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SUBMERGED MULTIPORT DIFFUSER THERMAL DISCHARGES
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ABSTRACT

This paper summarizes the design concept and thermal predictions for the James A. FitzPatrick Plant diffuser prior to the construction as well as the methodology and results of a series of postoperational thermal plume mapping.

Preoperational lake surveys were performed to provide detailed hydrographical data for conducting and evaluating the hydraulic model and analytical studies. Near-field and far-field thermal plumes were predicted by the laboratory and mathematical models for various lake current conditions.

Three postoperational hydrothermal surveys were conducted in June, August, and October, 1976. Three-dimensional thermal patterns are documented for ranges of ambient temperatures, current speeds and directions, and stratified and unstratified lake conditions. In addition, the diffuser performance in terms of dilution factors was given by dye concentrations existing in the lake after releasing dye into the circulating water system. These field surveys represent the first comprehensive performance test of a major multiport thermal diffuser.

Predicted and observed thermal plumes are compared, while dye concentration information is used to gain better understanding of the mixing mechanism and performance of the diffuser jets with respect to the natural lake thermal stratification and lake currents.

INTRODUCTION

The James A. FitzPatrick Nuclear Power Plant, utilizing a submerged multiport diffuser once through cooling discharge system, has been in commercial operation since July 1975. The 850 MWe plant is located on the south side of Lake Ontario near Oswego, New York.

The plant withdraws a maximum of 825 cfs from Lake Ontario for plant cooling. Flow from an intake tunnel under the lake bottom enters a free surface screen well from which three vertical shaft centrifugal pumps withdraw 785 cfs, and circulate it through the main condenser to produce a 32.4^{o} F temperature rise at full load. In addition, a maximum of 40 cfs is withdrawn for service water requirements, which will produce a 13.5^{o} F rise in temperature. A total of 825 cfs will therefore be discharged, with a maximum temperature

rise of 31.5° F at the offshore points of discharge after flowing from a free surface well through a tunnel under the lake bottom. The heat rejection rate in the condenser is 5.714×10^9 Btu/hr.

The concept of intake and discharge structures is to produce thermal patterns which would comply with the New York State thermal discharge criteria prevailing at the time of design. The design criteria were the natural surface ambient water temperature, which should not be raised more than 3° F except within a radius of 300 ft or equivalent area from the point of discharge, and the thermal discharges should be confined to the epilimnetic area.

DESIGN CONCEPT AND ENVIRONMENTAL STUDIES

The basic concept of the discharge structure consists of multiple submerged ports forming a diffuser. Sufficiently high initial jet velocities and relative submergence below the water surface produce rapid dilution of the condenser cooling water by entraining large quantities of colder ambient lake water. The characteristics of the diluted surface flow layer formed after the initial jet entrainment zone will be such that the intake will be in a region void of warm water and thus provide assurance that no recirculation will occur.

To provide a sound basis for developing and predicting the effect of the plant cooling water discharge, field surveys were conducted to measure lake temperatures and lake currents. Data obtained from these surveys were used in analytic and hydraulic model studies to develop the hydraulic design of the structures and to ensure that the temperature patterns to be produced by plant operation would comply with the thermal discharge criteria of the State of New York.

The following is a list of the environmental studies which lead to the final design of the plant cooling water circulating system:

A. <u>Field Studies</u>

1. Continuous recording of currents and temperatures at various depths for six months from late spring to fall.

2. Two overall lake current pattern surveys using drogues.

3. Two overall surface temperature pattern surveys using airborne infrared radiometry.

4. Four temperature profiles in deep water by traversing with single thermistor.

B. <u>Meteorological Studies</u>

Collection of wind speed and direction data from four weather stations and the adjacent Nine Mile Point Station anemometer to correlate with

lake currents.

C. Hydraulic Model Studies

1. Basic study of submerged jet dilution to determine characteristics of surface layer (1/26 scale).

2. Lake model. To select optimum orientation and direction of discharge (1/50 vertical, 1/200 horizontal scales).

3. Details of discharge structure. Selection of design characteristics of discharge nozzles (1/50 scale).

4. Complete discharge and intake model. Location and design of intake; temperature patterns with lake currents (1/81 scale).

D. Analytic Studies

1. Develop basic concept and design features of structures.

2. Predict overall hydrothermal patterns of cooling water discharge.

STUDY RESULTS AND ADOPTED DESIGN

Lake Conditions

Lake current and temperature measurements provided detailed information on the physical lake environment at the James A. FitzPatrick site. Lake currents at the site are primarily wind induced and low in magnitude, usually only a few tenths of a foot per second. The currents generally follow the lake topography. Temperatures of the lake water vary according to atmospheric conditions. The thermocline exists at 40 to 50 ft below the surface in deep water during late summer. The lake structures are in the epilimnion during times of stratification. In the vicinity of the lake structures, significant natural upwellings have been recorded, with colder hypolimnetic water replacing epilimnetic water. [1], [2]

Hydraulic Model Tests and Final Design

The extensive hydraulic model testing program, in conjunction with analytic studies, was used to develop the hydraulic design of the intake and discharge structures. A submerged diffuser structure discharging high velocity jets which produce rapid decrease in condenser cooling water temperature was selected as the final discharge structure of the power plant. The design of the diffuser was complicated by the fact that the direction of the warm surface flow has to be determined in order to locate an intake in a region unaffected by the warm water. Also, the existence of the Nine Mile Point Power Plant 3200 ft to the west was a factor, since the cumulative effects of both plants had to be considered. The most desirable scheme turned out to be a single line of submerged jets essentially parallel to the shore with the jets discharging horizontally toward the lake. A total of 12 jets are

discharged in pairs from six diffuser heads at an initial velocity of 14 fps at 5 to 6 ft above lake bottom. The direction of the discharge is lakeward and essentially perpendicular to the bottom contours. Fig. 1 shows the arrangement of intake and discharge system and Fig. 2 depicts the discharge structure diffuser head.

For all lake current conditions, i.e., no current, eastward and westward currents ranged from 0.2 fps to 0.8 fps, the model test results showed the surface water temperature would not be raised more than 3° F outside the permissible zone. It was also shown that the concept and location of the intake structure are satisfactory. No recirculation of warm water was detected with or without lake currents. Basic results from the model tests of the flow pattern and temperature distribution along a section perpendicular to the shoreline through the James A. FitzPatrick lake structures are shown on Fig. 3.

A more detailed description of the field study and hydraulic model test programs with the adopted design of intake and discharge structures can be found elsewhere.[3]

Far-Field Thermal Plume Prediction

Because of physical size limitations which precluded determining the overall site temperature patterns from the hydraulic models, the overall thermal patterns at the site were predicted analytically using the hydrothermal conditions determined from the model tests in the vicinity of the discharge structure. Analytic solutions of heat dispersion from the discharge were obtained for the condition of a static lake and for the condition of lake currents of different speeds.

For a static lake, analytic solutions for the discharge plume were obtained by analogy to a hypothetical surface jet. This hypothetical jet is defined such that it simulates the velocity and temperature distribution found in the model approximately 300 ft downstream from the diffuser structure. The predicted temperature pattern is shown in Fig. 4. It is evident that a symmetrical plume is formed lakeward of the diffuser, with a relatively rapid drop in temperature due to dispersion.

To analyze overall temperature patterns with lake currents, it was necessary to establish the center line of the discharge plume. The cooling water discharge is deflected in the direction of the prevailing current as the velocity of the jets decreases. Using the entire flow field as a single jet, available data on deflection of jets in moving environments were used to establish the flow center line. Lateral spread of the flow field along the center line was computed by considering the dispersion of a continuous line source. Fig. 5 shows the predicted temperature patterns for eastward current of 0.2 fps. In general, low current speeds produce a broader plume with less total area within the 0.5° F temperature rise isotherm than is the case for high currents. Analyses of heat loss to the atmosphere indicate only a small decrease in plume temperature at any point.

