EAI-TM-88-002A

PRELIMINARY DESIGN

OF

SUBMERGED MULTIPORT DIFFUSER

BY FRANK B. TATOM, P.E.

P.E. NO. 14,548

Prepared for

AWARE Incorporated
227 French Landing Drive
Nashville, Tennessee 37228

April 7, 1988

ENGINEERING ANALYSIS, INC.

715 Arcadia Circle
Huntsville, Alabama 35801-5909
(205)533-9391

STATEMENT OF THE PROBLEM

Engineering Analysis, Inc., (EAI), under Purchase Order 88-0347 with AWARE Incorporated, has developed a preliminary design of a diffuser for a projected wastewater discharge into the Pigeon River. The discharge would occur in the vicinity of the Newport Utilities Board (NUB) Wastewater Treatment Plant at mile number 4.04, as shown in Figure 1. The density of the effluent generally would be greater than the ambient water density, and thus, the diffuser design must allow for a negatively buoyant discharge. The basic objective of the study was to develop a design which would interact with a minimum fraction of the river cross-section while having a mixing zone which would extend downstream no more than 2400 feet under 3-day, 20-year low-flow conditions.

DESCRIPTION OF ENVIRONMENT

The body of water under consideration is the Pigeon River, specifically that portion extending downstream 2400 feet from river mile 4.04. The 3-day, 20-year low-flow rate is 63.7 ft^3/sec. The ambient temperature is taken to be 20^oC (68^oF) and the ambient total dissolved solids is approximately 155 ppm. The corresponding specific gravity for the water is 0.9984 [1]. Based on TVA hydraulic cross-sections at mile number 4.04 [2], the average water depth is taken to be 2.75 feet and the width 280 feet. This represents a cross-sectional area of 770 ft^2 and produces an average ambient velocity of 0.08272 ft/sec under low-flow conditions. The current NUB discharge is located approximately 200 feet downstream of the proposed diffuser site*. River bottom composition is reported to be rocky.

Approximately 300 feet downstream of the diffuser location, the river splits into three channels due to the presence of two islands, as indicated in Figure 2. The main channel, which is approximately 120 feet wide, passes along the left-hand side of the river (looking downstream) and is characterized by shallow, white-water rapids. The two shallow secondary

---

*The proposed site is more attractive than the current site because the water appears deeper (at the proposed site), and because more detailed hydraulic information is available.

