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

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# APPENDIX D

## STUDY METHODOLOGIES

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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 BOD₅ 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 streams.

- 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 measurable 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 indicate 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 BOD₅, 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:

\[
\text{Def}(n) = \text{Def}(0) \cdot \exp(-K_a t) + \frac{K_r}{(K_a - K_r)} \cdot (\exp(-K_r t) - \exp(-K_a t)) \cdot L(0) + \frac{K_n}{(K_a - K_n)} \cdot (\exp(-K_n t) - \exp(-K_a t)) \cdot L_n(0)
\]

Where:

- \(t = \frac{X}{(Q/A)}\)
- \(\text{Def}(n) = \) DO deficit at some distance \(n\), mg/l
- \(\text{Def}(0) = \) DO deficit at upstream boundary of model, mg/l
- \(K_a = \) reaeration rate, per day
- \(K_r = \) BOD decay rate, per day
- \(t = \) travel time from upstream boundary to point \(n\), days
- \(L(0) = \) ultimate BOD at upstream boundary, mg/l
- \(K_n = \) ammonia decay rate, per day
- \(L_n(0) = \) ultimate oxygen consumption of ammonia decay, mg/l
- \(X = \) distance, ft
- \(Q = \) flow, ft\(^3\)/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:

\[
[m]_b = \frac{([m]_u Q_u + [m]_w Q_w)}{(Q_u + Q_w)}
\]

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
- \(Q_u = \) flow upstream of the wastewater discharge
- \(Q_w = \) 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:

\[
Ka = 1.932^\frac{u^{0.273}}{d^{0.894}}
\]

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 \(20^\circ\text{C}\) 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 \(20.0^\circ\text{C}\)
- \(\omega\) = constant, 1.047 for BOD decay
- 1.083 for ammonia decay
- 1.019 for reaeration
- \(T\) = modelling temperature, \(\circ\text{C}\)

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°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: \( \frac{dC}{dt} \) = 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 0-1. 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.

<table>
<thead>
<tr>
<th>Stream</th>
<th>Number of Data Points</th>
<th>Velocity</th>
<th>Depth</th>
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<tr>
<td>Clear Fork Trinity</td>
<td>40</td>
<td>0.51Q^{0.5}</td>
<td>0.53Q^{0.4}</td>
</tr>
<tr>
<td>Town Creek</td>
<td>12</td>
<td>0.696Q^{0.35}</td>
<td>0.282Q^{0.3}</td>
</tr>
<tr>
<td>Walnut Creek</td>
<td>9</td>
<td>0.254Q^{0.5}</td>
<td>1.121Q^{0.4}</td>
</tr>
<tr>
<td>West Fork Trinity</td>
<td>37</td>
<td>0.445Q^{0.3}</td>
<td>0.2483Q + 0.0886</td>
</tr>
<tr>
<td>Big Sandy Creek</td>
<td>17</td>
<td>0.54Q^{0.4}</td>
<td>0.315Q^{0.4}</td>
</tr>
</tbody>
</table>

**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:

<table>
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<th>Discharger</th>
<th>Flow (MGD)</th>
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<td>Johnson County FWSD No. 1</td>
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</tr>
<tr>
<td>Texas Department of Highways</td>
<td>0.0025</td>
</tr>
<tr>
<td>Briar Oaks</td>
<td>0.152</td>
</tr>
<tr>
<td>Marshalsea Industries</td>
<td>0.0236</td>
</tr>
</tbody>
</table>

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.

**Town Creek, South Fork Trinity and Clear Fork Trinity.** 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 concentrations 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 similar. 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, than 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:

<table>
<thead>
<tr>
<th>Town Creek-South Fork</th>
<th>Clear Fork</th>
</tr>
</thead>
<tbody>
<tr>
<td>Weatherford</td>
<td>Willow Park</td>
</tr>
<tr>
<td>Annetta North</td>
<td>Annetta South</td>
</tr>
<tr>
<td>Annetta</td>
<td>Aledo</td>
</tr>
<tr>
<td>Hudson Oaks</td>
<td></td>
</tr>
<tr>
<td>2.154 MGD</td>
<td>0.464 MGD</td>
</tr>
<tr>
<td>0.262 MGD</td>
<td>0.089 MGD</td>
</tr>
<tr>
<td>0.094 MGD</td>
<td>0.262 MGD</td>
</tr>
</tbody>
</table>

The models were run using the unrestricted reaeration coefficient, and the required effluent quality was 10 mg/l BOD\textsubscript{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\textsubscript{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:

<table>
<thead>
<tr>
<th>City</th>
<th>Flow (MGD)</th>
</tr>
</thead>
<tbody>
<tr>
<td>Springtown</td>
<td>0.389</td>
</tr>
<tr>
<td>Azle-Walnut Creek</td>
<td>0.300</td>
</tr>
</tbody>
</table>

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 an 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 show 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°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 database 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.