The above-described analytical methods have been compiled by Argonne National Laboratory in the report "State-of-the-Art of Analytical Modeling."[4]

POSTOPERATIONAL HYDROTHERMAL SURVEYS

A program of hydrothermal field surveys were undertaken for the James A. FitzPatrick plant to determine the three-dimensional thermal patterns produced by the joint operation of a nearby 600 MWe station and the FitzPatrick plant. In addition the program was to determine the diffuser performance of the James A. FitzPatrick plant based on dye concentrations existing in the lake after releasing dye into the FitzPatrick plant circulating water system.

In 1976, extensive three-dimensional thermal and dye patterns were obtained in June, August, and October. The diffuser discharge plume was documented by on-boat temperature and dye measurements while traveling along established transects. The survey boat was specially equipped with a boat mounted fixture to record temperatures at 1, 2, 6, 10, and 15 ft and dye concentrations at 1, 6, and 10 ft simultaneously. A 20% solution of Rhodamine WT dye was injected into the plant's circulating water system at a rate of 7.5 pounds per hour. Injection of the dye upstream of the circulating water pumps assured that the dye was fully mixed prior to leaving the diffuser. Background fluorescence was determined before dye release was begun to allow for correction of all dye concentrations measured during the survey. A minimum of 12 hours of dye release was allowed for the establishment of steady state conditions in the lake.

The nearfield study area consisted of a system of transects marked by buoys and spaced typically 200 ft apart. In addition, a farfield study area was established to document the extent of the thermal plume in the flow-away zone and the interaction with the thermal plume of the nearby 600 MWe power plant. Figure 6 shows the location of the transects defining the nearfield and farfield study areas.

In addition to the measurements made along the transects, temperature and dye concentrations were obtained at 27 vertical profiling stations. An in situ tower, located 2,000 feet east of the centerline of the diffuser and 1,000 feet offshore, continuously recorded lake current speed and direction, lake temperature, and lake level during the survey period.

Aquatec, Incorporated of South Burlington, Vermont was contracted to carry out the field work. A total of 22 resolutions of the thermal plumes and dye concentrations in the FitzPatrick discharge area were obtained during 1976. The time span required for each plume resolution was generally limited to one and a half hours with one boat utilized for horizontal transects and two boats for vertical profiling. Five resolutions per day were attempted, however, weather conditions occasionally limited the number of resolutions taken in a day.

The survey results have been grouped into typical plume configurations which represent the plume behavior under various sets of lake conditions. Lake conditions considered of importance in effecting the behavior of the thermal plume are ambient temperature, lake current, lake level, and the amount of thermal stratification.

Plant Operating Conditions

During the hydrothermal surveys of 1976 the James A. FitzPatrick plant was operating at loads ranging between 85 and 93 percent of its rated megawatt capacity. The June and August surveys were conducted at plant loads of 780 and 790 megawatt, respectively. The plant load during the October survey was at 725 megawatt. The average temperature rise across the plant was approximately 29° F for the June and August survey and 26° F for the October survey.

June Survey

At this time of year, Lake Ontario exhibits a warming trend with weak thermal stratification. During the survey period, the lake surface temperatures fluctuate between 47° F and 62° F while the currents are variable in magnitude from both easterly and westerly directions at the study area.

On June 4 and 13, 1976, 6 different plume resolutions were obtained. Each near-field plume resolution consisted of 6 temperature maps and 3 dye concentration maps. One map each of temperature and dye concentration were obtained for the far-field study area. In the near-field study area, the 6 temperature maps consist of isotherms in increments of 1° F for 1-, 2-, 6-, 10-, and 15- ft depths and the surface temperature rise above ambient. The three dye concentration maps consist of isopleths in parts per billion for 2-, 6-, and 10- ft depths. Both temperature and dye concentration maps for the far-field study area are measured at 1.5 ft from the water surface.

In addition to the above, 27 vertical temperature and dye concentration profiles are documented over the study areas. The horizontal transect and vertical information yields the complete 3-dimensional plume characteristic prevailing at the time of measurement.

Fig. 6 represents the temperature rise above ambient at the water surface (1 ft depth) for June 13, 1976. This run was considered to be representative of the weak stratified lake condition with an insignificant lake current. Dye contours at the 2 ft depth taken for the same period of time as the thermal measurements are shown on Fig. 7.

Temperature rise observed at the water surface were less than 2° F within an area equivalent to a 300 ft radius circle for all six measurements. This illustrates that in respect to the surface temperature rise, the diffuser during the weak thermal stratified lake condition performs at a thermal efficiency better than that assumed for design.

The plant cooling water is well mixed with the ambient lake water, forming a uniform thermal plume thickness of approximate 20 ft directed offshore from the diffuser. The well defined dye plumes truely represent the configuration of the heated plume discharged from the diffuser. No dye concentration was found in the intake structure and near shore areas.

August Survey

The lake experienced moderate thermal stratification during the two-day survey on August 19 and 20, 1976. Temperature differences between surface and bottom waters were up to 6° F in the study area with average natural surface water temperatures of 69° F and 71° F for August 19 and 20, respectively. A total of 10 different plume resolutions, 5 per day, were obtained.

Fig. 8 represents the near-field surface plume map for a moderate stratified lake condition with an average westward current at 0.20 fps. The warmer surface water overlying the diffuser is noticeably cooled by the surfacing of the thermal plume. Fig. 9 demonstrates that the boundary of the thermal plume as marked by dye coincides with the region in which surface cooling is observed.

The presence of lower surface water temperatures at the diffuser discharge area was caused by entrainment of large quantities of cool bottom water into the discharge jets and efficient mixing with warmer surface water. There was no noticeable warm surface plume formed during the survey period. As evidenced in the June survey, the dye plumes also exhibited a well defined configuration in respect to the plume thickness, concentration level contour, and plume boundary. Except for one near-field plume resolution and scattered small areas, all of the dye concentration maps indicated a dilution factor of more than 10 was achieved in the near-field rapid mixing.

The effect of a submerged diffuser discharge on the overlying warmer surface water is further demonstrated in the far-field temperature measurements as shown on Fig. 10. The nearby Nine Mile Point Station discharge created a relatively thin warm surface layer at the J. A. FitzPatrick site area. The diffuser discharge essentially lowered the temperature of the near-field surface water and increased the temperature of a limited area in the far-field for no more than 1° F, by pushing the surface isotherms further toward the direction of the diffuser discharge. Very insignificant dye concentrations were detected in the intake water shaft.

October Survey

The third survey of 1976 was conducted on October 7 and 8. The wind direction was generally from the west and northwest during daylight hours of October 7, 1976. The wind direction changed overnight and by the time of October 8 daylight hours, the prevailing wind direction was from the northeast and north. At the study area, the lake also experienced changing in current directions from eastward during October 7 to the westward during October 8, 1976. The current speeds on October 7 were 0.4 fps in the norm-

ing and diminished to insignificant magnitudes in the afternoon. During the afternoon of October 8, the lake currents were fairly steady toward the west with speeds of about 0.5 fps.

Weak thermal stratification was observed on the first day of the survey with approximate 2° F temperature difference between the surface and bottom waters. However, during the afternoon of October 8, thermal stratification was absent due to substantial mixing by strong onshore winds and waves. The average natural surface water temperature was 60.5° F during the survey period.

Total of 6 different plume resolutions were obtained: two near-field and two far-field plume resolutions on October 7, and only one resolution for both the near-field and far-field plumes on October 8 due to the rough lake conditions.

Fig. 11 and 12 represent the surface temperature rise above ambient and dye concentration contours, respectively for the homogeneous lake condition with a westward current at 0.5 fps. It is interesting to note that dye concentration patterns correlate well with temperature patterns for this homogeneous lake condition.

DISCUSSION

A combination of field studies, hydraulic model tests, and analytical studies led to the final design of the cooling water intake and discharge structures for the James A. FitzPatrick Nuclear Plant. A good understanding of the hydrographic characteristics of the receiving water body and the behavior of diffuser discharges proved to be essential for the final design. Based on the extensive postoperational surveys conducted during 1976, the design of submerged diffuser and intake structures are adequate and have functioned as expected with minimum impact on the environment.