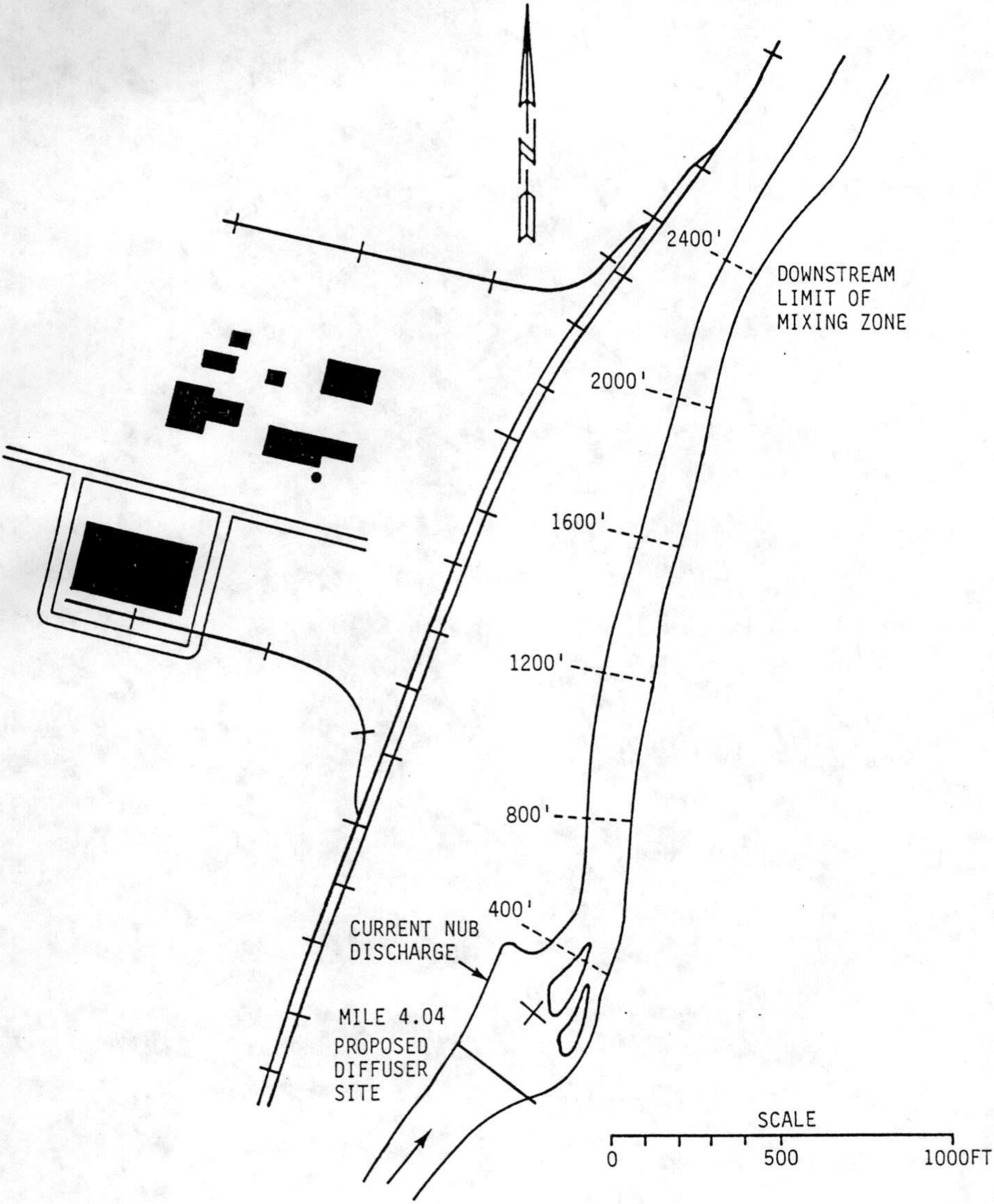


Figure 1. Pigeon River in Vicinity of Newport, Tennessee

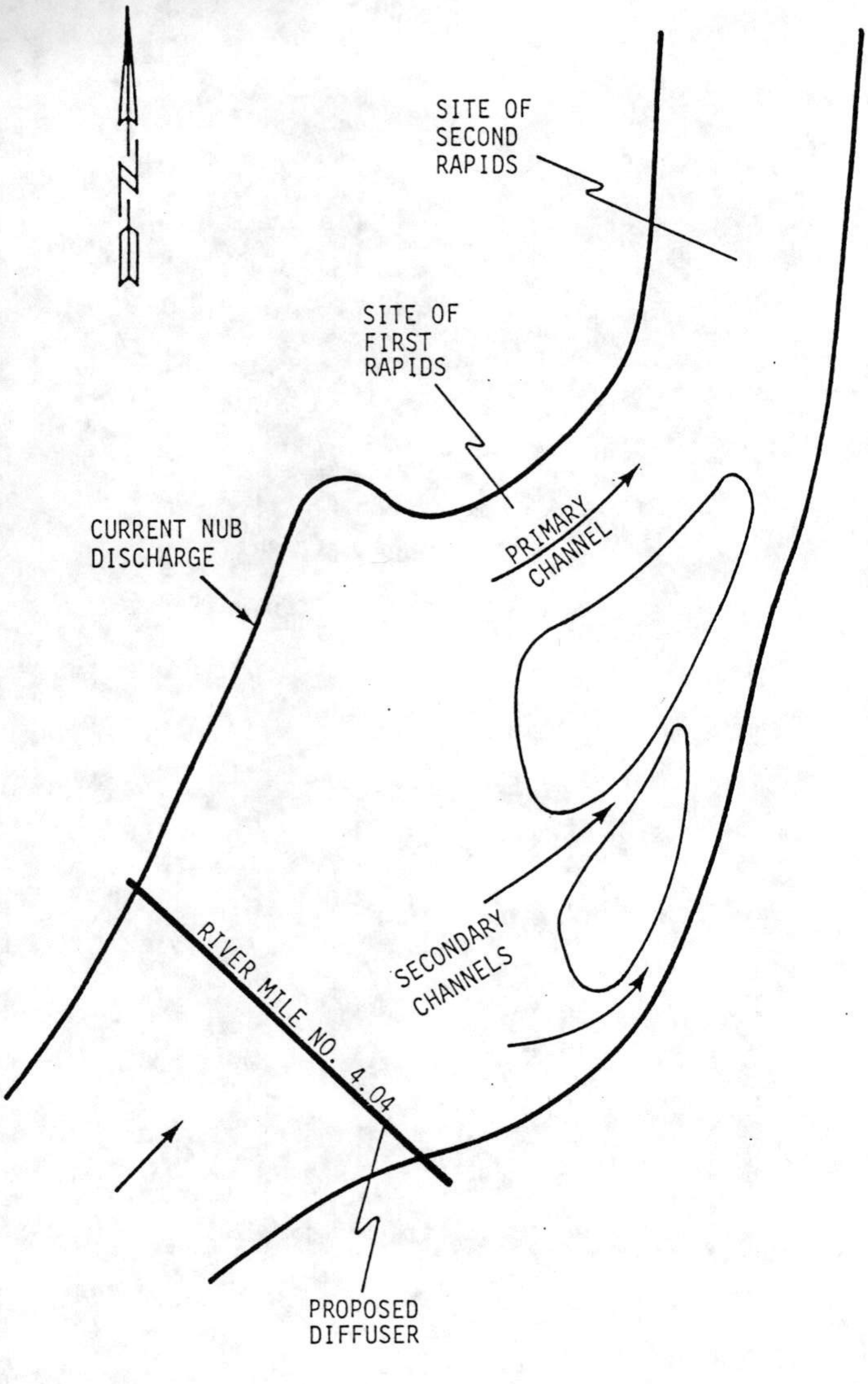


Figure 2. Channel Geometry in Vicinity of Diffuser Site

channels pass behind the two islands and appear to represent less than 10% of the total flow. Downstream of the islands, the channels merge to produce a single channel with a relatively uniform width of approximately 140 feet, which is also characterized by shallow rapids. Recent photographs taken along the Pigeon River in the vicinity of the proposed diffuser location are presented in Appendix A.

DISCHARGE CHARACTERISTICS

The treated effluent would be transported to the diffuser site by means of a 24-inch pipe. As indicated in Table 1, two flow rates have been considered; an average value of 4.2 mgd with a dissolved solids concentration of 2450 ppm, and a maximum value of 6.0 mgd with a dissolved solids concentration of 1715 ppm. Under conditions of minimum or average discharge temperatures the jet is negatively buoyant, but under conditions of maximum discharge temperatures the jet is very slightly positively buoyant.

TABLE 1. EFFLUENT CHARACTERISTICS

	Flow Conditions	
	Average	Maximum
Discharge Rate (mgd)	4.2	6.0
(cfs)	6.5	9.3
Dissolved Solids Concentration (ppm)	2450	1715
Temperature		
Minimum	10°C (50°F)	10°C (50°F)
Average	19°C (66°F)	19°C (66°F)
Maximum	27°C (81°F)	27°C (81°F)
Specific Gravity		
Maximum	1.0014	1.0010
Average	1.0001	.9996
Minimum	.9980	.9977

DIFFUSER CHARACTERISTICS

Based on the nature of the discharge site combined with the characteristics of the effluent, a simple discharge from the left bank will produce stratified flow, and will result in a plume which tends to cling to the left bank [2]. The stated objective calls for causing minimum blockage of the river cross-section while limiting the extent of the mixing zone to 2400 feet downstream of the discharge point. This objective can best be achieved by means of a submerged, multiport diffuser. Of the several designs considered, the most effective is that shown in Figure 3.

