TARRANT COUNTY WATER CONTROL AND IMPROVEMENT DISTRICT NUMBER ONE

TEXAS WATER DEVELOPMENT BOARD

Upper West Fork and Clear Fork Trinity River Basin Water Quality and Regional Facility Planning Study

FINAL REPORT

APPENDIX D
STUDY METHODOLOGIES

August 1988

Alan Plummer and Associates, Inc.
CIVIL/ENVIRONMENTAL ENGINEERS • ARLINGTON–FORT WORTH, TEXAS

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METHODOLOGY APPENDIX

WATER QUALITY SIMULATION

An evaluation of the impact of municipal wastewater treatment plant discharges on the receiving water bodies in the Upper Trinity River Basin was conducted using mathematical models that contain varying degrees of complexity. The type of model used in the analysis depended on the information available. The impact of discharges on all streams was first assessed using a simplified model that estimated dissolved oxygen in the stream based on BOD_5 and ammonia degradation and reaeration. For areas where rapid growth was anticipated, intensive surveys of the streams that would receive the wastewater were conducted. The information gathered in the intensive surveys was then used in the simplified model, and in some cases, the information was used in a more complicated model.

The impact of nutrient loads entering the lakes in the Upper Trinity River Basin was evaluated using a mathematical model that estimated algae production based on summer conditions. The lake analysis used data and samples collected in Lake Worth, Benbrook Lake, and Eagle Mountain Lake. Water quality data were also obtained in Lake Bridgeport and Lake Weatherford.

DATA COLLECTION

Water Quality Sampling and Sampling Locations

Water quality data were collected as part of the study. Four of the lakes in the study area (Lake Worth, Lake Bridgeport, Benbrook Lake, and Lake

Weatherford) were sampled during the summer period at four to five locations. Measurements were obtained from surface and bottom waters. Two other lakes in the study area were not sampled. Eagle Mountain Lake is currently under study by the Texas Water Commission (TWC), which has conducted intensive sampling on the lake over the past year and is developing a sophisticated model of the lake. Lake Arlington, also in the study area, was not sampled or modelled, because the existing data base in Lake Arlington is fairly extensive. furthermore, the lake is soon to receive water diverted from Richland-Chambers Reservoir and the hydrologic balance will be dramatically changed. Sampling following the flow diversion should be considered.

Several areas in the Upper Trinity River Basin were identified as having a high probability of rapid growth in the near future. These areas included Azle and the communities west of Fort Worth to and including Weatherford. Water quality surveys were conducted in portions of five streasms.

- Walnut Creek
- Ash Creek
- Town Creek
- Clear Fork Trinity River
- South Fork Trinity River

All field measurements and analyses of water quality samples for sites sampled as part of the study are presented in Appendix E (Tables E-6 and E-8).

Lake Worth

Lake Worth was sampled at five locations on July 14, 1987. The locations of the sampling sites are shown in Appendix E (Figure E-2). At each site, dissolved oxygen, specific conductance, and pH were measured at 5-foot intervals. Secchi depth was also measured. The data indicate that, in general, the lake was not stratified on the sampling day. Only site 2, the deepest site, showed any difference in vertical water quality. Both dissolved oxygen and pH decreased with depth, suggesting bottom processes may be affecting water quality. The secchi depths imply that light penetration is inhibited.

Samples were taken just below the surface and 15 feet above the bottom at each of the five sites. The chlorophyll "a" concentrations indicate that algae populations were fairly uniform throughout the lake. Initial examination suggests that any nutrient limitations may be associated with phosphorous.

Lake Bridgeport

Lake Bridgeport was sampled on two occasions. The first sampling took place on July 13, 1987, and included five sites. The second sampling took place on August 11, 1987. and included only sites 1, 3, and 4. The locations of the sampling sites are shown in Appendix E (Figure E-6). The field data show that the lake was stratified at the deeper sites. The measurements indicate a sharp gradient for both temperature and dissolved oxygen. Exchange between waters above and below the thermocline is limited. Secchi depths indicate the water is relatively clear.

Laboratory data collected during the two surveys for chlorophyll "a" concentrations indicate that algae populations are low, with the headwaters (site 5) having slightly higher concentrations than the main body (sites 1 through 4).

Benbrook Lake

Benbrook Lake was sampled twice. The first sampling was on July 15, 1987 and included four sites. The second sampling was on August 12, 1987, and included sites 1, 2 and 4. The locations of the sampling sites are shown in Appendix E (Figure E-5). The field data suggest that the lake may be periodically stratified. The data from the July sampling show small changes in temperature over depth, with measureable declines in dissolved oxygen and pH. The data from the August survey indicate weak thermal gradients. The dissolved oxygen concentrations from the August survey show a rapid decline as depth increases, with almost no dissolved oxygen in the deeper waters. Even the shallow site (site 4) shows a rapid decline in dissolved oxygen, possibly indicating a high bottom demand for oxygen and limited vertical mixing. Secchi depths suggest somewhat limited light penetration.

The results of the laboratory analyses from the August sampling suggest that ammonia may be released into the bottom waters during periods of low dissolved oxygen. The August data suggest that nitrogen may be the limiting nutrient under existing conditions. Chlorophyll "a" concentrations indicate that algae populations are fairly uniformly over the lake.

Lake Weatherford

Sampling was conducted in Lake Weatherford on two occasions during the study. The lake was sampled on August 3, 1987, at five sites and on August 17, 1987, at sites 1, 3, and 5. Appendix E (Figure E-2) shows the locations of the sampling sites. The field measurements indiciate that the lake was stratified. A temperature change over depth was noted, especially during the August 3 sampling. Dissolved oxygen concentrations changed dramatically with depth. During the August 3 sampling, even the shallow sites showed a large difference in dissolved oxygen between the surface and bottom. The weak stratification that was present, which limited vertical mixing, and the bottom oxygen demand may have caused the bottom dissolved oxygen concentrations to approach zero.

The results of laboratory analyses indicate chlorophyll "a" concentrations are relatively uniform throughout the lake.

Town Creek, South Fork Trinity River, and Clear Fork Trinity River

An intensive survey of the three streams was conducted on July 7, 1987, and included 12 river sampling sites and two wastewater treatment plants. Field measurements and samples were taken morning and afternoon at each site, and the two samples were composited. Sample sites are shown in Appendix E (Figure E-2). The field measurements included water temperature, dissolved oxygen, pH, specific conductance, and flow. The laboratory analyses included BOD_5, total suspended solids, total Kjeldahl nitrogen, ammonia nitrogen, nitrate nitrogen, nitrite nitrogen, total nitrogen, total phosphorus, and orthophosphorous.

The survey was conducted during a period of moderately low flow and warm water temperatures. The observed dissolved oxygen was above designated stream standards. The major impact of the wastewater treatment plants was seen in the nutrient concentrations of the streams. Nitrogen concentrations were increased substantially below the wastewater discharge. As the flow moved downstream, the nitrogen levels returned to levels observed above the discharge. Phosphorus concentrations also were substantially increased below the wastewater discharge, but, unlike nitrogen, they tended to remain high in all downstream reaches.

Walnut Creek

An intensive survey was conducted on Walnut Creek on July 28, 1987. The field measurements and laboratory analyses were identical to the Clear Fork survey. The locations of the sample sites are shown in Appendix E (Figure E-3). Most of Walnut Creek below Springtown is made up of large pools with interconnecting riffles. The stream appeared to have a high algal and plant population during the survey. The dissolved oxygen levels observed in the stream show the effect of the algae and plant life. The morning observations were below the dissolved oxygen saturation, and one site (site 5) was below the designated standard of 3.0 mg/l of dissolved oxygen. The afternoon observations of dissolved oxygen were near or above the saturation value for all stream sites.

The nutrient levels in the stream reflect the high plant and algal populations. The available nutrients for plant and algal growth (nitrate, nitrite, ammonia, and orthophosphorus) were at low levels except for the site directly below the wastewater discharge (site 3). Total nitrogen and phosphorus decreased in concentration in the downstream direction. The decreasing concentrations could be associated both with an increase in plant and algae biomass and with removals by absorption and settling.

Ash Creek

Ash Creek was sampled on November 4, 1987. Field measurements and samples were taken above, below, and in the wastewater treatment plant discharge, and dissolved oxygen was monitored in Ash Creek Cove. The sampling sites are shown in Appendix E (Figure E-3). Dissolved oxygen measurements in the stream were above the standard of 3.0 mg/l, and dissolved measurements in the cove were all at or above 6.0 mg/l. The data from the laboratory analyses indicate that the main impact of the wastewater discharge is an increase in orthophosphorus and total phosphorus. There is also a slight increase in total Kjeldahl nitrogen.

WATER QUALITY MATHEMATICAL MODELS

Model Selection

Three models were used to evaluate the impact of municipal wastewater treatment plant discharges on the receiving waters. Two models were used for streams, and one model was used for lakes.

The simplified stream model is based on the Streeter-Phelps equation of decay for BOD and ammonia. QUAL-TX, a more complicated stream model developed by the TWC, is based on the EPA model QUAL-2. All streams were originally modelled using the simplified model. The Clear Fork Trinity-South Fork Trinity-Town Creek system and Walnut Creek were also modelled using QUAL-TX. The QUAL-TX analysis used data collected during the intensive surveys to adjust coefficients to more closely reflect observed conditions in the stream.

The lake model used to evaluate the impact of future loading was an adaptation of the EPA model WASP. The subroutine in the model that calculates the change in water quality due to biological, chemical, and physical transformations (other than flow and dispersion) was modified to reflect the basic phenomena that are assumed to occur. The model was developed to be used with a very limited data base, and should be thought of as a screening model. All models are discussed in detail below.

Simplified Stream Model

The simplified stream model provides an estimate of the dissolved oxygen (DO) in the stream based on decay of BOD and ammonia and reaeration. The model is based on the steady-state Streeter-Phelps dissolved oxygen equations that simulate BOD, ammonia, and DO as a function of travel time. The equation for estimating the steady-state DO deficit is:

$$Def(n) = Def(0)*\exp(-Ka*t)+Kr/(Ka-Kr)*(\exp(-Kr*t)-\exp(-Ka*t))*L(0)+ Kn/(Ka-Kn)*(\exp(-Kn*t)-\exp(-Ka*t))*Ln(0) \quad (D-1)$$

$$t = X/(Q/A) \quad (D-2)$$

Where: Def(n) = DO deficit at some distance n, mg/l
Def(0) = DO deficit at upstream boundary of model, mg/l
Ka = reaeration rate, per day
Kr = BOD decay rate, per day
t = travel time from upstream boundary to point n, days
L(0) = ultimate BOD at upstream boundary, mg/l
Kn = ammonia decay rate, per day
Ln(0) = ultimate oxygen consumption of ammonia decay, mg/l
X = distance, ft
Q = flow, ft^3^3/day
A = cross section area ft^2

The concentration at the upstream boundary of the model is calculated by combining a headwater quality and flow with the wastewater discharge quality and flow using a mass balance. The calculation for the concentration of parameter "m" would be:

$$[m]b = ([m]u*Qu+[m]w*Qw)/(Qu+Qw) \quad (D-3)$$

Where: [m]b = concentration of m at boundary
[m]u = concentration of m upstream of the wastewater discharge
[m]w = concentration of m in the wastewater discharge
Qu = flow upstream of the wastewater discharge
Qw = flow of the wastewater discharge

The reaeration in the deficit equation, Ka, is calculated using the "Texas Equation," a relationship of velocity and depth to the reaeration rate developed by the Texas Water Commission for modelling. The equation is:

$$Ka = 1.932*(u^{0.273})/(d^{0.894}) \quad (D-4)$$

Where: u = average velocity, meters per second
d = average depth, meters

All rates, reaeration (Ka), BOD decay (Kr), and ammonia decay (Kn), are adjusted to reflect the assumed temperature of the simulation. The rates given in the model are for 20°C and are adjusted to the modelling temperature using the van't Hoff-Arrhenius temperature relationship:

$$KT = K20*omega^{(T-20.0)}$$

Where: KT = decay rate at modelling temperature T
K20 = decay rate at 20.0°C
omega = constant, 1.047 for BOD decay
1.083 for ammonia decay
1.019 for reaeration
T = modelling temperature. °C

The velocity and depth of the stream are assumed to be functions of the flow. They are usually expressed as:

$$u = a*Q^b$$
$$d = c*Q^e + f$$

Where: a,b,c,e, and f are constants developed from data of cross sectional measurements and discharge or are defined by default values that have been developed to represent some broad average for Texas streams.

The model requires an estimation of upstream water quality and flow at low-flow conditions, the characteristics of the wastewater discharge, the low-flow hydraulics of the reaches simulated, the decay rates, and critical temperatures. The conditions modelled reflect the critical low-flow, high-temperature period. The critical period is usually during the summer, when water temperature is at its peak and flows are low. The flow above the discharge point is generally assumed to be the average 7-day low-flow that occurs once every 2 years (7Q2). The critical period temperature used in the model is generally calculated from the existing data as the average summertime temperature plus one standard deviation ($30^{o}C$ often used).

QUAL-TX Model

QUAL-TX is a steady-state, one-dimensional, finite-difference model developed by the TWC from the EPA model QUAL-2. It assumes the water quality to be uniform in the river cross section. The finite-difference solution scheme is a technique that divides the stream into small elements and calculates the water quality in each element. All conditions are assumed constant in time, but can vary in space. Thus a steady-state solution is obtained.

QUAL-TX is based on the principle of conservation of mass. The general equation the model is built upon is:

$$dC/dt = -d(u*C)/dt+d(E*(dC/dt))/dt+SL+SB+SK$$

Where: dC/dt = change in concentration over time for a given element
u = velocity downstream
E = diffusion coefficient
SL = point and nonpoint source loading rate
SB = boundary loading rate
SK = kinetic transformation rate

Since the model provides a steady-state solution, the above equation is set to zero and solved. The kinetics of QUAL-TX are nonlinear, with some reaction rates dependent on the dissolved oxygen concentration. The solution technique used requires a first estimate of the solution. The rates used to generate the solution are compared to rates based on the calculated dissolved oxygen. If the rates differ, they are adjusted and a new solution obtained. This process continues until the rates used in the solution are very close to the rates based on the calculated dissolved oxygen.

QUAL-TX considers a number of sources and sinks for each constituent. In simulating dissolved oxygen, for example, sources include reaeration and photosynthesis, and sinks include BOD decay, ammonia decay, bottom oxygen demand, and respiration. There are a large number of coefficients and constants used in the model that can, to some extent, be used to regulate the complexity of the simulation.

Because of the large number of coefficients and constants in the QUAL-TX computation, a great deal of information must be known about the stream that is to be simulated. The first step in developing the model is to divide the stream into segments. A segment is a reach of the stream where the physical, chemical, and biological processes are assumed uniform. Each segment is further divided into elements. Each element is assumed to have homogenous water quality within it. The model calculates the water quality within each element, so the element sizes should be small.

The information gathered during intensive surveys provides a basis for estimating model coefficients based on a comparison of calculated and observed water quality profiles. The model is considered to be calibrated when the observed and calculated profiles are in general agreement for all constituents.

Once the model has been calibrated, it is verified by using data from a second intensive survey, modifying only the observed changes in flow, waste discharge quality, and temperature. The kinetic coefficients are not changed. If the observed and calculated constituent concentrations are in reasonable agreement, then the model is considered verified, and the kinetic coefficients are assumed to be valid approximations of the processes in the stream. Due to project constraints, no verification data sets were collected. No other data sets exist for the streams modelled. Thus, the models were calibrated, but not verified.

This is a limitation, because it is likely that several sets of model coefficients could produce comparable comparisons for an observed and computed water quality profile. Different sets of coefficients could yield different water quality management decisions. The coefficients used are typical of Texas streams.

Water quality projections are normally developed for critical low-flow, high-temperature conditions. Selected coefficients may be modified to reflect expected future conditions. As an example, the settling coefficient could be reduced if the existing discharge has suspended solids concentrations that are significantly higher than the solids concentrations expected in the future. The settling rates should be reduced to account for the change in effluent quality. The model needs to be modified to reflect critical conditions and future treatment levels. The modified model can be used to estimate effluent requirements by comparing calculated water quality with water quality standards or goals.

WASP Model

WASP is a flexible computer program that can be used to create water quality models, including nonlinear models of phytoplankton growth and death in lakes. The user of WASP must supply a subroutine that calculates the change in concentration due to chemical, biological, or physical processes other than advective and diffusive flow. A listing of the subroutine developed for this study is presented in Figure D-1. The model assumes that the lake will be divided into upper and lower layers. The upper layer is the zone where sufficient light is available for algae growth and is the layer influenced by advective flows. The model computations are developed for summer steady-state conditions.

MODEL APPLICATION AND RESULTS

Simplified Stream Model

The simplified model was applied to all streams receiving wastewater discharges in the study area. The West Fork of the Trinity River was modelled from below Lake Bridgeport to the headwaters of Eagle Mountain Lake. Three tributaries of the West Fork were also modelled and provided estimates of tributary loadings to the West Fork. The tributaries were Martin's Branch, Big Sandy Creek, and Dry Creek. The Clear Fork Trinity-South Fork Trinity-Town Creek system was also analyzed. The analyses for these streams were also coupled. The calculated downstream quality of one segment model was used as input into the next downstream model. Village Creek was simulated using the simplified model from above Burleson to the headwaters of Lake Arlington. Walnut Creek was simulated from Springtown to Eagle Mountain Lake. Ash Creek was simulated from just above the Azle-Ash

Creek Wastewater Treatment PLant to Eagle Mountain Lake. Each stream system will be discussed in detail in later sections of this appendix.

To evaluate the quality required of effluent from the municipal wastewater treatment plants, flows for the year 2005 were determined based on the projected population of each community. The projected flows were then used in the model, and the effluent quality was varied until the projected dissolved oxygen in the stream met the stream standard.