Four surveys were planned for 1976 to document the submerged diffuser discharge plume resulting from the operation of the James A. FitzPatrick plant under all possible lake conditions. Due to severe lake conditions during the winter season, the scheduled survey in December was canceled. As a result, three surveys were conducted for the months of June, August and October. However, during the survey periods the lake experienced wide range of variations in respect to temperature, current and thermal stratification. The parameters considered important for the purpose of measuring the thermal plume are those of lake temperature, current speed and direction, lake thermal stratification, lake level, onshore and offshore winds, nearby Nine Mile Point Station discharge, and plant operating conditions. The surveys were conducted for the plant operating continuously at loads greater than 80%.

Inclusion of the dye tracer measurement program in the survey scope of work has provided very important information, such as, the interaction of the FitzPatrick plume and the Nine Mile Point plume, the configuration of diffuser discharge plume, and the mechanisms of diffuser performance. The interaction of two nearby cooling water discharges can be easily and clearly

assessed by evaluating the temperature and dye concentration maps. Under thermal stratified lake conditions, temperature distributions of the thermal plume are not well defined because of the low temperature rise of the plume and large variation of the natural water temperatures. Injection of dye into the cooling water system and complete mixing with the discharge water provided a display of the well defined plume in respect to the horizontal boundary extents, plume thickness, and the mixing behavior of jets under all lake conditions.

Since the hydraulic model tests and analyses were performed for homogeneous lake conditions, meaningful comparison of the predicted and field measured temperatures should be based on the same homogeneous density conditions. Therefore, with dye concentration information, the actual diffuser performance for each condition can be evaluated to assess the accuracy of predicted results.

The survey results clearly indicated that the diluted surface warm layer, formed after the initial jet rapid mixing, was directed toward offshore and thus avoid recirculation through the intake structure. During a majority of all survey periods there was no recirculation, however, for several short periods of time dye was detected in the intake water shaft representing an insignificant amount of temperature rise, less than 1° F.

ACKNOWLEDGMENT

The James A. FitzPatrick Nuclear Power Plant is owned by the Power Authority of the State of New York, which sponsored all the studies that led to the final design and the postoperational field surveys.

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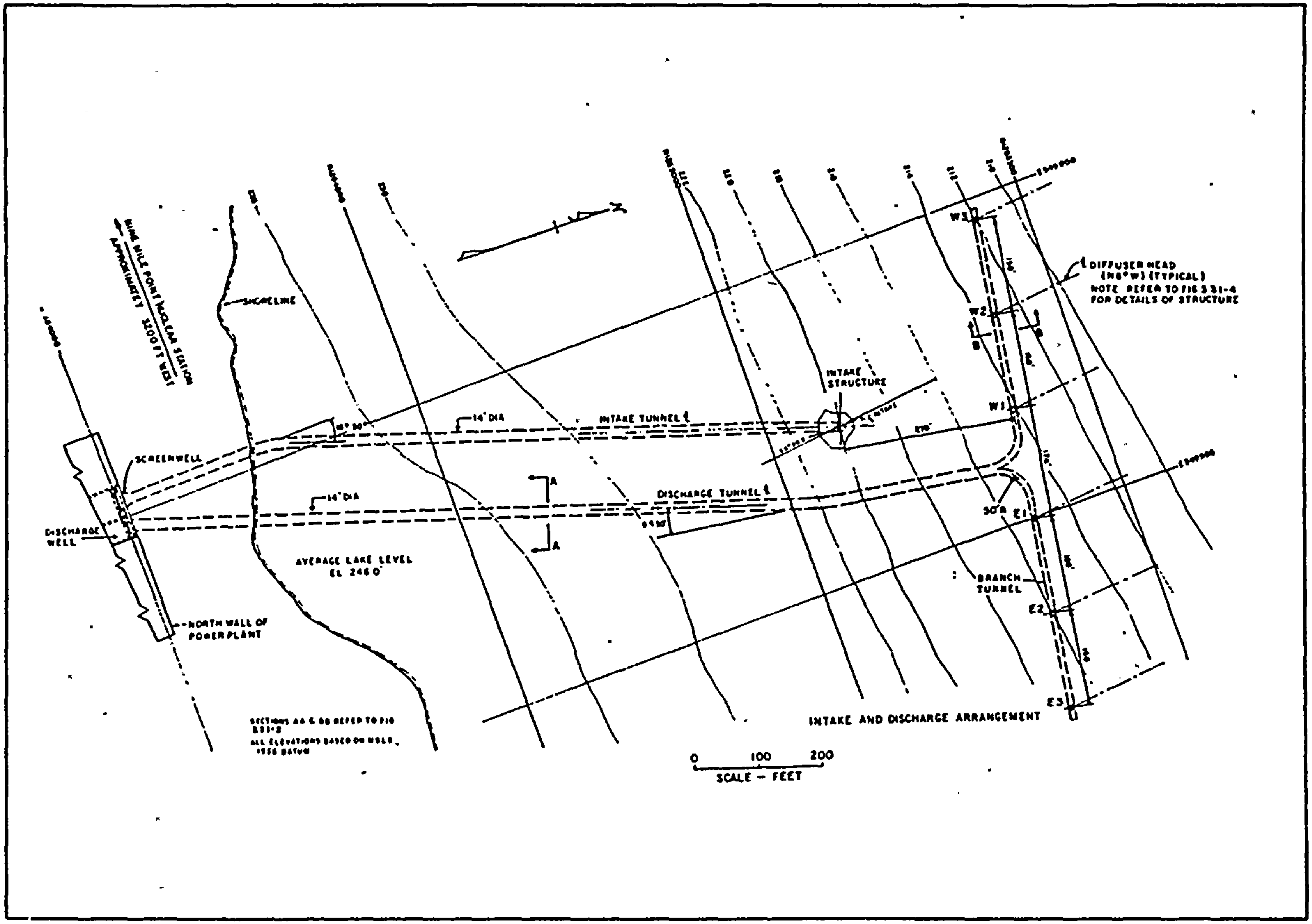

