SOAH DOCKET NO. 582-22-0585
TCEQ DOCKET NO. 2021-1001-MWD

APPLICATION BY	**§**	**BEFORE THE STATE OFFICE**
CITY OF GRANBURY,	**§**	**OF**
FOR TPDES PERMIT NO.	**§**	**ADMINISTRATIVE HEARINGS**
WQ0015821001	**§**	
	§	

EXHIBIT GF-302

IN THE MATTER OF
THE APPLICATION OF
NORTH TEXAS MUNICIPAL
WATER DISTRICT

BEFORE THE
TEXAS WATER
COMMISSION

EXHIBIT NO. ________

BOD/OXYGEN DEFICIT MODEL FOR THE WEST ARM OF LAKE LAVON

By

S.C. CHAPRA, PH.D.

and

S.E. ESMOND, P.E.

JANUARY 1983

BOD/Oxygen Deficit Model for the West Arm of Lavon Lake

by

S. C. Chapra, Ph.D. and S. E. Esmond, P.E.

INTRODUCTION

Models are developed for carbonaceous and nitrogenous BOD and for dissolved oxygen deficit in the west arm of Lavon Lake. Due to the hydrodynamic characteristics of the west arm and the kinetic characteristics of BOD-oxygen deficit reactions, one dimensional advection-diffusion equations are used to simulate BOD and oxygen levels along the longitudinal axis of the arm. These equations are directly analogous to the classical Streeter-Phelps model for stream oxygen with appropriate modifications to account for turbulent diffusion along the bay's longitudinal axis. Among other things, this model predicts the magnitude and location of the maximum dissolved oxygen deficit along the arm's axis due to both carbonaceous and nitrogenous BOD discharges at the head end of the arm.

MODEL FORMULATION

Thomann (1973) has proposed the following criterion for determining the proper model to characterize one-dimensional advective/diffusive systems with reaction

$$n = \frac{KE}{U^2} \tag{1}$$

where K is a first order reaction rate (d^{-1}); E is a diffusion coefficient ($m^2\ d^{-1}$); U is the longitudinal velocity ($m\ d^{-1}$); and n is the dimensionless coefficient where $n < 0.1$ indicates that advection is predominant; $n > 10$ indicates that diffusion predominates and $0.1 < n < 10$ indicates that both are important.

For carbonaceous BOD in the west arm of Lavon Lake, n = 0.9 (using the data in Table 1) indicating that both are important. Similar computations for nitrogenous BOD and for dissolved oxygen lead to the same conclusion. For this reason, a one-dimensional advection/diffusion model with first order reactions will be used to characterize oxygen levels in the arm. A further idealization is that the arm will be treated as having uniform dimensions as in Figure 1.

BOD

The following one-dimensional advection/diffusion equation can be used to characterize BOD concentration along the longitudinal (i.e., x) axis of the arm (Figure 1)

$$\frac{\partial L}{\partial t} = -U_x \frac{\partial L}{\partial x} + D_x \frac{\partial^2 L}{\partial x^2} - k_1 L \tag{2}$$

