Results of Computer Modelling of Alluvium and Terrace Deposits in Western Tillman Co. and Along the Washita River, Southwestern Oklahoma, for Water Supply Capability

July 1, 1976 - June 30, 1978

FINAL REPORT
SUBMITTED TO
The Oklahoma Water Resources Board

By
Oklahoma State University
and
Scientific and Education Administration

Cooperative Agreement
No. 12-14-7001-825

By
Douglas C. Kent
and
James W. Naney

JULY 1978

Contents of this report are for administrative purposes only and may not be published or reproduced in any form without prior consent of the cooperators involved.
# TABLE OF CONTENTS

<table>
<thead>
<tr>
<th>Section</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>I. Introduction.</td>
<td>1</td>
</tr>
<tr>
<td>II. Previous Work and Present Project</td>
<td>2</td>
</tr>
<tr>
<td>III. Objectives.</td>
<td>5</td>
</tr>
<tr>
<td>IV. Procedures.</td>
<td>5</td>
</tr>
<tr>
<td>V. Methodology and Results—Tillman Alluvium and Terrace.</td>
<td>6</td>
</tr>
<tr>
<td>VI. Methodology and Results—Washita River Alluvium.</td>
<td>5</td>
</tr>
<tr>
<td>VII. Cited References.</td>
<td>50</td>
</tr>
<tr>
<td>Fig. No</td>
<td>Title</td>
</tr>
<tr>
<td>--------</td>
<td>----------------------------------------------------------------------</td>
</tr>
<tr>
<td>1</td>
<td>Relationship between hydraulic coefficient and grain size...</td>
</tr>
<tr>
<td>2</td>
<td>Transmissivity (July 1, 1973)...........................................</td>
</tr>
<tr>
<td>3</td>
<td>Transmissivity (July 1, 1973)...........................................</td>
</tr>
<tr>
<td>4</td>
<td>Bedrock Depth.......................................................................</td>
</tr>
<tr>
<td>5</td>
<td>Water Head Elevation (July 1, 1973)</td>
</tr>
<tr>
<td>6</td>
<td>Water Depth (July 1, 1973)................................................</td>
</tr>
<tr>
<td>7</td>
<td>Prior Appropriation Annual Pumpage........................................</td>
</tr>
<tr>
<td>8</td>
<td>Prior Appropriation and Allocation of One Acre Foot-Annual Pumpage</td>
</tr>
<tr>
<td>9</td>
<td>Prior Appropriation and Allocation of One Acre Foot-Annual Pumpage</td>
</tr>
<tr>
<td>10</td>
<td>Recommended Well Spacing..... .............................................</td>
</tr>
<tr>
<td>11</td>
<td>Cumulative Curve..............................................................</td>
</tr>
<tr>
<td>12</td>
<td>Histogram-Area vs. Saturated Thickness.................................</td>
</tr>
<tr>
<td>13</td>
<td>Histogram-Area vs. Saturated Thickness (Detailed)........................</td>
</tr>
<tr>
<td>14</td>
<td>Histogram-Volume vs. Saturated Thickness..................................</td>
</tr>
<tr>
<td>15</td>
<td>Mass Balance Distribution Chart...........................................</td>
</tr>
<tr>
<td>16</td>
<td>Dry Area (July 1, 1973)...................................................</td>
</tr>
<tr>
<td>17</td>
<td>Dry Area (July 1, 1978)...................................................</td>
</tr>
<tr>
<td>18</td>
<td>Dry Area (July 1, 1983)...................................................</td>
</tr>
<tr>
<td>19</td>
<td>Dry Area (July 1, 1988)...................................................</td>
</tr>
<tr>
<td>20</td>
<td>Dry Area (July 1, 1993)...................................................</td>
</tr>
<tr>
<td>21</td>
<td>Saturated Thickness (July 1, 1993)......................................</td>
</tr>
<tr>
<td>22</td>
<td>Water Head Elevation (July 1, 1993)....................................</td>
</tr>
<tr>
<td>23</td>
<td>Water Depth-Feet Below Ground (July 1, 1993)................................</td>
</tr>
<tr>
<td>24</td>
<td>Transmissivity (July 1, 1973)...........................................</td>
</tr>
<tr>
<td>25</td>
<td>Depth to Bedrock.....................................................................</td>
</tr>
<tr>
<td>26</td>
<td>Water Head Elevation-Known Pumpage Only (July 1, 1973)................</td>
</tr>
<tr>
<td>27</td>
<td>Recommended Well Spacing....................................................</td>
</tr>
<tr>
<td>28</td>
<td>Mass Balance Distribution...................................................</td>
</tr>
<tr>
<td>29</td>
<td>Dry Area (July 1, 1973)...................................................</td>
</tr>
<tr>
<td>30</td>
<td>Dry Area (July 1, 1978)...................................................</td>
</tr>
<tr>
<td>31</td>
<td>Dry Area (July 1, 1983)...................................................</td>
</tr>
<tr>
<td>32</td>
<td>Dry Area (July 1, 1988)...................................................</td>
</tr>
<tr>
<td>33</td>
<td>Dry Area (July 1, 1993)...................................................</td>
</tr>
<tr>
<td>34</td>
<td>Water Head Elevation-Known Pumpage Plus 2.0 Ac. Ft./Ac. (July 1, 1993)</td>
</tr>
<tr>
<td>35</td>
<td>Water Depth-Feet Below Ground (July 1, 1993)................................</td>
</tr>
</tbody>
</table>
PERSONNEL INVOLVED

