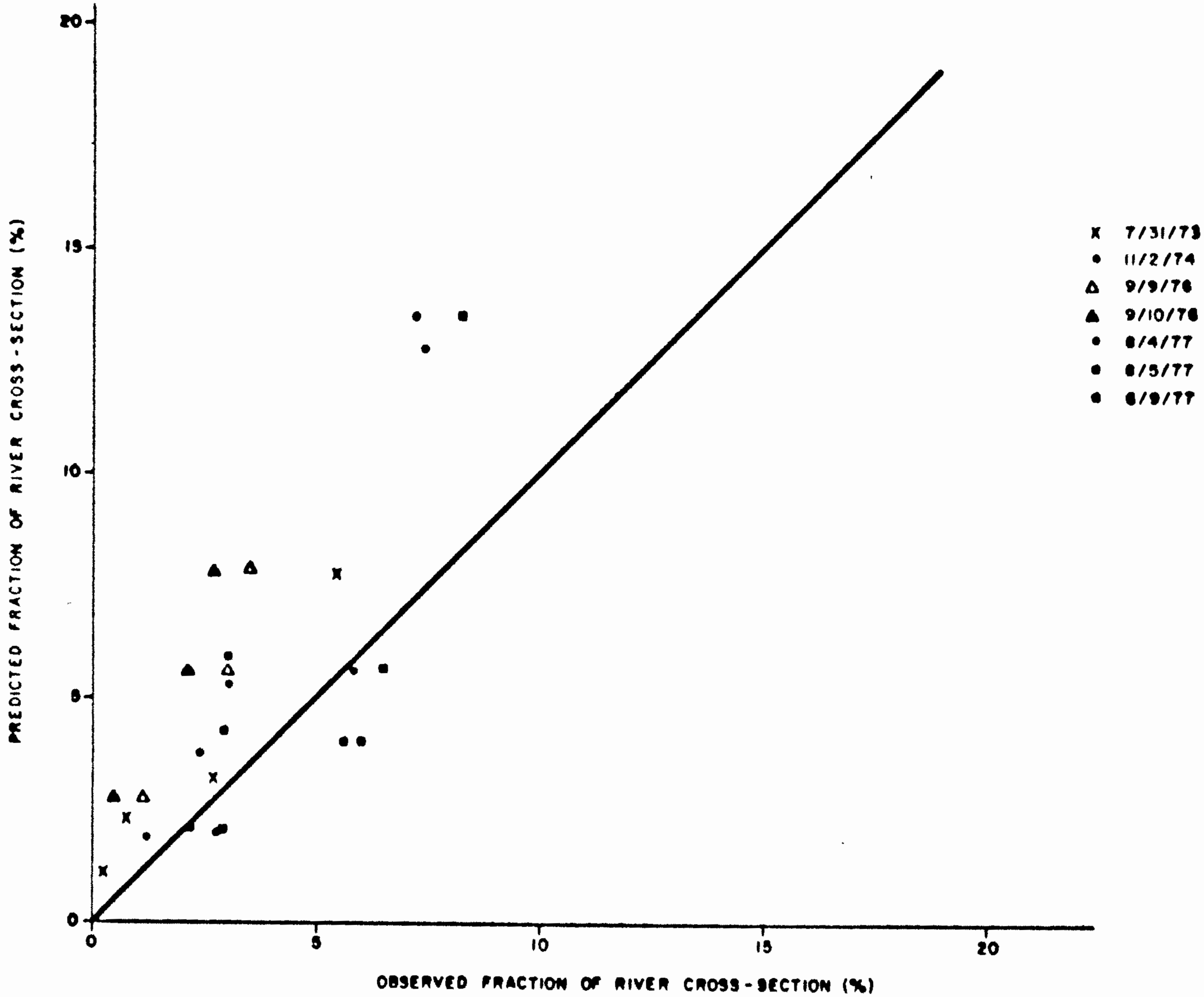
LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	EXCESS ISOTHERMS (°F) AT THE SURFACE BEFORE WATERFORD 3 DISCHARGE – SEPTEMBER 9, 1976 LOW FLOW CONDITION	Figure A-18