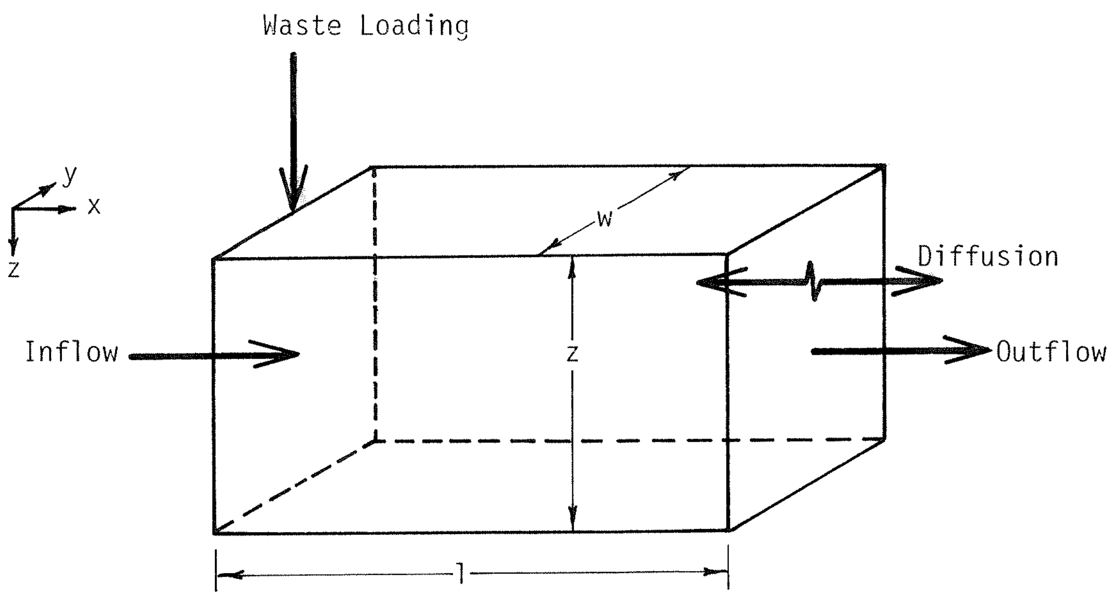

FIGURE 1. - ONE-DIMENSIONAL MODEL WITH CONSTANT DIMENSIONS

where L = BOD concentration (g m^{-3});

t = time (d);

U_x = advective velocity along the longitudinal axis (m d^{-1})

x = distance along the x-axis where x = 0 at the head end of the arm (m),

D_x = the turbulent diffusion coefficient along the longitudinal dimension ($m^2 d^{-1}$), and

k_1 = the first order decay rate for BOD (d^{-1})

At steady state ($\partial L/\partial t = 0$) and applying appropriate boundary conditions, Equation 2 can be solved for

$$L = \frac{2W_1/Q}{1 + \sqrt{1 + \frac{4k_1 D_x}{U_x^2}}} \; e^{\frac{U_x}{2D_x}\left(1 - \sqrt{1 + \frac{4k_1 D_x}{U_x^2}}\right)x} \qquad (3)$$

where W_1 = the rate of mass loading of BOD at the head end of the arm [g d^{-1}].

D.O. Deficit

An equation for D.O. deficit can be written as

$$\frac{\partial D}{\partial t} = -U_x \frac{\partial D}{\partial x} + D_x \frac{\partial^2 D}{\partial x^2} - k_2 D + k_1 L \qquad (4)$$

where k_2 = the reaeration rate (d^{-1}), and D = oxygen deficit (g m^{-3}) where

$$D = c_s - c \qquad (5)$$

where c_s = saturation concentration of dissolved oxygen (g m^{-3}) and

c = concentration of dissolved oxygen (g m^{-3}).

At steady state, with appropriate boundary conditions, Equation 4 can be solved for

$$D = \frac{k_1}{k_2 - k_1} \frac{2W_1/Q}{1 + \sqrt{1 + \frac{4k_1D_x}{U_x^2}}} \left\{ e^{\frac{U_x}{2D_x}\left(1 - \sqrt{1 + \frac{4k_1D_x}{U_x^2}}\right) x} - \frac{1 - \sqrt{1 + \frac{4k_1D_x}{U_x^2}}}{1 + \sqrt{1 + \frac{4k_2D_x}{U_x^2}}} e^{\frac{U_x}{2D_x}\left(1 - \sqrt{1 + \frac{4k_2D_x}{U_x^2}}\right) x} \right\} \quad (6)$$

MODEL APPLICATION

Using the information in Tables 1 and 2, the dissolved oxygen deficit for the West Arm can be computed. The results for maximum deficit/minimum D.O. concentration are listed in Table 3.