<table>
<thead>
<tr>
<th>County</th>
<th>1979 Median Household Income</th>
<th>Financial Capability</th>
</tr>
</thead>
<tbody>
<tr>
<td>Tarrant</td>
<td>$18,642</td>
<td>$325</td>
</tr>
<tr>
<td>Parker</td>
<td>17,245</td>
<td>300</td>
</tr>
<tr>
<td>Wise</td>
<td>16,381</td>
<td>245</td>
</tr>
</tbody>
</table>
### TABLE D-1

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

<table>
<thead>
<tr>
<th>Alternative</th>
<th>Weatherford WWTP</th>
<th>Hudson Oaks WWTP</th>
<th>Lake Weatherford WWTP</th>
<th>Willow Park WWTP</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Flow MGD</td>
<td>BOD₅ mg/l</td>
<td>NH₃-N mg/l</td>
<td>DO mg/l</td>
</tr>
<tr>
<td>1</td>
<td>2.24</td>
<td>10</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>2</td>
<td>1.5</td>
<td>10</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>1.5</td>
<td>10</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>4</td>
<td>1.5</td>
<td>10</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td></td>
<td>0.33</td>
<td>10</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>5</td>
<td>22.24</td>
<td>10</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>6</td>
<td>1.8</td>
<td>10</td>
<td>22</td>
<td>5</td>
</tr>
<tr>
<td>7</td>
<td>1.8</td>
<td>10</td>
<td>2</td>
<td>5</td>
</tr>
<tr>
<td>8</td>
<td>2.04</td>
<td>10</td>
<td>2</td>
<td>5</td>
</tr>
</tbody>
</table>

1. New Plant Constructed downstream of existing Weatherford Plant
TABLE D-2
LAKE WORTH MODEL CALIBRATION

<table>
<thead>
<tr>
<th>Variable</th>
<th>Observed</th>
<th></th>
<th>Calculated</th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Top</td>
<td>Bottom</td>
<td>Top</td>
<td>Bottom</td>
</tr>
<tr>
<td>UP mg/l</td>
<td>.02</td>
<td>.02</td>
<td>.025</td>
<td>.025</td>
</tr>
<tr>
<td>OP mg/l</td>
<td>&lt;.01</td>
<td>&lt;.01</td>
<td>.001</td>
<td>.002</td>
</tr>
<tr>
<td>NO₃ mg/l</td>
<td>&lt;.02</td>
<td>&lt;.02</td>
<td>.002</td>
<td>.004</td>
</tr>
<tr>
<td>NH₃ mg/l</td>
<td>.29</td>
<td>.23</td>
<td>.04</td>
<td>.05</td>
</tr>
<tr>
<td>ON mg/l</td>
<td>.59</td>
<td>.63</td>
<td>.27</td>
<td>.27</td>
</tr>
<tr>
<td>Chl 'a'</td>
<td>15.2</td>
<td>--</td>
<td>15.4</td>
<td>--</td>
</tr>
</tbody>
</table>

key: UP: Unavailable phosphorus
      OP: Orthophosphorus
      NO₃: Nitrate Nitrogen
      NH₃: Ammonia Nitrogen
      ON: Organic Nitrogen
      Chl 'a': Chlorophyll 'a'
### TABLE D-3