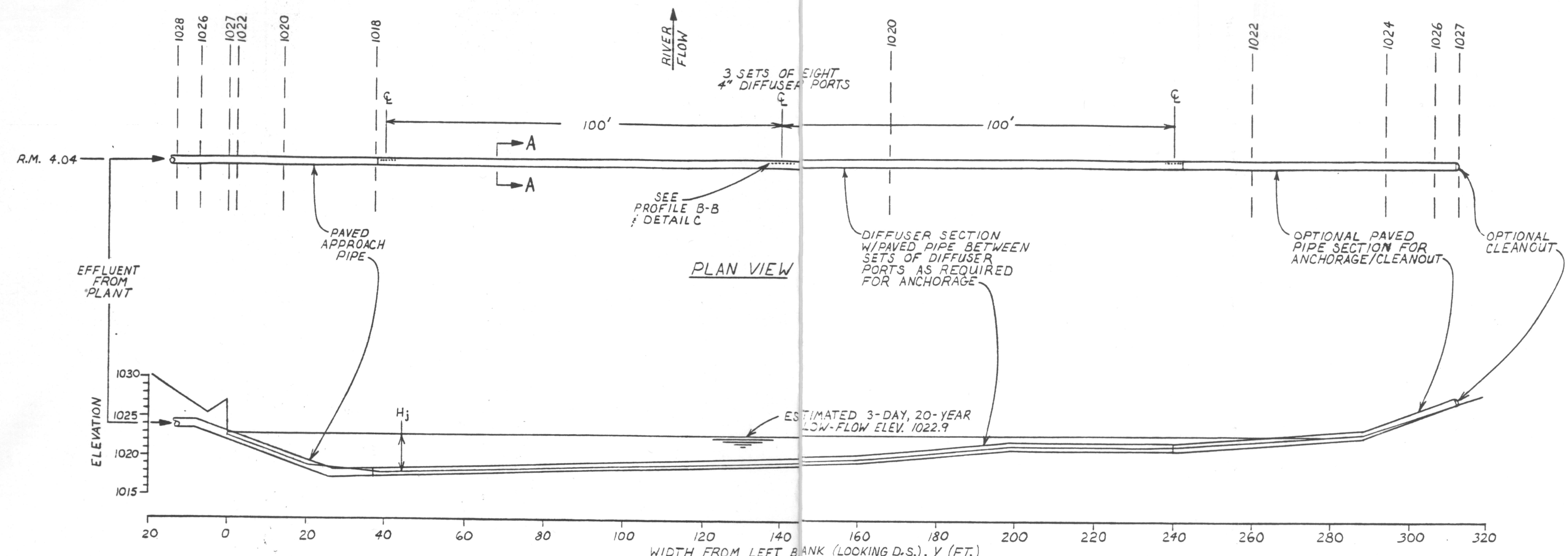
The submerged diffuser design is based primarily on design considerations for negatively buoyant jets [3] but with adjustments to allow for cases involving positive buoyancy [4]. The half-buried 1-foot diameter diffuser pipe would extend across the river, with three sets of diffuser ports, located at 40, 140 and 240 feet from the right bank. Each set of diffuser ports would consist of eight 4-inch holes spaced six inches apart. The holes would be oriented 45^{o} from the vertical in the downstream direction. Because of the proposed hydraulic configuration, a discharge rate from each diffuser port, which is directly proportional to water depth, should be achievable, as noted in Figure 3*. Thus, the greatest discharge would occur in the deepest water near the left bank, and the smallest discharge would occur in the shallow water 40 feet from the right bank.

DIFFUSER PERFORMANCE

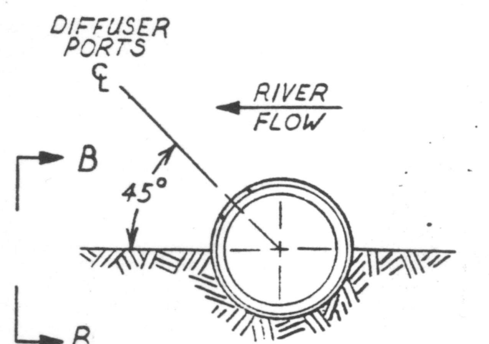
The performance of the proposed diffuser, in the immediate vicinity of the discharge, has been calculated based on semi-empirical models derived from experimental data for both negatively and positively buoyant jets [3,5]. The transport and dilution of the plume were computed by means of the EAI Steady-State River Diffusion Model, with distributed sources representing the multiport diffuser. This three-dimensional (x = longitudinal, y = lateral, and z = vertical) model utilizes pairs of sources in the y-z (cross-sectional) plane to model the river bottom and surface, and both river banks [6,7]. The model takes into account the effects of bottom roughness (in

---

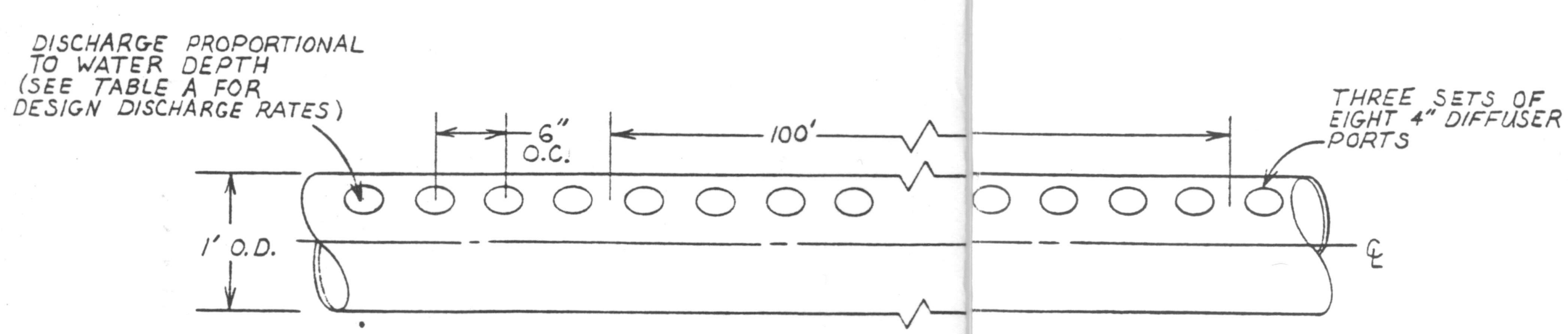
*Some adjustment in diffuser port diameter and spacing may be necessary to achieve discharge rates <u>precisely</u> proportional to water depth.



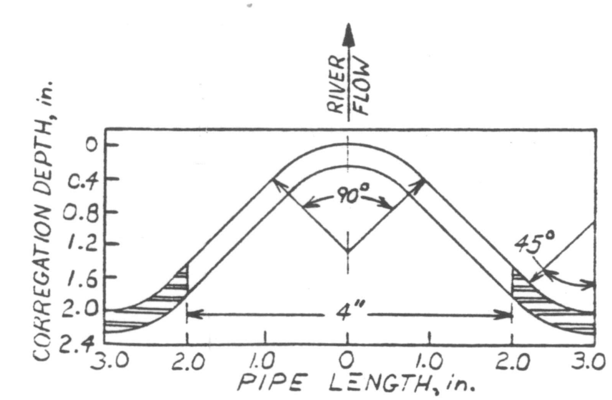
CROSS-SECTION, PIGEON RIVER MILE 4.04



SECTION A-A
2"x6" CORRUGATED PLATE UNPAVED GALVANIZED STEEL PIPE



PROFILE B-B
PORT ARRANGEMENT



DETAIL C
4" DIAMETER PORTS IN STRUCTURAL PLATE CORREGATION

TABLE A. DESIGN DISCHARGE RATES FOR DIFFUSER PORTS

j	Y(ft.)	H_j(ft.)	$\bar{Q}_{pj}$ (cfs)	Q_{pj}(max) (cfs)	$\bar{U}_{pj}$ (fps)	U_{pj}(max) (fps)
1	40	4.9	.410	.586	4.701	6.716
2	140	3.4	.285	.407	3.263	4.661
3	240	1.4	.117	.168	1.344	1.919