Figure 1. Intake and Discharge Arrangement

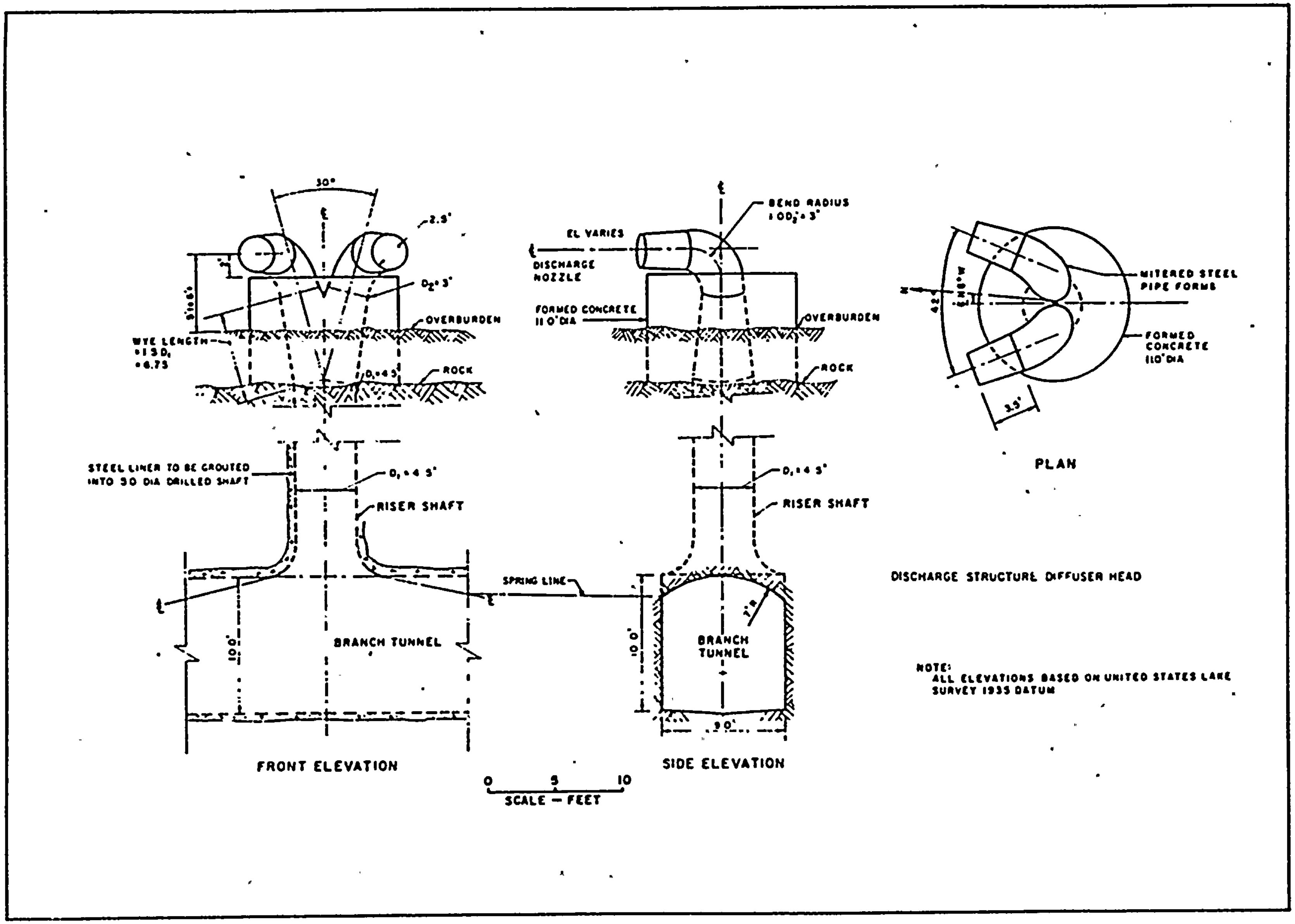

Figure 2. Discharge Structure Diffuser Head

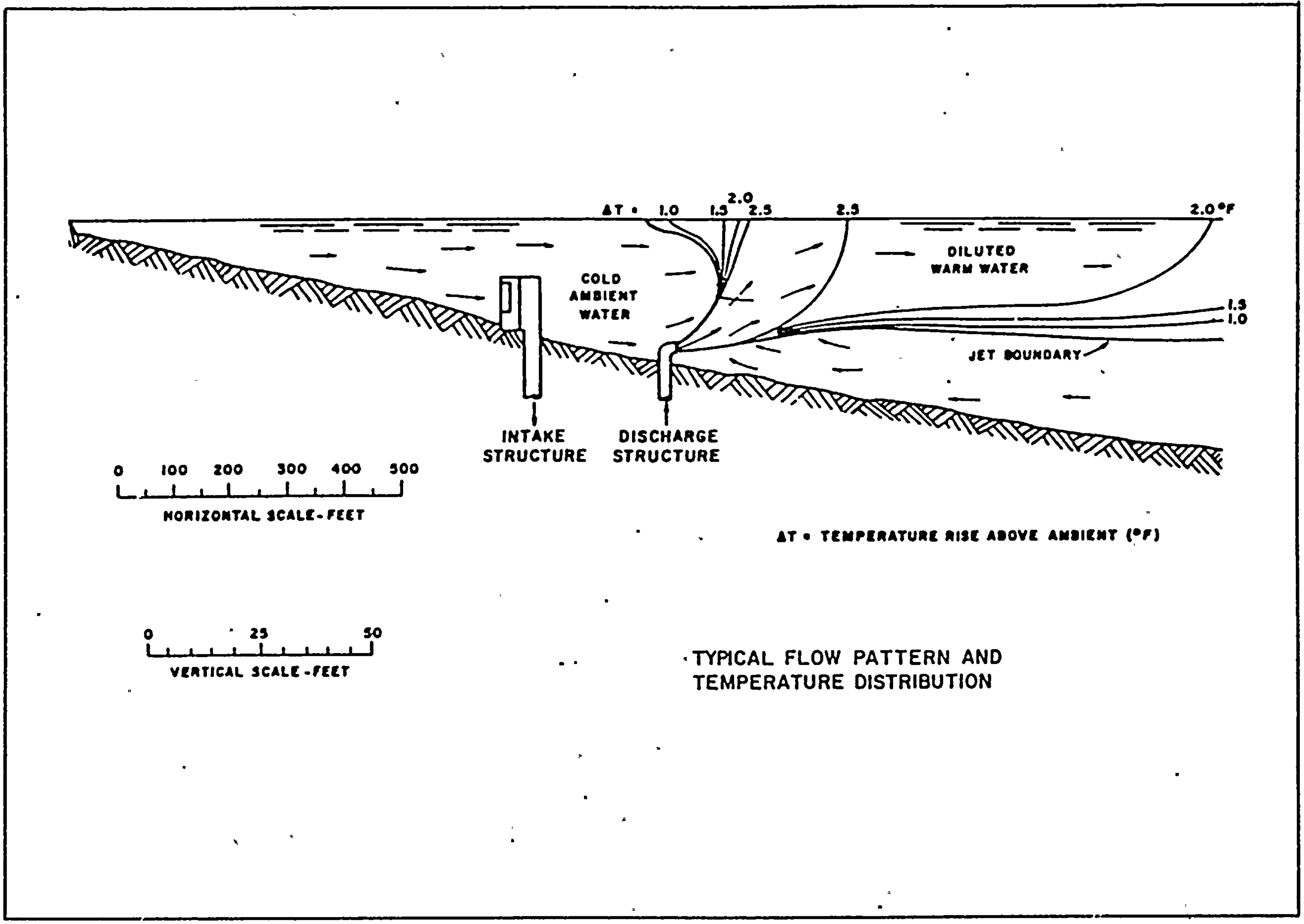

Figure 3. Typical Flow Pattern and Temperature Distribution