**LAKE BENBROOK CALIBRATION**

<table>
<thead>
<tr>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
<th></th>
</tr>
</thead>
<tbody>
<tr>
<td>TP mg/l</td>
<td>.056</td>
<td>.04</td>
<td>.02</td>
<td>.07</td>
<td>.058</td>
<td>.06</td>
<td>.05</td>
<td>.09</td>
</tr>
<tr>
<td>UP mg/l</td>
<td>.05</td>
<td>.03</td>
<td>0</td>
<td>.06</td>
<td>.05</td>
<td>.05</td>
<td>.03</td>
<td>.08</td>
</tr>
<tr>
<td>OP mg/l</td>
<td>.006</td>
<td>.01</td>
<td>&lt;.01</td>
<td>.02</td>
<td>.008</td>
<td>.01</td>
<td>&lt;.01</td>
<td>.03</td>
</tr>
<tr>
<td>NO₃ mg/l</td>
<td>.0002</td>
<td>.02</td>
<td>&lt;.01</td>
<td>.04</td>
<td>.01</td>
<td>.02</td>
<td>&lt;.01</td>
<td>.04</td>
</tr>
<tr>
<td>NH₃ mg/l</td>
<td>.04</td>
<td>.04</td>
<td>&lt;.03</td>
<td>.1</td>
<td>.05</td>
<td>.12</td>
<td>&lt;.03</td>
<td>.3</td>
</tr>
<tr>
<td>ON mg/l</td>
<td>1.</td>
<td>1.06</td>
<td>1.03</td>
<td>1.20</td>
<td>1.</td>
<td>1.</td>
<td>.86</td>
<td>1.6</td>
</tr>
<tr>
<td>DO mg/l</td>
<td>6.4</td>
<td>8.2</td>
<td>5.7</td>
<td>10</td>
<td>63</td>
<td>4.3</td>
<td>0</td>
<td>7.8</td>
</tr>
<tr>
<td>Chl ‘a’ ug/l</td>
<td>11</td>
<td>10.6</td>
<td>2.4</td>
<td>20</td>
<td>--</td>
<td>--</td>
<td>--</td>
<td>--</td>
</tr>
</tbody>
</table>

**Key:**
- TP: Total Phosphorus
- UP: Unavailable Phosphorus
- OP: Orthophosphorus
- NO₃: Nitrate Nitrogen
- NH₃: Ammonia Nitrogen
- ON: Organic Nitrogen
- DO: Dissolved Oxygen
- Chl ‘a’: Chlorophyll ‘a’
TABLE D-4
PROJECTED CHLOROPHYLL "a" FOR LAKE BENBROOK

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Nutrient Removal</th>
<th>Chl 'a' ug/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>Flow, MGD</td>
<td></td>
</tr>
<tr>
<td>Existing</td>
<td>2.4</td>
<td>None</td>
</tr>
<tr>
<td>Existing</td>
<td>2.4</td>
<td>P to 1 mg/l</td>
</tr>
<tr>
<td>Existing</td>
<td>2.4</td>
<td>N to 5 mg/l</td>
</tr>
<tr>
<td>2005</td>
<td>3.67</td>
<td>None</td>
</tr>
<tr>
<td>2005</td>
<td>3.67</td>
<td>P to 1 mg/l</td>
</tr>
<tr>
<td>2005</td>
<td>3.67</td>
<td>N to 5 mg/l</td>
</tr>
<tr>
<td>Variable</td>
<td>Calc.</td>
<td>Observed&lt;sup&gt;1&lt;/sup&gt;</td>
</tr>
<tr>
<td>-----------</td>
<td>-------</td>
<td>---------------------</td>
</tr>
<tr>
<td>Top</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP mg/l</td>
<td>.044</td>
<td>.05</td>
</tr>
<tr>
<td>UP mg/l</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td>OP mg/l</td>
<td>.014</td>
<td>.02</td>
</tr>
<tr>
<td>NO&lt;sub&gt;3&lt;/sub&gt; mg/l</td>
<td>.3</td>
<td>.1</td>
</tr>
<tr>
<td>NH&lt;sub&gt;3&lt;/sub&gt; mg/l</td>
<td>.06</td>
<td>.08</td>
</tr>
<tr>
<td>ON mg/l</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>DO mg/l</td>
<td>5.6</td>
<td>--</td>
</tr>
<tr>
<td>Chl 'a' ug/l</td>
<td>17.3</td>
<td>17.5</td>
</tr>
<tr>
<td>Bottom</td>
<td></td>
<td></td>
</tr>
<tr>
<td>TP mg/l</td>
<td>.044</td>
<td>.05</td>
</tr>
<tr>
<td>UP mg/l</td>
<td>.03</td>
<td>.03</td>
</tr>
<tr>
<td>OP mg/l</td>
<td>.014</td>
<td>.02</td>
</tr>
<tr>
<td>NO&lt;sub&gt;3&lt;/sub&gt; mg/l</td>
<td>.3</td>
<td>.1</td>
</tr>
<tr>
<td>NH&lt;sub&gt;3&lt;/sub&gt; mg/l</td>
<td>.06</td>
<td>.08</td>
</tr>
<tr>
<td>ON mg/l</td>
<td>1.5</td>
<td>1.7</td>
</tr>
<tr>
<td>DO mg/l</td>
<td>5.6</td>
<td>--</td>
</tr>
<tr>
<td>Chl 'a' ug/l</td>
<td>17.3</td>
<td>17.5</td>
</tr>
</tbody>
</table>