Q_{pj} DENOTES DISCHARGE RATE FROM INDIVIDUAL PORTS

PRELIMINARY DIFFUSER DESIGN - AWARE, INC.
PIGEON RIVER MILE 4.04

SCALE:	APPROVED BY: Frank B. Eaton	DRAWN BY SJB
DATE: 3/22/88		REVISED 4/28/88
ENGINEERING ANALYSIS, INC. 715 ARCADIA CIRCLE HUNTSVILLE, AL. 35801-5909		DRAWING NUMBER

terms of the Manning coefficient) [8] and density stratification (in terms of the gradient Richardson number) [9] on turbulent diffusion.

River flow conditions were consistent with those already given. Likewise, the characteristics of the effluent were consistent with Table 1 and the discharge conditions were in accordance with Table A in Figure 3. In carrying out the computations, a Manning coefficient of .0675 was assumed, based on a combination of observations derived from a site inspection, and empirical data [10]. Because of the vigorous vertical mixing produced by the diffuser configuration, a gradient Richardson number of 0.0 was assumed.

The diffuser performance calculations have revealed that the mixing region associated with the diffuser can be divided in three subdivisions, as shown in Figure 4. In the first subdivision, which extends downstream approximately 100 feet, the eight jets from each of the three sets of diffuser ports merge to form three planar jets while rising to the surface. As indicated in Figure 5, the total blockage due to the jets interacting with the river flow at the diffuser would amount to approximately 51 ft^2, less than 7% of the river cross-section. Because of the shallowness of the water, the jets, upon reaching the surface, will produce a surface boil approximately five to ten feet wide and of similar length*. Downstream of this point, the jets will generally fall back toward the river bottom due to negative buoyancy. In the case of slightly positive buoyancy, the jets will remain on the surface while proceeding downstream. In either case, due to the shallowness of the water and the velocity of the jets, vertical mixing will tend to occur within the 100-foot distance downstream, producing three vertically-mixed plumes with centerlines spread 100 feet apart.

In the second subdivision, which extends downstream from the 100-foot limit to approximately 650 feet from the diffuser, the three vertically-mixed plumes spread laterally as they move downstream. Ultimately these three plumes merge, marking the limit of the second subdivision.

---

*If the surface boil is considered unacceptable, it can be eliminated by increasing the number of diffuser ports for each set from eight to approximately 40. Such an increase in the number of ports, however, would increase blockage of the river cross-section from ∿7% to ∿35%.