There are two key assumptions used in the analysis. The first is the assumption that nitrification will occur. This assumption, which is usually employed by the State of Texas in all water quality analysis, results in the projected requirement for effluent nitrification under almost all circumstances where the effluent flow is a significant percentage of the total stream flow during low-flow periods. The second assumption considers an upper bound on the value of reaeration rates. The assumption of an upper bound on the reaeration coefficient attempts to account for the effects of pools that may be in the system at low flows. Both of the assumptions can have major influence on the effluent treatment required and the associated costs for treatment.

The rates for BOD and ammonia decay were set to 0.1/day and 0.2/day, respectively. The BOD decay is typical for most streams in Texas and has been found to be valid in many other studies. The decay rate for ammonia tends to be more variable, and nitrification may not be observed in some streams or under some conditions. As part of the initial development of the model, only the six major treatment plants in the area were used as model input. The nitrification rate was varied in the model to determine the effect on calculated dissolved oxygen. Figure D-2 shows the calculated dissolved oxygen for six of the streams when the nitrification rate was varied. The model runs used 1986 reported effluent flows and quality and the restricted reaeration rate. As can be seen from the graphs, the nitrification rate has a large impact on the calculated dissolved oxygen. The intensive survey data showed rapid losses in ammonia, without the associated increases in nitrate. (In some instances, Nitrate concentrations did not change.) The reduction in Ammonia could be due to the influence of algae, plant life, or other factors. The ammonia nitrification rate could not be determined. The nitrification rate used for projections was 0.2/day.

Equations used in the model that calculated velocity and depth as a function of flow were developed from observations made during the intensive surveys and from data collected by the U.S. Geological Survey. No data were available for Village Creek, Martin's Branch, or Dry Creek, so the relationships developed for the Clear Fork were used in the models of those three streams. The relationships between flow and depth and flow and velocity for the modelled streams are shown below.

Stream	Number of Data Points	Velocity	Depth
Clear Fork Trinity	40	$0.51Q^{.5}$	$0.53Q^{.4}$
Town Creek	12	$0.696Q^{.35}$	$0.282Q^{.3}$
Walnut Creek	9	$0.254Q^{.5}$	$1.121Q^{.4}$
West Fork Trinity	37	$0.445Q^{.3}$	$0.2483Q + 0.0886$
Big Sandy Creek	17	$0.54Q^{.4}$	$0.315Q^{.4}$

West Fork Trinity System. The West Fork Trinity was modelled from below Lake Bridgeport to the headwaters of Eagle Mountain Lake. The model also simulated Martin's Branch, Big Sandy Creek, and Dry Creek. The following lists the municipal wastewater treatment plant discharges for each stream and the projected year 2005 flows.

West Fork Trinity	
Lake Bridgeport	0.064 MGD
Bridgeport	0.497 MGD
Paradise	0.065 MGD
Boyd	0.1 MGD
Martin's Branch	
Decatur	0.701 MGD
Big Sandy Creek	
Alvord	0.112 MGD
Dry Creek	
Chico	0.129 MGD

In addition, Dry Creek also had two industrial dischargers in the simulation, General Portland at 0.034 MGD and Pioneer Aggregates at 4.2 MGD. Neither industrial discharger contributed any oxygen-consuming compounds above the background levels. The headwater quality was set to 6.56 mg/l dissolved oxygen, 1 mg/l BOD_5, and 0.1 mg/l ammonia for all streams above the treatment plants. The 7Q2 flows were 4.3 cfs for the West Fork and 0.1 cfs for all other streams.

Results of the model, using the unrestricted reaeration coefficient, showed that the required quality of effluent for all municipal wastewater treatment plants would be 20 mg/l BOD_5, 15 mg/l ammonia, and 5 mg/l dissolved oxygen. Using the restricted reaeration coefficient, the required effluent quality for all municipal wastewater treatment plants would be 10 mg/l BOD_5, 3 mg/l ammonia, and 5 mg/l dissolved oxygen.

Village Creek. Village Creek was simulated from just above the Johnson County Fresh Water Supply District No. 1 (FWSD No. 1) Wastewater Treatment Plant, which serves Burleson, to the headwaters of Lake Arlington. Headwater flow and quality above the wastewater treatment plant were assigned values identical to those used for the small streams in the West

Fork system. There were three municipal wastewater dischargers and one industrial discharger included in the simulation. The dischargers and flow estimated for the year 2005 were:

Johnson County FWSD No. 1	0.5 MGD
Texas Department of Highways	0.0025 MGD
Briar Oaks	0.152 MGD
Marshalsea Industries	0.0236 MGD

Results of the model, using the unrestricted reaeration coefficient, showed that all dischargers would have to maintain an effluent quality of 20 mg/l BOD_5, 15 mg/l ammonia, and 5 mg/l dissolved oxygen. A concern about per-capita flows from the Johnson County plant led to consideration of alternative flows. The Johnson County FWSD No. 1 discharge was increased to 1.0 MGD and 2.0 MGD. In both cases, the simulation showed the same effluent quality was necessary to maintain the desired quality in the stream. The model was also run using the restricted reaeration coefficient, and the flow to the Johnson County plant was again varied. In all three flow scenarios, the required effluent quality to maintain the desired 3.0 mg/l dissolved oxygen level in the stream was 10 mg/l BOD_5, 3 mg/l ammonia, and 5 mg/l dissolved oxygen.

<u>Town Creek, South Fork Trinity and Clear Fork Trinity</u>. Town Creek and the South Fork Trinity River were simulated from just above the Weatherford Wastewater Treatment Plant to the junction of the South and Clear Forks. The Clear Fork model began just below the Lake Weatherford Dam and continued to the headwaters of Benbrook Lake. The Clear Fork model included the results of the Town Creek-South Fork model as input at the junction of the South and Clear Forks.

A preliminary analysis of various alternatives for treatment of wastewater in the Weatherford area was conducted using the simplified model before intensive survey data were collected. Five alternatives were explored. Those five alternatives were:

1. Ten wastewater treatment plants located in individual communities
2. A single regional plant located on the Clear Fork near Turkey Creek
3. A single regional plant located on the Clear Fork just below Lake Weatherford
4. Two subregional plants, one located on the Clear Fork just below Lake Weatherford and the second on Town Creek at the location of Weatherford's existing wastewater treatment plant
5. A single regional wastewater treatment plant located on the Clear Fork near Turkey Creek, with the discharge diverted to Mary's Fork

The alternatives were run using the restricted reaeration coefficient, and the results showed that the required effluent quality was 10 mg/l BOD_5, 2 mg/l ammonia, and 5 mg/l dissolved oxygen.

The data from the intensive survey were compared to the water quality computed by the simplified model for comparable conditions.

1. The predicted dissolved oxygen concnetrations were consistently lower in the model than the observed values in Town Creek, but they did follow the general pattern of the observed values. In the Clear Fork, the predicted values were inconsistent compared to the observed values.
2. The predicted BOD concentrations were generally higher than observed values, especially downstream of the point sources. The pattern of BOD concentrations was similiar. The rate of decline of the calculated BOD concentrations was much greater than that of the observed concentrations, probably due to the effect of pools in the system that increased detention time.

3. Projected ammonia nitrogen concentrations were much higher, below the point sources, then observed values. The observed rate of decline in ammonia was much faster than predicted perhaps due to the influence of plant life in the pools.

The population projections for the Weatherford study area were finalized and the wastewater flows reevaluated. A scenario was developed for the area where seven local wastewater treatment plants served the communities. Four municipal wastewater treatment plants discharged to the Town Creek-South Fork, and three municipal wastewater treatment plants discharged to the Clear Fork. The dischargers and predicted year 2005 flows were:

Town Creek-South Fork

Weatherford	2.154 MGD
Annetta North	0.262 MGD
Annetta	0.094 MGD
Hudson Oaks	0.241 MGD

Clear Fork

Willow Park	0.464 MGD
Annetta South	0.089 MGD
Aledo	0.262 MGD

The models were run using the unrestricted reaeration coefficient, and the required effluent quality was 10 mg/l BOD_5, 3 mg/l ammonia, and 5 mg/l dissolved oxygen to maintain the desired stream quality of 3.0 mg/l dissolved oxygen in Town Creek and the South Fork and 5.0 mg/l dissolved oxygen in the Clear Fork. Using the restricted reaeration coefficient, the required effluent quality was 5 mg/l BOD_5, 2 mg/l ammonia, and 5 mg/l dissolved oxygen.

Walnut Creek. Walnut Creek was simulated from Springtown to Eagle Mountain Lake. Headwater flows and quality were identical to those used for the small streams in the West Fork system. There were two municipal wastewater treatment plants used in the simulation. The dischargers and the projected 2005 flows were:

Springtown	0.389 MGD
Azle-Walnut Creek	0.300 MGD

Results of the model using the unrestricted reaeration coefficient showed that the required effluent quality to maintain 3.0 mg/l dissolved oxygen in Walnut Creek was 20 mg/l BOD_5, 15 mg/l ammonia, and 5 mg/l dissolved oxygen. Running the model with a restricted reaeration coefficient showed that the required effluent quality should be 10 mg/l BOD_5, 3 mg/l ammonia, and 5 mg/l dissolved oxygen.

Ash Creek. Ash Creek was modelled from just above the Azle-Ash Creek Wastewater Treatment Plant to Eagle Mountain Lake, a total distance of about 1.8 km. The only discharger was the Azle plant, with a projected year 2005 flow of 0.96 MGD. The model was run with the unrestricted reaeration coefficient, and the required effluent quality to maintain 3.0 mg/l dissolved oxygen in Ash Creek was 20 mg/l BOD_5, 15 mg/l ammonia, and 5 mg/l dissolved oxygen. Using the restricted reaeration coefficient in the model required an effluent quality of 10 mg/l BOD_5, 3 mg/l ammonia, and 5 mg/l dissolved oxygen to maintain the creek's dissolved oxygen standard.

QUAL-TX Model

The intensive surveys of the Town Creek-South Fork-Clear Fork system and Walnut Creek gathered enough information to develop a data set that could be used to calibrate QUAL-TX for these systems. The configuration of both streams consists of pools separated by riffles. The reaeration in the pools during the time of the intensive surveys and during periods of low flow would be low (perhaps Ka=2/H). The reaeration coefficient varies with geometry and is low in the pools and elevated in the riffled sections. The details of the system geometries are not known. Therefore, the reaeration coefficient was set to 2.0 per day in a effort to reflect the impact of the pools in the streams.

Town Creek-South Fork-Clear Fork System. Town Creek, the South Fork Trinity, and the Clear Fork Trinity were simulated in the same model, similar to the simplified model. The system was divided into 12 segments. A schematic of the model's segmentation is shown in Figure D-3. The conditions observed during the intensive survey were incorporated in the model, and coefficients were adjusted until the predicted values approximated the observed values. Figures D-4 through D-7 shows the calculated and observed dissolved oxygen, BOD, ammonia, and nitrate values. The model's approximation of dissolved oxygen in Town Creek and the South Fork was good, while in the Clear Fork the calculated values were consistently higher than the observed values. Calculated BOD, nitrate and ammonia concentrations in Town Creek and the South Fork were good. Calculated BOD and nitrate concentrations in the Clear Fork showed the same trend as observed values, but were not as close as the estimates of Town Creek. Calculated ammonia concentrations for the Clear Fork were different compared to observed values.

The model was modified to reflect critical conditions. All headwater flows were set to the 7Q2 flow, which was 0.1 cfs for all streams. The modelling temperature was set to 29.0^{o}C. Eight alternative wastewater treatment plant scenarios were developed. The alternatives divided the flow among four areas: Weatherford, Hudson Oaks, Lake Weatherford, and Willow Park. The alternatives were:

1. A regional plant located downstream of the existing Weatherford plant that treats all wastewater flows
2. Upgrading Weatherford's existing plant and constructing a new facility near Hudson Oaks that would treat flow from Hudson Oaks, Lake Weatherford, and Willow Park
3. Upgrading Weatherford's existing plant and building new facilities at Hudson Oaks and Lake Weatherford
4. Upgrading Weatherford's existing plant and constructing a new plant downstream to treat all flows above the original plant's capacity
5. Upgrading Weatherford's existing plant to treat all wastewater flows
6. Upgrading Weatherford's existing plant and building new plants at Hudson Oaks, Lake Weatherford, and Willow Park
7. Upgrading Weatherford's existing plant and building new facility in Willow Park to treat flows from Hudson Oaks, Lake Weatherford, and Willow Park
8. Upgrading Weatherford's existing plant to treat flows from Weatherford and Hudson Oaks and building a new facility at Willow Park to treat flows from Willow Park and Lake Weatherford

Results from running the alternatives showed that the effluent quality necessary to maintain a dissolved oxygen level of 3.0 mg/l in Town Creek and the South Fork Trinity was 10 mg/l BOD_5, 2 mg/l ammonia, and 5 mg/l dissolved oxygen. To maintain the 5.0 mg/l dissolved oxygen standard in the Clear Fork Trinity required plants discharging into the Clear Fork to have an effluent quality of 5 mg/l BOD_5, 1 to 2 mg/l ammonia, and 5 to 6 mg/l dissolved oxygen. All flows and required effluent quality for each scenario are listed in Table D-1.

Walnut Creek. Water quality in Walnut Creek was simulated from Springtown to Eagle Mountain Lake. The reach to be modelled was divided into six segments, and conditions observed during the intensive survey were used as input to the model. The model's segmentation is shown in Figure D-8. During the course of the analysis, it became obvious that among the major mechanisms controlling water quality in Walnut Creek were biomass, oxygen production and utilization from aquatic vegetation, and algae. These factors masked and overwhelmed the effects of oxidation of CBOD and ammonia. Analysis of this type of complex system is beyond the scope of the current study.

WASP Model

Two lakes in the study area now receive and are anticipated to receive significant amounts of wastewater flow. They are Benbrook Lake and Eagle Mountain Lake. These two lakes were examined with respect to the effects of nutrients and nutrient control options. Lake Worth was also modelled, but no projections were developed. No projections for nonpoint-source nutrient controls were developed as part of this study.

The projected increases in wastewater flows were based on the facility planning tasks of this project. The increased nutrient loads to the lakes were used to calculate the projected nutrient concentrations in the lakes, and based on the in-lake nutrient concentration, the resulting chlorophyll "a" concentration was estimated. The chlorophyll "a" concentration was used as a measure of lake quality.

Lake Worth. The Lake Worth observed (July 14, 1987, data set) and calculated concentrations of key parameters are shown in Table D-2, and the input data set for the model is shown in Figure D-9.

Lake Benbrook. Benbrook Lake was simulated using the average concentrations from the two intensive surveys to develop kinetic coefficients. Table D-3 presents the observed and calculated concentrations, and Figure D-10 presents the data set for the model.

Projected water quality was developed for existing and year 2005 wastewater flows with and without nutrient removal. Table D-4 presents the results of the projections. The removal of nutrients for the existing wastewater flows was projected to reduce chlorophyll "a" concentrations from 11 ug/l to approximately 8 ug/l. The projected wastewater flows for the year 2005, with no nutrient removal, were projected to increase the chlorophyll "a" concentration to 13.6 ug/l. With nutrient removal, the projected chlorophyll "a" concentration with the 2005 wastewater flow was between 7 and 9 ug/l.

The trend of the projections shows that, with nutrient removal, the chlorophyll "a" concentration will be reduced by about 4 ug/l. Without nutrient removal, the chlorophyll "a" concentration was projected to increase by about 2 ug/l. The changes in chlorophyll "a" concentrations are projected on a lake-wide basis. It is anticipated that, in the shallower areas, the chlorophyll "a" concentrations will be higher. The variations in chlorophyll "a" concentrations lake-wide are on the same order as the projected reductions with nutrient removal, so improved water quality as a result of nutrient loading reductions would not be measurable.

Eagle Mountain Lake. The Eagle Mountain Lake model was developed using data collected by the TWC to estimate the kinetic coefficients. Table D-5 presents the observed and calculated concentrations of the key parameters, and Figure D-11 presents the data set used in the model. The table also presents the range of the observed data and the standard deviation of the observed data. Eagle Mountain Lake has been intensively surveyed by the TWC over the last year as part of an effort to model the lake, so a large data base has been developed.

The model of the lake was used to predict chlorophyll "a" concentrations for existing and projected wastewater flows for the year 2005 with and without nutrient removal. Two scenarios of routing wastewater flow to Fort Worth's Village Creek Wastewater Treatment Plant were also explored. Table D-6 presents the results of the model runs. Chlorophyll "a" concentrations are estimated to decrease from 17 to about 15 ug/l for existing wastewater flows if nutrient removal is implemented. With the projected wastewater flow for the year 2005 of 5.1 MGD being discharged into the lake and no nutrient removal implemented, the chlorophyll "a" concentration was estimated to increase to about 20 ug/l. Reducing the 2005 discharge to the lake to 2.86 MGD by directing flow to the Fort Worth Plant, the chlorophyll "a" was estimated to be 18.6 ug/l. Nutrient removal would reduce the chlorophyll "a" concentration by 3 to 4 ug/l for the projected flows for all scenarios.

As with Benbrook Lake, the projected changes in chlorophyll "a" concentrations would occur on a lake-wide basis. Shallow areas, and areas near the discharge locations, could be expected to have higher chlorophyll "a" concentrations. Part of the variability of chlorophyll "a" in the lake may be estimated by the standard deviation of the chlorophyll "a" concentration data collected by the TWC. The standard deviation of the TWC data is about twice the expected change of the chlorophyll 'a' concentration due to nutrient controls. With such high observed variations, the improved quality with nutrient removal may be difficult or impossible to measure.

CONCLUSIONS

The results of the dissolved oxygen water quality analysis are summarized in Table D-7. Information is presented for the two levels of reaeration coefficients examined in the current study. The restriction on the average reaeration coefficient attempts to make an allowance for the effects of pools in the water bodies. However, pools would also provide locations suitable for sources of dissolved oxygen and sinks of ammonia from phytoplankton, algae, and plant growth that are not included in the analysis. The data collected suggest that these sources of oxygen and sinks of ammonia may be quite significant. Thus, the analysis with the reaeration restriction appears very conservative and quite restrictive.