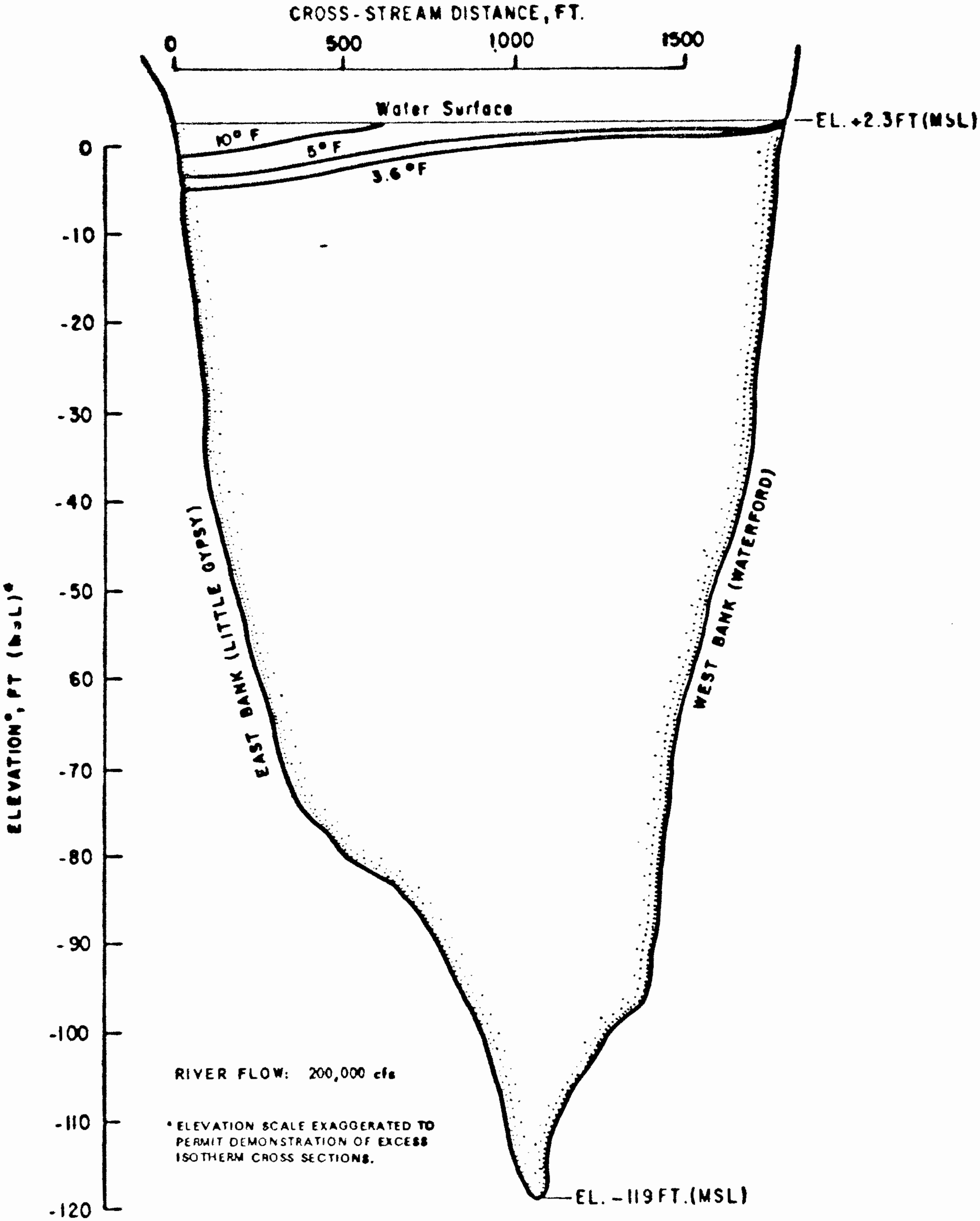
LOUISIANA POWER & LIGHT CO.
Waterford Steam Electric Station