Table 1. Physical Parameters for the West Arm of Lavon Lake

Parameter	Symbol		
Length			
Width	w	1067	m
Mean depth	z	3.66	m
Cross-sectional area	A_c	3902	m^2
Flow	Q	5.43×10^5	$m^3\ d^{-1}$
Velocity	U_x	139.1	$m\ d^{-1}$
Turbulent diffusion	D_x	8.64×10^4	$m^2\ d^{-1}$

Table 2 Parameters for BOD/D.O. Deficit Computations for Lavon Lake

Parameter	Symbol	Value	Units
Deoxygenation rate	k_1	0.2	d^{-1}
Reaeration rate	k_2	0.042	d^{-1}
Ultimate BOD loading	W_1		$g\ d^{-1}$
Existing Plants (current conditions)		6.63×10^5	
Existing Plants (future conditions)		8.98×10^5	
Treatment Level A			
8 MGD		2.67×10^6	
24 MGD		8.01×10^6	
Treatment Level B			
8 MGD		8.68×10^5	
24 MGD		2.61×10^6	
Treatment Level C			
8 MGD		5.92×10^5	
24 MGD		1.78×10^6	

Table 3. Maximum deficit and minimum oxygen concentrations for the West Arm assuming a saturation concentration of 7.4 mg l^{-1} (corresponding to a temperature of 30°C)

Scenario	Dissolved Oxygen (mg l^{-1}) Maximum Deficit	Dissolved Oxygen (mg l^{-1}) Minimum Concentration
1. Existing plants (current conditions)	0.651	6.75
2. Existing plants (future conditions)	0.881	6.52
3. Treatment Level A - 8 MGD	2.619	4.78
4. Treatment Level A - 24 MGD	7.858	-0.46
5. Treatment Level B - 8 MGD	0.852	6.55
6. Treatment Level B - 24 MGD	2.558	4.84
7. Treatment Level C - 8 MGD	0.581	6.82
8. Treatment Level C - 24 MGD	1.746	5.65

Table 4.
(taken from Exhibit # 64)

POINT SOURCE
OXYGEN DEMAND CONSTITUENT
LOADINGS TO
EAST FORK ARM OF
LAKE LAVON

CONDITION	FLOW	DISCHARGE	CRITERIA (mg/l)	LOADS (lb/yr x 1000)		
	(MGD)	BOD5	NH3-N	BOD5	NH3-N	UOD
Existing Plants (Current Conditions)	1.7	20	16	155	378	533
Existing Plants (Future Conditions)	2.3	20	16	210	512	722
Existing Plants Plus Proposed Regional Plant with Treatment Level A	8.0 24.0	10 10	16 16	365 1096	1781 5342	2146 6438
Existing Plants Plus Proposed Regional Plant with Treatment Level B	8.0 24.0	10 10	3 3	365 1096	333 1000	698 2096
Existing Plants Plus Proposed Regional Plant with Treatment Level C	8.0 24.0	10 10	1 1	365 1096	111 334	476 1430

DISCUSSION

The results of the model are depicted on Table 3 and on Figures 2, 3, and 4. Table 3 gives the maximum dissolved oxygen deficit and minimum dissolved oxygen concentration for each of the proposed levels of treatment. For reference, a portion of Exhibit #64 has been reproduced in this report and appears as Table 4, which specifies the levels of treatment for both the 8 MGD and 24 MGD cases. The flows and oxygen demands used in the model were taken directly from this table.

Figure 2 shows the dissolved oxygen profile downstream of the proposed 24 MGD discharge, comparing Level A against Level B. The hydraulic condition for these profiles is a "median lake inflow" condition, which is taken as the mean flow in the East Fork and Wilson Creek tributaries of Lake Lavon. Since there is considerable variation in the flow rate in these tributaries, the mean inflow condition has little or no physical meaning. It is presented here simply to illustrate the impact of an "average" condition as opposed to a more restrictive or even "worst-case" condition. Note that Level A produces a zero D.O. condition approximately 3,000 ft. downstream of the discharge. This condition prevails until about 7,500 ft., and from that point onward the recovery is seen. The dissolved oxygen standard of 5.0 mg/l is violated in virtually all of the West Arm of Lake Lavon, and in fact does not recover completely prior to entering the main body of the lake. On the other hand, Level B depresses the D.O. concentration to a minimum of 4.84 mg/l, followed by a slow recovery. The stream standard of 5.0 mg/l is only slightly violated over a limited portion of the West Arm of the Lake under median lake flow and Level B effluent quality.