Douglas C. Kent (OSU)  Principal Investigator
James W. Naney (SEA-FR)  Sponsoring Scientist
Bill B. Barnes (SEA-FR)  Computer Specialist
Fred J. Witz (OSU)  Systems Analyst
Samuel C. Bingaman (SEA-FR)  Engineering Tech.
Charles G. Hunt (SEA-FR)  Engineering Tech.
Albert Lavallee (SEA-FR)  Draftsman
Abdul Al-Sumait (OSU)  Graduate Assistant
Ron W. Neafus (OSU)  Graduate Assistant
Project Title: Results of Computer Modelling of Alluvium and Terrace Deposits in Western Tillman Co. and Along the Washita River, Southwestern Oklahoma, for Water Supply Capability.

Principal Investigators: Douglas C. Kent and James W. Naney, Department of Geology, Oklahoma State University and Scientific Educational Administration (SEA), USDA, respectively.

Institution Funded: Scientific Educational Administration (SEA), USDA, and Oklahoma State University.

Summary:

Tillman Terrace

The objective of this research is to determine the maximum annual yield of fresh water that can be produced from the alluvium and terrace deposits of the North Fork of the Red River in Tillman County. The determination of maximum annual yield was based on computer simulation of all prior appropriative and subsequent allocated pumping for twenty years (July 1, 1973 to July 1, 1993). The maximum annual yield is 70,000 acre feet/yr proportioned as 1.0 acre feet/acre/year. This was based on the following parameters: (1) the total land area overlying the alluvium in the main reaches of the North Fork is 189,760 acres, (2) the amount of water in storage in the basin as of July 1, 1973 is 1,047,000 acre feet, (3) the cumulative amount of water in storage over the twenty-year life of the basin is 2,288,000 acre feet, (4) the estimated rate of natural recharge is 2.87 inches/yr, and (5) the average transmissibility is 13,000 gpd/ft and average specific yield of the alluvium is 0.30. In addition, the predicted water table of July 1, 1993 indicates that the possibility of natural pollution within the alluvium was evident within one and one-half miles of the main reach of the Red River during later periods of pumping.

Washita River

The objective of this research is to determine the maximum annual yield of fresh water that can be produced from the alluvium and terrace deposits of the Washita River, between Anadarko and Alex, Oklahoma. The determination of maximum annual yield was based on computer simulation of all known pumpage and subsequent allocated pumping for twenty years (July 1, 1973 to July 1, 1993). The maximum annual yield is 97,000 acre feet/yr proportioned as 2.0 acre feet/acre/year. This was based on the following parameters: (1) the total land area overlying the alluvium in the main reaches of the North Fork is 69,760 acres, (2) the amount of water in storage in the basin as of July 1, 1973 is 1,423,000 acre feet, (3) the cumulative amount of water in storage over the twenty-year life of the basin is 2,363,500 acre feet, (4) the estimated rate of natural recharge is 1.44 inches/yr, and (5) the average transmissibility is 20,000 gpd/ft and average specific yield of the alluvium is 0.30. In addition, the predicted water table of July 1, 1993 indicates that the possibility of natural pollution within the alluvium was evident in an 8 mile reach of the Washita River north of Verden, Oklahoma, during later periods of pumping.
Results of Computer Modelling of Alluvium and Terrace Deposits in Western Tillman Co. and Along the Washita River, Southwestern Oklahoma, for Water Supply Capability

I. Introduction

The Oklahoma Water Resources Board is responsible under Oklahoma statute no's. 82§1020.4 and 82§1020.5 for completing hydrologic surveys of each fresh ground water basin or subbasin within the state of Oklahoma and determining a maximum annual safe yield which will provide a 20 year minimum life for each basin or subbasin. Surveys of major aquifers in Oklahoma including the Ogallala formation in the panhandle of western Oklahoma, the Rush Springs sandstone in southwestern Oklahoma, and the Garber-Wellington formation in central Oklahoma are in progress by personnel of the OWRB Ground Water Branch and their cooperators.