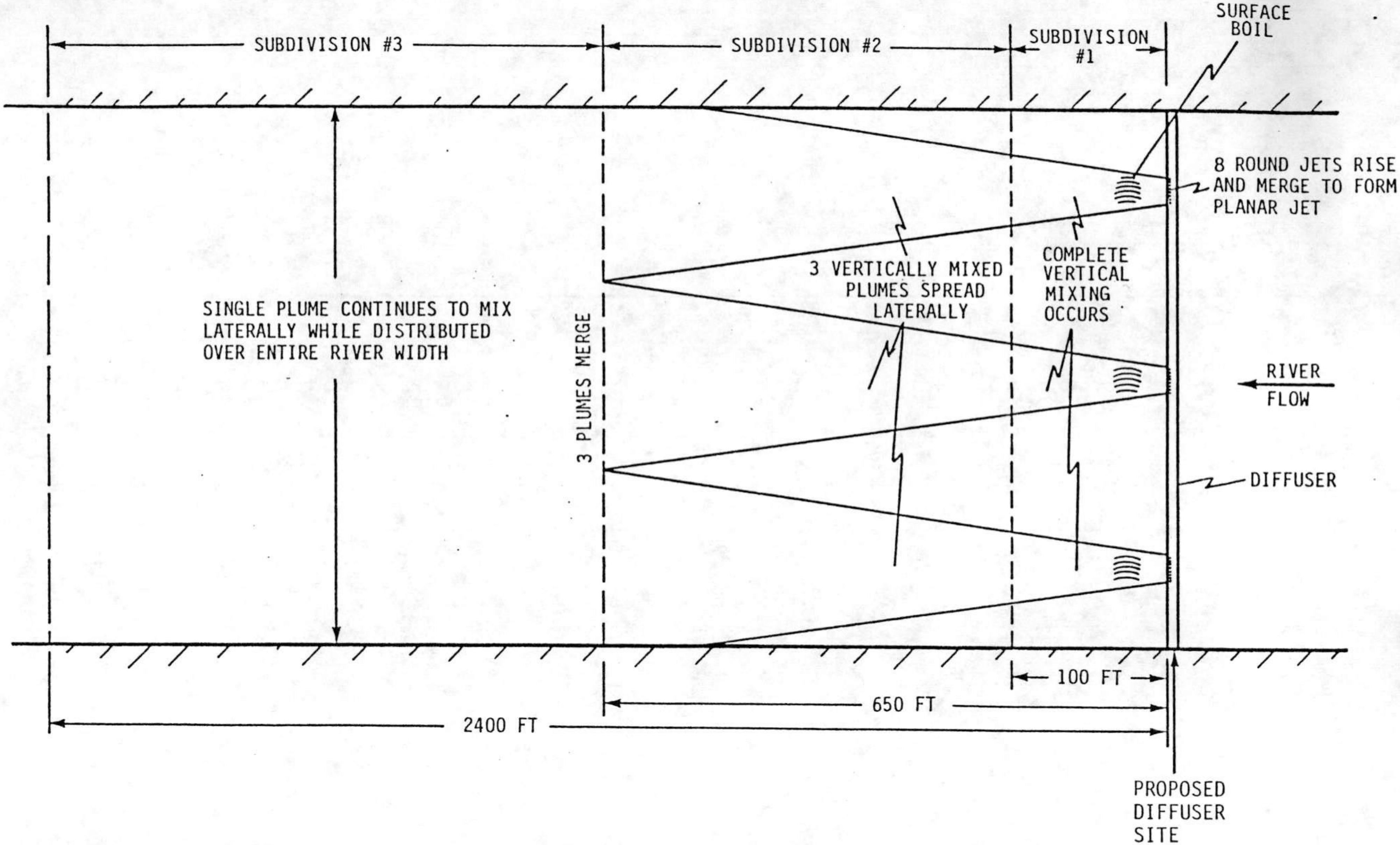


Figure 4. Subdivisions of Mixing Zone

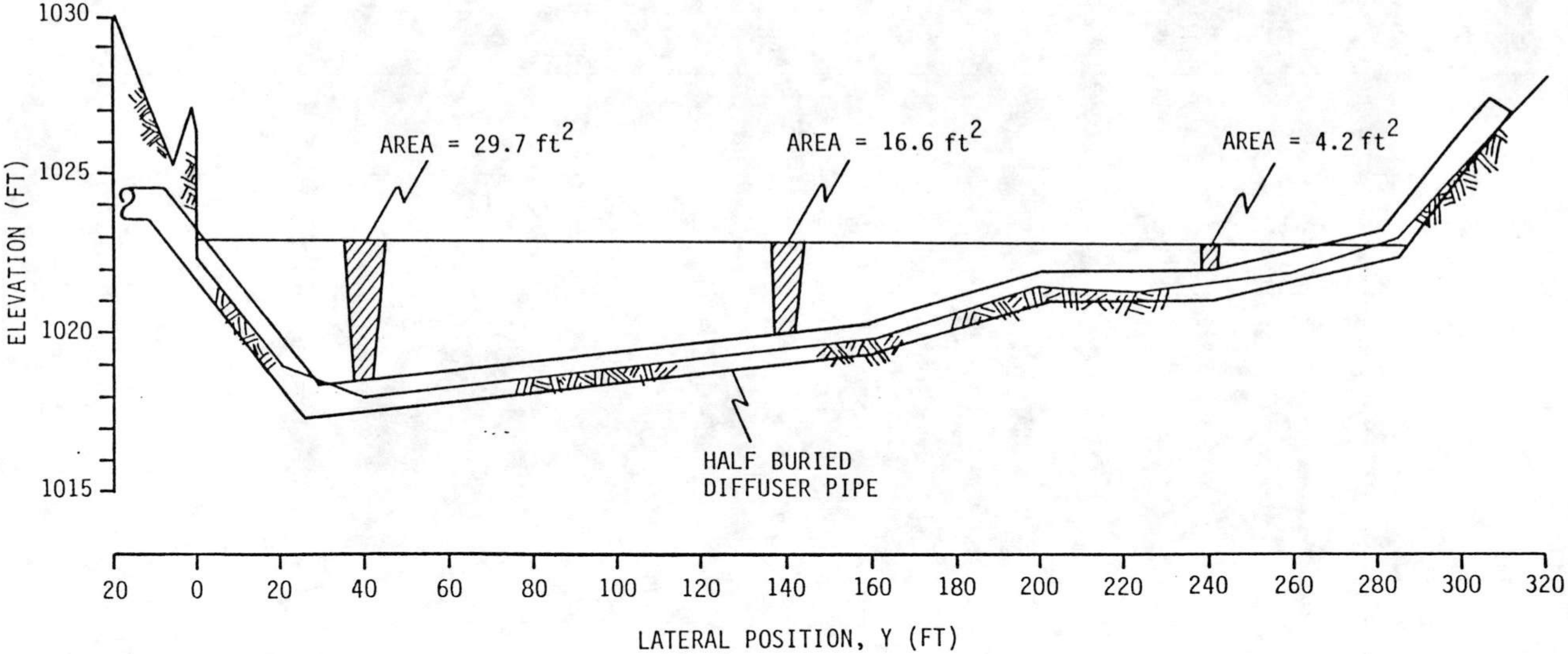


Figure 5. Channel Blockage Due to Diffuser

In the third subdivision, which extends downstream beyond the 650-foot limit to the 2400-foot boundary, the flow is characterized by further lateral mixing and spreading, until ultimately the plume is distributed across the entire width of the river. Uniform lateral mixing is not totally achieved at the downstream boundary, but the total dissolved solids concentration is less than 500 ppm at all points in the river cross-section at this boundary.

Based on the numerical output of the Steady-State River Diffusion Model, dissolved solids concentration profiles, corresponding to 400, 800, 1200, 1600, 2000, and 2400 feet are presented in Figure 6. The river width for each profile corresponds to the total width indicated in Figure 1. The concentration profile for 400 feet, shown in Figure 6a, is representative of the pattern present in the second subdivision of the mixing region*. The remaining profiles fall within the third subdivision. The nonuniform effects of the three clusters of diffuser ports are gradually smoothed out, but, as already noted, variation with lateral position remains at the downstream boundary. The maximum concentration of 439 ppm is within the 500 ppm limit.

Notice should be taken that in carrying out the analysis, the presence of the shallow rapids commencing approximately 300 feet downstream of the diffuser was not taken into account. In this section of the river, the bottom is quite rocky and would correspond to a Manning coefficient of approximately 0.100 [10]. The combination of shallow rapids and higher Manning coefficient would further promote mixing, both vertical and lateral, and should enhance diffuser performance. Thus, the diffuser performance predictions, as presented, should tend to be conservative.

CONCLUSIONS

The proposed diffuser design satisfies the requirement for meeting the 500 ppm standard for dissolved solids within 2400 feet downstream, while inter-

---

*Because of the limitations of the Steady-State River Diffusion Model, the presence of more than one channel in the river, as indicated in Figures 1 and 2, could not be treated for this cross-section.