EXCESS ISOTHERMS (°F) AT THE SURFACE
BEFORE WATERFORD 3 DISCHARGE - SEPTEMBER 10, 1976
LOW FLOW CONDITION

Figure A-19

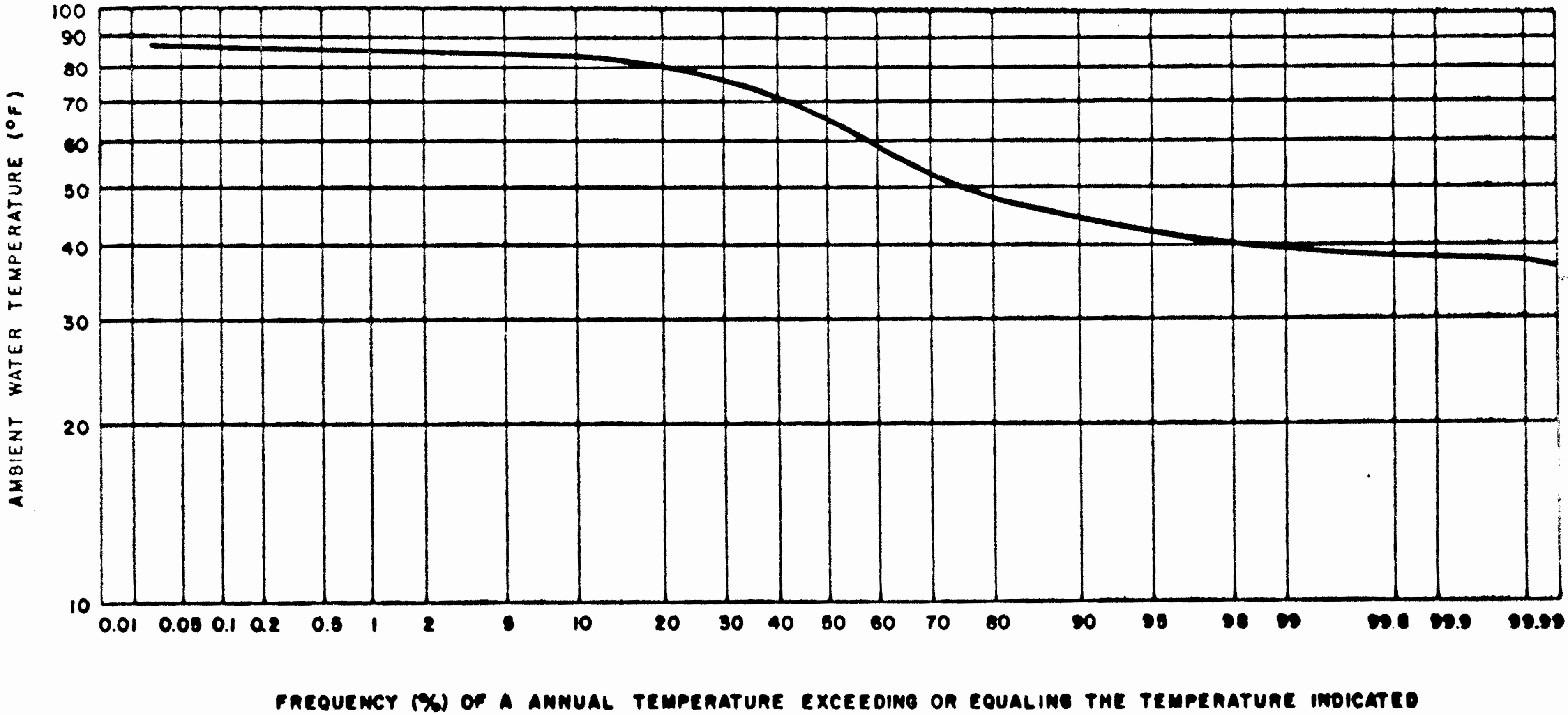


LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	COMPARISONS BETWEEN PREDICTED & OBSERVED FRACTIONS OF RIVER CROSS-SECTION (%) AFFECTED BY A GIVEN EXCESS ISOTHERM	Figure A-20



SOURCE: RIVER CROSS SECTION CONSTRUCTED FROM CONTOUR MAP FROM US ARMY CORPS OF ENGINEERS, NEW ORLEANS, LA. "MISSISSIPPI RIVER HYDROGRAPHIC SURVEY – 1973 TO 1975 – BLACK HAWK, LA. TO HEAD OF PASSES, LA." 1976

LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	COMBINED THERMAL PLUME CROSS-SECTION AT LITTLE GYPSY FOR TYPICAL LOW FLOW CONDITIONS	Figure A-21



LOUISIANA POWER & LIGHT CO. Waterford Steam Electric Station	ANNUAL TEMPERATURE FREQUENCY ANALYSIS BASED ON DAILY RIVER TEMPERATURE TAKEN AT CARROLLTON STATION (1961 THROUGH 1977)	Figure A–22