A basic policy issue exists in terms of the desirability and affordability of nutrient control policies for Benbrook Lake and Eagle Mountain Lake. In both situations, there will be an increase in chlorophyll "a" concentrations with increases in nutrient loads associated with population growth. The calculated increases in chlorophyll "a" associated with population growth were found through modelling to be eliminated by nutrient removal at point sources. Tangible benefits or improvements from a nutrient control program will be difficult or impossible to measure and quantify.

If nutrient controls are identified as appropriate for either or both systems, then the current analysis indicates that phosphorous controls will be the most effective choice for summer conditions. Nonpoint source controls of phosphorous should be considered in the overall management of water quality if nutrient removal is considered appropriate.

The current analysis is for summer average conditions. It is possible that an analysis of data from other seasons could identify a need for nitrogen control. It is unlikely that the issues associated with the relationship of water usage to water quality or the difficulty of measuring changes in water quality will be affected by analysis of additional seasons.

FACILITY PLANNING METHODOLOGY

Treatment requirements for each of the proposed sewerage systems are being identified through the water quality modelling efforts. Costs were prepared for each system to reflect each of the permit scenarios listed in Table D-8.

EPA cost curves, updated to reflect 1987 dollars, were used to identify treatment facility requirements and costs. Table D-9 lists the unit processes assumed necessary for each of the proposed permit scenarios. All four of the permit scenarios shown in Table D-8 were evaluated during the Phase I studies, while the Phase II studies concentrated only on the 10/15 and 10/15/2 permit scenarios.

A typical computer-generated cost estimate based on the EPA cost curves is presented as Table D-10.

An iterative process was followed in which water quality limits were used as input the facility planning process. The water quality planning provided specific recommendations for the protection of the quality of the lakes in the study area. Specific discharge quality requirements have been recommended for consideration in issuing future wastewater discharge permits. Any recommended regional facility should meet those water quality protection requirements and be cost-effective.

Table D-11 presents an outline of the procedures used in determining facility needs and costs for each of the sewerage systems evaluated. This general procedure was followed for each local, subregional, and regional system layout. Alternative procedures were followed where necessitated by geographical, political, or other constraints, or where communities had an existing sewerage system. Details of the evaluations for each facility planning region are presented in Appendices A, B, and C.

The wastewater facility planning costing studies also included a general review of the financial capability of the local community to support the construction, operation, and maintenance of the proposed facilities. A detailed analysis of the financial characteristics of the community (including evaluation of existing debt, revenues, assessed value of property, income distribution, bond ratings, planned capital expenditures, and other miscellaneous factors and trends) is not warranted at this time and should be made during the implementation phase of a given system. However, the general review presented here utilized EPA affordability guidelines that consider the project to have excessive costs when the total annual costs exceed the following percentages of annual household median income:

1% - when median income is under $10,000
1.5% - when median income is between $10,000 and $17,000
1.75% - when median income exceeds $17,000

The 1979 median household incomes for Tarrant, Parker, and Wise counties were obtained from Bureau of the Census publications, and the following financial capability indicators (rounded to nearest $5.00) were utilized in evaluating costs for proposed systems in the respective areas.

County	1979 Median Household Income	Financial Capability
Tarrant	$18,642	$325
Parker	17,245	300
Wise	16,381	245

TABLES

TABLE D-1

SUMMARY OF FLOWS AND REQUIRED EFFLUENT QUALITY FOR ALTERNATIVES IN THE CLEAR FORK SYSTEM EXAMINED USING QUAL-TX

	Weatherford WWTP				Hudson Oaks WWTP				Lake Weatherford WWTP				Willow Park WWTP			
Alternative	Flow MGD	BOD_5 mg/l	NH_3-N mg/l	DO m/gl	Flow MGD	BOD_5 mg/l	NH_3-N mg/l	DO mg/l	Flow MGD	BOD5 mg/l	NH_3-N mg/l	DO mg/l	Flow MGD	BOD_5 mg/l	NH_3-N mg/l	DO mg/l
1	2.24	10	2	5	0				0				0			
2	1.5	10	22	5	0.77	10	2	5	0				0			
3	1.5	10	2	5	0.57	10	2	5	0.202	5	2	5	0			
4	1.5	10	2	5	0				0				0			
	0.33	10	2	5												
5	22.24	10	2	5	0				0				0			
6	1.8	10	22	5	0.241	10	2	5	0.202	5	2	5	0.464	5	2	5
7	1.8	10	2	5	0				0				0.907	5	1	5
														or 5	2	6
8	2.04	10	2	5	0				0				0.67	5	1	5
														or 5	2	6

1. New Plant Constructed downstream of existing Weatherford Plant

TABLE D-2

LAKE WORTH MODEL CALIBRATION

Variable	Observed Top	Observed Bottom	Calculated Top	Calculated Bottom
UP mg/l	.02	.02	.025	.025
OP mg/l	<.01	<.01	.001	.002
NO_3 mg/l	<.02	<.02	.002	.004
NH_3 mg/l	.29	.23	.04	.05
ON mg/l	.59	.63	.27	.27
Chl 'a' ug/l	15.2	--	15.4	--

key:
UP: Unavailable phosphorus
OP: Orthophosphorus
NO_3: Nitrate Nitrogen
NH_3: Ammonia Nitrogen
ON: Organic Nitrogen
Chl 'a': Chlorophyll 'a'

TABLE D-3

LAKE BENBROOK CALIBRATION

	Top Layer				Bottom Layer			
		Observed				Observed		
Variable	Calc.	Avg.	Min.	Max.	Calc.	Avg.	Min.	Max.
TP mg/l	.056	.04	.02	.07	.058	.06	.05	.09
UP mg/l	.05	.03	0	.06	.05	.05	.03	.08
OP mg/l	.006	.01	<.01	.02	.008	.01	<.01	.03
NO_3 mg/l	.0002	.02	<.01	.04	.01	.02	<.01	.04
NH_3 mg/l	.04	.04	<.03	.1	.05	.12	<.03	.3
ON mg/l	1.	1.06	1.03	1.20	1.	1.	.86	1.6
DO mg/l	6.4	8.2	5.7	10	63	4.3	0	7.8
Chl 'a' ug/l	11	10.6	2.4	20	--	--	--	--

Key:
TP: Total Phosphorus
UP: Unavailable Phosphorus
OP: Orthophosphorus
NO_3: Nitrate Nitrogen
NH_3: Ammonia Nitrogen
ON: Organic Nitrogen
DO: Dissolved Oxygen
Chl 'a': Chlorophyll 'a'

TABLE D-4

PROJECTED CHLOROPHYLL "a" FOR LAKE BENBROOK

Conditions			
Year	Flow, MGD	Nutrient Removal	Chl 'a' ug/l
Existing	2.4	None	11.3
Existing	2.4	P to 1 mg/l	7.3
Existing	2.4	N to 5 mg/l	7.9
2005	3.67	None	13.6
2005	3.67	P to 1 mg/l	7.3
2005	3.67	N to 5 mg/l	9.0

TABLE D-5

EAGLE MOUNTAIN LAKE CALIBRATION

	Top					Bottom				
		Observed[1]					Observed[1]			
Variable	Calc.	Avg.	Std.	Min.	Max.	Calc.	Avg.	Std.	Min.	Max.
TP mg/l	.044	.05	.03	.01	.15	.03	.07	.05	.01	.22
UP mg/l	.03	.03	--	--	--	.01	.02	--	--	--
OP mg/l	.014	.02	.01	.01	.06	.02	.05	.014	.01	.22
NO_3 mg/l	.3	.1	.15	.01	.3	.33	.11	.17	.01	.6
NH_3 mg/l	.06	.08	.07	.01	.27	.09	.11	.12	.01	.43
ON mg/l	1.5	1.7	1.2	.01	3.2	1.5	1.9	.46	1.0	2.7
DO mg/l	5.6	--	--	--	--	4.7	--	--	--	--
Chl 'a' ug/l	17.3	17.5	8.6	2.7	25.6	12.7	12.1	9.0	2.7	18.8

1. Observed data from joint study by TWC/SEML/TWCID performed in summer 1986-1987.

Key:
- TP: Total Phosphorus
- UP: Unavailable phosphorus
- OP: Orthophosphorus
- NO_3: Nitrate Nitrogen
- NH_3: Ammonia Nitrogen
- ON: Organic Nitrogen
- DO: Dissolved Oxygen
- Chl 'a': Chlorophyll 'a'

TABLE D-6

PROJECTED CHLOROPHYLL "a" FOR
EAGLE MOUNTAIN LAKE

Year	Conditions Flows, MGD Into Lake	 To Fort Worth	Nutrient Removal	Chl 'a' ug/l
Existing	1.8	--	None	17.3
Existing	1.8	--	P to 1 mg/l	14.8
Existing	1.8	--	N to 3.3 mg/l	15.6
2005	5.1	--	None	20.3
2005	5.1	--	P to 1 mg/l	16.2
2005	5.1	--	N to 5 mg/l	17.3
2005	3.85	1.26	None	19.5
2005	3.85	1.26	P to 1 mg/l	16.9
2005	3.85	1.26	N to 5 mg/l	16.0
2005	2.86	2.25	None	18.6
2005	2.86	2.25	P to 1 mg/l	14.9
2005	2.86	2.25	N to 5 mg/l	16.0

TABLE D-7

SUMMARY OF RESULTS

Water Body[1]	Effluent Requirements[2] Conventional Reaeration[3]	Reaeration Restriction[4]	Method of Analysis
West Fork Trinity	20/15/5	10/3/5	Streeter-Phelps[5]
Martins Branch	20/15/5	10/3/5	Streeter Phelps[5]
Big Sandy Creek	20/15/5	10/3/5	Streeter Phelps[5]
Dry Creek	20/15/5	10/3/5	Streeter Phelps[5]
Village Creek	20/15/5	10/3/5	Streeter Phelps[5]
Town Creek, South Fork, Clear Fork	10/3/5	5/2/5	Streeter Phelps[7]
Walnut Creek	20/15/5	10/3/5	Streeter Phelps[7]
Ash Creek	20/15/5	10/3/5	Streeter Phelps[6]
Town Creek and South Fork	10/2/5	---	Qual-Tx[7]
Clear Fork	5/2/6	---	Qual-Tx[7]

Notes:
1. Projections for the municipal discharges at 2005 flows.
2. $CBOD_5/NH_3$-N/DO.
3. Texas reaeration formula used.
4. Reaeration coefficient restricted to ka $\leq$ 2/day in an attempt to account for pools in the stream.
5. No data of calibration.
6. Some limited water quality data available.
7. One usable data set for calibration.

TABLE D-8

PERMIT SCENARIOS EVALUATED

Permit Scenario	Average BOD_5 (mg/l)	Average TSS (mg/l)	Ammonia (mg/l)
1	30	30	N/A
2	20	20	N/A
3	10	15	N/A
4	10	15	2

TABLE D-9

UNIT PROCESSES NECESSARY FOR PERMIT SCENARIOS EVALUATED

Process	Permit Scenario 1	2	3	4
Influent pumping	X	X	X	X
Preliminary sedimentation	X	X	X	X
Primary sedimentation		(1)	(1)	(1)
Activated sludge		X	X	X
Oxidation ditch	X			
Filtration			X	X
Chlorination	X	X	X	X
Effluent outfall	X	X	X	X
Sludge drying beds	X	X	X	X
Aerobic digestion	X	X	X	X

(1) Primary sedimentation used for plant capacities 1 MGD and larger

TABLE D-10

EXAMPLE COST ESTIMATE

	Coed	Power	Flow (mgd)	Cost	Engineer Adj Cost
Equalization	67600	.6	0	0	0
Influent Pumping	131000	.63	.025	12823	19662
Communitors	19800	.56	0	0	0
Preliminary Treatment	64300	.76	.025	3896	5974
Primary Sediment	120000	.7	0	0	0
Activated Sludge	519000	.75	.025	32630	50035
Oxidation Ditch	468000	.57	0	0	0
RBC	609000	.77	0	0	0
Trickling Filter	3666000	.46	0	0	0
Stabilization Pond	708000	.67	0	0	0
Aerated Lagoon	687000	.79	0	0	0
Chemical Additions	54600	.91	0	0	0
Secondary Screens	12000	.58	0	0	0
Mixed Media Filter	242000	.79	0	0	0
Sand Filter	214000	.61	0	0	0
All Filtrations	215000	.74	0	0	0
Chlorination	63300	.65	.0225	5755	8835
Land Treatment	398000	.71	0	0	0
Effluent Outfall	61000	.77	.025	3562	5463
Las/Maint Building	193000	.58	0	0	0
Land Spread Sludge	44800	.39	0	0	0
Land Application	41900	.45	0	0	0
Gravity Thicken	69100	.7	0	0	0
Sludge Drying Beds	69400	.73	.025	4697	7203
Sludge Lagoons	66900	.72	0	0	0
Anaerobic Digest	269000	.92	0	0	0
Aerobic Digestion	199000	.78	.025	11201	17175
Heat Treatment	332000	.53	0	0	0
Incineration	264000	1.00	0	0	0
Mobilization	63400	.69	.05	4974	7626
Sitework W/Excav	196000	.82	.025	9518	14595
Sitework WO/Excav	111000	.57	0	0	0
Excavation	133000	.64	0	0	0
Special Foundation	66000	.57	0	0	0
Electrical	167000	.73	.025	11303	17333
Controls & Installation	77800	.78	.025	4379	6715
All Piping	223000	.77	.025	13023	19970
Yard Piping	115000	.71	0	0	0
Process Piping	151000	.82	0	0	0
Total				117763	180575

TABLE D-11

FACILITY PLANNING METHODOLOGY SUMMARY

I. Define Planning Area Boundaries
   A. Locate all natural watersheds that are affected by city.
      B. Include all areas inside city limits plus outlying areas within watersheds that contain portions of the city.
      C. Divide planning area into individual sewersheds or "sewer areas."
      D. For each service area, compute:
         1. Total land area (acres)
         2. Land area within city limits (acres)

II. Develop Population Projections for Individual Planning Areas
   A. Assemble available population estimate from the following sources (listed in order of preference):
      1. NCTCOG 1987 estimates
      2. Estimates generated through aerial photo house counts (assume 2.8 persons per household)
      3. Estimates generated through local water or wastewater planning efforts
      4. Estimates provided by city personnel
      5. 1980 census data
   B. Establish 1987 city population
      1. If sources other than NCTCOG are used, document reasons.
   C. Allocate 1987 city population among service areas.
      1. If aerial photographs are available, allocate the 1987 population proportionately with houses counted in each service area.
      2. If aerial photographs are not available, allocate the 1987 population in accordance with the best available information.
   D. Determine the "rural" or out-of-city population of each service area.
      1. Establish these populations by house counts if aerial photographs are available.
      2. If aerial photographs are not available, assume the average rural population density for the affected county applies.
   E. Project 2005 population for planning area.
      1. Calculate 2005 in-city population.
         a. If 1980 census data are available, extrapolate populations linearly from 1980 through 1987 to 2005.

TABLE D-11

FACILITY PLANNING METHODOLOGY SUMMARY
(continued)

b. If 1980 census data are not available, consider available projections from:
   i. NCTCOG
   ii. City or utility district estimates
   iii. Population based on full development of planning area at maximum permitted density.

2. Allocate 2005 in-city population among service areas based on percentages used for 1987.
3. Compute 2005 rural population for each service area assuming total percent growth from 1987 to 2005 for in-city areas also.

III. Develop Layout of Proposed Individual Regional and Sub-Regional Sewerage Systems for Each Planning Area.

A. On an 11x17 map, locate:
   1. Wastewater treatment plant(s)
   2. Outfall structure and pipeline
   3. Major interceptors and branch lines
      a. Throughout existing developments
      b. To downstream edge of known future developments
   4. Pump stations and force mains
   5. Major geographical features
      a. Main roads
      b. Creeks, rivers, and lakes
      c. Planning area boundaries

B. Develop alternative layouts for each area as appropriate.

IV. Estimate "Current" and "Ultimate" Wastewater Flows, Loadings, and Sludge Production Rates for Each Scenario

A. Assume 100 gpcd for wastewater flow rate calculation for unsewered areas. For sewered areas use flow based on review of historical data up to maximum of 120 gpcd.

B. Calculate effluent BOD and TSS loads assuming each of the following permit conditions:

BOD	TSS	Ammonia
30	30	15
20	20	15
10	15	15
10	15	2

TABLE D-11

FACILITY PLANNING METHODOLOGY SUMMARY
(continued)

C. Calculate "current" and "ultimate" sludge production assuming 1950 lbs/million gallons for 30/30 permit condition, 2100 lbs/-million gallons for 20/20 permit conditions, and 2200 lbs/million gallons for 10/15 permit conditions.

V. Estimate Size and Cost of Sewerage Facilities

A. Calculate initial capital costs for wastewater system

1. Gravity Collection System

a. Calculate average 2005 flow from each service area.

b. Calculate size and cost of gravity sewer based on criteria in the table below and on the system layout map developed in Step III.

Sizing and Costing of Gravity Collection System Lines

Design discharge range (MGD)	Pipe diameter (inches)	Cost/linear foot (1987 dollars)
0.08 or less	6	$ 20
0.08-0.17	8	25
0.17-0.29	10	30
0.29-0.47	12	34
0.47-0.82	15	42
0.82-1.3	18	49
1.3-1.9	21	56
1.9-2.7	24	63
-	27	70
-	30	77

2. Calculate initial capital costs for lift stations.

a. From system layout map and population projections, estimate required capacity of each lift station.

b. Estimate cost of lift station based on criteria in Figure D-12.

c. If lift station locations cannot be readily identified, use 1980 TDWR Criteria to estimate number of lift stations.

TABLE D-11

FACILITY PLANNING METHODOLOGY SUMMARY
(continued)

3. Estimate cost of force mains.
   a. Using system layout map, service area population estimates, and Figure D-13 estimate force main size.
   b. Estimate cost of force mains using Figure D-14, adjusted to 1987 dollars.
4. Compute total capital cost for collection system as follows:
   a. Base Sewer Cost: Gravity Collection System Cost + Lift Station Cost + Force Main Cost
   b. Total Capital Cost for Sewer System = (R) x (Fe + Fc + 1.0) where Fe and Fc are as shown in Figure D-15.