Approximately one million acres of land in Oklahoma are located in alluvial valleys and stream terraces as reported by H. E. Bailey, et al (1). These unconsolidated deposits contain significant quantities of ground water. U. S. Senate Document No. 13 (2) recognizes that these deposits are potential sources of water supply to several small communities. Increased productivity can be realized when alluvium and terrace wells are used for supplemental irrigation water supplies to augment natural precipitation, particularly in Oklahoma where rainfall is unevenly distributed, both temporally and spatially. However, before maximum use of these water resources is attained, computer models, such as the one applied in this project, can be used to evaluate the dependable yield of these basins based on available information.
II. Previous Work and Present Project

This research project consisted of the calibration of an existing mathematical model and prediction of ground water conditions to July 1, 1993. Geological and hydrological data from a 109 square-mile area of the Washita River alluvium and terrace deposits* as mapped by Thompson (3) and from a 285 square-mile area of the Tillman alluvium and terrace deposits by Wichersham (32) were used in calibration and validation in this project. Locations of these deposits are shown in Figure la. Application of the model along with review of available data was used to determine the boundary conditions, hydraulic properties, and reliability of each ground water basin for water supply.

A finite difference model developed by Trescott and Pinder (4) which uses initial ground water levels, surface discharge, and transmissibility as input parameters was used to model the aquifers. Simulation includes recharge (precipitation, leaky aquifer conditions, seepage, and bank storage) and discharge (pumped withdrawals, evapotranspiration, and loss-to-surface discharge) and temporal and spatial distribution of these variables. The model output is a map of predicted ground water head elevations and an estimated volume of ground water in storage at the end of the specified time period.

Rovey (5) developed a model of flow in a stream-aquifer system and tested the model on a 40-mile reach of the Arkansas River in Colorado. The model was reviewed as background information for the modelling done in this project.

Levings (6) made a water budget analysis for the Sugar Creek alluvium

*Alluvium and terrace deposits as used in this report technically refer to flood plain alluvium and terrace alluvium deposits, respectively.
OKLAHOMA

LOCATION MAP

FIGURE 1a
above Gracemont, Oklahoma. Data from that reconnaissance study were used for model calibration and verification.

Because the alluvium and terraces are for the most part discontinuous layers of clay, silt, and sand, the work of Bredehoeft and Pinder (7, 8), Hantush (9), and Neuman and Witherspoon (10) was used to develop insight into modelling nonhomogeneous, anisotropic, or leaky aquifer conditions.

Nelson's (11, 12, 14, 15, 16, 17, 18) and Risenaur's (19, 20) earlier work in multiphase flow problems and permeability distribution were used to estimate the distribution of transmissibility as accurate as possible.

Sechrist, Clayborn, Rayner, and Wells' model (21), used to predict dewatering of the Ogallala basin, as well as work of Loo (22) and DeVries and Kent (23) on the sensitivity of models to vertical variability of aquifer properties, was considered when developing input parameters to the mathematical model.

Methodology developed by Kent, et al (24) was used for distributing hydrogeologic parameters. Data from SEA-FR annual reports and the hydrologic study of the Tillman Terraced deposits by Wickersham, et al (32) was used as model inputs and test values where available. Naney (25) and Schoof and Naney (26) estimated recharge (seepage) from earthen flood water retarding structures which returns to subsurface alluvial storage. These estimates were used as recharge parameters in alluvial areas where structures could influence long-term storage changes.

Moench, Sauer, and Jennings (27) showed the effect of channel loss and base flow on routed streamflow on the North Canadian River in Oklahoma, but did not attempt to evaluate alluvial basin performance or capability. Marine (28), Bedinger and Reed (29), Cooper and Rorabaugh (3), and Pinder Bredehoeft, and Cooper (31) studied stream-induced aquifer responses.
III. Objective

The objective of this research is to determine the maximum annual yield of fresh water that can be produced from the alluvium and terrace deposits of the North Fork of the Red River in Tillman County, Oklahoma. A maximum annual yield which will assure a minimum basin life of 20 years is presented which is established within the guidelines of existing Waters and Water Rights Legislation for the State of Oklahoma. The following tasks were performed to accomplish this objective:

1) Calibration and validation of an existing mathematical model for predicting changes in ground water storage over time in the Tillman alluvium and terrace deposits in Tillman Co. and on the segment of the Washita River alluvium and terrace deposits, between Anadarko and Alex, Oklahoma.

2) Selection of data on ground water levels and other geohydrological properties available for computer retrieval and use as input data for the mathematical model. These data were provided by the OWRB for the Tillman alluvium and terrace deposits and by the Southern Great Plains Research Watershed (SEA-PR), Chickasha, Oklahoma for the Washita alluvium and terrace deposits.

3) Assignment of spatially distributed hydraulic properties to alluvium and terrace deposits based on available geological and hydrological data.