Key:  
TP: Total Phosphorus  
UP: Unavailable phosphorus  
OP: Orthophosphorus  
NO<sub>3</sub>: Nitrate Nitrogen  
NH<sub>3</sub>: Ammonia Nitrogen  
ON: Organic Nitrogen  
DO: Dissolved Oxygen  
Chl 'a': Chlorophyll 'a'
### TABLE D-6
**PROJECTED CHLOROPHYLL "a" FOR EAGLE MOUNTAIN LAKE**

<table>
<thead>
<tr>
<th>Conditions</th>
<th>Flows, MGD</th>
<th>Nutrient Removal</th>
<th>Chl 'a' ug/l</th>
</tr>
</thead>
<tbody>
<tr>
<td>Year</td>
<td>Into Lake</td>
<td>To Fort Worth</td>
<td></td>
</tr>
<tr>
<td>Existing</td>
<td>1.8</td>
<td>--</td>
<td>None</td>
</tr>
<tr>
<td>Existing</td>
<td>1.8</td>
<td>--</td>
<td>P to 1 mg/l</td>
</tr>
<tr>
<td>Existing</td>
<td>1.8</td>
<td>--</td>
<td>N to 3.3 mg/l</td>
</tr>
<tr>
<td>2005</td>
<td>5.1</td>
<td>--</td>
<td>None</td>
</tr>
<tr>
<td>2005</td>
<td>5.1</td>
<td>--</td>
<td>P to 1 mg/l</td>
</tr>
<tr>
<td>2005</td>
<td>5.1</td>
<td>--</td>
<td>N to 5 mg/l</td>
</tr>
<tr>
<td>2005</td>
<td>3.85</td>
<td>1.26</td>
<td>None</td>
</tr>
<tr>
<td>2005</td>
<td>3.85</td>
<td>1.26</td>
<td>P to 1 mg/l</td>
</tr>
<tr>
<td>2005</td>
<td>3.85</td>
<td>1.26</td>
<td>N to 5 mg/l</td>
</tr>
<tr>
<td>2005</td>
<td>2.86</td>
<td>2.25</td>
<td>None</td>
</tr>
<tr>
<td>2005</td>
<td>2.86</td>
<td>2.25</td>
<td>P to 1 mg/l</td>
</tr>
<tr>
<td>2005</td>
<td>2.86</td>
<td>2.25</td>
<td>N to 5 mg/l</td>
</tr>
</tbody>
</table>
### TABLE D-7

**SUMMARY OF RESULTS**

<table>
<thead>
<tr>
<th>Water Body</th>
<th>Effluent Requirements</th>
<th>Method of Analysis</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>Conventional</td>
<td>Reaeration</td>
</tr>
<tr>
<td></td>
<td>Reaeration Restriction</td>
<td></td>
</tr>
<tr>
<td>West Fork Trinity</td>
<td>20/15/5</td>
<td>10/3/5</td>
</tr>
<tr>
<td>Martins Branch</td>
<td>20/15/5</td>
<td>10/3/5</td>
</tr>
<tr>
<td>Big Sandy Creek</td>
<td>20/15/5</td>
<td>10/3/5</td>
</tr>
<tr>
<td>Dry Creek</td>
<td>20/15/5</td>
<td>10/3/5</td>
</tr>
<tr>
<td>Village Creek</td>
<td>20/15/5</td>
<td>10/3/5</td>
</tr>
<tr>
<td>Town Creek, South Fork,</td>
<td></td>
<td></td>
</tr>
<tr>
<td>Clear Fork</td>
<td>10/3/5</td>
<td>5/2/5</td>
</tr>
<tr>
<td>Walnut Creek</td>
<td>20/15/5</td>
<td>10/3/5</td>
</tr>
<tr>
<td>Ash Creek</td>
<td>20/15/5</td>
<td>10/3/5</td>
</tr>
<tr>
<td>Town Creek and South Fork</td>
<td>10/2/5</td>
<td>---</td>
</tr>
<tr>
<td>Clear Fork</td>
<td>5/2/6</td>
<td>---</td>
</tr>
</tbody>
</table>