B. Calculate the capital cost of new treatment facilities for each of the following permit scenarios:
   1. 10/15 (Use Figure D-16).
   2. 10/15/2 (Use Figure D-16).

C. Calculate annualized capital cost of system for each permit scenario assuming 100 percent financing at 4 1/2 percent annual compounding interest over a 20-year term (Multiplier = 0.0769).

D. Compute annual O&M costs for system
   1. Collection system O&M cost = L x $.59/ft. Where L = total length of all force mains and gravity sewers in system.
   2. Treatment plant O&M cost may be determined from Figure D-17.
   3. Lift station O&M cost may be determined from Figure D-18 if included in system.

E. Add the annualized capital costs, collection system O&M costs, and treatment plant O&M costs for each permit scenario to obtain the total annual cost of the system.

F. Divide the total annual cost by the number of households served in both 1990 and 2005 to obtain the annual cost per household for the proposed system. Number of households for 1990 based on linear extrapolation of population/households between values for 1987 and 2005.

FIGURES

```
$NOFLOATCALLS
$STORAGE:2
      SUBROUTINE WASPB
C  SCREENING MODEL - 2 VERTICAL SEGMENT LAKE
$INCLUDE:'WSPCMN.F4P'
C*************************************************************
      REAL KPT,KZ,KMP,KN,KP,IA,LN,KDN,KNH3ON,KNO3ON,KPO4UNP,IS
         REAL NH3,NO3,NIT,P,PO4,IO
         DIMENSION TEMP(4),THICK(4)
C
C     INITIALIZATION OF CONSTANTS, ALL RATES PER DAY
C
      IF(INITB.EQ.1) GO TO 1000
         INITB=1
      MXDMP=1
       NTF=0
C MAXIMUM GROWTH RATE OF PHYTOPLANKTON AT 20 C
      KPT=CONST(1)
C TEMPERATURE CORRECTION FOR GROWTH RATE, THETA
      TG=CONST(2)
C OPTIMUM SOLAR RADIATION, Ly/DAY
      IS=CONST(3)
      E=2.71828
C RESPIRATION RATE
         KZ=CONST(4)
C RESPIRATION RATE TEMPERATURE THETA
         TD=CONST(5)
C M-M HALF SATURATION CONSTANT - NITROGEN, mg/l
      KN=CONST(6)
C M-M HALF SATURATION CONSTANT - PHOSPHORUS, mg/l
      KP=CONST(7)
C SETTLING RATE FOR PHYTOPLANKTON, FEET/DAY
      WP=CONST(8)
C AMMONIA OXIDATION RATE
      KDN=CONST(9)
C AMMONIA UPTAKE RATE DUE TO PHYTOPLANKTON GROWTH, mg/l/mg PHYTO
      A1=CONST(10)
C CONVERSION RATE OF ORGANIC N TO NH4
         KNH3ON=CONST(11)
      THICK(2)=CONST(12)
      THICK(3)=CONST(13)
C NITRATE UPTAKE FOR PHYTOPLANKTON GROWTH, mg/l/mg PHYTO GROWN
      A3=CONST(14)
C ORGANIC NITROGEN RELEASE FROM PHYTOPLANKTON DEATH, mg/l/mg PHYTO
         A5=CONST(15)
C SETTLING RATE ORGANIC N, FEET/DAY
         SETON=CONST(16)
C CONVERSION RATE NONUSABLE P TO PO4
      KPO4UNP=CONST(17)
C PO4 UPTAKE FOR PHYTOPLANKTON GROWTH, mg/l/mg PHYTO
         A7=CONST(18)
C UNAVAILABLE PHOSPHORUS SETTLING
         SETUNP=CONST(19)
C UAVAIL.-P RELEASE FROM PHYTOPLANKTON DEATH, mg/l/mg PHYTO
         A8=CONST(20)
C DO INCREASE FOR PHYTOPLANKTON GROWTH, mg/l/mg PHYTO
```

Figure D-1
WASP Kinetic Subroutine

```
C GROWTH OF PHYTOPLANKTON=MAXIMUM GROWTH(TEMPERATURE CORRECTED) *
C     LIGHT LIMITATION * NUTRIENT LIMITATION
          GP=KPT*(TG**(TEMP(ISEG)-20))*R*LN
C PHYTOPLANKTON DIFFERENCE
          IF(ISEG.EQ.2) THEN
C DIFFERENCE=(GROWTH-DEATH)*CONCENTRATION-SETTLING*CONC (+ SETTLED
C FROM LAYER ABOVE)
          CD(7,2)=((GP-DP)*P-SS*P)*BVOL(2)
          XP1=P*SS
          ELSE
          CD(7,3)=((GP-DP)*P-SS*P+XP1)*BVOL(3)
          ENDIF
C          NITROGEN CYCLE
C AMMONIA
C CHECK TO SEE IF NH3 OR NO3 = 0, IF SO UPTAKE CONSTANT CHANGES SO
C  ALL UPTAKE IS FROM REMAINING NITROGEN SOURCE
       IF(NH3.EQ.0.) THEN
       A3=A5
       A1=0
       ELSE
       A1=CONST(10)
       A3=CONST(14)
       ENDIF
       IF(NO3.EQ.0.) THEN
       A3=0
       A1=A5
       ELSE
       A1=CONST(10)
       A3=CONST(14)
       ENDIF
C NH3 DIFFERENCE = - NH3 OXIDATION (TEMPERATURE CORRECTED) -
C  PHYTOPLANKTON UPTAKE + ORGANIC N TRANSFORMATION (TEMPERATURE
C  CORRECTED)
          CD(4,ISEG)=(-KDN*NH3*(1.047**(TEMP(ISEG)-20))-A1*GP*P+
      &KNH3ON*ON*(1.047**(TEMP(ISEG)-20)))*BVOL(ISEG)
C NITRATE DIFFERENCE = NH3 OXIDATION (TEMPERATURE CORRECTED) -
C PHYTOPLANKTON UPTAKE
          CD(3,ISEG)=(KDN*NH3*(1.047**(TEMP(ISEG)-20))-A3*GP*P)*BVOL(ISEG)
C ORGANIC NITROGEN DIFFERENCE = ON TO NH3 TRANSFORMATION (TEMPERATURE
C CORRECTED)+ RELEASE BY PHYTOPLANKTON RESPIRATION - SETTLING (+
C SETTLING FROM LAYER ABOVE)
          IF(ISEG.EQ.2) THEN
          CD(5,2)=(-KNH3ON*ON*(1.047**(TEMP(ISEG)-20))+
      &A5*DP*P-SETON*ON/THICK(2))*BVOL(ISEG)
          XON=SETON*ON/THICK(2)
          ELSE
          CD(5,3)=(-KNH3ON*ON*(1.047**(TEMP(ISEG)-20))+
      &A5*DP*P-SETON*ON/THICK(3)+XON)*BVOL(ISEG)
          ENDIF
C PHOSPHORUS CYCLE
C CONVERSION OF UNAVAILABLE PHOSPHORUS TO PO4 (TEMPERATURE CORRECTED)
          UNPCONV=KPO4UNP*UNP*(1.047**(TEMP(ISEG)-20))
C PO4 CHANGE = UNAVAILABLE P CONVERSION - PHYTOPLANKTON UPTAKE
          CD(2,ISEG)=(UNPCONV-A7*GP*P)*BVOL(ISEG)
C UNAVAILABLE PHOSPHORUS DIFFERENCE = PHYTOPLANKTON RELEASE -
C SETTLING - CONVERSION TO PO4 (+SETTLED P FROM LAYER ABOVE)
```

Figure D-1
WASP Kinetic Subroutine
(continued)

```
          A10=CONST(21)
C DO DECREASE FOR PHYTOPLANKTON DEATH, mg/l/mg PHYTO
          A11=CONST(22)
C DO BOTTOM DEMAND
          B1=CONST(23)
       DEPTH1=CONST(24)
1000   CONTINUE
C EVALUATE PIECEWISE LINEAR FUNCTIONS OF TIME
          IF(TIME.GE.NTF) CALL WASP8(MFUNC,BFUNC,NFUNC,4,ITIME,NTF,73)
C
       TEMP(2)=MFUNC(1)*(TIME-NFUNT(1))+BFUNC(1)
       TEMP(3)=MFUNC(2)*(TIME-NFUNT(2))+BFUNC(2)
       IA=MFUNC(3)*(TIME-NFUNT(3))+BFUNC(3)
       TSS=MFUNC(4)*(TIME-NFUNT(4))+BFUNC(4)
       F=MFUNC(5)*(TIME-NFUNT(5))+BFUNC(5)
        VSS=MFUNC(6)*(TIME-NFUNT(6))+BFUNC(6)
C
C BEGIN EVALUATION OF DIFFERENTIALS FOR ALL SEGMENTS
C
       DO 200 ISEG=2, 3
C INITIALIZE CONCENTRATIONS
C PHYTOPLANKTON = P
          P=C(7,ISEG)
          NH3=C(4,ISEG)
          ON=C(5,ISEG)
          UNP=C(1,ISEG)
          PO4=C(2,ISEG)
          DO=C(6,ISEG)
          NO3=C(3,ISEG)
C
C SETTLING = SETTLING RATE \LAYER THICKNESS
          SS=WP/THICK(ISEG)
C DEATH RATE, TEMPERATURE CORRECTED
          DP=KZ*(TD**(TEMP(ISEG)-20.))
C LIGHT INDUCED REDUCTION OF GROWTH
C LIGHT EXTINCTION BASED ON TSS, VSS AND PHYTOPLANKTON CONCENTRATION
       XKE=.087*TSS+.208*VSS+.0145*P*1000+.1
C EXTINCT LIGHT TO TOP OF LAYER TWP
       IF(ISEG.EQ.3) THEN
       IO=IA*EXP(-XKE*DEPTH1)
       ELSE
       IO=IA
       ENDIF
          AO=IO/(IS*F)
          AL=AO*EXP(-XKE*THICK(ISEG))
C REDUCTION IN GROWTH DUE TO LIGHT LIMITATIONS
          R=E*F/(XKE*THICK(ISEG))*(EXP(-AL)-EXP(-AO))
C NUTRIENT INDUCED REDUCTION, BASED ON MICHALIS-MENTON RELATIONSHIP
          NIT=NH3+NO3
          XL1=NIT/(NIT+KN)
          XL2=PO4/(PO4+KP)
          IF(XL1.LT.XL2) THEN
          LN=XL1
          ELSE
          LN=XL2
          ENDIF
```

Figure D-1
WASP Kinetic Subroutine
(continued)

```
         IF(ISEG.EQ.2) THEN
         CD(1,2)=(A8*DP*P-SETUNP*UNP/THICK(2)-UNPCONV)*BVOL(ISEG)
         XTP=UNP*SETUNP/THICK(2)
         ELSE
         CD(1,3)=(A8*DP*P-SETUNP*UNP/THICK(3)-UNPCONV+XTP)*BVOL(ISEG)
      ENDIF
C DISSOLVED OXYGEN
C SATURATION VALUE AT SURFACE
         IF(ISEG.EQ.2) THEN
         CS=14.62-.3898*TEMP(2)+.006969*(TEMP(2)**2)-5.897E-5*
     &(TEMP(2)**3)
C DISSOLVED OXYGEN DIFFERENTIAL
      DODIFF=CS-DO
      IF(DODIFF.LT.0) DODIFF=0.
C DO DIFFERENCE = (REAERATION) + PHYTOPLANKTON CONTRIBUTION -
C PHYTOPLANKTON UPTAKE - NH3 OXIDATION USE (TEMPERATURE CORRECTED)
         CD(6,2)=(2.0/THICK(2)*(DODIFF)+A10*GP*P-A11*DP*P-
     &4.33*KDN*NH3*(1.047**(TEMP(2)-20)))*BVOL(ISEG)
         ELSE
         CD(6,3)=(A10*GP*P-A11*DP*P-B1-
     &4.33*KDN*NH3*(1.047**(TEMP(3)-20)))*BVOL(ISEG)
         ENDIF
200   CONTINUE
C CHECKS TO SEE IF IT IS TIME TO STORE OUTPUT
      IF(IDISK.EQ.0) GO TO 300
      PTIME=TIME*1.0000000001
      DTIME(IREC)=PTIME
      IDFRC(1)=MXDMP*NOSEG*(IREC-1)
      DO 120 I=1, 4
      IDF=IDFRC(1)+MXDMP*(I-1)
      DVAR(IDF+1,1)=C(1,I)
      DVAR(IDF+1,2)=C(2,I)
      DVAR(IDF+1,3)=C(3,I)
      DVAR(IDF+1,4)=C(4,I)
      DVAR(IDF+1,5)=C(5,I)
      DVAR(IDF+1,6)=C(6,I)
      DVAR(IDF+1,7)=C(7,I)
120   CONTINUE
300   IDISK=0
      RETURN
      END
```

Figure D-1
WASP Kinetic Subroutine
(continued)