IV. Procedures

A finite difference type mathematical model was adapted, as necessary; and calibrated and validated on data from a segment of the Washita River alluvium and terraces. The model was used to the extent possible to predict temporal and spatial variation in ground water storage in both ground water basins and to make estimates of ground water supply capability.
In addition to the data derived by simulation techniques, data in the form of geologic maps and reports, water levels, streamflow records, and other pertinent hydrological data were reviewed and interpreted to develop a broad data base from which to draw conclusions about basin performance and water supply capability. Methodology and an understanding of the type of data base required for successful mathematical model application to other alluvial areas of the Washita River, the North Fork of the Red River, and other major rivers in Oklahoma were enhanced in the pursuit of the goals of this project.

The result of this research was to determine the maximum annual yield of fresh water that can be produced from the alluvium and terrace deposits of the Tillman Terrace of the North Fork of the Red River in Tillman Co. in southwestern Oklahoma and from the segment of the alluvium and terrace deposits of the Washita River, between Anadarko and Alex, Oklahoma.

V. Methodology and Results - Tillman Terrace*

The following data have been analyzed using the Tillman Co. report (32) and other data provided by the Water Resources Board:

1) Water table maps 1970-1975
2) Bedrock elevations
3) Driller's logs
4) Pump Test Analyses
5) Prior Appropriative pumpage, July 1, 1973

Values of the coefficient of permeability and specific yield were assigned to all nodes based on driller's logs and pump test data from the area.

*Tillman Terrace as used herein refers to the location of the ground water basin and not to differentiated geologic deposits.
Assignments of the coefficient of permeability and specific yield were based on the grain size distribution—coefficient of permeability envelope developed by Kent, et al (24) as shown in Figure 1b. These data were contoured, digitized and used in the program. The relationship shown in Figure 1b was also used to aid in the assignment of specific yield.

Transmissibility* was computed for each node in the model and is shown in Figures 2 and 3. This parameter was based on the coefficient of permeability, depth of bedrock (Figure 4) and 1973 water head (Figure 5). The water depth as of July 1, 1973 is shown in Figure 6. Transmissibility and specific yield were used to determine the volume and rate of ground-water flow in the basin**. Other data used as input into the model were net recharge (2.87 inches/year) which include the effects of precipitation, evapotranspiration and prior appropriative pumpage as established by the Oklahoma Water Resources Board. The latter is shown in Figure 7.

The maximum annual yield for the basin was determined by computer simulation of all prior appropriative and subsequent allocated pumping for the twenty-year period from July 1, 1973 to July 1, 1993. These pumping rates are shown in Figure 8. An example of the computer output of this data is shown in Figure 9.

A well spacing of one-half mile at a rate of 100 gpm (1.0 acre feet/acre/year for 160 acres) was based on available pump test data and the maximum annual yield. The maximum annual yield of 70,000*** acre feet per year (proportioned at 1.0 acre feet/acre/year) was determined for this basin by selecting the model simulation run using an allocated annual pumpage

*The terms transmissibility and transmissivity are used synonymously in this report. They are reported in units of gallons per day per foot (gpd/ft).

**Basin as used herein denotes a ground water basin which consists of ground water stored in undifferentiated alluvium and terrace deposits as described in Figure 1a.

***Values rounded off.
Figure 1b
Figure 2
Figure 3
Figure 4

BEDROCK DEPTH

EXPLANATION

ZONE | DEPTH (FT)
-----|----------
5    | 0–15'
4    | 16–30'
3    | 31–45'
2    | 46–60'
1    | >60'

TILLMAN TERRACE
Figure 6
If INIUS o

PRIOR APPROPRIATION
ANNUAL PUMPAGE (Ac.Ft./Ac.)

EXPLANATION

<table>
<thead>
<tr>
<th>ZONE</th>
<th>RATE</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>&gt;20</td>
</tr>
<tr>
<td>4</td>
<td>1.5—20</td>
</tr>
<tr>
<td>3</td>
<td>1.0—1.5</td>
</tr>
<tr>
<td>2</td>
<td>0.5—1.0</td>
</tr>
<tr>
<td>1</td>
<td>0.0—0.5</td>
</tr>
</tbody>
</table>

TILLMAN TERRACE

Figure 7
Figure 8

Prior Appropriation and Allocation of 1.00 Acre Foot Annual Pumpage (Ac. Ft.)

Explanations:

<table>
<thead>
<tr>
<th>ZONE</th>
<th>RATE (Ac.Ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>&gt;3.00</td>
</tr>
<tr>
<td>4</td>
<td>2.51—3.00</td>
</tr>
<tr>
<td>3</td>
<td>2.01—2.50</td>
</tr>
<tr>
<td>2</td>
<td>1.51—2.00</td>
</tr>
<tr>
<td>1</td>
<td>1.00—1.50</td>
</tr>
</tbody>
</table>
which caused 50% of the total area to go dry by July 1, 1993. The prior appropriative allocations (from Oklahoma Water Resource Board) were used together with allocated annual pumpage in the computer simulation runs. The recommended pump rate to produce the maximum annual yield was established for a well spacing of one-half mile and is shown in Figure 10. The distribution of the remaining saturated thickness for the 50% dry criterion as a result of the model simulation for twenty years is represented by the curve in Figure 11. The area and volume of water remaining in 1993 for the same criterion is presented graphically in Figures 12, 13, and 14. The histograms are represented in tabular form in Table 1. The water budget (Mass Balance) developed by the final computer simulation for the twenty-year period between July 1, 1973 and July 1, 1993 is shown in Table 2. The components of the water budget considered in this model simulation are shown in Figure 15.