**Notes:**

1. Projections for the municipal discharges at 2005 flows.
2. CBODs/NH<sub>3</sub>-N/DO.
3. Texas reaeration formula used.
4. Reaeration coefficient restricted to ka ≤ 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>
<thead>
<tr>
<th>Permit Scenario</th>
<th>Average BOD$_5$ (mg/l)</th>
<th>Average TSS (mg/l)</th>
<th>Ammonia (mg/l)</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>30</td>
<td>30</td>
<td>N/A</td>
</tr>
<tr>
<td>2</td>
<td>20</td>
<td>20</td>
<td>N/A</td>
</tr>
<tr>
<td>3</td>
<td>10</td>
<td>15</td>
<td>N/A</td>
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<tr>
<td>4</td>
<td>10</td>
<td>15</td>
<td>2</td>
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</table>

**TABLE D-8**

**PERMIT SCENARIOS EVALUATED**
TABLE D-9
UNIT PROCESSES NECESSARY FOR PERMIT SCENARIOS EVALUATED

<table>
<thead>
<tr>
<th>Process</th>
<th>Permit Scenario</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>1</td>
</tr>
<tr>
<td>Influent pumping</td>
<td>X</td>
</tr>
<tr>
<td>Preliminary sedimentation</td>
<td>X</td>
</tr>
<tr>
<td>Primary sedimentation</td>
<td></td>
</tr>
<tr>
<td>Activated sludge</td>
<td></td>
</tr>
<tr>
<td>Oxidation ditch</td>
<td></td>
</tr>
<tr>
<td>Filtration</td>
<td></td>
</tr>
<tr>
<td>Chlorination</td>
<td>X</td>
</tr>
<tr>
<td>Effluent outfall</td>
<td>X</td>
</tr>
<tr>
<td>Sludge drying beds</td>
<td>X</td>
</tr>
<tr>
<td>Aerobic digestion</td>
<td>X</td>
</tr>
</tbody>
</table>

(1) Primary sedimentation used for plant capacities 1 MGD and larger
<table>
<thead>
<tr>
<th>Process</th>
<th>Coed</th>
<th>Power</th>
<th>Flow (mgd)</th>
<th>Cost</th>
<th>Engineer Adj Cost</th>
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</thead>
<tbody>
<tr>
<td>Equalization</td>
<td>67600</td>
<td>.6</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Influent Pumping</td>
<td>131000</td>
<td>.63</td>
<td>.025</td>
<td>12823</td>
<td>19662</td>
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<tr>
<td>Communitors</td>
<td>19800</td>
<td>.56</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>Preliminary Treatment</td>
<td>64300</td>
<td>.76</td>
<td>.025</td>
<td>3896</td>
<td>5974</td>
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<tr>
<td>Primary Sediment</td>
<td>120000</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Activated Sludge</td>
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<td>.75</td>
<td>.025</td>
<td>32630</td>
<td>50035</td>
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<td>Oxidation Ditch</td>
<td>468000</td>
<td>.57</td>
<td>0</td>
<td>0</td>
<td>0</td>
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<tr>
<td>RBC</td>
<td>609000</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Trickling Filter</td>
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<td>.0225</td>
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<td>.025</td>
<td>3562</td>
<td>5463</td>
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<td>Las/Maint Building</td>
<td>193000</td>
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<td>Land Spread Sludge</td>
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<td>Land Application</td>
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<td>Gravity Thickener</td>
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<td>.025</td>
<td>9518</td>
<td>14595</td>
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<td>0</td>
<td>0</td>
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<tr>
<td>Excavation</td>
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<td>0</td>
<td>0</td>
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<td>0</td>
<td>0</td>
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<td>.025</td>
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<td>.025</td>
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<td>6715</td>
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<td>All Piping</td>
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<td>.025</td>
<td>13023</td>
<td>19970</td>
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<td>Total</td>
<td></td>
<td></td>
<td>117763</td>
<td>180575</td>
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</table>
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.
         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.