Figure 3 shows the dissolved oxygen profile from the minimum 30-day lake inflow condition and 8 MGD wastewater discharge. The minimum 30-day inflow is the actual inflow recorded during August 1981, which was 500 ac. ft. This lower inflow, of course, presents a more critical condition in terms of maintenance of dissolved oxygen downstream of the discharge. Level A at 8 MGD causes a dip in the D.O. profile, which reaches a minimum value of 0.3 mg/l at a point about 500 ft. downstream of the discharge. The recovery zone is relatively short as compared with Figure 2, and the D.O. concentration is back up to 5.0 mg/l at about 8,500 ft. downstream of the discharge. Level B causes a similar response to dissolved oxygen, butthe minimum value is 5.1 mg/l.

Figure 4 presents the dissolved oxygen profile for the same minimum 30-day lake inflow condition described above, but with the 24 MGD wastewater discharge superimposed. In the case of Level A, the D.O. drops to zero very rapidly, and no recovery is seen until a point 9,000 ft. downstream. A recovery begins at this point, until the D.O. concentration attains 5.0 mg/l approximately 15,000 ft. downstream of the discharge. Level B also produces a sharp initial decline in D.O., but the minimum value in this case is 1.6 mg/l. Level C also produces a sharp initial decline, but the minimum value is 3.4 mg/l.