The extent of dry basin area which results from computer simulation of maximum annual yield pumpage between July 1, 1973 and July 1, 1993 is shown on maps at five-year increments in Figures 16-20. These maps show the progressive extent of basin area becoming dry when pumping the recommended maximum annual yield of 70,000* acre feet/year (proportioned as 1.0 acre feet/acre/year). Wells with 5 feet or less saturated thickness are considered to be dry because of the assumed position of the pump at the bottom of the well. Distribution of the basin area (50%) which is predicted to be dry in 1993, as described graphically in Figure 11, is shown in Figure 20. The resultant saturated thickness, water head elevation and water depth are described on maps in Figures 21, 22, and 23 respectively.

In conclusion, the maximum annual yield for the ground water basin in western Tillman Co. was determined by computer simulation of all prior

*Values rounded off.
appropriative and subsequent allocated pumping for twenty years (July 1, 1973 to July 1, 1993). The maximum annual yield was calculated to be 70,000* acre feet/year (proportioned as 1.0 acre feet/acre/year). Pumping at this rate for the twenty-year period totals 1,400,000* acre feet and represents 61.2% of the cumulative water in the ground water basin.

The parameters from which maximum annual yield was determined are:

1. the total land area overlying the alluvium and terrace deposits in the basin is 189,760 acres,
2. the amount of water in storage in the basin as of July 1, 1973 is 1,047,000* acre feet; the cumulative amount of water in storage over the twenty-year life of the basin is 2,288,000* acre feet, which includes the estimated natural recharge of 2.87 inches/year, and
3. the average transmissibility is 13,000* gpd/ft and the average specific yield is 0.30 for the basin. In addition, the predicted water table on July 1, 1993 (Figure 22) indicates that the possibility of natural pollution within the basin exists within one and one-half miles of the main reach of the Red River during later stages of pumping.

*Values rounded off.
RECOMMENDED WELL SPACING FOR MAXIMUM ANNUAL YIELD
TILLMAN TERRACE

Well Spacing used for Determination of Maximum Annual Yield

Cross Section of Expected well Drawdown

Maximum Annual Yield (4 dams)
Indicated by Pump Test Data and Model Results

Well Spacing for Proportional pumping by 1/3 section

---

Maximum Annual Yield
Pump Rate: One well 1/4 sec.
100 gpm/well (1 year)
300 gpm/well (1/3 year)*

---

Maximum Annual Yield
Pump Rate: 4 wells 1/4 sec.
75 gpm/well (1 year)
25 gpm/well (1/3 year)*

---

Maximum Annual Yield
Pump Rate: 8 wells 1/4 sec.
8 1/4 gpm/well (1 year)
25 gpm/well (1/3 year)*

* Pumpage during Irrigation season only (June 1 to September 30)

Figure 10
CUMULATIVE PERCENTAGE DRY AREA

JULY 1, 1993
1.00 ACRE FT./ACRE/YR
ALLOCATION

TILLMAN TERRACE

Figure 11
TILLMAN TERRACE

THICKNESS DISTRIBUTION
JULY 1, 1993
1.00 ACRE FT./ACRE/YR.
ALLOCATION

AREA (1000 ACRES)

SATURATED THICKNESS (FT.)

TILLMAN TERRACE

Figure 12
21
DETAILED THICKNESS DISTRIBUTION
JULY 1, 1993
1.00 ACRE FT./ACRE/YR. ALLOCATION

AREA (1000 ACRES)

SATURATED THICKNESS (FT.)