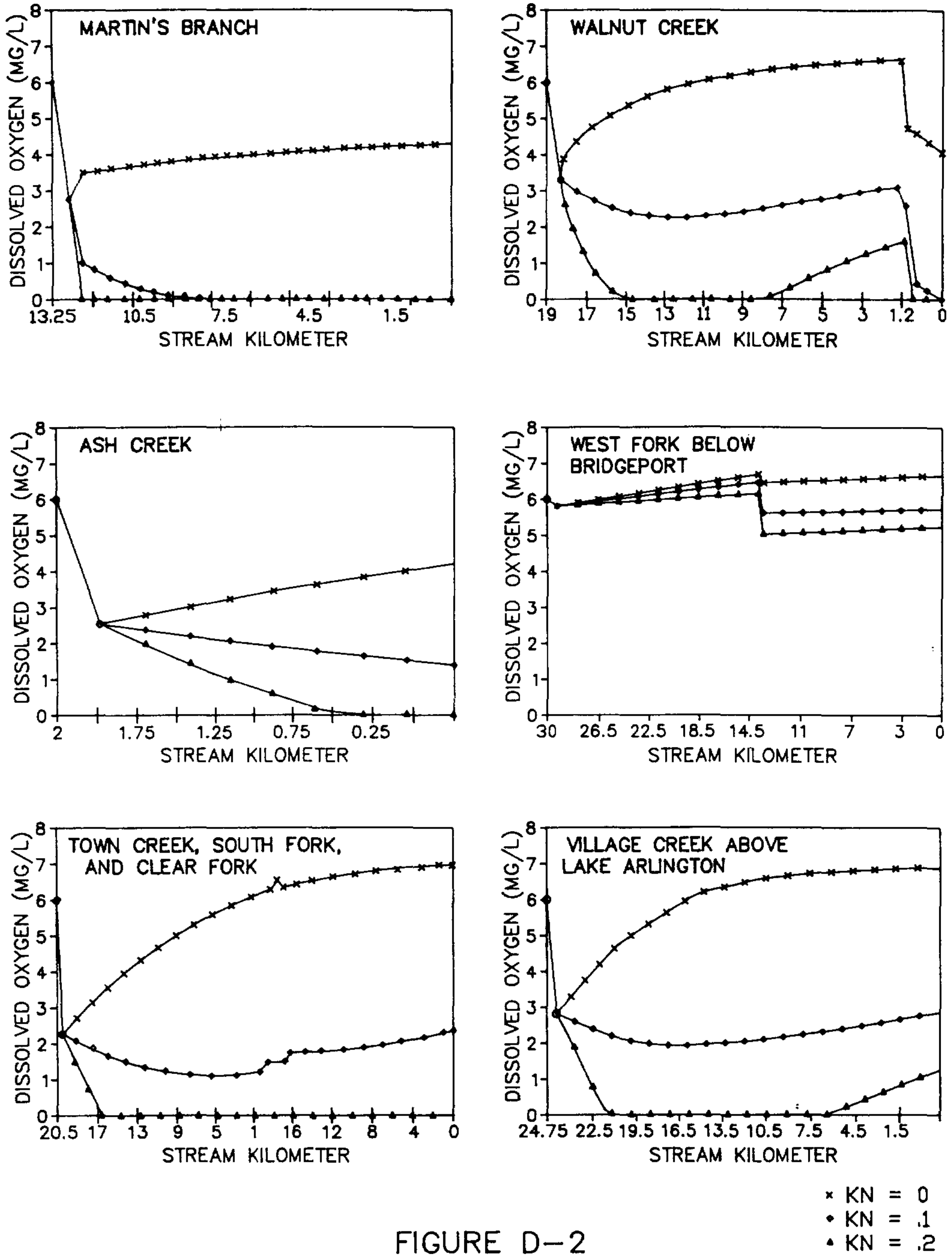


FIGURE D-2
PRELIMINARY SCREENING ANALYSIS
STREAM RESPONSE TO 1986 WASTE LOADS AT
VARYING NITRIFICATION RATES

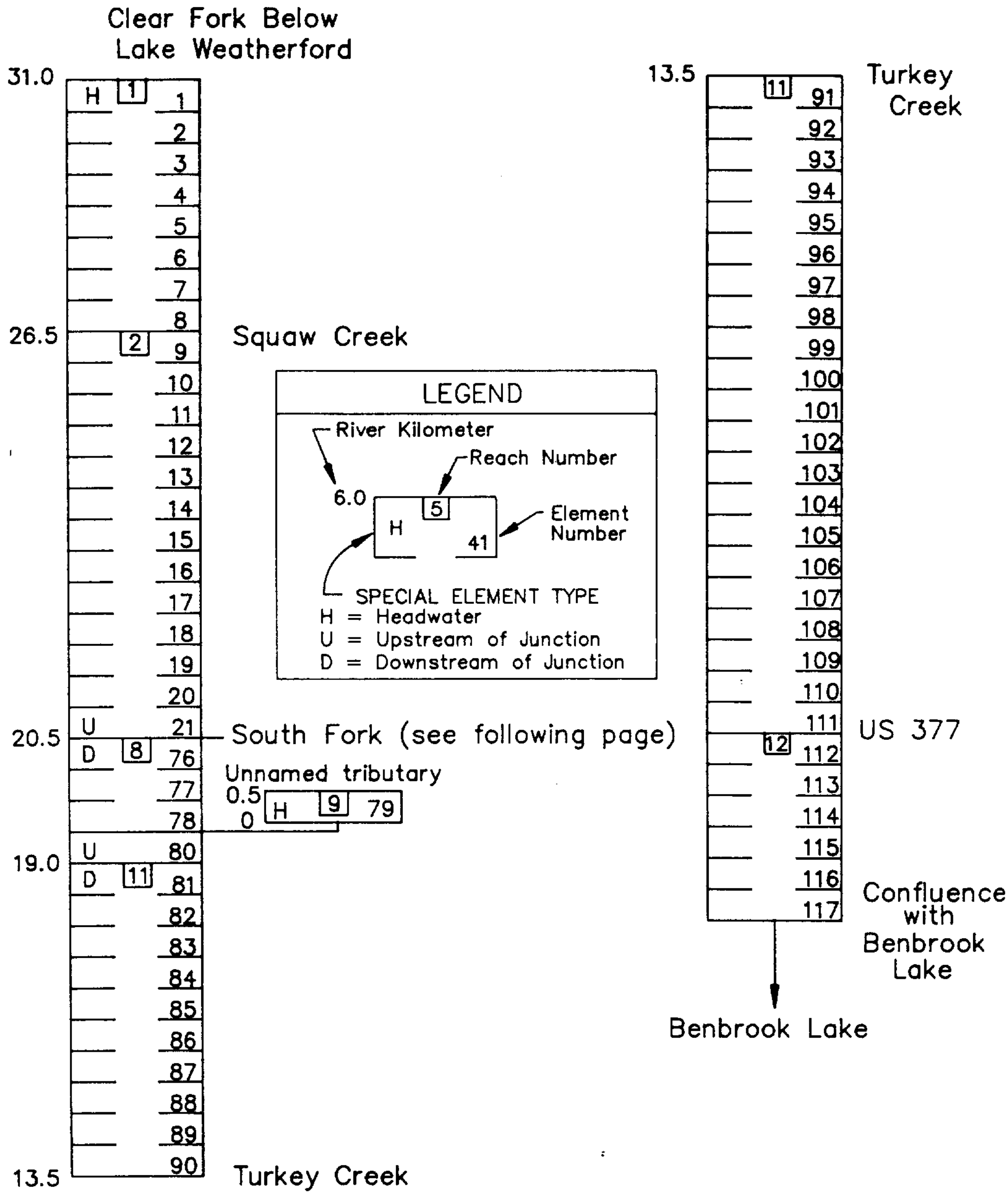


FIGURE D–3
MODEL SCHEMATIC OF CLEAR FORK, TOWN CREEK AND SOUTH FORK MODEL

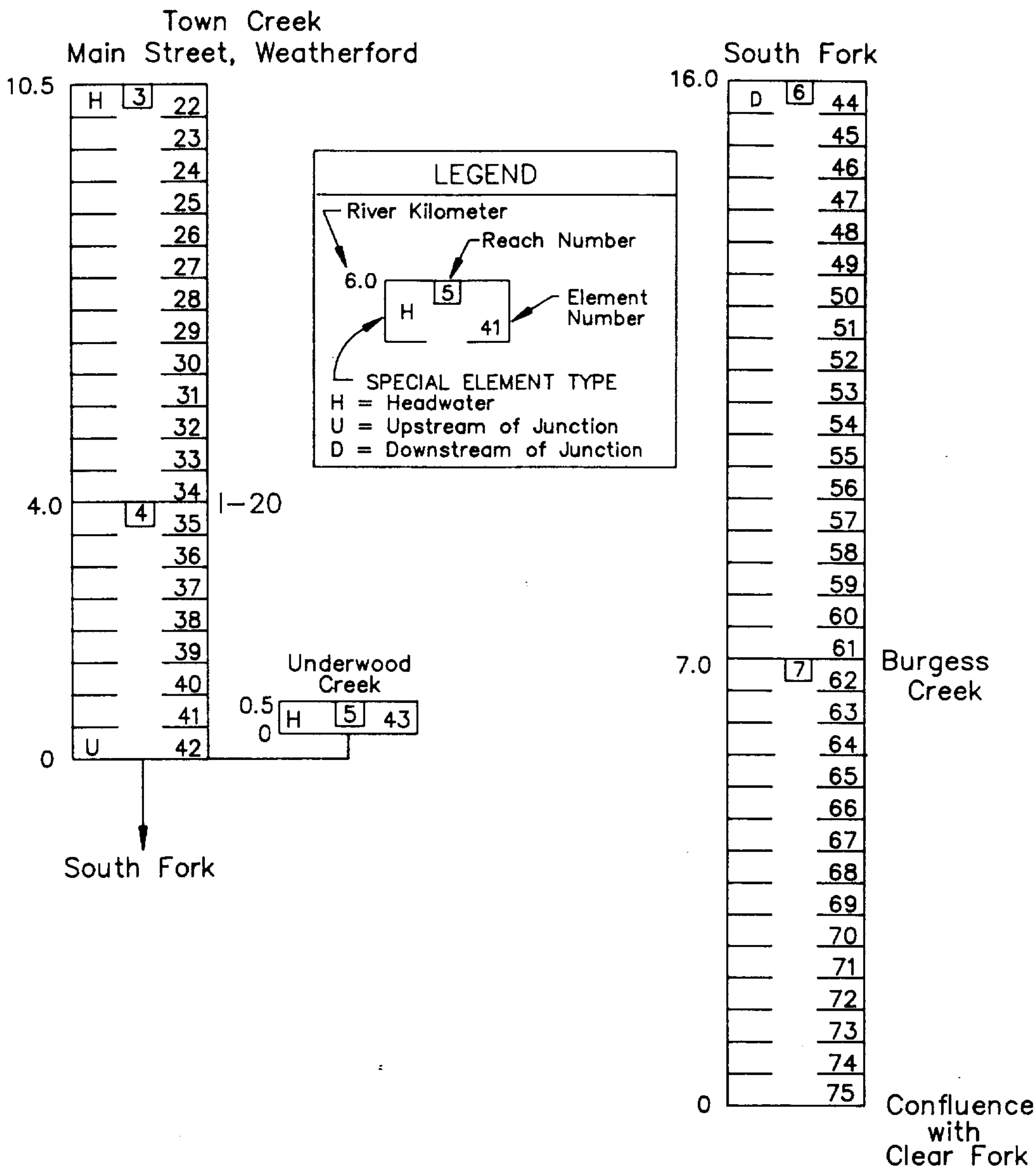
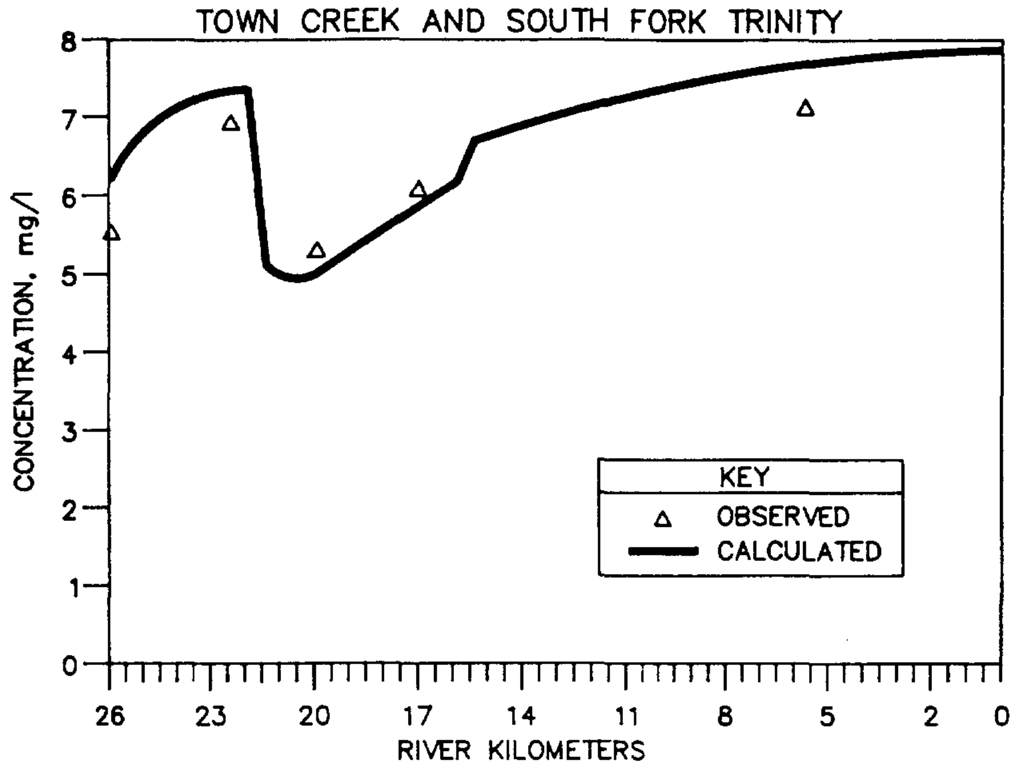


FIGURE D-3
MODEL SCHEMATIC OF CLEAR FORK, TOWN CREEK AND SOUTH FORK MODEL (CONTINUED)



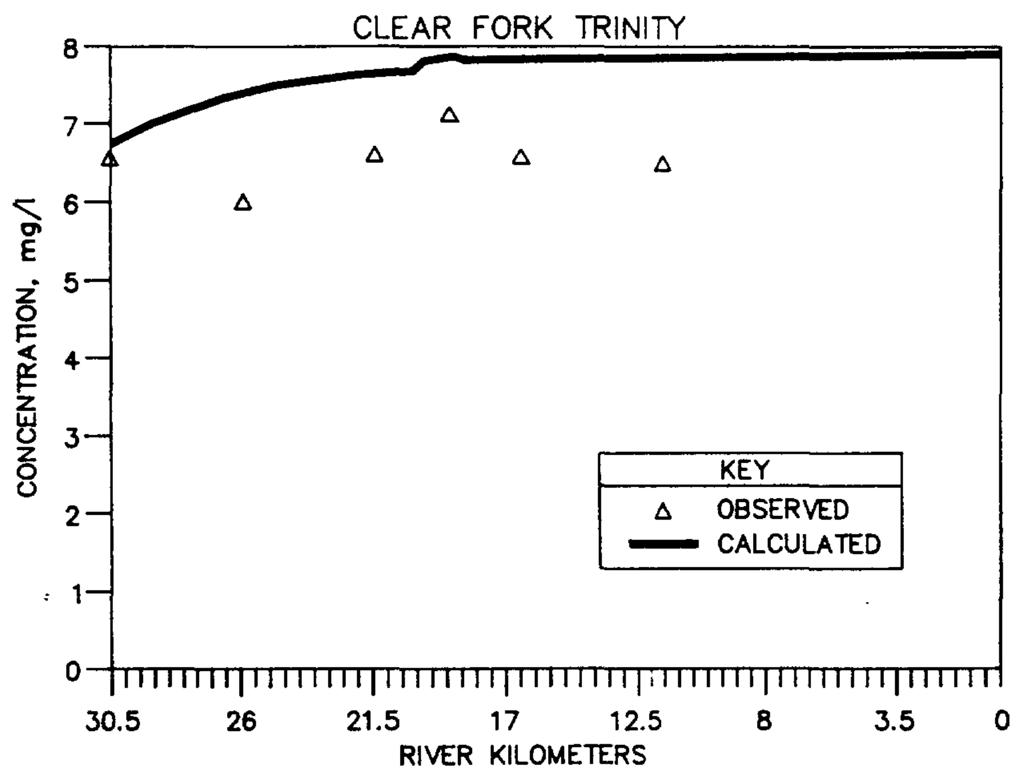


FIGURE D–4
CALCULATED AND OBSERVED DISSOLVED OXYGEN FOR THE CLEAR FORK SYSTEM USING QUAL–TX.

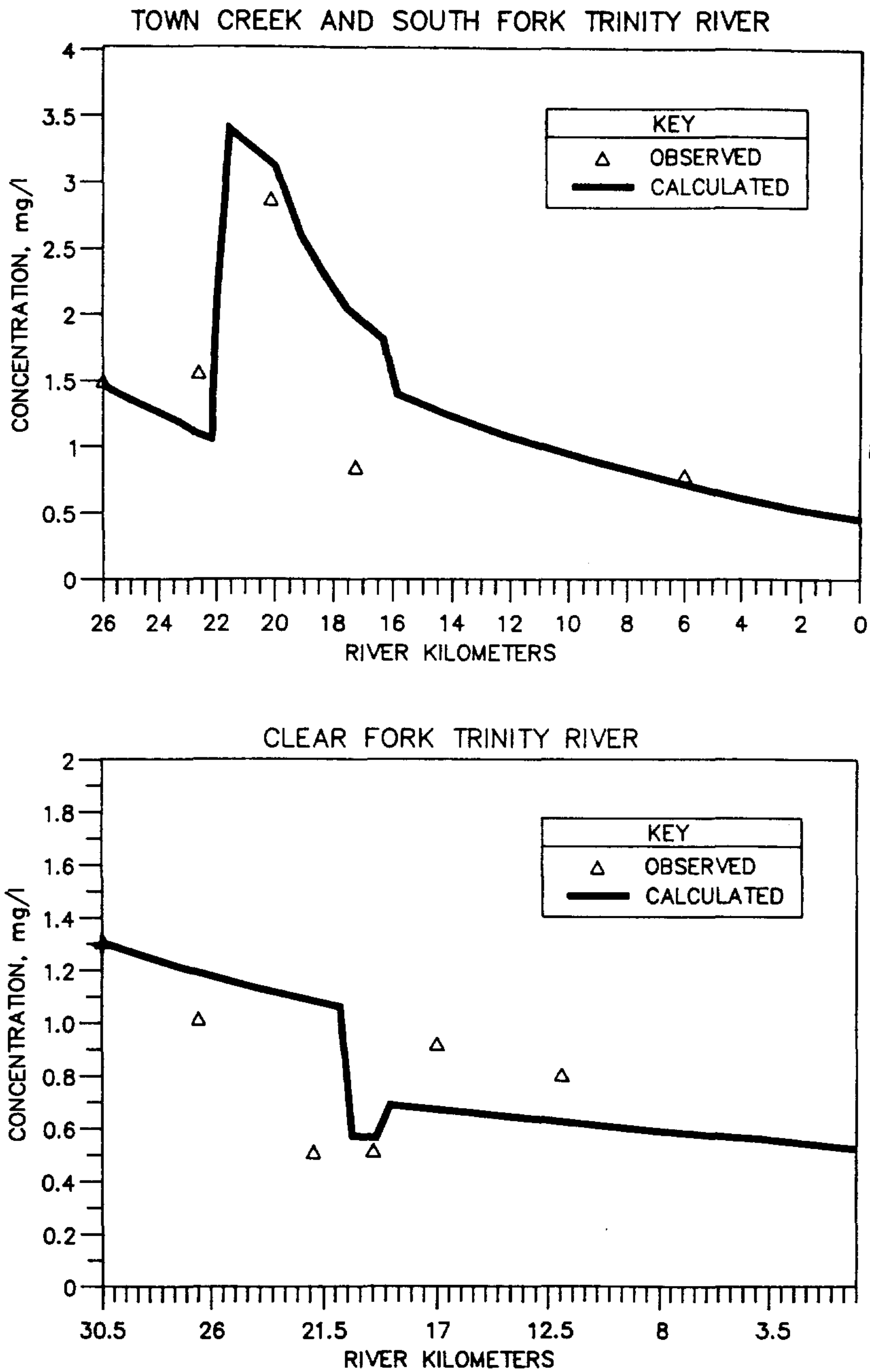
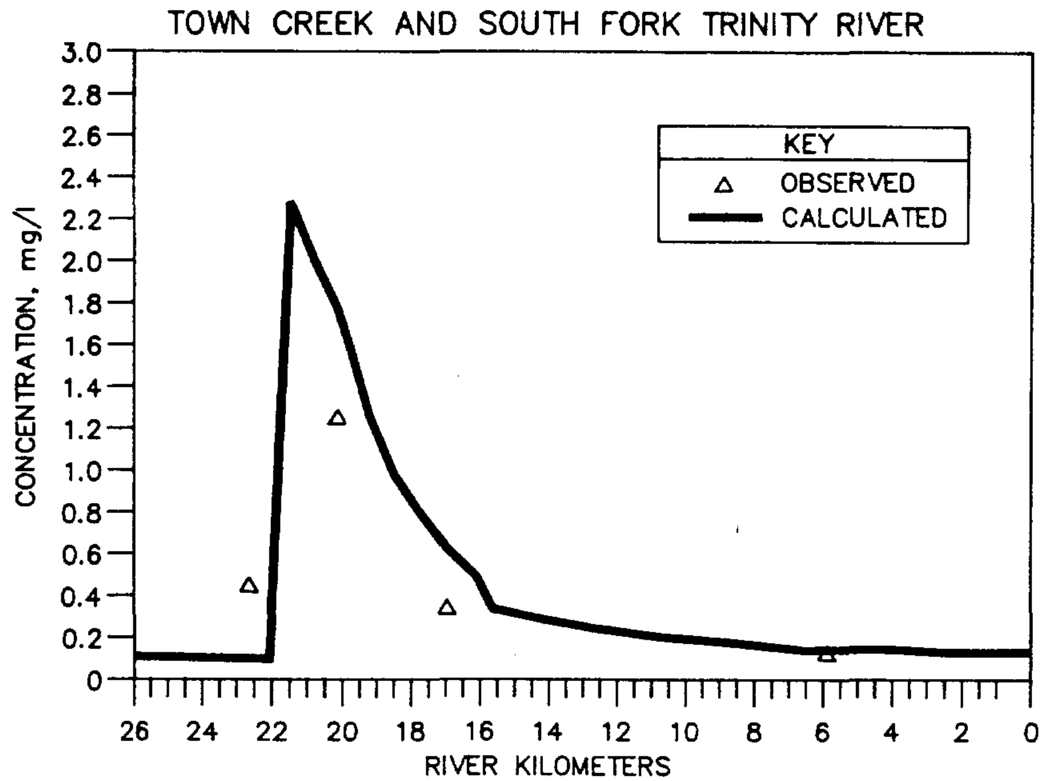


FIGURE D–5
CALCULATED AND OBSERVED BOD_5 FOR THE
FOR THE CLEAR FORK SYSTEM USING QUAL–TX.