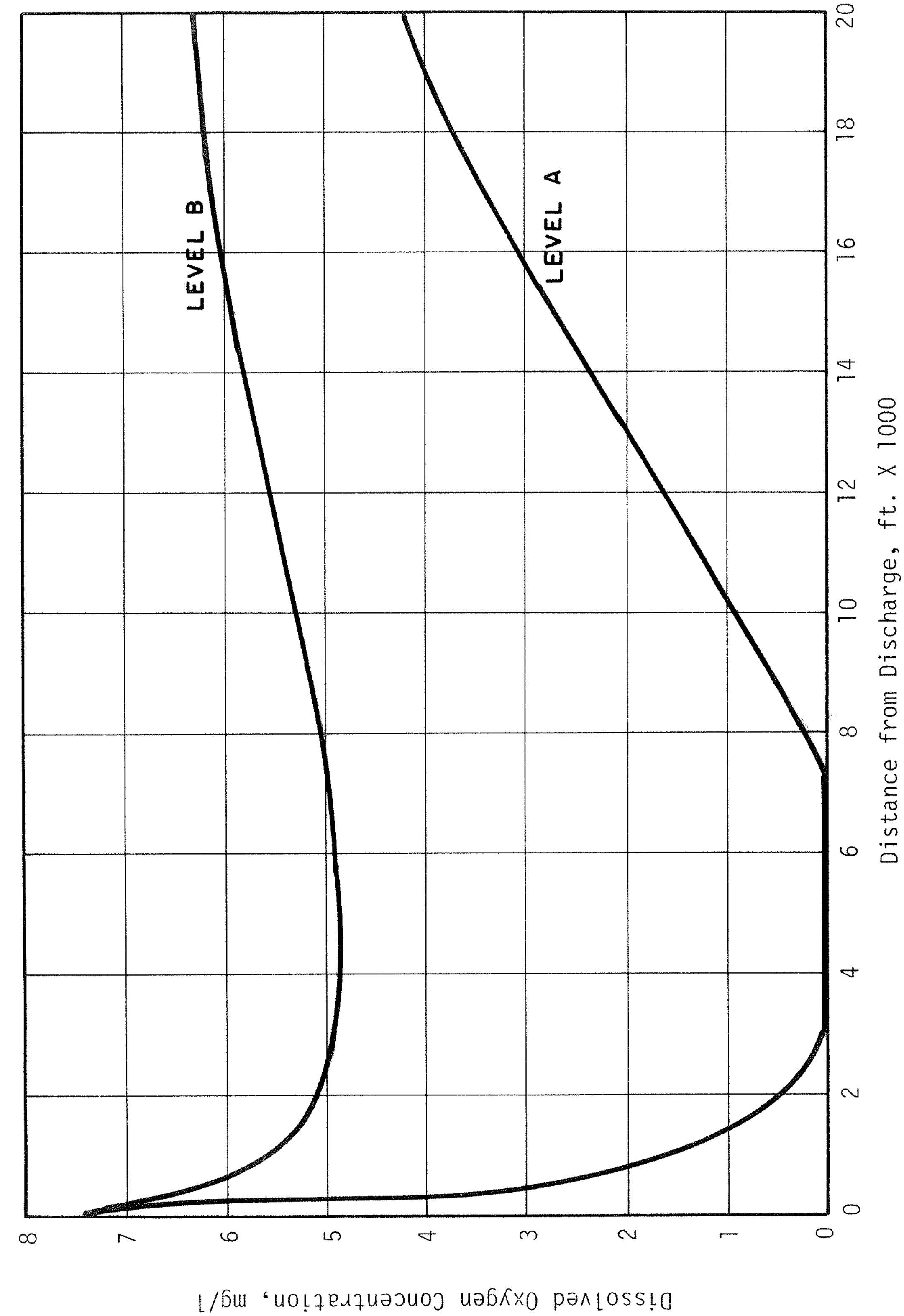

FIGURE 2. - Dissolved Oxygen Profile for Median Lake Inflow Condition and 24 MGD Wastewater Discharge.