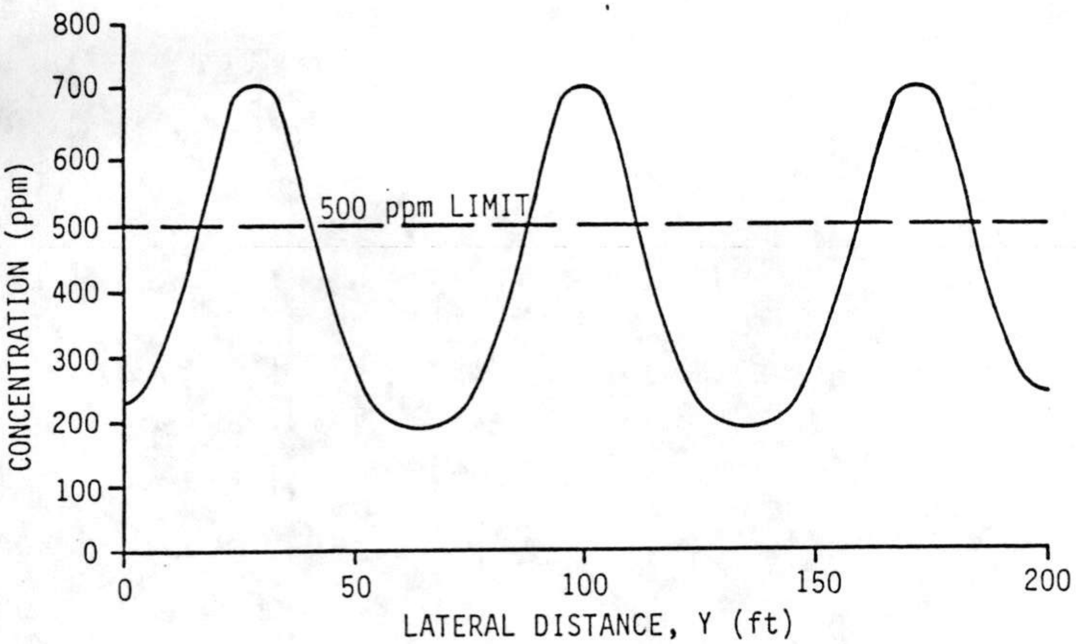


Figure 6a. Concentration Profiles Downstream of the Diffuser (x = 400 ft)

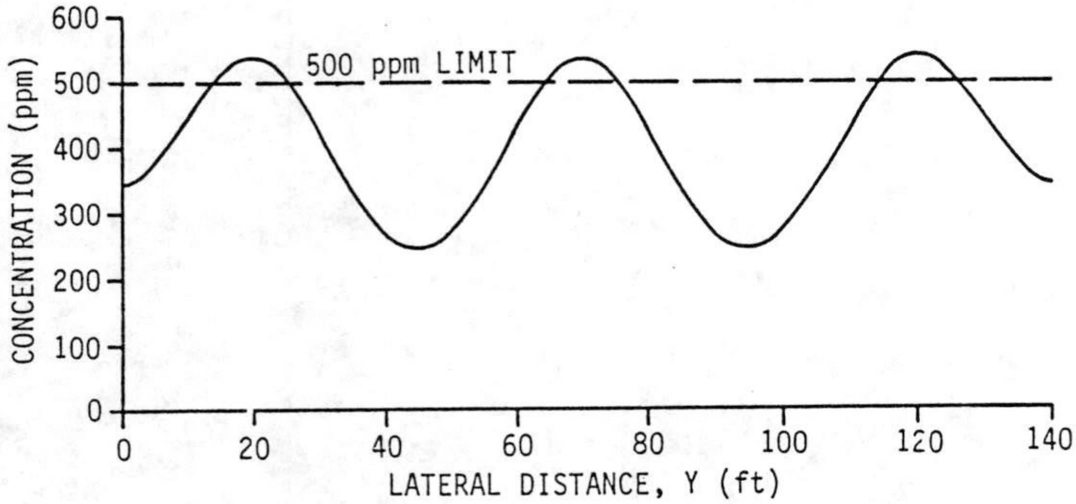


Figure 6b. Concentration Profiles Downstream of the Diffuser (x = 800 ft)

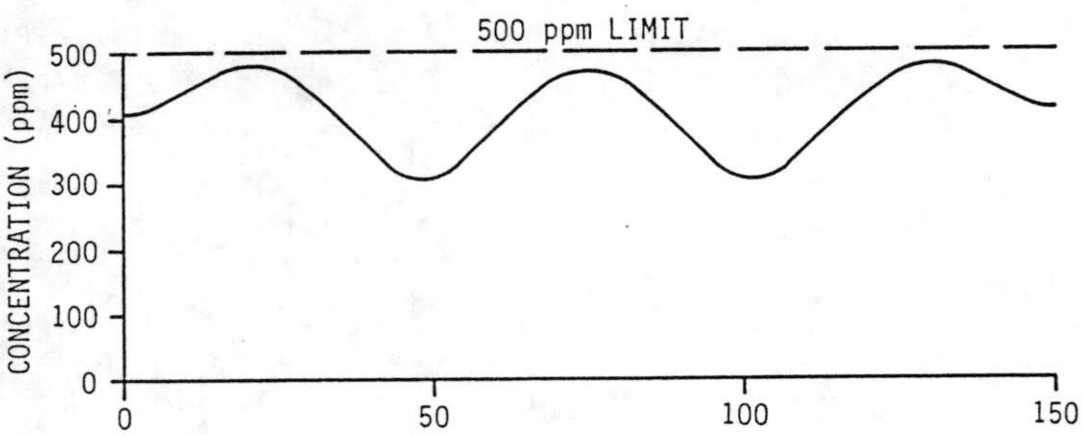


Figure 6c. Concentration Profiles Downstream of the Diffuser (x = 1200 ft)

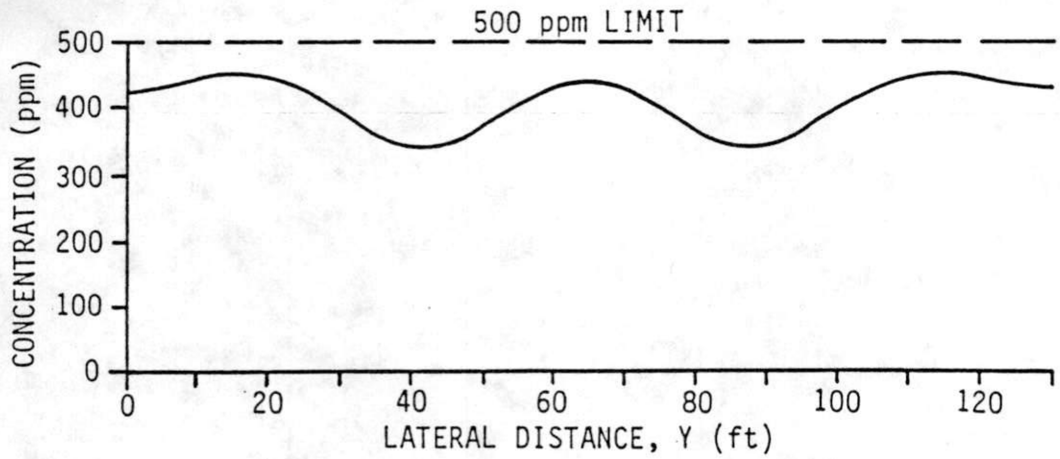


Figure 6d. Concentration Profiles Downstream of the Diffuser (x = 1600 ft)