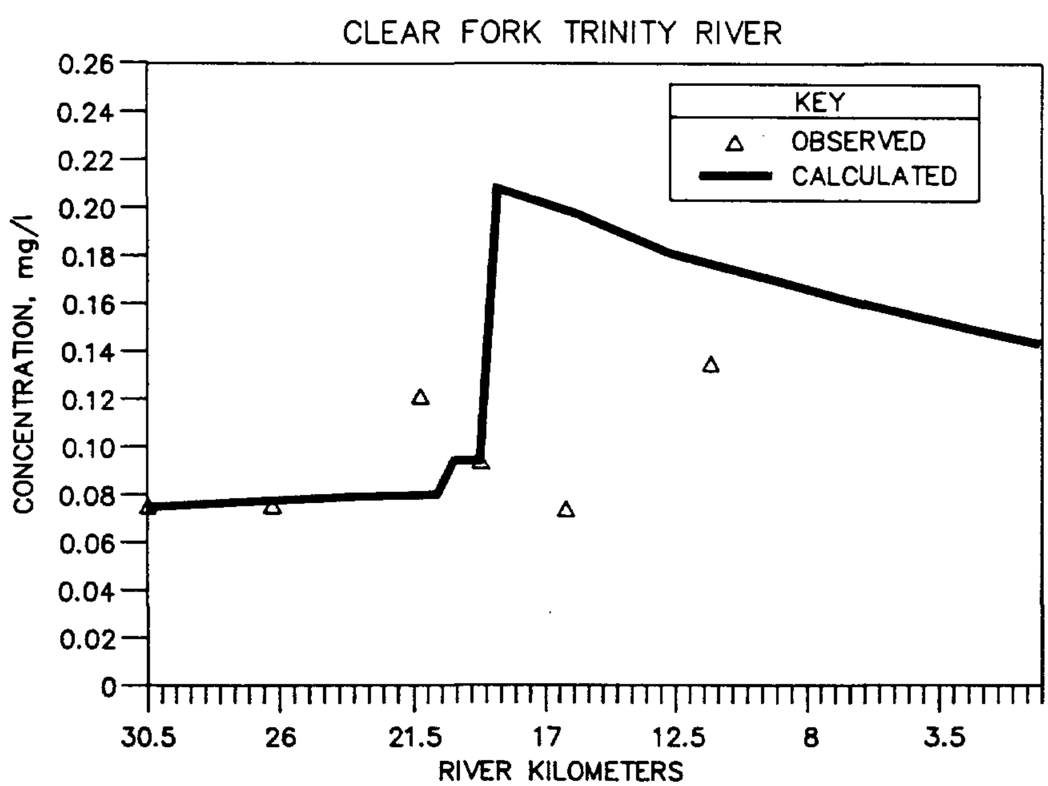
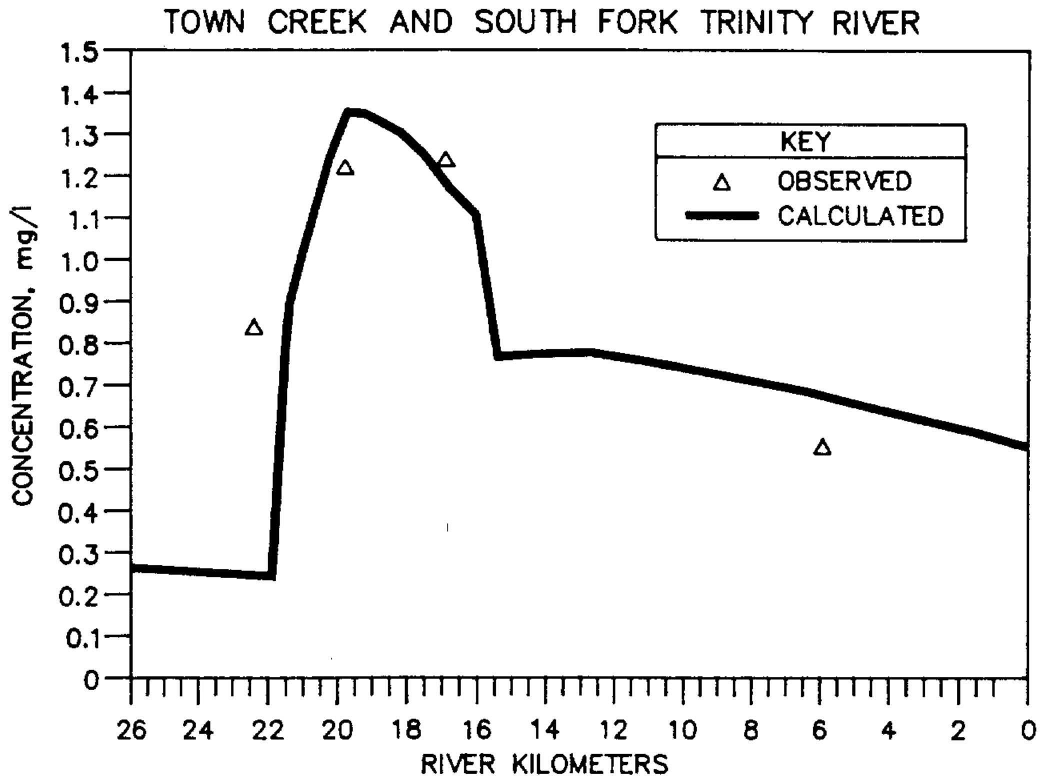


FIGURE D-6
CALCULATED AND OBSERVED AMMONIA FOR THE CLEAR FORK SYSTEM USING QUAL-TX.



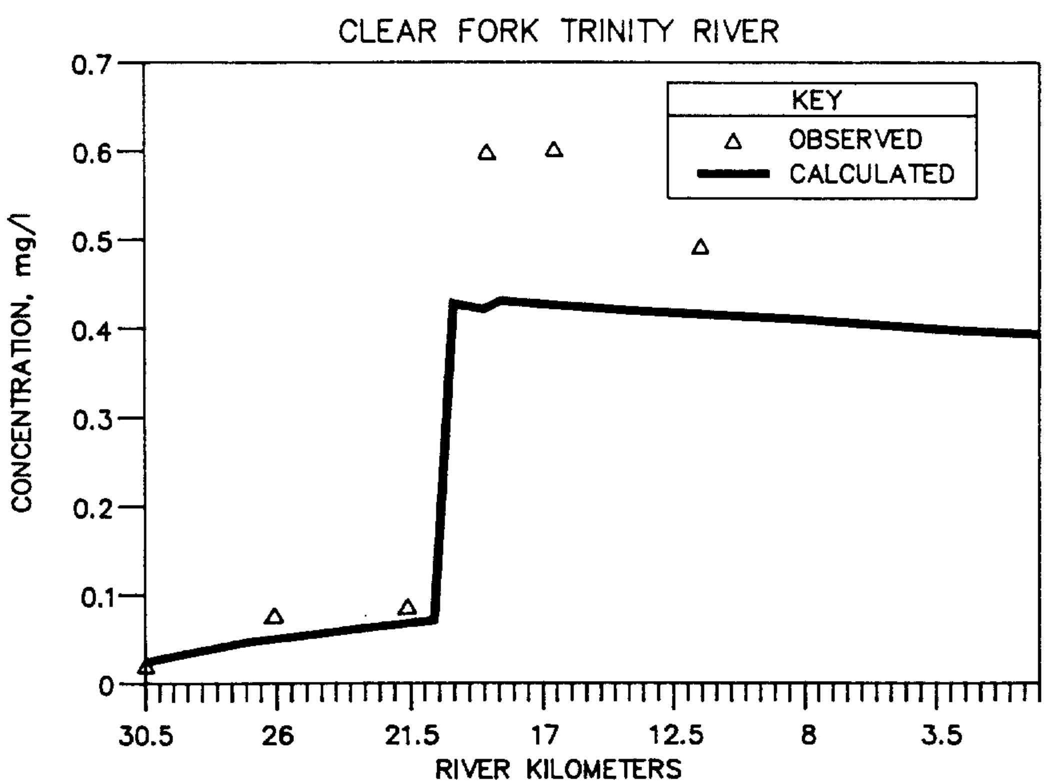


FIGURE D–7
CALCULATED AND OBSERVED NITRATE FOR THE CLEAR FORK SYSTEM USING QUAL–TX.

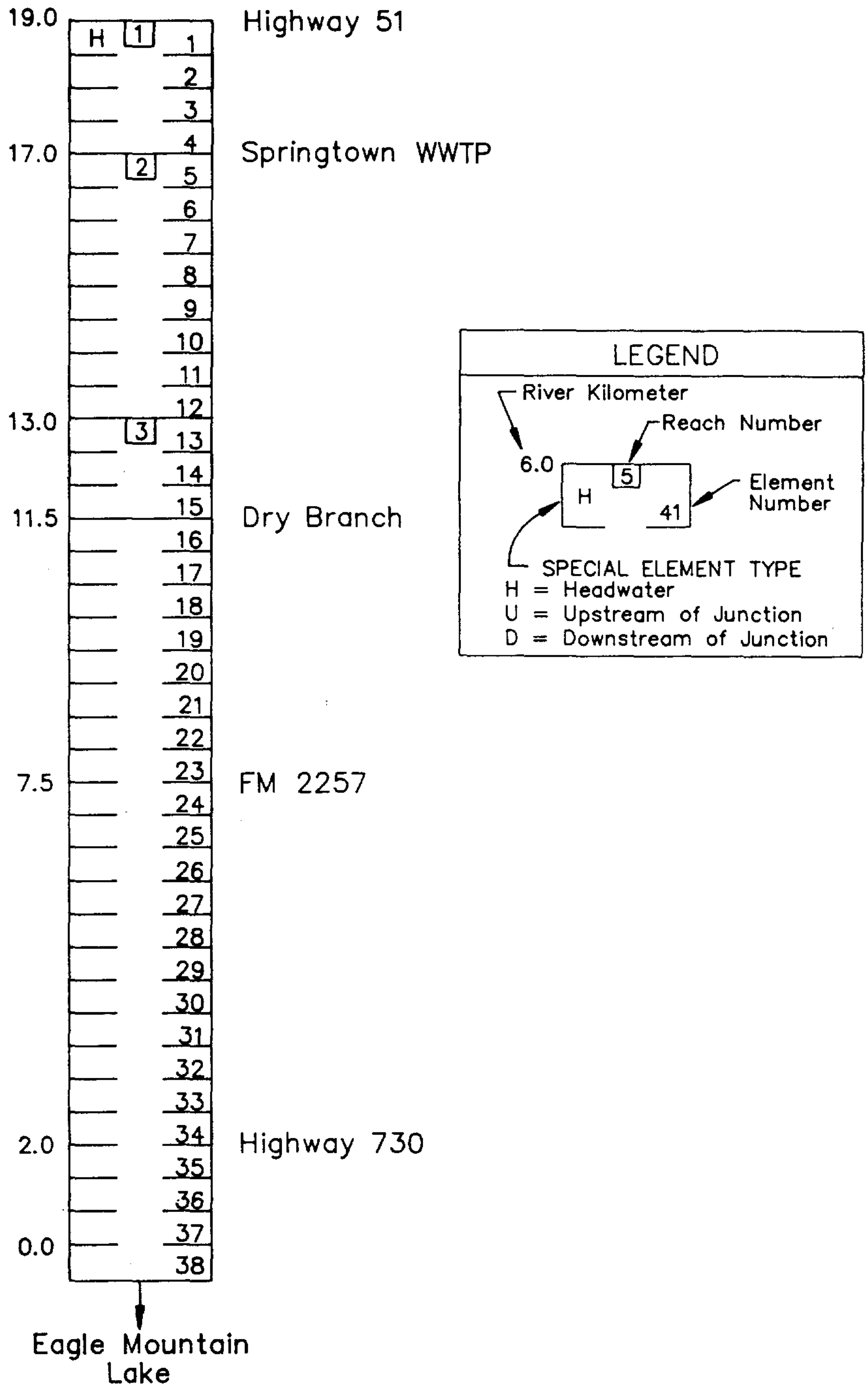


FIGURE D-8
MODEL SCHEMATIC OF WALNUT CREEK

```
   1    2    1    4    7    0    0
LAKE WORTH DATA SET - CALIBRATION
  VERTICAL LAYER MODEL - WITH UPSTREAM BOUNDRY CONDITION
 0 0 0 0 0 0 0   SYSTEM BYPASSES
    4    1          EXCHANGE COEFFICIENTS
    1.0     1.0
.00000333 75141000.  5.35 7.85    2    3
 0 0 0 0 0 0 0
    1    4            NUMBER OF VOLUMES
  1.0        1.0       SCALE FOR VOLUMES
   40.0      498.762   500.94     40.0
    3    4         NUMBER OF FLOWS
     1.0     1.0      SCALE FOR FLOWS
    0    1    2        NPS INFLOWS
    390.      0.        390.      400.
    1    2    2
    390.      0.        390.      400.
    2    4    2
    371.0     0.        371.0     400.
    4    0    2
    371.0     0.        371.0     400.
 0 0 0 0 0 0 0       BYPASS OPTION
    1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 1 - UNAVAILABLE PHOSPHORUS
    1.0       1.0
   .03        1     .03      4
    1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 2 - ORTHOPHOSPHATE
    1.0       1.0
   .020       1     .02      4
    1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 3 - NITRATE N
    1.0       1.0
   .05        1     .05      4
    1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 4 - AMMONIA N
    1.0       1.0
   .08        1     .30      4
    1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 5 - ORGANIC N
    1.0       1.0
   0.4        1     0.6      4
    1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 6 - DISSOLVED OXYGEN
    1.0       1.0
   7.6        1     8.0      4
    1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 7 - CHLOROPHYLL 'a'
    1.0       1.0
   .0010      1     .0010    4
    1    0    0     NUMBER OF FORCING FUNCTIONS SYSTEM 1 - UNP
    1    0    0    NUMBER OF FORCING FUNCTIONS SYSTEM 2 - PO4
    1    0    0    NUMBER OF FORCING FUNCTIONS SYSTEM 3 - NO3
    1    0    0    NUMBER OF FORCING FUNCTIONS SYSTEM 4 - NH3
    1    0    0    NUMBER OF FORCING FUNCTIONS SYSTEM 5 - ON
    1    0    0    NUMBER OF FORCING FUNCTIONS SYSTEM 6 - DO
    1    0    0    NUMBER OF FORCING FUNCTIONS SYSTEM 7 - CH'a'
    0      NUMBER OF PARAMETERS
   24      NUMBER OF CONSTANTS
  KPT     2.        TG     1.06      IS     300.      KZ     0.1       TD     1.047
   KN     0.025     KP     0.001     WP     .164    KDN     0.1       A1      5.0
NH3ON     0.03   THCK1     5.35   THCK2     7.85     A3     5.0       A5      10.
SETON    0.164   PO4UP     0.06   A7         1.0  SETUP     .164      A8      1.0
  A10    .133      A11     0.133     B2     .2462 DPTH1     5.35
    6      NUMBER OF TIME FUNCTIONS
TEMP1     3
```

Figure D-9

Lake Worth Model Data Set

```
   29.0        0.0        29.0        212.      29.0       365.
 TEMP2     3
   28.0        0.0        28.0        212.      28.0       365.
   LAR     3
    505.       0.0        505.        212.       505.      365.
   TSS     3
    11.5       0.0        11.5        212.       11.5      365.
 PHOTO     3
    0.58       0.0        0.58        212.       0.58      365.
   VSS     3
    0.0        0.0        0.0         212.       0.0       365.
   UNP  0.030      UNP   0.03      UNP    0.03   UNP     .03
   PO4  0.02       PO4   0.02      PO4    0.02   PO4     .02
   NO3  0.06       NO3   0.06      NO3    0.06   NO3     .06
   NH3  0.30       NH3   0.30      NH3    0.30   NH3     .30
    ON  0.6         ON   .60        ON    .60     ON     .60
    DO   7.6        DO    7.6       DO     7.6    DO     7.6
   CHA  0.0010     CHA   0.0010    CHA    0.0010 CHA     .0010
    20.        20.       20.0      20.0      20.0       26.0      20.0       MAX VAL
   0.0        0.0        0.0       0.0       0.0        0.0       0.0        MIN VAL
    50                  1        PRINT CONTROL
   0 01
  2 0  0.0                     INTEGRATION STEP
   1.0       0.0               TIME WARP SCALE FACTOR
     1                         NUMBER OF INTEGRATION TIME STEPS
  .10          200.                TIME STEPS
    UNP
   1  1  2  3  4

    PO4
   1  1  2  3  4

    NO3
   1  1  2  3  4

    NH3
   1  1  2  3  4

     ON
   1  1  2  3  4

     DO
   1  1  2  3  4

   CH 'a'
   1  1  2  3  4

  0 0
```