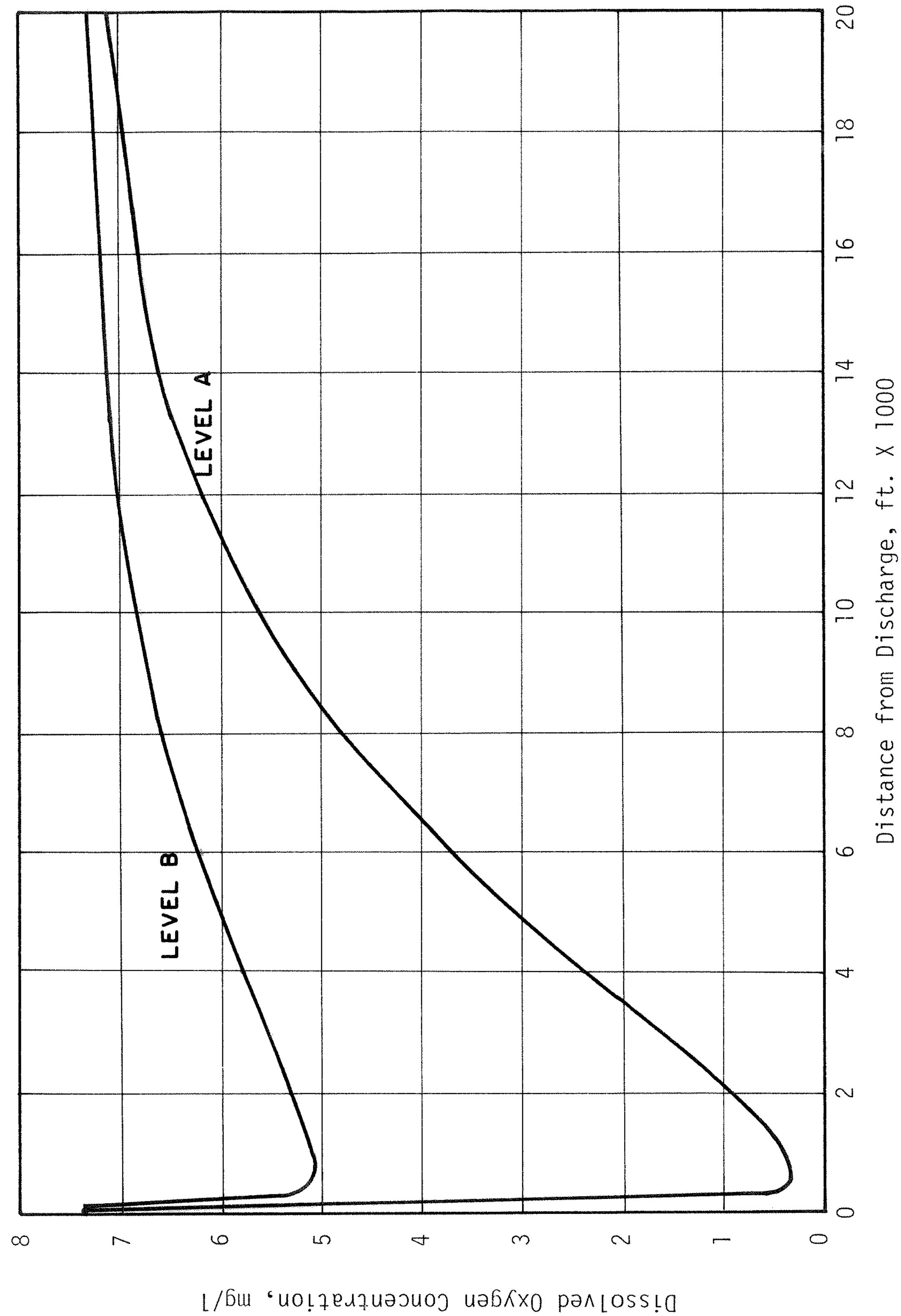

FIGURE 3. - Dissolved Oxygen Profile for Minimum 30-Day Lake Inflow Condition and 8 MGD Wastewater Discharge.