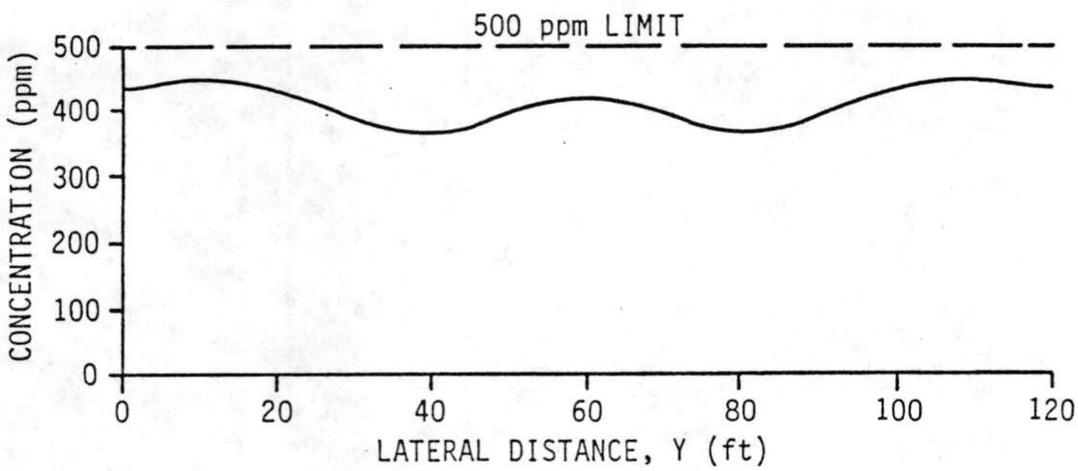


Figure 6e. Concentration Profiles Downstream of the Diffuser (x = 2000 ft)

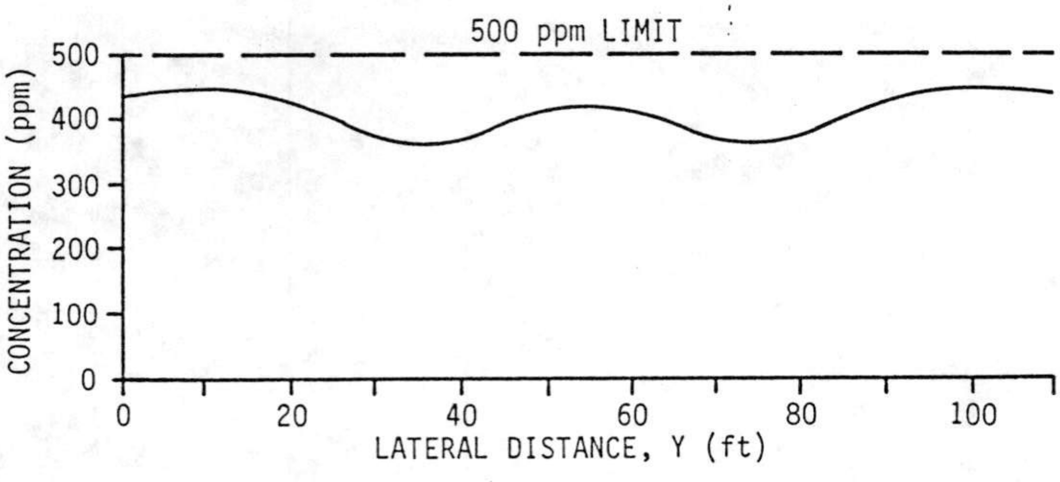


Figure 6f. Concentration Profiles Downstream of the Diffuser (x = 2400 ft)

acting with less than 7% of the river cross-sections at the site of the diffuser. The design is based on experience with both negatively buoyant and positively buoyant jets, and appears appropriate for the discharge under consideration.

REFERENCES CITED

1. Handbook of Chemistry and Physics, Fiftieth Edition, Robert C. Weast, Editor, The Chemical Rubber Company, Cleveland, Ohio, 1969.

2. Tatom, Frank B., "Evaluation of Total Dissolved Solids (TDS) in the Pigeon River Based on a Modified Discharge from a Wastewater Treatment Plant", EAI-TM-87-001A, Engineering Analysis, Inc., Huntsville, Alabama, September 8, 1987.

3. Tong, Siu Shing, and Stolzenback, Keith D., "Submerged Discharges of Dense Effluent", Report No. 243, School of Engineering, Department of Civil Engineering, Massachusetts Institute of Technology, Cambridge, Massachusetts, July 1979.

4. Ungate, Christopher D., "Multiport Diffuser System Design", Report No. 9-2009, Tennessee Valley Authority, Division of Water Management, Water Systems Development Branch, Norris, Tennessee, September 1975.

5. Shirazi, Mostafa, and Davis, Lorin R., "Workbook of Thermal Plume Prediction", Volume I - Submerged Discharge, EPA-R2-005a, August 1972, and Volume II - Surface discharge, EPA-R2-005b, May 1974, National Environmental Research Center, Office of Research and Monitoring, U.S. Environmental Protection Agency, Corvallis, Oregon.

6. Carslaw, H. S., and Jaeger, J. C., Conduction of Heat in Solids, Second Edition, Oxford University Press, 1959.

7. Hinze, J. O., Turbulence, Second Edition, McGraw-Hill, Inc., New York, 1975.

8. Fischer, Hugo B., et al, Mixing in Inland and Coastal Waters, Academic Press, New York, 1979.

9. Munk, W., and Anderson, E. R., "Notes on a theory of the thermocline", Journal of Marine Research, Volume 7, pp 276-295, 1948.

10. Chow, Ven Te, Open-Channel Hydraulics, McGraw-Hill Book Company, Inc., New York, 1959.

APPENDIX A.

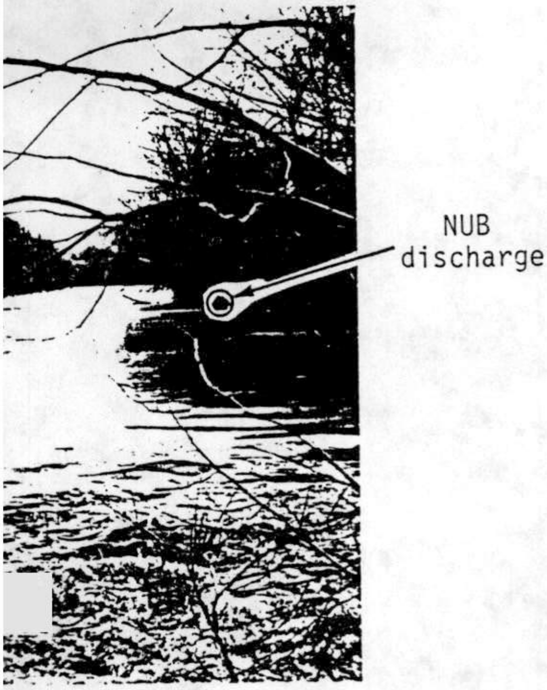
PHOTOGRAPHS ALONG THE PIGEON RIVER
IN THE VICINITY OF PROPOSED DIFFUSER SITE

In an effort to assist in visualizing the diffuser site and the associated mixing zone, 15 photographs are presented. Figures A-1 through A-11 were taken under high water conditions while Figures A-12 through A-15 were taken under low water conditions. In each case the sequence generally proceeds from the current NUB discharge site downstream toward the rapids.