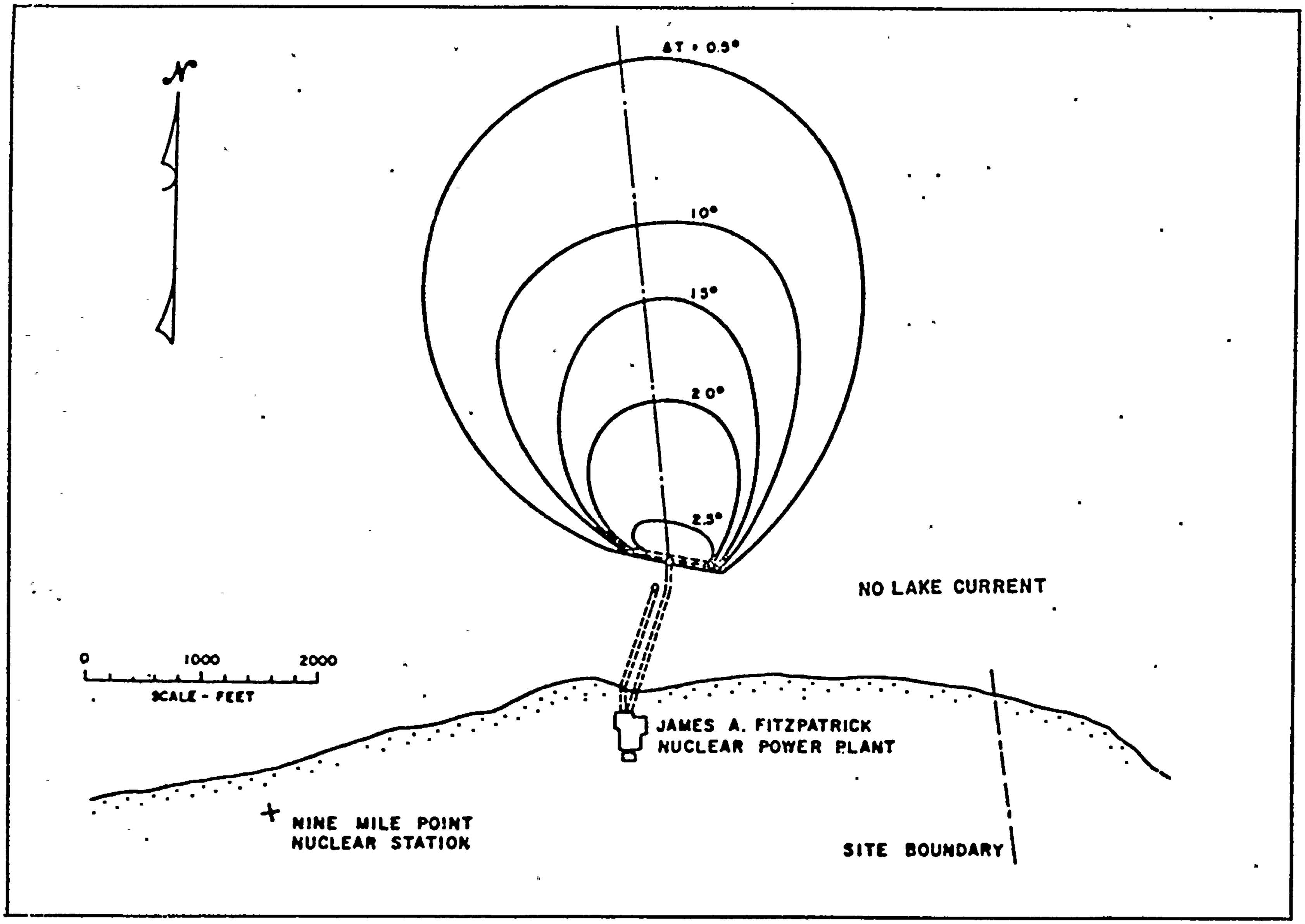

Figure 4. Predicted Surface Temperature Patterns - No Current

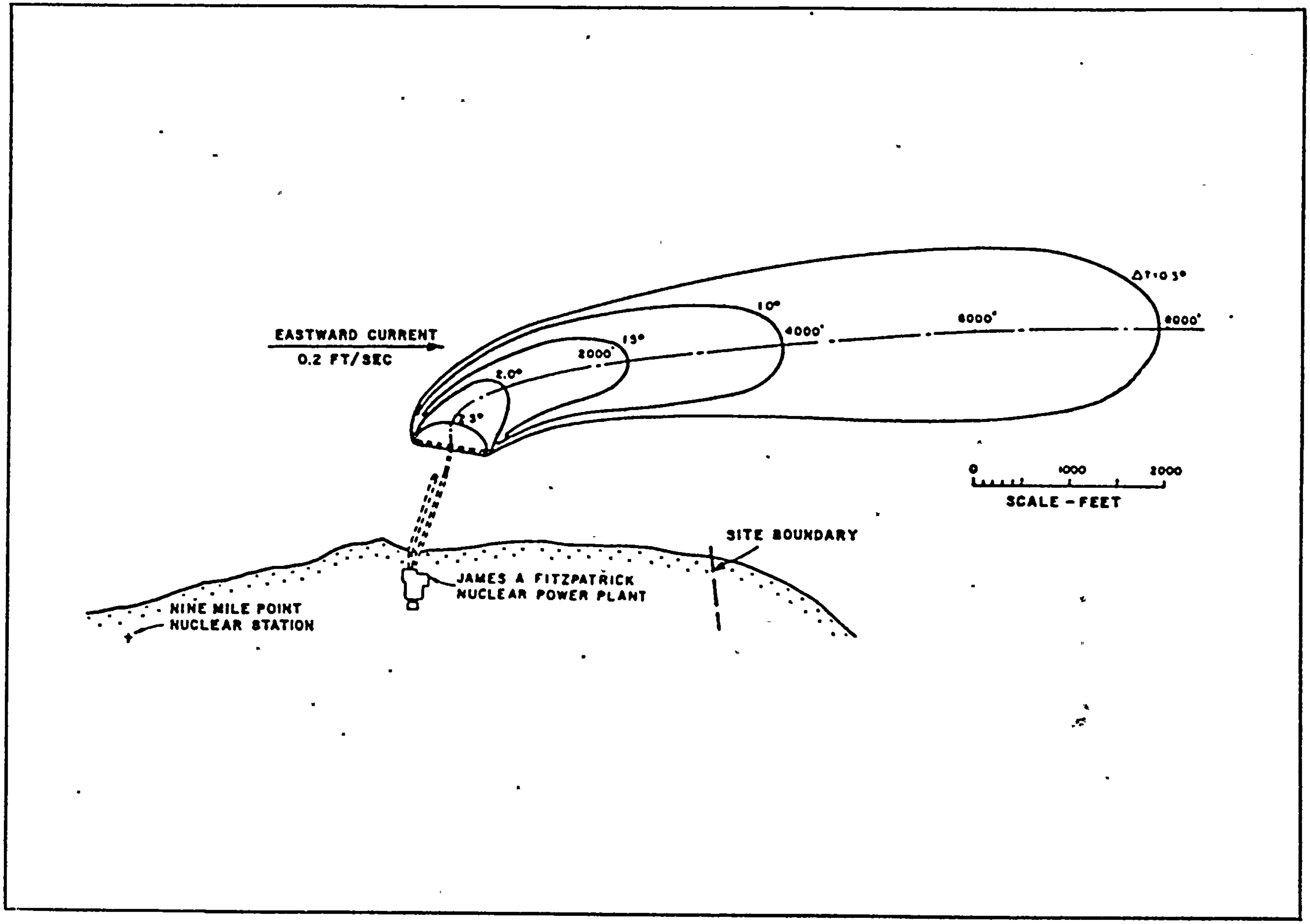

Figure 5. Predicted Surface Temperature Patterns — With Current