TILLMAN TERRACE

Figure 13
WATER DISTRIBUTION
BY VOLUME
JULY 1, 1993
1.00 ACRE FT./ACRE/YR.
ALLOCATION

TILLMAN TERRACE

Figure 14
<table>
<thead>
<tr>
<th>SATURATED THICKNESS RANGE (FEET)</th>
<th>% AREA</th>
<th>AREA (ACRES)</th>
<th>AVERAGE SATURATED THICKNESS (FEET)</th>
<th>SPECIFIC YIELD</th>
<th>STORED WATER (AC.FT.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>26.3</td>
<td>49,920</td>
<td>5.1</td>
<td>.3</td>
<td>77,066</td>
</tr>
<tr>
<td>10-20</td>
<td>29.9</td>
<td>56,800</td>
<td>15.6</td>
<td>.3</td>
<td>265,371</td>
</tr>
<tr>
<td>20-30</td>
<td>28.8</td>
<td>54,560</td>
<td>24.6</td>
<td>.3</td>
<td>401,874</td>
</tr>
<tr>
<td>30-40</td>
<td>12.1</td>
<td>23,040</td>
<td>33.8</td>
<td>.3</td>
<td>233,571</td>
</tr>
<tr>
<td>40-50</td>
<td>2.8</td>
<td>5,280</td>
<td>42.4</td>
<td>.3</td>
<td>67,146</td>
</tr>
<tr>
<td>50-60</td>
<td>0.1</td>
<td>160</td>
<td>50.0</td>
<td>.3</td>
<td>2,400</td>
</tr>
<tr>
<td>TOTALS</td>
<td>100.0</td>
<td>189,760</td>
<td>18.4 (AVE)</td>
<td></td>
<td>1,047,429</td>
</tr>
</tbody>
</table>

<table>
<thead>
<tr>
<th>SATURATED THICKNESS RANGE (FEET)</th>
<th>% AREA</th>
<th>AREA (ACRES)</th>
<th>AVERAGE SATURATED THICKNESS (FEET)</th>
<th>SPECIFIC YIELD</th>
<th>STORED WATER (AC.FT.)</th>
</tr>
</thead>
<tbody>
<tr>
<td>0-10</td>
<td>86.7</td>
<td>164,640</td>
<td>4.9</td>
<td>.3</td>
<td>242,140</td>
</tr>
<tr>
<td>10-20</td>
<td>7.5</td>
<td>14,240</td>
<td>14.4</td>
<td>.3</td>
<td>61,629</td>
</tr>
<tr>
<td>20-30</td>
<td>3.2</td>
<td>6,080</td>
<td>25.0</td>
<td>.3</td>
<td>45,614</td>
</tr>
<tr>
<td>30-40</td>
<td>1.7</td>
<td>3,200</td>
<td>35.3</td>
<td>.3</td>
<td>33,877</td>
</tr>
<tr>
<td>40-50</td>
<td>0.8</td>
<td>1,600</td>
<td>43.9</td>
<td>.3</td>
<td>21,073</td>
</tr>
<tr>
<td>50-60</td>
<td>-</td>
<td>-</td>
<td>-</td>
<td></td>
<td>-</td>
</tr>
<tr>
<td>TOTALS</td>
<td>100.0</td>
<td>189,760</td>
<td></td>
<td></td>
<td>404,332*</td>
</tr>
</tbody>
</table>

* Includes effects of pumpage and net gain in available storage over 20 years. See Fig. 1.
TILLMAN TERRACE
MASS BALANCE

Prior Appropriative+
1.0 Acre Ft/Acre Allocation

JULY 1, 1973 to JULY 1, 1993

<table>
<thead>
<tr>
<th></th>
<th>IN (ACRE FT.)</th>
<th>OUT</th>
<th>IN (ACRE FT.)</th>
<th>OUT</th>
</tr>
</thead>
<tbody>
<tr>
<td>PUMPAGE</td>
<td>-93,971</td>
<td></td>
<td>-1,879,420</td>
<td></td>
</tr>
<tr>
<td>LEAKAGE</td>
<td>+17,205</td>
<td>634</td>
<td>+344,105</td>
<td>12,685</td>
</tr>
<tr>
<td>CONST FLUX</td>
<td>+ 91</td>
<td>68</td>
<td>+ 1,823</td>
<td>1,350</td>
</tr>
<tr>
<td>EVAPORATION</td>
<td></td>
<td>302</td>
<td>-638,360</td>
<td></td>
</tr>
<tr>
<td>RECHARGE</td>
<td>+45,760</td>
<td></td>
<td>+915,202</td>
<td></td>
</tr>
<tr>
<td>TOTALS</td>
<td>+63,057</td>
<td>-94,975</td>
<td>+1,261,130</td>
<td>-1,899,490</td>
</tr>
<tr>
<td>NET CHANGE</td>
<td>-31.918</td>
<td></td>
<td>-638,360</td>
<td></td>
</tr>
</tbody>
</table>

Table 2
MASS BALANCE DISTRIBUTION
TILLMAN TERRACE

Recovery Factor (Total Maximum Yield)
1,400,967 = 61.2% of cumulative volume is pumped over 20 years at a rate of 1 acre ft/acre/yr.

Recovery Factor (Prior Appropriative Only)
478,453 = 20.9% of cumulative volume is pumped over 20 years by prior appropriative owners.

Figure 15
Figure 16
PRIOR RIGHTS + 1.0 AcFt/Ac/Yr
SATURATED THICKNESS

Figure 17
Figure 19
Figure 20

PRIOR RIGHTS + 1.0 Ac Ft/Ac/Yr
SATURATED THICKNESS

NORTH FORK R.

FREDERICK

RED R.