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:

<table>
<thead>
<tr>
<th>BOD</th>
<th>TSS</th>
<th>Ammonia</th>
</tr>
</thead>
<tbody>
<tr>
<td>30</td>
<td>30</td>
<td>15</td>
</tr>
<tr>
<td>20</td>
<td>20</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>15</td>
<td>2</td>
</tr>
</tbody>
</table>
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

<table>
<thead>
<tr>
<th>Design discharge range (MGD)</th>
<th>Pipe diameter (inches)</th>
<th>Cost/linear foot (1987 dollars)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0.08 or less</td>
<td>6</td>
<td>$20</td>
</tr>
<tr>
<td>0.08-0.17</td>
<td>8</td>
<td>25</td>
</tr>
<tr>
<td>0.17-0.29</td>
<td>10</td>
<td>30</td>
</tr>
<tr>
<td>0.29-0.47</td>
<td>12</td>
<td>34</td>
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<tr>
<td>0.47-0.82</td>
<td>15</td>
<td>42</td>
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<tr>
<td>0.82-1.3</td>
<td>18</td>
<td>49</td>
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<td>1.3-1.9</td>
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<td>24</td>
<td>63</td>
</tr>
<tr>
<td></td>
<td>27</td>
<td>70</td>
</tr>
<tr>
<td></td>
<td>30</td>
<td>77</td>
</tr>
</tbody>
</table>

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.
SUBROUTINE WASPB

C SCREENING MODEL - 2 VERTICAL SEGMENT LAKE

C INCLUDE: 'WSFCMN.F4P'

REAL KPT,KZ,KMP,KN,KP,IA,LN,KDN,KNH3ON,KNO3ON,KP04UNP,IS
REAL NH3,N03,NIT,P,P04,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
KP04UNP=CONST(17)

C PO4 UPTAKE FOR PHYTOPLANKTON GROWTH, mg/l/mg PHYTO
A7=CONST(18)

C UNAVAILABLE PHOSPHORUS SETTLING
SETUNP=CONST(19)

C UNAVAIL.-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 * (TB ** (TEMP(ISEG) - 20)) * RN
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 +
& KDNON*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) = (-KHN3ON*ON*(1.047**((TEMP(ISEG) - 20))) +
&A5*DP*P - SETTON*ON/THICK(2) * BVOL(ISEG)
XON = SETON*ON/THICK(2)
ELSE
CD(5,3) = (-KHN3ON*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)
C 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,TIME,NTF,73)
C
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
C DO 200 ISEG=2,3
C INITIALIZE CONCENTRATIONS
C PHYTOPLANKTON = P
   P=C(7,ISEG)
   NH3=C(4,ISEG)
   ON=C(5,ISEG)
   UNF=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**2)*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*DEPH1)
   ELSE
      IO=IA
   ENDIF
   AO=IO/(IS*F)
   AL=AO*EXP(-XKE*THICK(ISEG))
C REDUCTION IN GROWTH DUE TO LIGHT LIMITATIONS
   F=EXP(-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 SATURATION VALUE
IF (ISEG.EQ.2) THEN
  CS=14.62-.3898*TEMP(2)+.006969*(TEMP(2)**2)-5.897E-5*
& (TEMP(2)**3)
ENDIF

C DISSOLVED OXYGEN DIFFERENTIAL
DODIFF=CS-DO
IF (DODIFF.LE.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-
& 8.33*KDN*NH3*(1.047**(TEMP(2)-20)))*BVOL (ISEG)
ELSE
  CD (6,3) = (A10*GP*P-A11*DP*P-B1-
& 8.33*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*1.00000000001
  DTIME(IREC)=PTIME
  IDFRC(I)=MDMF*NOSEG*(IREC-1)
  DO 120 I=1,4
    IDF=IDFRC(I)+MDMF*(I-1)
    DVAR(IDF+1,1)=C(I,1)
    DVAR(IDF+1,2)=C(I,2)
    DVAR(IDF+1,3)=C(I,3)
    DVAR(IDF+1,4)=C(I,4)
    DVAR(IDF+1,5)=C(I,5)
    DVAR(IDF+1,6)=C(I,6)
    DVAR(IDF+1,7)=C(I,7)
  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

* KN = 0
* KN = .1
* KN = .2
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 TOWN CREEK AND SOUTH FORK TRINITY RIVER SYSTEM USING QUAL-TX.