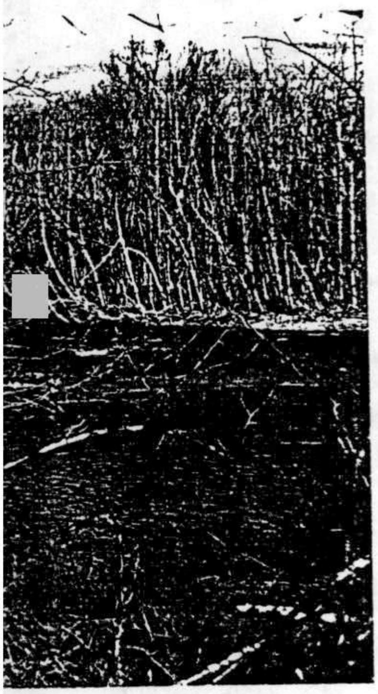
A-1. Current NUB discharge in foreground (high water level)

A-2. Slightly downstream of current NUB discharge (high water level)

A-3. Further downstream prior to reaching first rapids (high water level)




st rapids (high water level)

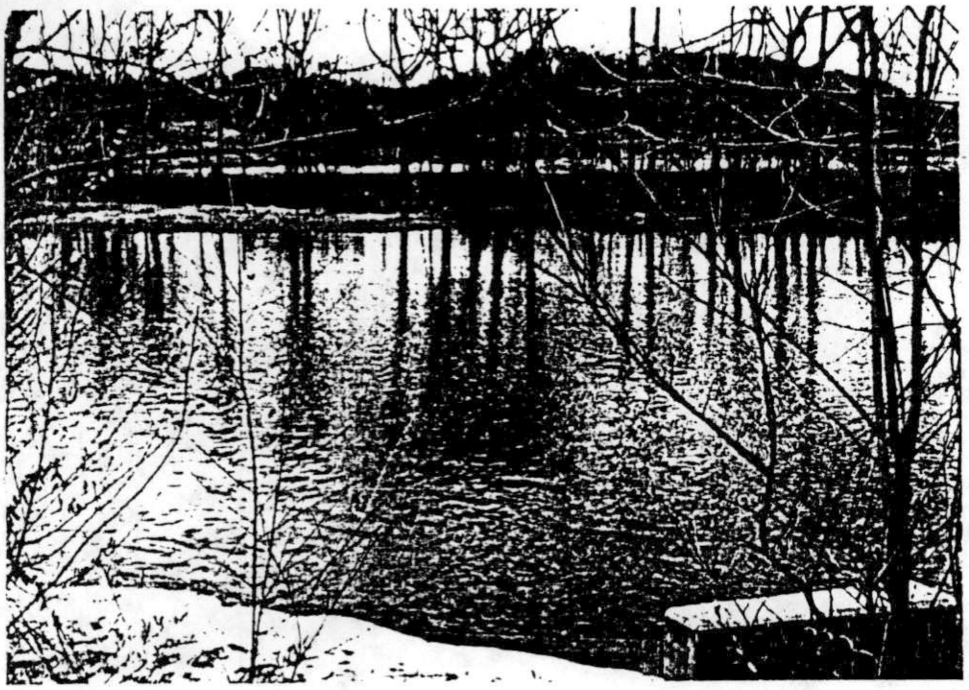


ds (high water level)

ter level)

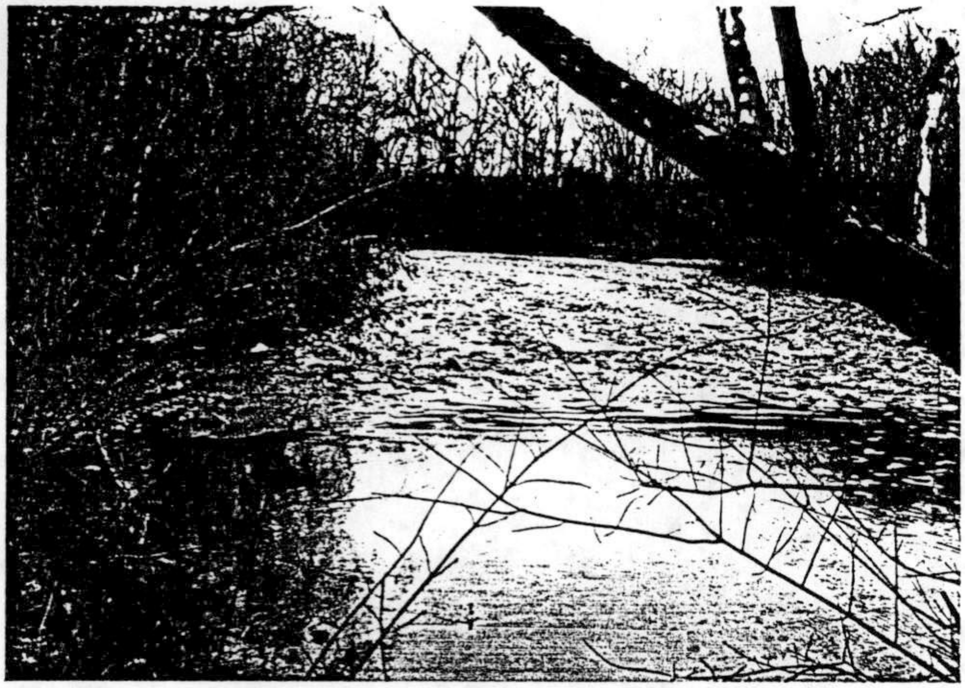
A-10. Second rapids downstream of the island (high water level)

A-11. Second rapids further downstream (high water level)



A-12. Current NUB discharge in foreground (low water level)

A-13. Slightly downstream of current NUB discharge (low water level)



A-14. Further downstream near onset of first rapids (low water level)

A-15. Just upstream of onset of first rapids (low water level)