TILLMAN TERRACE

JULY 1, 1993

SCALE IN MILES
0 1 2

DRY AREA
SAT > 5'

Figure 20
PRIOR APPROPRIATION
AND ALLOCATION
OF 1.0 ACRE FOOT
JULY 1, 1993 RESULTS
SATURATED THICKNESS

ZONE
5
4
3
2
1

THICKNESS (Ft.)
0–10'
11–20'
21–30'
31–40'
>40'

SCALE IN MILES

TILLMAN TERRACE

Figure 21
PRIOR APPROPRIATION AND ALLOCATION OF 1.0 ACRE FOOT
JULY 1, 1993 RESULTS
WATER HEAD ELEVATION
CONTOUR INTERVALS = 10'

TILLMAN TERRACE

Figure 22
PRIOR APPROPRIATION AND ALLOCATION OF 1.0 ACRE FOOT
JULY 1, 1993 RESULTS

WATER DEPTH EXPLANATION

<table>
<thead>
<tr>
<th>ZONE</th>
<th>DEPTH (Ft)</th>
</tr>
</thead>
<tbody>
<tr>
<td>5</td>
<td>&gt;40'</td>
</tr>
<tr>
<td>4</td>
<td>31-40'</td>
</tr>
<tr>
<td>3</td>
<td>21-30'</td>
</tr>
<tr>
<td>2</td>
<td>11-20'</td>
</tr>
<tr>
<td>1</td>
<td>0-10'</td>
</tr>
</tbody>
</table>

Figure 23
VI. Methodology and Results - Washita River*

The following data developed at the Southern Great Plains Research Watershed were used for the modeling of the Washita alluvium and terrace deposits:

1) Water table maps 1971-1976
2) Bedrock elevations
3) Test-hole data
4) Pump Test Analyses
5) Inventory of existing wells

Values of the coefficient of permeability and specific yield were assigned to all nodes based on test-hole logs and pump test data from the area. Assignments of the coefficient of permeability and specific yield were based on the grain size distribution-coefficient of permeability envelope developed by Kent, et al (24) as shown in Figure 1b. These data were contoured, digitized and used in the program. The relationship shown in Figure 1b was also used to aid in the assignment of specific yield.

Transmissibility was computed for each node in the model and is shown in Figure 24. This parameter was based on the coefficient of permeability, bedrock depth (Figure 25) and 1973 water head (Figure 26). Transmissibility and specific yield were used to determine the volume and rate of groundwater flow in the basin. Other data used as input into the model were net recharge (1.44 inches/year) which includes the effects of precipitation, evapotranspiration and known pumpage.

A well spacing of one-half mile at a rate of 200 gpm (2.9 acre feet/ 

*Washita River as used herein refers to the location of the ground water basin and not to differentiated geologic deposits.
WASHITA RIVER
ARS MODEL AREA

July 1, 1973
T = (100 GPD/FT.)

CODE T
5  300 +
4  250 - 300
3  150 - 250
2  75 - 150
1  0 - 75

Transmissivity Map

Scale in Miles
0 1 2 3 4 5

Figure 24
Figure 25

WASHITA RIVER
ARS MODEL AREA

DEPTH TO BEDROCK

CODE RANGE IN FEET

1 \( \leq 40 \)
2 41–60
3 61–80
4 81–100
5 \( >100 \)

SCALE IN MILES

0 1 2 3 4 5

Anadarko

Alex
WASHITA RIVER
ARS MODEL AREA

WATER HEAD ELEVATION
KNOWN PUMPAGE ONLY
JULY 1, 1973
CONTOUR INTERVAL = 10'

SCALE IN MILES
0 1 2 3 4 5

Figure 26
acre/year for 160 acres) was based on available pump test data and the maximum annual yield. The maximum annual yield of 99,000* acre feet per year (proportioned at 2.0 acre feet/acre/year) was determined for this basin by selecting the model simulation run using an allocated annual pumpage which caused 50% of the total area to go dry by July 1, 1993. Prior appropriations were not established and, therefore, not used in these simulation runs. However, the known pumpage was used together with allocated annual pumpage in computer simulation runs for determining the maximum annual yield. The recommended pump rate to provide the maximum annual yield was established for a well spacing of one-half mile as shown in Figure 27. The components of the water budget considered in the final model simulation are shown in Figure 28.

The extent of dry basin area resulting from computer simulation of maximum annual yield pumping between July 1, 1973 and July 1, 1993 is shown on maps at 5-year increments in Figures 29-33. These maps show the progressive extent of basin area becoming dry when pumping the recommended maximum annual yield of 97,000* acre feet/year (proportioned at 2.0 acre feet/acre/year). Wells with 5 feet or less saturated thickness are considered to be dry because of the assumed position of the pump at the bottom of the well. Distribution of the basin area (50%) which is predicted to be dry in 1993 is shown in Figure 33. The resultant water head elevation and water depth are described on maps in Figures 35 and 35 respectively.