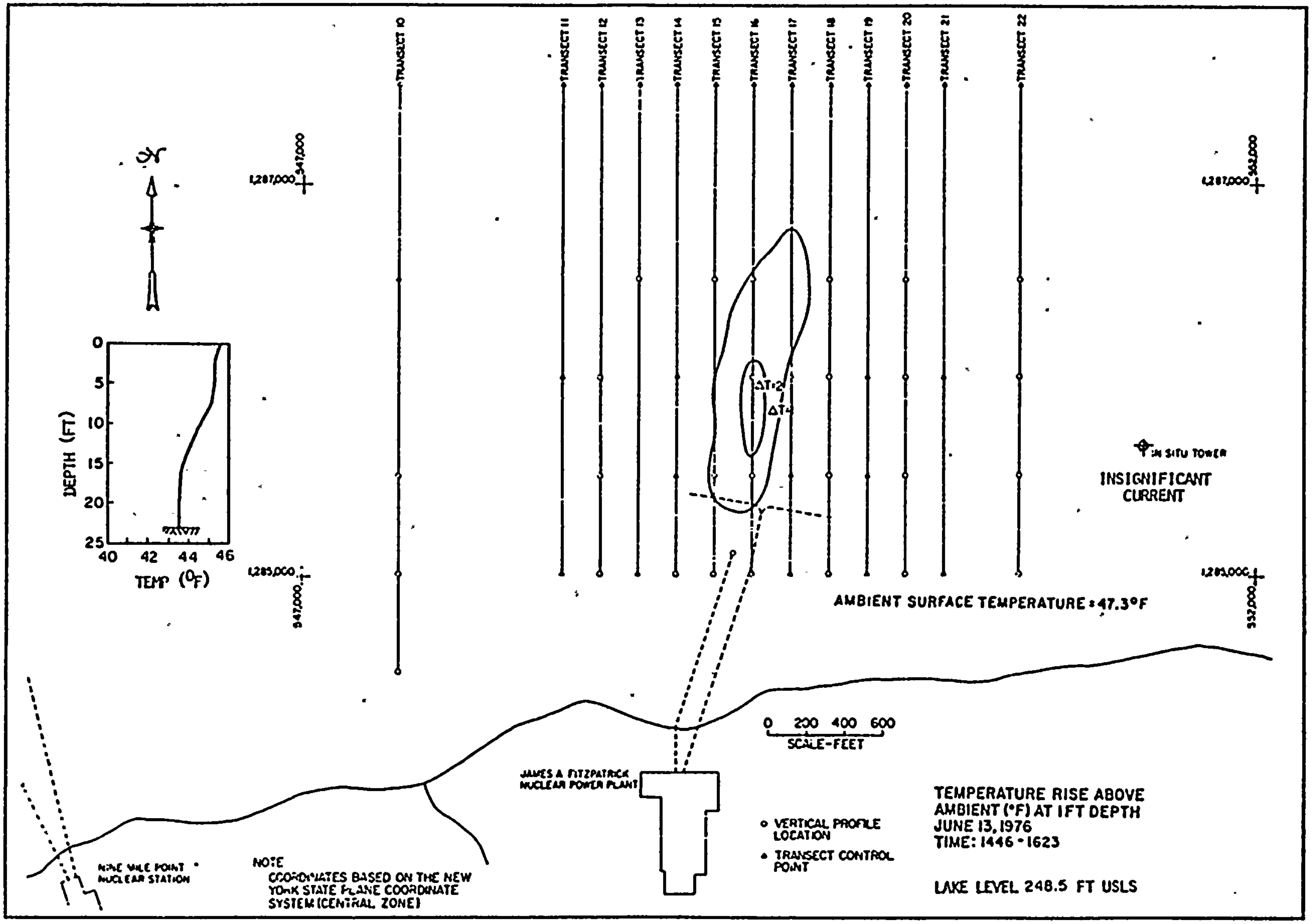

Figure 6. Weak Stratified Lake Condition - Temperature

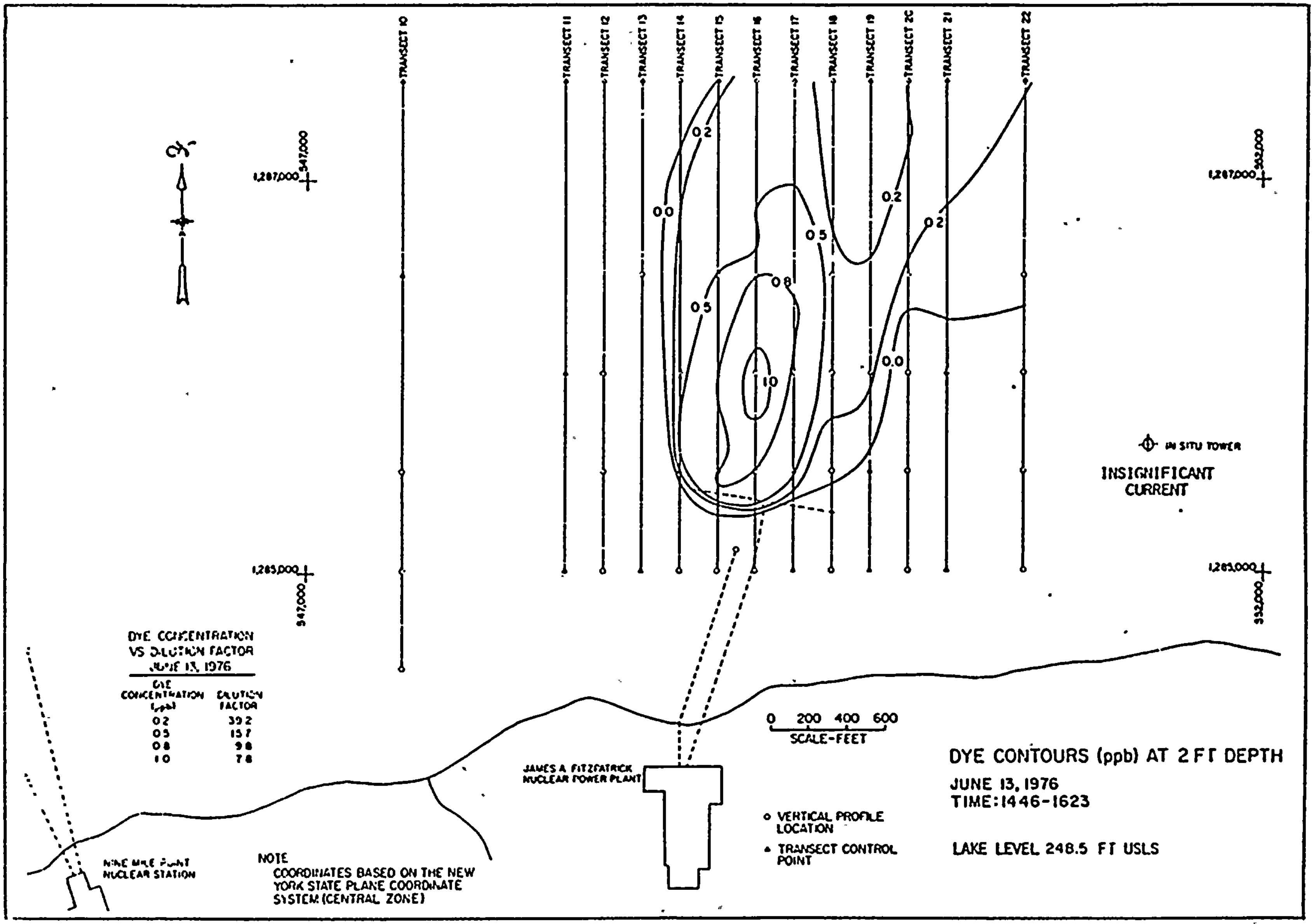

Figure 7. Weak Stratified Lake Condition - Dye

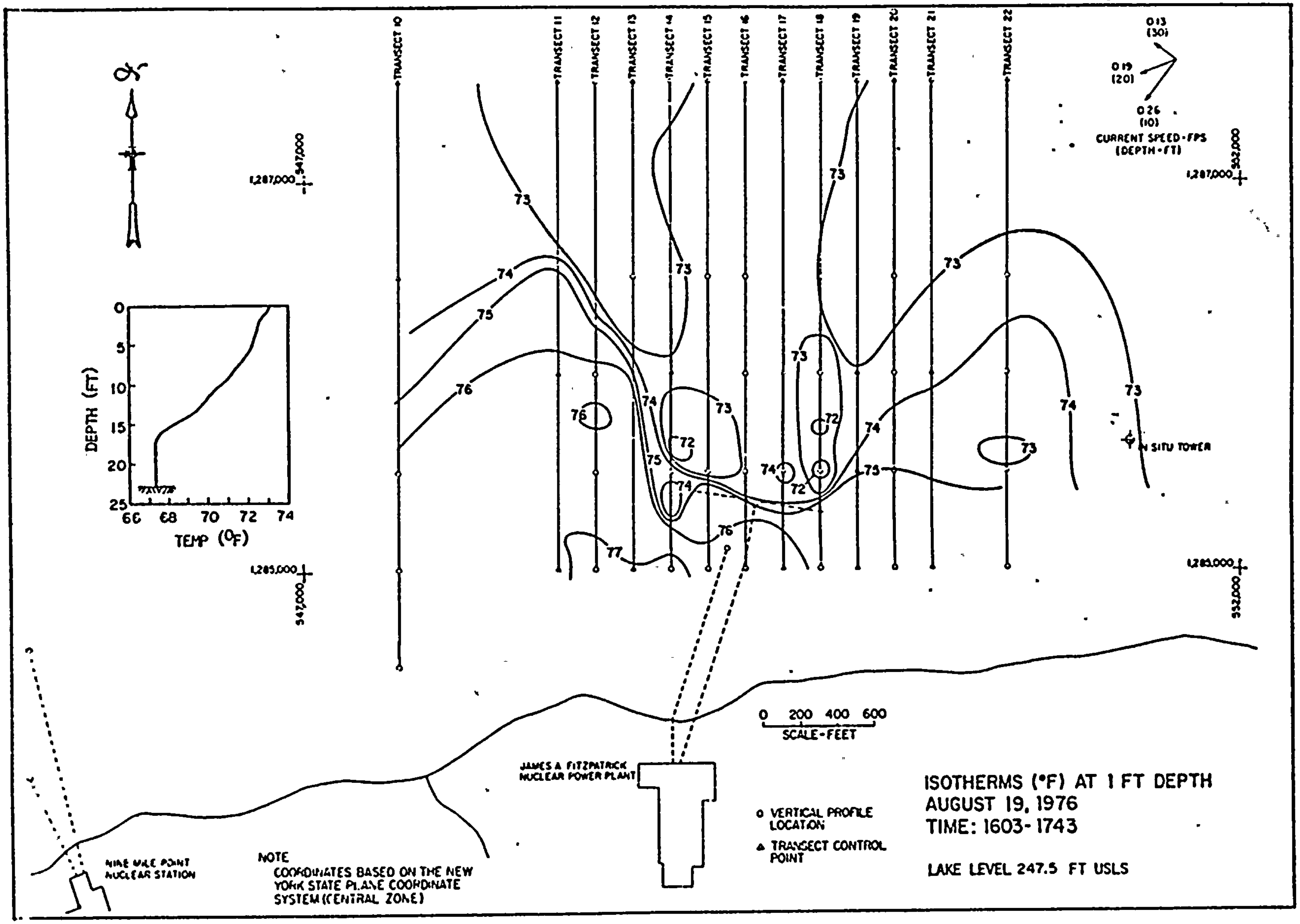