Figure D-9
Lake Worth Model Data Set
(continued)

```
   1    2    1    4    7    0    0
BENROOK LAKE DATA SET - CALIBRATION
7 VERTICAL LAYER MODEL - WITH UPSTREAM BOUNDRY CONDITION
 0 0 0 0 0 0 0   SYSTEM BYPASSES
   4    1          EXCHANGE COEFFICIENTS
    1.0      1.0
.00000333 141570000.  6.0 7.8      2     3
 0 0 0 0 0 0 0
   1    4            NUMBER OF VOLUMES
  1.0        1.0       SCALE FOR VOLUMES
   40.0       969.2   2875.0     40.0
   3    4          NUMBER OF FLOWS
    1.0    1.0      SCALE FOR FLOWS
   0    1    2         NPS INFLOWS
   95.0      0.         95.0      400.
   1    2    2
   95.0      0.         95.0      400.
   2    4    2
   66.0      0.         66.0      400.
   4    0    2
   66.0      0.         66.0      400.
 0 0 0 0 0 0 0          BYPASS OPTION
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 1 - UNAVAILABLE PHOSPHORUS
   1.0       1.0
  .03        1      .03       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 2 - ORTHOPHOSPHATE
   1.0       1.0
  .01        1      .01       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 3 - NITRATE N
   1.0       1.0
  .02        1      .02       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 4 - AMMONIA N
   1.0       1.0
  .01        1      .01       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 5 - ORGANIC N
   1.0       1.0
  .6         1      .6        4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 6 - DISSOLVED OXYGEN
   1.0       1.0
  8.5        1      8.5       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 7 - CHLOROPHYLL 'a'
   1.0       1.0
  .001       1      .001      4
   1    0    0   NUMBER OF FORCING FUNCTIONS SYSTEM 1 - UNP
   1    0    0   NUMBER OF FORCING FUNCTIONS SYSTEM 2 - PO4
   1    0    0   NUMBER OF FORCING FUNCTIONS SYSTEM 3 - NO3
   1    0    0   NUMBER OF FORCING FUNCTIONS SYSTEM 4 - NH3
   1    0    0   NUMBER OF FORCING FUNCTIONS SYSTEM 5 - ON
   1    0    0   NUMBER OF FORCING FUNCTIONS SYSTEM 6 - DO
   1    0    0   NUMBER OF FORCING FUNCTIONS SYSTEM 7 - CH'a'
   0     NUMBER OF PARAMETERS
  24     NUMBER OF CONSTANTS
  KPT    2.        TG     1.06     IS    300.      KZ     0.1      TD    1.047
   KN    0.015     KP     0.001    WP    .164      KDN    0.1      A1     5.0
 NH3ON   0.01   THCK1     9.01  THCK2   18.62      A3     5.0      A5     10.
SETON   0.164  PO4UP      0.02     A7    1.00   SETUP   0.164      A8    1.00
  A10   .133      A11     0.133    B2    .08    DPTH1   9.01
   6     NUMBER OF TIME FUNCTIONS
TEMP1    3
```

Figure D-10
Lake Benbrook Data Set

```
   28.6         0.0       28.6       212.      28.6       365.
 TEMP2     3
   26.1         0.0       26.1       212.      26.1       365.
 SOLAR     3
    505.        0.0       505.       212.       505.      365.
   TSS     3
    6.3         0.0       6.3        212.       6.3       365.
 PHOTO     3
    0.58        0.0       0.58       212.       0.58      365.
   VSS     3
   0.0          0.0       0.0        212.       0.0       365.
  UNP   0.03       UNP    0.03      UNP    0.03    UNP     .03
  PO4   0.01       PO4    0.01      PO4    0.01    PO4     .01
  NO3   0.02       NO3    0.02      NO3    0.02    NO3     .02
  NH3   0.01       NH3    0.01      NH3    0.12    NH3     .01
   ON   .60         ON    .60        ON    .60      ON     .60
   DO    8.5        DO     8.5       DO     2.0     DO     8.5
  CHA   0.001      CHA    0.001     CHA    0.001   CHA     .001
   20.         20.        20.0      20.0      20.0      26.0      20.0      MAX VA
  0.0         0.0         0.0       0.0       0.0       0.0       0.0       MIN VA
  100                1          PRINT CONTROL
  0 01
 2 0   0.0                    INTEGRATION STEP
  1.0        0.0              TIME WARP SCALE FACTOR
    1                         NUMBER OF INTEGRATION TIME STEPS
 .10           200.               TIME STEPS
    UNP
  1   1   2   3   4

    PO4
  1   1   2   3   4

    NO3
  1   1   2   3   4

    NH3
  1   1   2   3   4

     ON
  1   1   2   3   4

     DO
  1   1   2   3   4

  CH 'a'
  1   1   2   3   4

 0 0
```

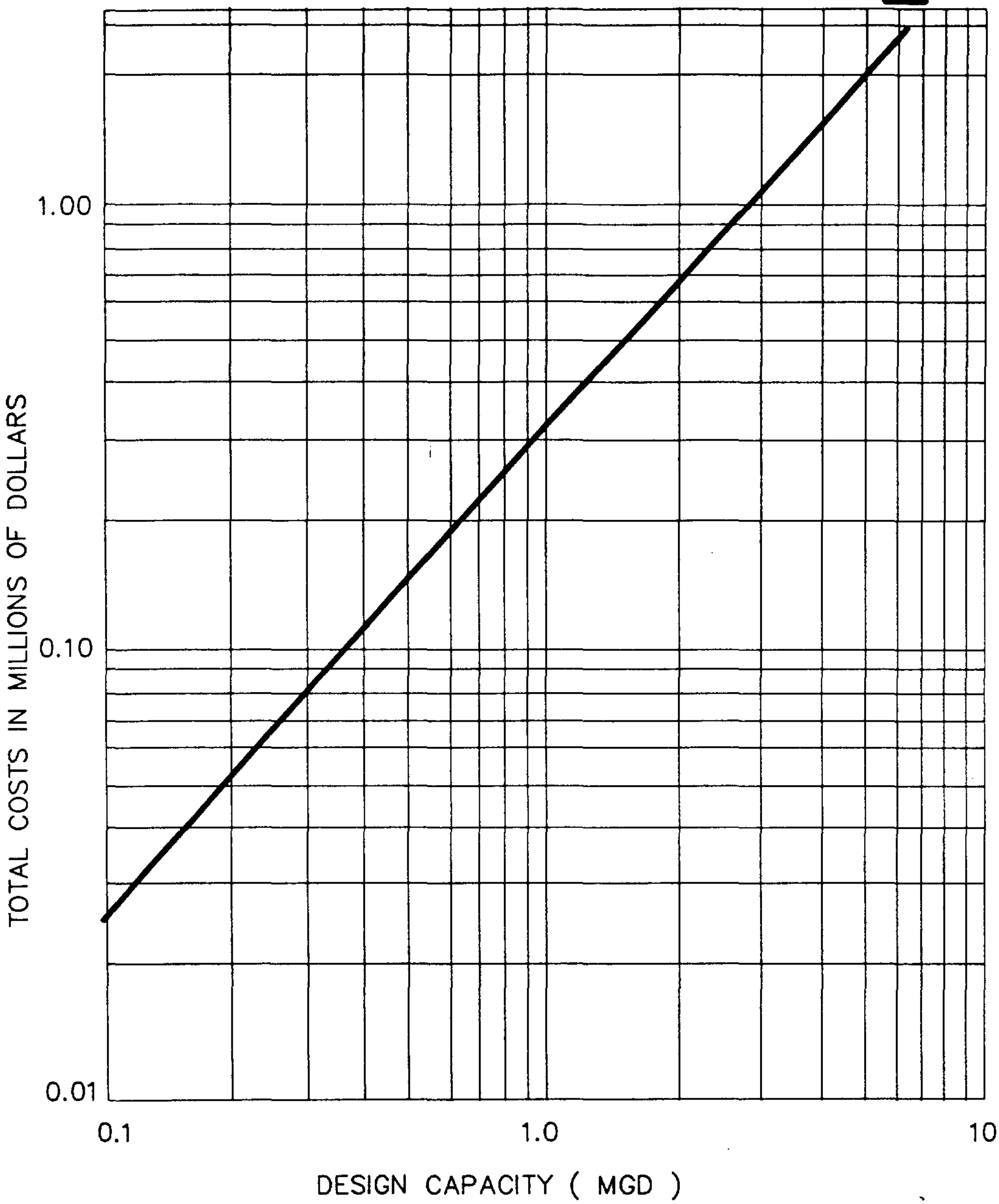
Figure D-10
Lake Benbrook Data Set
(continued)

```
EAGLE MOUNTAIN LAKE DATA SET - CALIBRATION
? VERTICAL LAYER MODEL - WITH UPSTREAM BOUNDRY CONDITION
 0 0 0 0 0 0   SYSTEM BYPASSES
   4    1         EXCHANGE COEFFICIENTS
   1.0      1.0
.00000663 130000000.  6.0 18.5    2    3
 0 0 0 0 0 0 0
   1    4              NUMBER OF VOLUMES
  1.0        1.0          SCALE FOR VOLUMES
   40.0      2400.    5894.      40.0
   3    4           NUMBER OF FLOWS
    1.0     1.0       SCALE FOR FLOWS
   0    1    2           NPS INFLOWS
   260       0.         260       400.
   1    2    2
   260       0.         260       400.
   2    4    2
   189       0.         189       400.
   4    0    2
   189       0.         189       400.
 0 0 0 0 0 0 0         BYPASS OPTION
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 1 - UNAVAILABLE PHOSPHORUS
   1.0       1.0
  .02        1      .02       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 2 - ORTHOPHOSPHATE
   1.0       1.0
  .01        1      .01       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 3 - NITRATE N
   1.0       1.0
  .01        1      .01       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 4 - AMMONIA N
   1.0       1.0
  .04        1      .04       4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 5 - ORGANIC N
   1.0       1.0
  .9         1      .9        4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 6 - DISSOLVED OXYGEN
   1.0       1.0
  8.0        1     8.0        4
   1    2  NUMBER OF BOUNDRY CONDITIONS SYSTEM 7 - CHLOROPHYLL 'a'
   1.0       1.0
  .001       1      .001      4
   1    0    0      NUMBER OF FORCING FUNCTIONS SYSTEM 1 - UNP
   1    0    0     NUMBER OF FORCING FUNCTIONS SYSTEM 2 - PO4
   1    0    0     NUMBER OF FORCING FUNCTIONS SYSTEM 3 - NO3
   1    0    0     NUMBER OF FORCING FUNCTIONS SYSTEM 4 - NH3
   1    0    0     NUMBER OF FORCING FUNCTIONS SYSTEM 5 - ON
   1    0    0     NUMBER OF FORCING FUNCTIONS SYSTEM 6 - DO
   1    0    0     NUMBER OF FORCING FUNCTIONS SYSTEM 7 - CH'a'
   0     NUMBER OF PARAMETERS
  24     NUMBER OF CONSTANTS
  KPT   1.5       TG     1.047    IS    225.     KZ     0.1      TD     1.047
   KN    0.025     KP     0.001    WP    .164    KDN     0.1      A1      5.
 130N    0.01  THCK1     6.0   THCK2  18.4      A3     5.       A5     10.
SETON   0.164  PO4UP     0.05     A7     1.00  SETUP   0.164     A8     1.00
  A10   .133     A11     0.133    B2     .24   DPTH1    6.0
   6     NUMBER OF TIME FUNCTIONS
TEMP1    3
```

Figure D-11
Eagle Mountain Lake Data Set

```
   29.0         0.0        29.0        212.       29.0       365.
 TEMP2     3
   27.9         0.0        27.9        212.       27.9       365.
 SOLAR     3
    505.        0.0        505.        212.        505.      365.
  TSS      3
    11.5        0.0        11.5        212.        11.5      365.
 PHOTO     3
    0.58        0.0        0.58        212.        0.58      365.
  VSS      3
    0           0.0        0           212.        0         365.
  UNP   0.02       UNP   0.02     UNP    0.02    UNP     .02
  PO4   0.007      PO4   0.007    PO4    0.007   PO4     .007
  NO3   0.01       NO3   0.01     NO3    .01     NO3     .01
  NH3   0.04       NH3   0.04     NH3    0.04    NH3     .04
   ON   .9          ON   .9        ON    .9       ON     .9
   DO    8.0        DO    8.0      DO     3.2     DO     8.
  CHA   .001       CHA   .001     CHA    0.001   CHA     .001
    20.         20.        20.0     20.0      20.0      26.0      20.0       MAX VAL
  0.0         0.0        0.0      0.0       0.0       0.0       0.0        MIN VAL
   100.                 1       PRINT CONTROL
  0 01
 2 0   0.0                    INTEGRATION STEP
  1.0       0.0               TIME WARP SCALE FACTOR
    1                         NUMBER OF INTEGRATION TIME STEPS
 .10          200.                TIME STEPS
   UNP
  1  1  2  3  4

   PO4
  1  1  2  3  4

   NO3
  1  1  2  3  4

   NH3
  1  1  2  3  4

    ON
  1  1  2  3  4

    DO
  1  1  2  3  4

  CH 'a'
  1  1  2  3  4

 0 0
```

Figure D-11
Eagle Mountain Lake Data Set
(continued)



SOURCE: EPA, 1978. Adjusted for inflation to 1987 dollars.

FIGURE D–12
CAPITAL COSTS FOR LIFT STATIONS

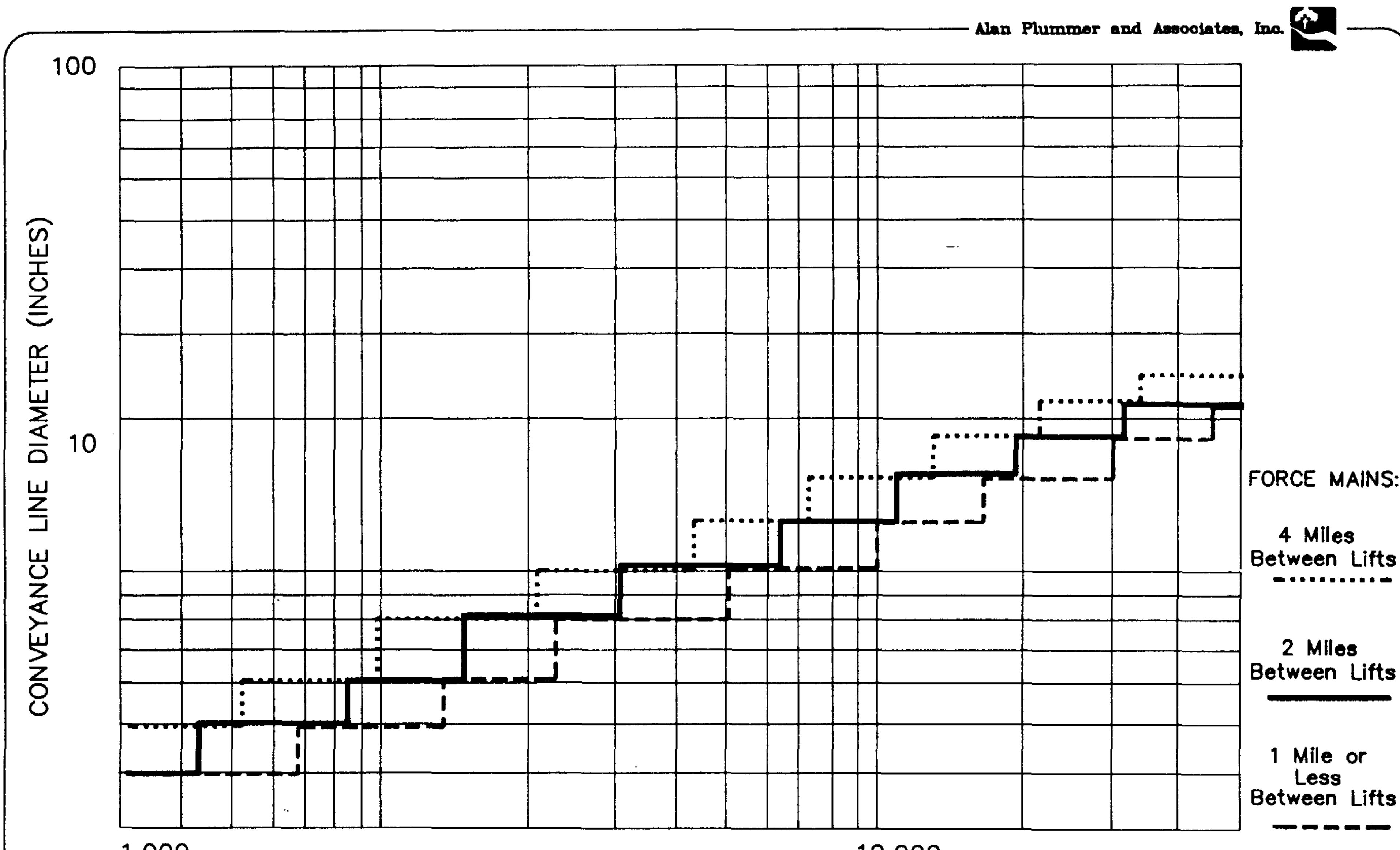
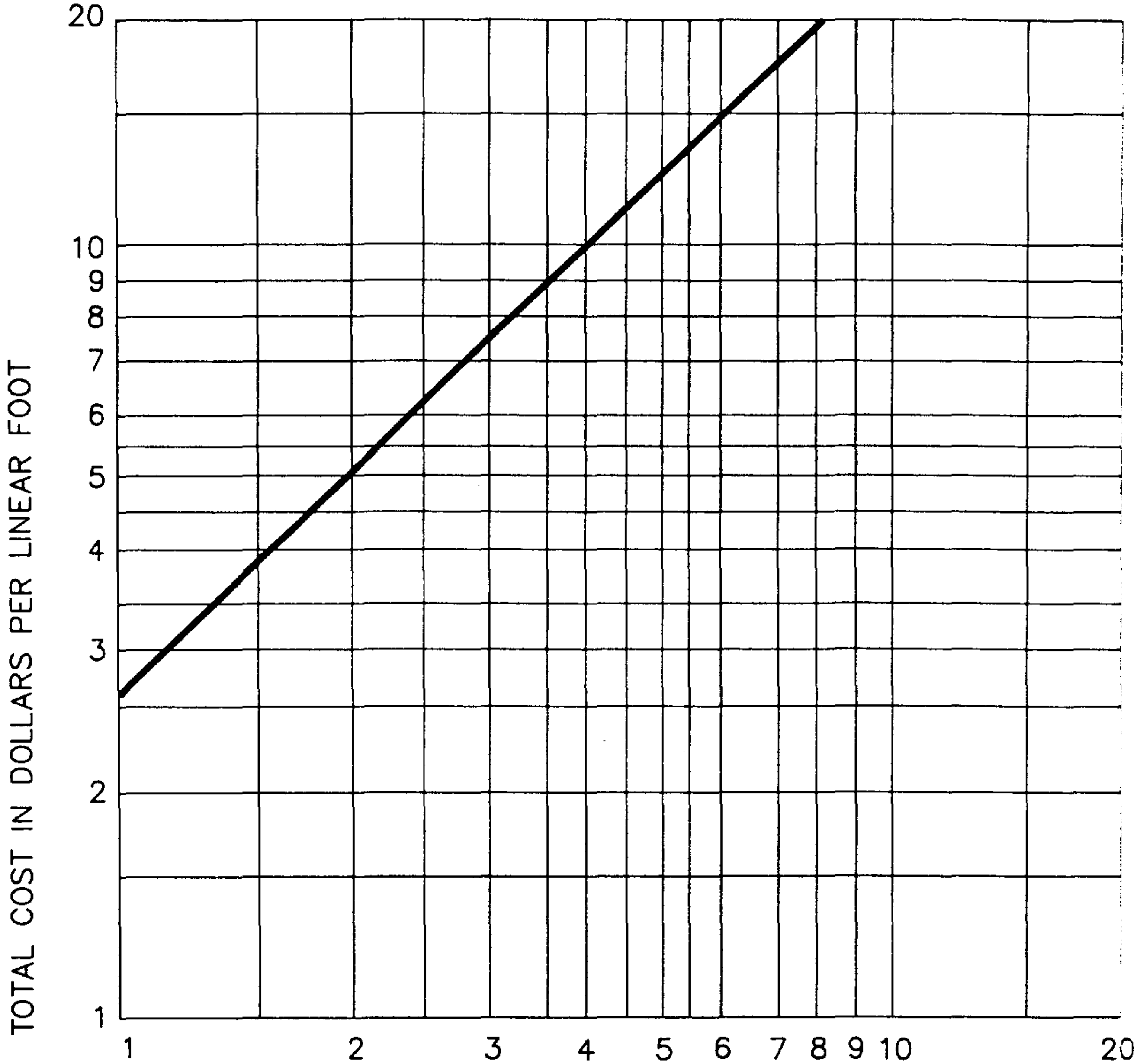


FIGURE D-13
POPULATION OF NEW SERVICE AREA

Source: Texas Water Quality Board



SOURCE: EPA, 1978. Adjusted for inflation to 1987 dollars.