In conclusion, the maximum annual yield for the ground water basin of the Washita River between Anadarko and Alex was determined by computer simulation of known pumpage and subsequent allocated pumping for the twenty-year period from July 1, 1973 to July 1, 1993. The maximum annual yield

*Values rounded off.
was calculated to be 97,000* acre feet per year (proportioned as 2.0 acre feet/acre/year). Pumping at this rate for the twenty-year period totals 1,946,000* acre feet and represents 82.3% of the cumulative water in the ground water basin.

Parameters from which maximum annual yield was determined are: (1) the total land area overlying the alluvium and terrace deposits in the ground water basin is 69,760 acres, (2) the amount of water in storage in the basin as of July 1, 1973 is 1,423,000* acre feet; the cumulative amount of water in storage over the twenty-year life of the basin is 2,363,500* acre feet, (3) the estimated rate of natural recharge is 1.44 inches per year, and the average transmissibility is 20,000* gpd/ft and the average specific yield is 0.30 for the basin. In addition, the predicted water table on July 1, 1993 (Figure 34) indicates that the possibility of natural pollution within the basin is evident in an eight mile reach north of Verden, Oklahoma, during later stages of pumping.

*Values rounded off.
RECOMMENDED WELL SPACING FOR MAXIMUM ANNUAL YIELD

WASHITA RIVER ALLUVIUM

Well Spacing used for Determination of Maximum Annual Yield

Cross Section of Expected well Drawdown

Maximum Annual Yield (6 mo.)

Indicated by Pump Test Data and Model Results

Well Spacing for Proportionate pumping by 1/4 section

Well Spacing for Proportionate pumping by 1/8 section

Maximum Annual Yield
Pump Rate: One well/1/4 sec.
200 gpm/well (1 year)
600 gpm/well (1/3 year)*

Maximum Annual Yield
Pump Rate: 4 wells/1/4 sec.
50 gpm/well (1 year)
150 gpm/well (1/3 year)*

Maximum Annual Yield
Pump Rate: 16 wells/1/4 sec.
16 1/2 gpm/well (1 year)
50 gpm/well (1/3 year)*

* Pumpsage during irrigation season only (July 1 to October 31)

Figure 27
MASS BALANCE DISTRIBUTION
WASHITA RIVER

54,000 Ac. Ft.
Pumpage, Prior Appropriative (1973-1993)

1,946,445 Ac. Ft. (97,322 acre ft/yr) Pumpage, Total max. yield
(max. annual yield)

395,043 Ac. Ft.
Recharge from rainfall

1,423,104 Acre feet
(1973)

2,363,594 Acre feet
(1973-1993)

563,162 Ac. Ft. + 2,750 Ac. Ft.
(River Leakage) (Boundary Flow)

276 Ac. Ft. + 20,229 Ac. Ft.
(Boundary Flow)

(97,322 acre ft/yr)

Recovery Factor (Total Maximum Yield)

1,946,445 = 82.3% of cumulative
2,363,594 volume is pumped
over 20 years
at a rate of
2 acre ft/acre/yr.

(Less Prior Appropriative)

Recovery Factor (Prior Appropriative Only)

54,000 = 2.3% of cumulative
volume is pumped
over 20 years by
prior appropriative owners.

Figure 28
WASHITA RIVER ARS MODEL AREA

KNOWN PUMPAGE PLUS 2.0 AC.FT./AC./YR.
SATURATED THICKNESS
JULY 1, 1973

- DRY
- SAT > 5'

SCALE IN MILES
0 1 2 3 4 5

Figure 29
Known pumpage and allocation of 2.0 acre foot saturated thickness July 1, 1978

Dry

Sat > 5'

Washita River ARS model area

Scale in miles

0 1 2 3 4 5

Figure 30
WASHITA RIVER
ARS MODEL AREA

KNOWN PUMPAGE
PLUS 2.0 AC.FT./AC./YR.
SATURATED THICKNESS
JULY 1, 1983

- DRY
- SAT >5'

SCALE IN MILES

Figure 31
WASHITA RIVER
ARS MODEL AREA

KNOWN PUMPAGE
PLUS 2.0 AC.FT./AC./YR.
SATURATED THICKNESS
JULY 1, 1988

☐ DRY
☐ SAT > 5'

SCALE IN MILES
0 1 2 3 4 5

Figure 32
Figure 33

KNOWN PUMPAGE
PLUS 2.0 AC.FT./AC./YR.
SATURATED THICKNESS
JULY 1, 1993

- DRY
- SAT > 5'

SCALE IN MILES

WASHITA RIVER
ARS MODEL AREA
WASHITA RIVER
ARS MODEL AREA

DEPTH TO WATER
JULY 1, 1993
KNOWN PUMPAGE PLUS
2.0 AC. FT./AC.
CONTOUR INTERVAL = 20'

CODE DEPTH
0 ≤ 20
1 21 – 40
2 41 – 60
3 61 – 80
4 81 – 100
5 > 100

Figure 35
CITED REFERENCES