Figure 8. Moderate Stratified Lake Condition - Temperature

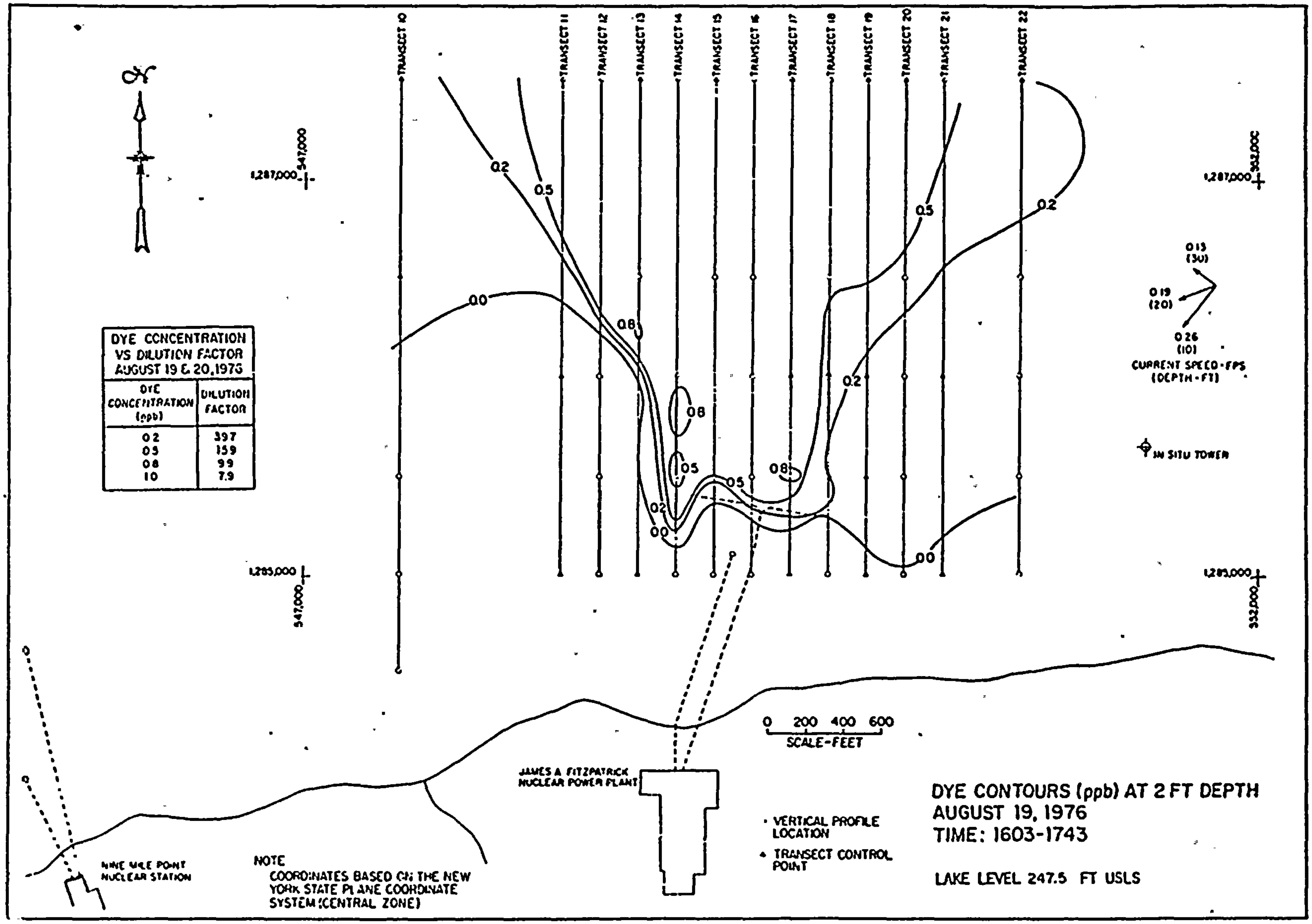

Figure 9. Moderate Stratified Lake Condition - Dye

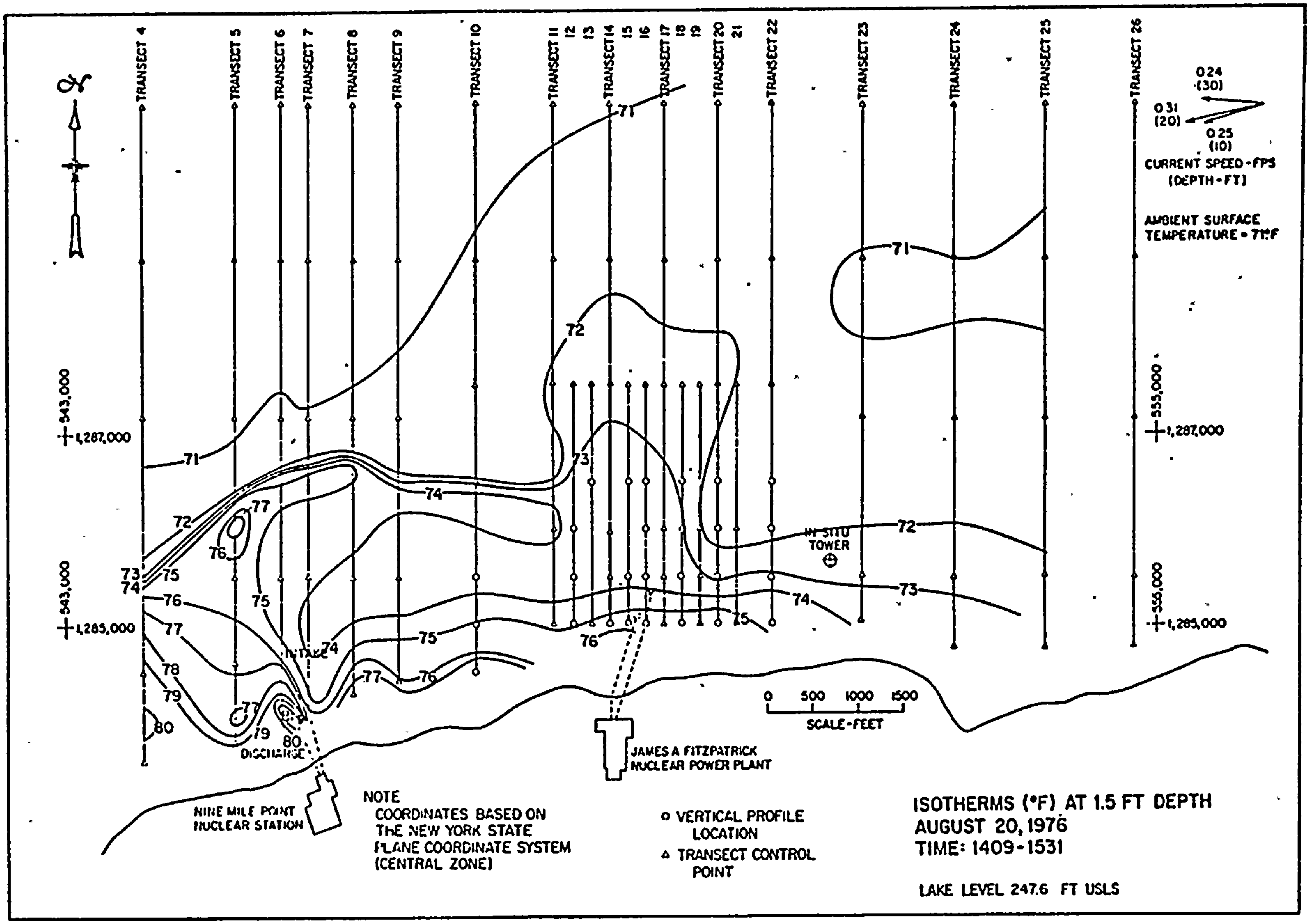