CALCULATED AND OBSERVED BOD$_5$ FOR THE CLEAR FORK TRINITY RIVER 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
Lake Worth Data Set - Calibration

Vertical Layer Model - With Upstream Boundary Condition

System Bypasses

Exchange Coefficients

Number of Volumes

Scale for Volumes

Number of Flows

Scale for Flows

NPS Inflows

Number of Forcing Functions System 1 - Unavailable Phosphorus

Number of Forcing Functions System 2 - Orthophosphate

Number of Forcing Functions System 3 - Nitrate N

Number of Forcing Functions System 4 - Ammonia N

Number of Forcing Functions System 5 - Organic N

Number of Forcing Functions System 6 - Dissolved Oxygen

Number of Forcing Functions System 7 - Chlorophyll 'a'

Number of Parameters

Number of Constants

Kpt 0.025 KP 0.001 WP 0.164 KDN 0.1 A1 5.0

K1 0.0010 TG 1.06 IS 300. KZ 0.1 TD 1.047

Kn 0.025 THCK1 5.55 THCK2 7.85 A3 5.0 A5 10.0

A10 0.164 PD4UP 0.06 A7 1.0 SETUP .164 AB 1.0

A11 0.133 B2 .2462 DPTH1 5.35

Number of Time Functions

Figure D-9

Lake Worth Model Data Set
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**Figure D-9**
Lake North Model Data Set
(continued)
Figure D-10
Lake Benbrook Data Set
Figure D-10
Lake Benbrook Data Set
(continued)
EAGLE MOUNTAIN LAKE DATA SET - CALIBRATION

VERTICAL LAYER MODEL - WITH UPSTREAM BOUNDARY CONDITION

SYSTEM BYPASSES

4 1 EXCHANGE COEFFICIENTS

1.0 1.0

0.00000663 1300000000. 60 18.5 2 3

0 0 0 0 0 0

NUMBER OF VOLUMES

1.0 1.0 SCALE FOR VOLUMES

40.0 2400. 5894. 40.0

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 BYPASS OPTION

1 2 NUMBER OF BOUNDARY CONDITIONS SYSTEM 1 - UNAVAILABLE PHOSPHORUS

1.0 1.0

.02 1 .02 4

1 2 NUMBER OF BOUNDARY CONDITIONS SYSTEM 2 - ORTHOPHOSPHATE

1.0 1.0

.01 1 .01 4

1 2 NUMBER OF BOUNDARY CONDITIONS SYSTEM 3 - NITRATE N

1.0 1.0

.01 1 .01 4

1 2 NUMBER OF BOUNDARY CONDITIONS SYSTEM 4 - AMMONIA N

1.0 1.0

.04 1 .04 4

1 2 NUMBER OF BOUNDARY CONDITIONS SYSTEM 5 - ORGANIC N

1.0 1.0

.9 1 .9 4

1 2 NUMBER OF BOUNDARY CONDITIONS SYSTEM 6 - DISSOLVED OXYGEN

1.0 1.0

8.0 1 8.0 4

1 2 NUMBER OF BOUNDARY 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 - P04

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 PARAMETERS

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.

KDN 0.01 THCK1 6.0 THCK2 18.4 A3 5. A5 10.

SETON 0.164 P04UP 0.05 A7 1.00 SETUP 0.164 AB 1.00

A10 .133 A11 .133 B2 .24 DPTHI 6.0

6 NUMBER OF TIME FUNCTIONS

Figure D-11

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

FIGURE D-12
CAPITAL COSTS FOR LIFT STATIONS
FORCE MAIN LINE SIZING

FIGURE D-13
POPULATION OF NEW SERVICE AREA

Source: Texas Water Quality Board
FIGURE D-14
CAPITAL COSTS FOR FORCE MAINS

THE FACTORS $F_e$ AND $F_c$ AS A FUNCTION OF TOTAL BASE COST OR TOTAL SEWER COST

Source: Texas Water Quality Board
WITH AMMONIA REMOVAL (10/15/2)
WITHOUT AMMONIA REMOVAL (10/15)


FIGURE D-16
CAPITAL COSTS FOR 10/15 AND 10/15/2 TREATMENT PLANTS WITH LESS THAN 1.0 MGD
20/20 (ACTIVATED SLUDGE)
10/15 ADVANCED TREATMENT
10/15/2

TOTAL O & M COST IN MILLIONS OF DOLLARS

ACTUAL FLOW (MGD)
(1000 M = 3.785 MGD)


FIGURE D-17
TOTAL O & M COST VS. ACTUAL FLOW
FIGURE D-18
O & M COSTS FOR LIFT STATION