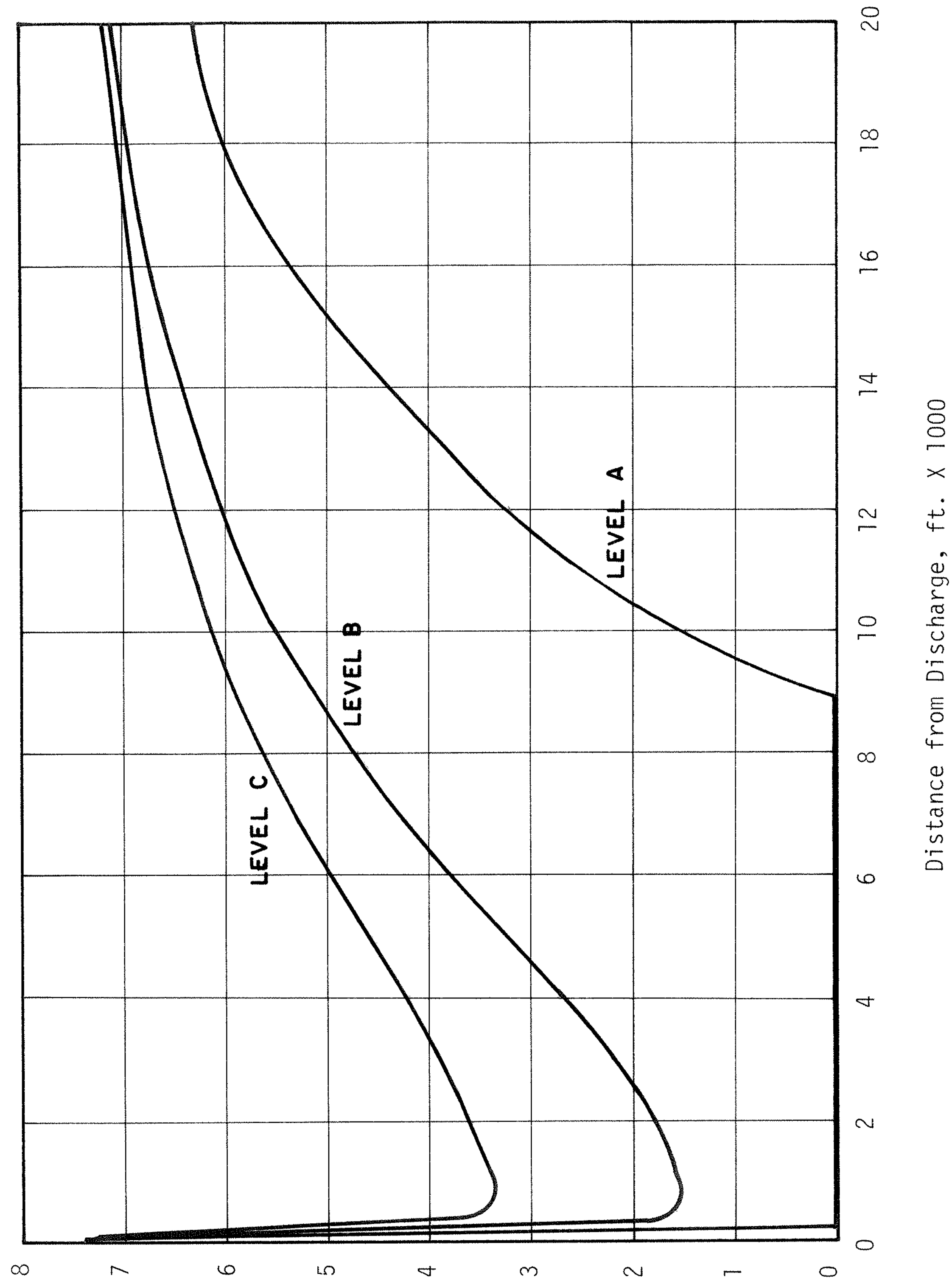

FIGURE 4. - Dissolved Oxygen Profile for Minimum 30-Day Lake Inflow Condition and 24 MGD Wastewater Discharge.