Figure 10. Farfield Surface Temperature

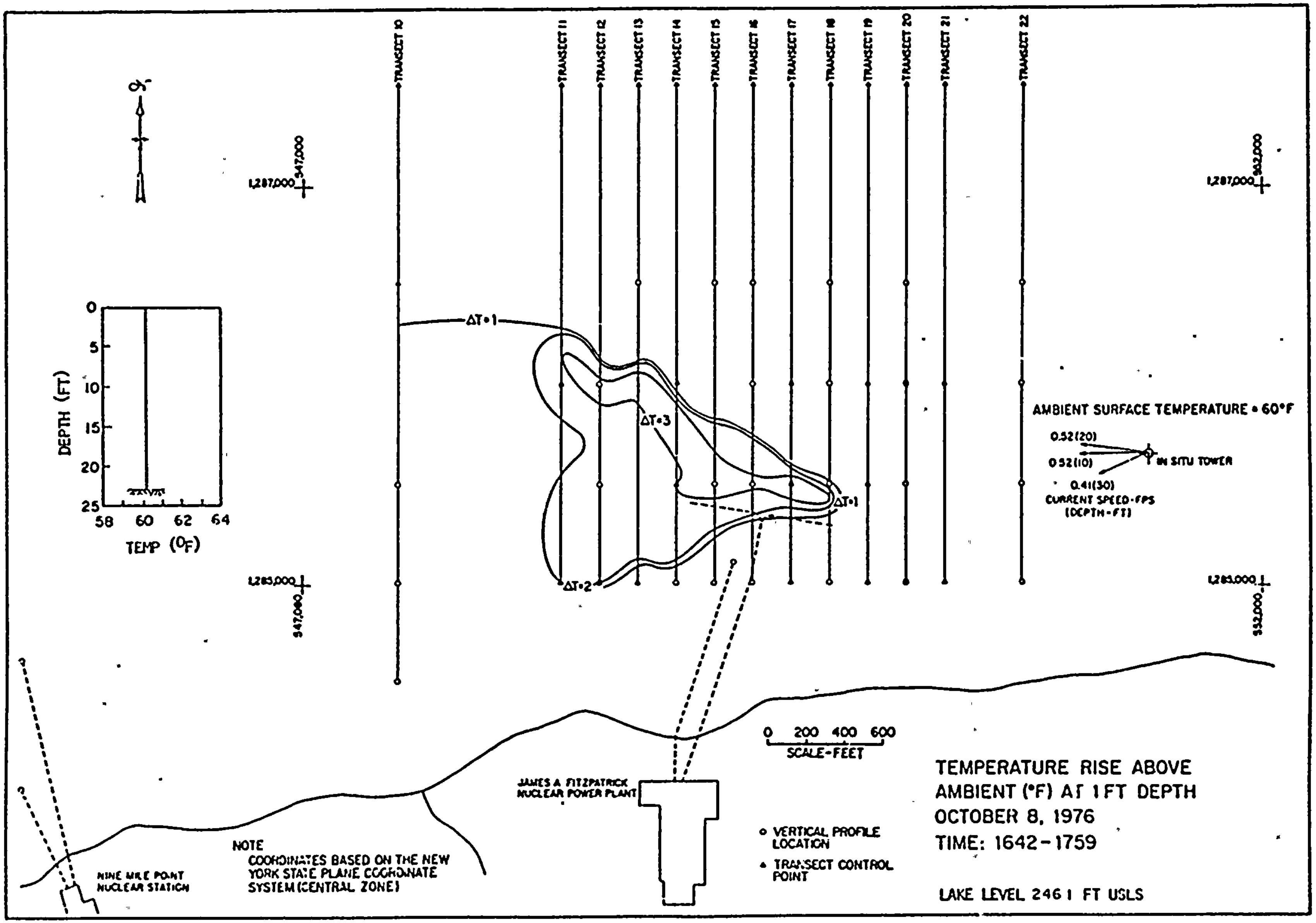

Figure 11. Homogeneous Lake Condition - Temperature

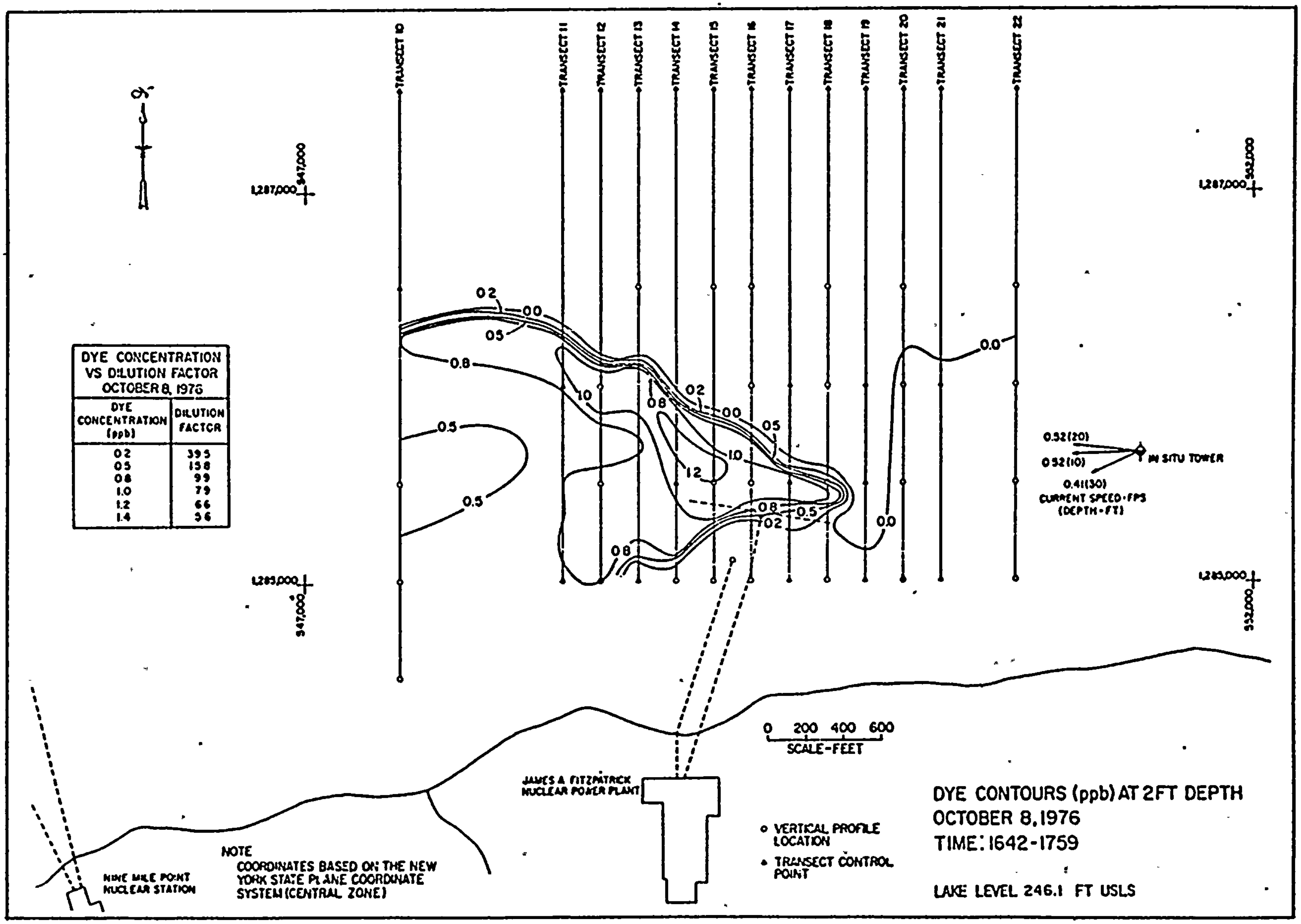

Figure 12. Homogeneous Lake Condition - Dye