FIGURE D–14
CAPITAL COSTS FOR FORCE MAINS

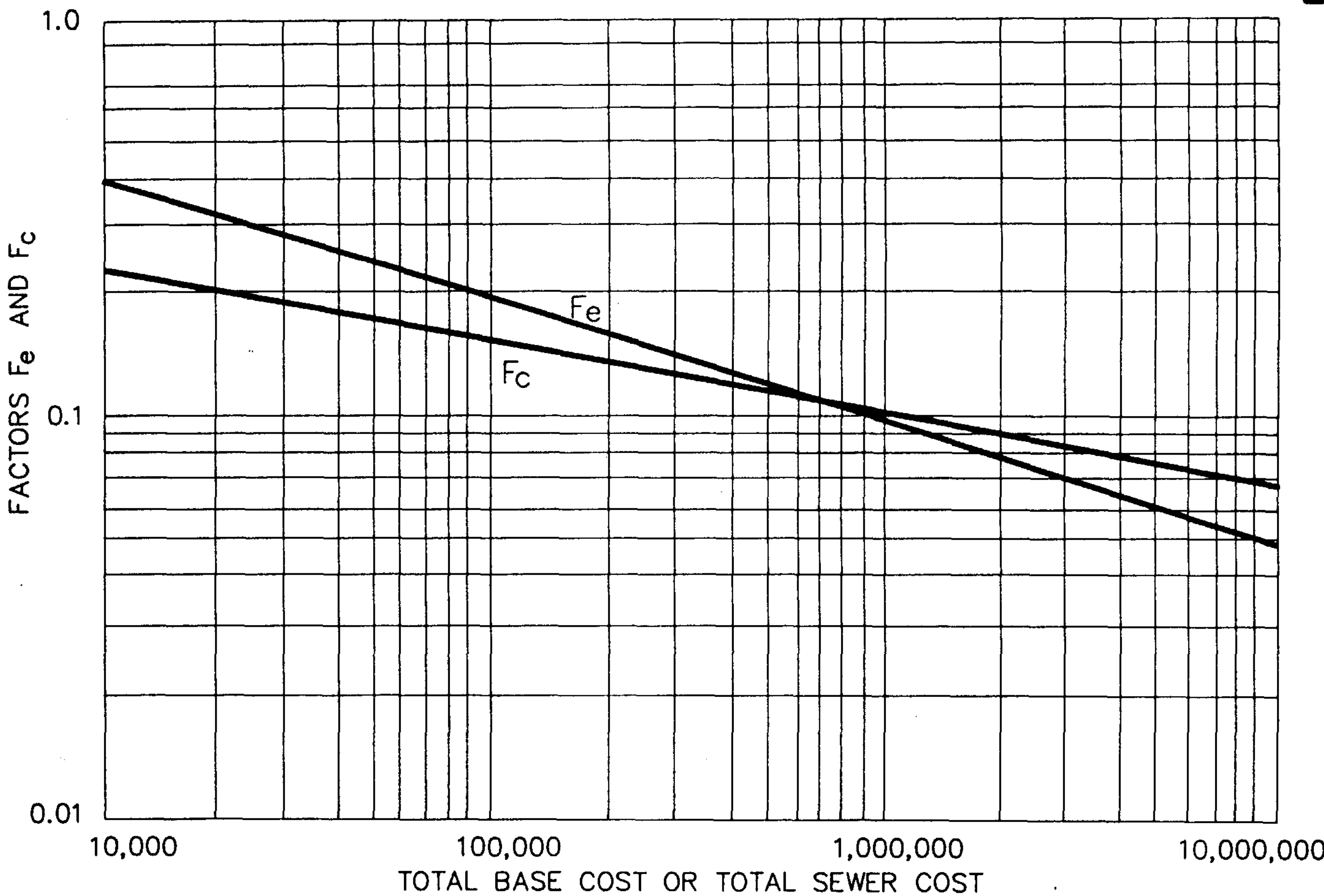
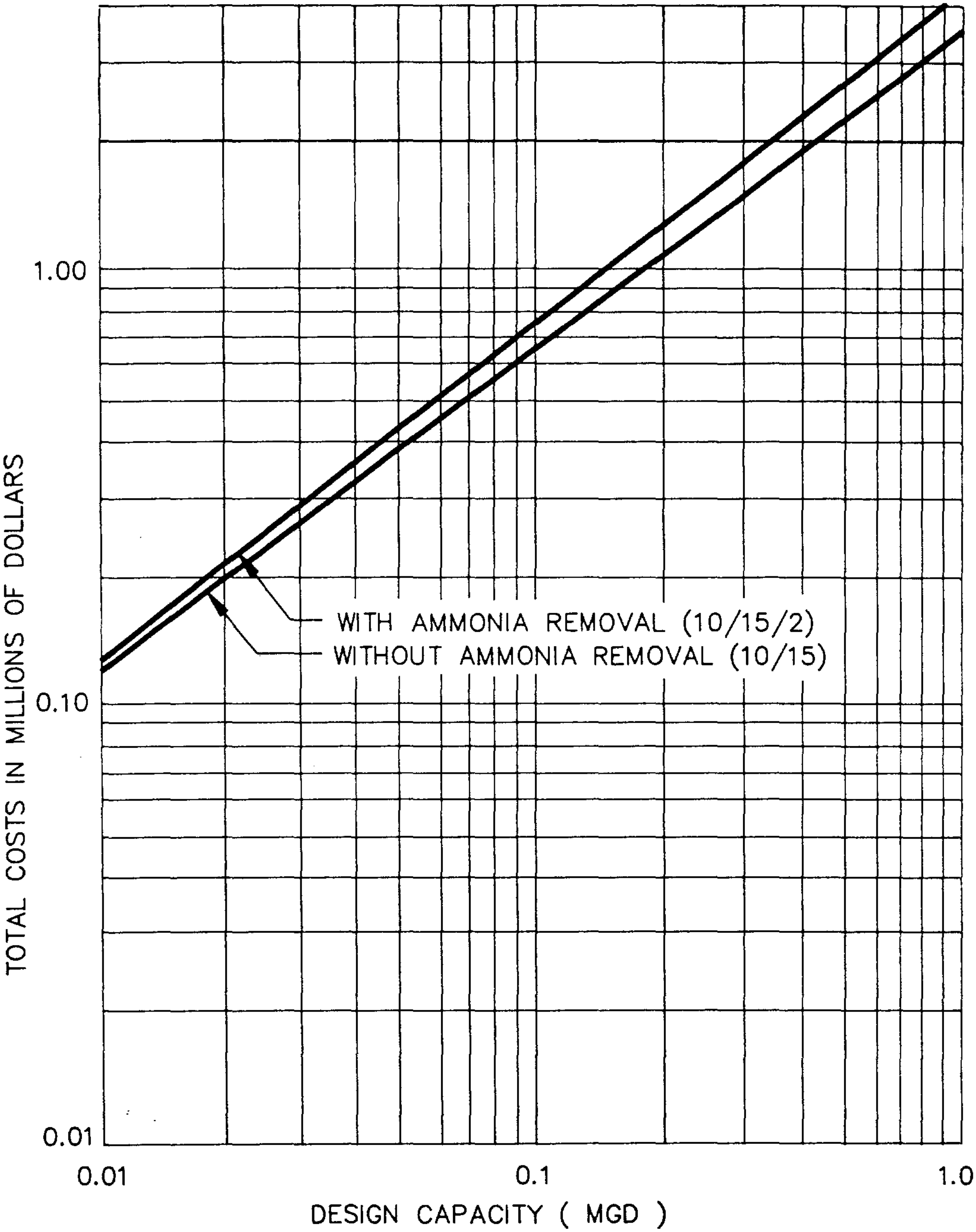


FIGURE D–15
THE FACTORS F_e AND F_c AS A FUNCTION
OF TOTAL BASE COST OR TOTAL SEWER COST

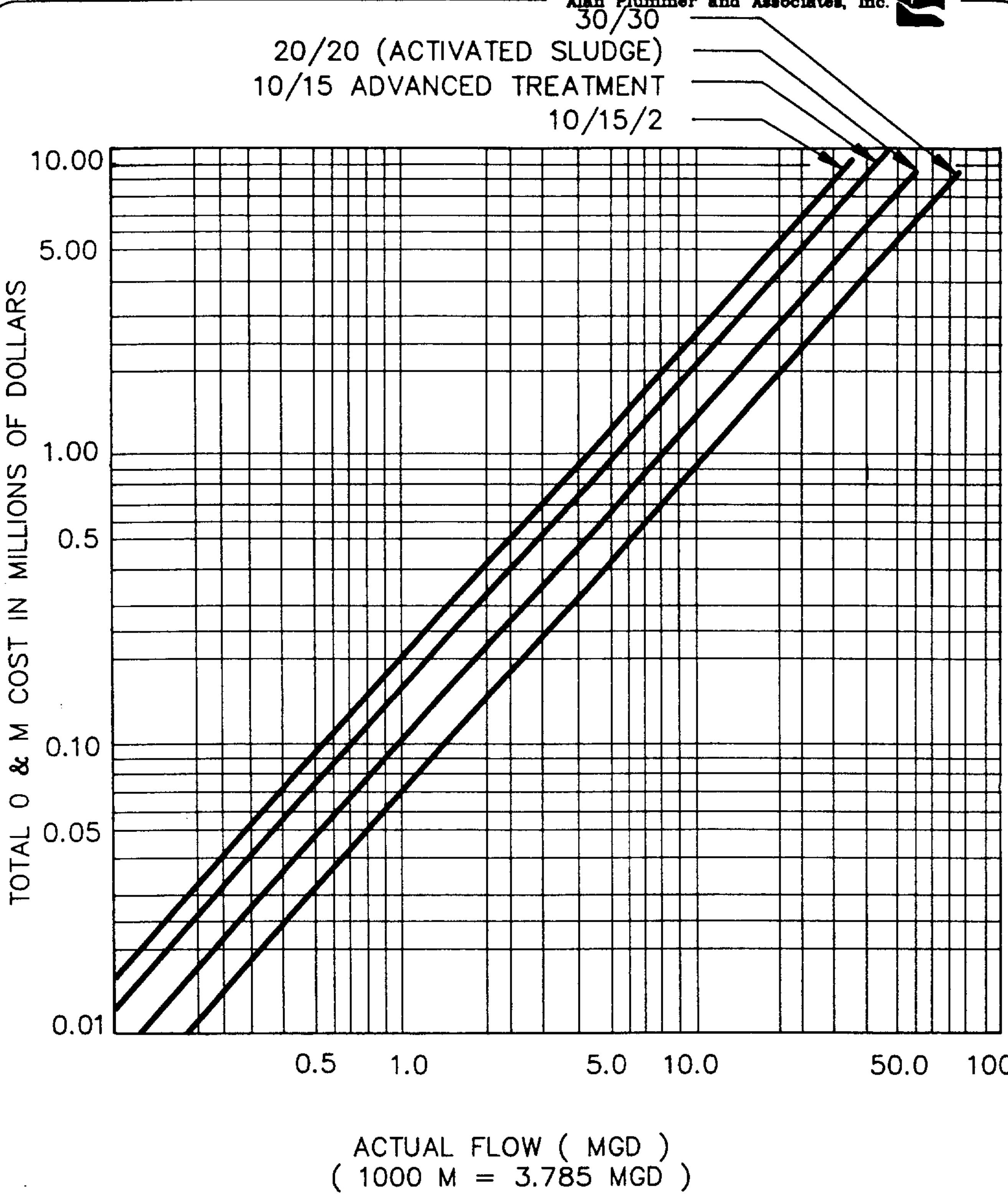
Source: Texas Water Quality Board



SOURCE: EPA, 1978. Adjusted for inflation to 1987 dollars.

FIGURE D–16

CAPITAL COSTS FOR 10/15 AND 10/15/2 TREATMENT PLANTS WITH LESS THAN 1.0 MGD



SOURCE: EPA, 1978. Adjusted for inflation to 1987 dollars.

FIGURE D–17
TOTAL O & M COST VS. ACTUAL FLOW

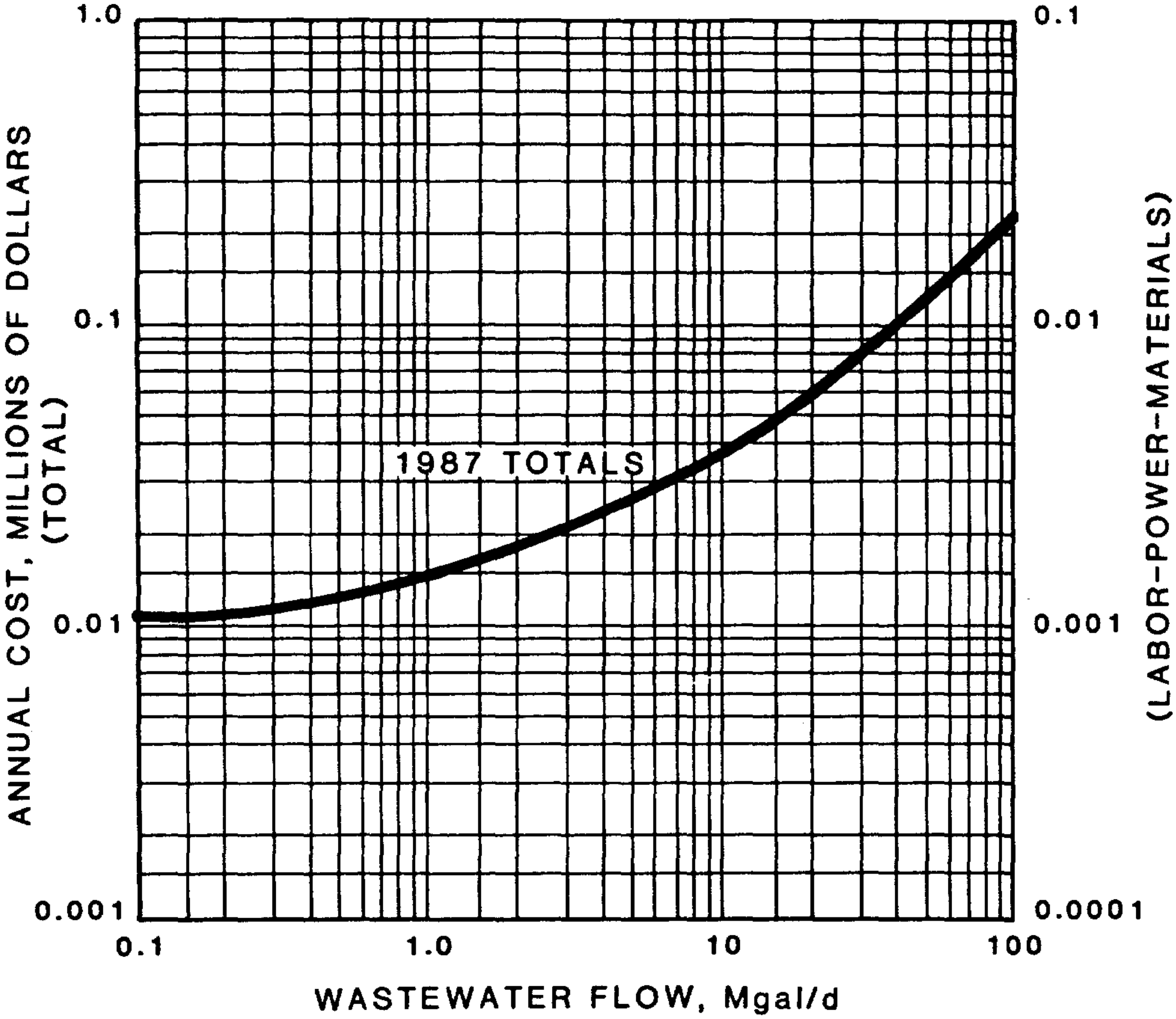


FIGURE D-18
O & M COSTS FOR LIFT STATION