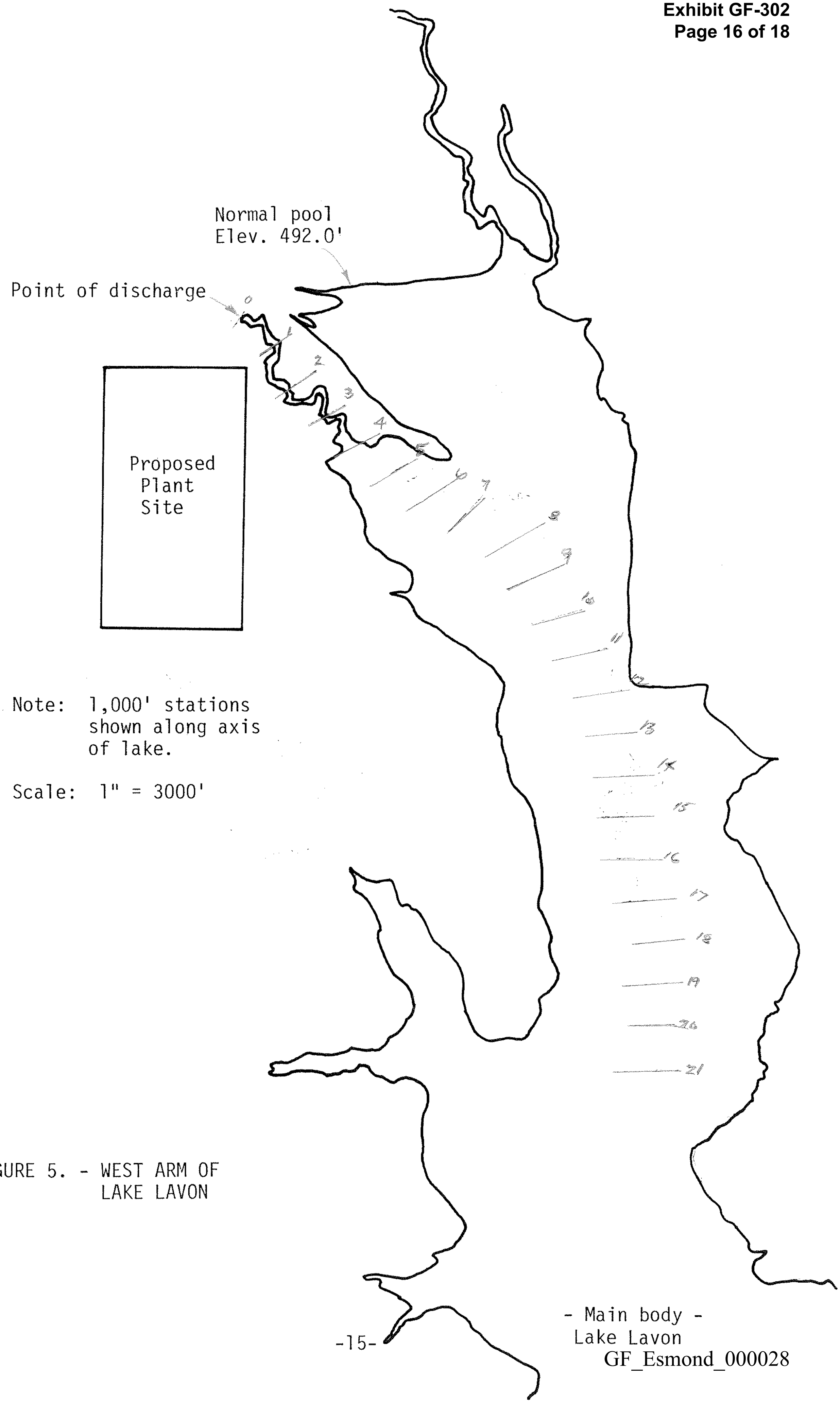

FIGURE 5. - WEST ARM OF
LAKE LAVON

RECOMMENDATION

In light of the results of the model, it appears that Level A will produce an unacceptable level of degredation in the West Arm of Lake Lavon. At 8 MGD, the D.O. standard of 5.0 mg/l would be violated from the point of discharge to approximately 8,500 ft. downstream. At 24 MGD, Level A would create anoxic conditions in approximately half of the West Arm, and would violate the D.O. criteria over nearly all of the West Arm. In light of the results of the model, Level A must be ruled out on the basis of the sheer magnitude of its impact on the West Arm of the lake.

Level B produces a considerable improvement in dissolved oxygen compared to Level A. At 8 MGD, the D.O. standards are not appreciably violated. At 24 MGD, the standards are violated at low flows, but not to the extent that anoxic conditions would persist downstream of the discharge.

Level C produces a further improvement in dissolved oxygen downstream of the discharge. Although the D.O. standard of 5.0 mg/l is also violated in the mixing zone, the area impacted is only 6,000 ft. downstream of the point of discharge. Also, the minimum D.O. is 3.4 mg/l at 24 MGD, which is high enough for rough fish to survive. Hence, Level C provides distinct water quality advantages over Level B.

In comparing the difference between Levels B and C, there are two criteria which should come into play.

1. Special consideration must be given to the fact that the proposed discharge is directly into the lake. The mixing zone is actually part of the lake itself and not a tributary. Both Level B and C will have an adverse impact on the West Arm, although the impact of Level B is somewhat greater.

2. If a cost-effective analysis indicates a substantial difference between the cost of producing Level C versus Level B, perhaps it could be demonstrated that the benefit/cost ratio of Level B exceeds the benefit/cost ratio of Level C. In such an instance, Level B could be justified over Level C.