PREFERENTIAL FLOW PATHS IN AN UNCONFINED LIMESTONE AQUIFER IN A JUNIPER/OAK DOMINATED WATERSHED MCLENNAN COUNTY, TEXAS

A Thesis Submitted to the Faculty of Baylor University in Partial Fulfillment of the Requirements for the Degree of Master of Science

by

Carol S. Tatay

Waco, Texas
August, 1995
CONTENTS

ILLUSTRATIONS ........................................................................................................... vi
TABLES ......................................................................................................................... ix
ACKNOWLEDGMENTS ................................................................................................... x

CHAPTER 1: INTRODUCTION ......................................................................................... 1

Purpose ......................................................................................................................... 1
Location ......................................................................................................................... 2
Methods ......................................................................................................................... 4

Precipitation .................................................................................................................. 7
Overland Flow .............................................................................................................. 7
Shallow Soil Flow ....................................................................................................... 10
Shallow Fracture Flow and Deep Flow ...................................................................... 13
Discharge from the Tributary .................................................................................... 17

CHAPTER 2: PHYSICAL ENVIRONMENT ...................................................................... 19

Watershed ..................................................................................................................... 19
Flow Systems ............................................................................................................... 19
Geology ........................................................................................................................ 23
Hydrogeology .............................................................................................................. 28
Soils ............................................................................................................................... 32
<table>
<thead>
<tr>
<th>Figure</th>
<th>Illustration Description</th>
<th>Page</th>
</tr>
</thead>
<tbody>
<tr>
<td>1</td>
<td>Location map of the study area</td>
<td>3</td>
</tr>
<tr>
<td>2</td>
<td>Location map of the monitoring equipment used for this study</td>
<td>5</td>
</tr>
<tr>
<td>3</td>
<td>Cross-sectional view of the location of the eight monitoring stations</td>
<td>6</td>
</tr>
<tr>
<td>4</td>
<td>Diagram of the runoff troughs</td>
<td>8</td>
</tr>
<tr>
<td>5</td>
<td>Photograph of the runoff trough</td>
<td>9</td>
</tr>
<tr>
<td>6</td>
<td>Diagram of the mini-piezometer</td>
<td>11</td>
</tr>
<tr>
<td>7</td>
<td>Photograph of the mini-piezometer</td>
<td>12</td>
</tr>
<tr>
<td>8</td>
<td>Diagram of the piezometer design used to monitor the shallow fracture flow and deep flow zones</td>
<td>14</td>
</tr>
<tr>
<td>9</td>
<td>Diagram of the placement and location of hydro-deep well (HDW) and hydro-shallow well (HSW)</td>
<td>15</td>
</tr>
<tr>
<td>10</td>
<td>Diagram of the placement and location of hydro-shallow well (HSW), upper weir well (UWW) and lower weir well (LWW)</td>
<td>16</td>
</tr>
<tr>
<td>11</td>
<td>Photograph of the 120° V-notched weir used to monitor the discharge of the tributary</td>
<td>18</td>
</tr>
<tr>
<td>12</td>
<td>Topographic map of the study area</td>
<td>20</td>
</tr>
<tr>
<td>13</td>
<td>Diagram of the four flow zones unidentified in the watershed</td>
<td>22</td>
</tr>
<tr>
<td>14</td>
<td>Stratigraphic column and a photograph representative of the geology in the watershed</td>
<td>24</td>
</tr>
<tr>
<td>15</td>
<td>Photograph of the characteristic limestone ledge found at the base of the Duck Creek limestone</td>
<td>27</td>
</tr>
<tr>
<td>16</td>
<td>Diagram of the interbedded limestones and shales</td>
<td>30</td>
</tr>
</tbody>
</table>
17. Diagram of the generalized geology in the watershed.......................... 31
18. Diagram of the Aledo soil series and the Crawford soil serie.............. 33
19. Photograph of the Aledo soil............................................................... 34
20. Photograph showing the dense tree coverage found in the study area......................................................... 36
21. Photograph of the pasture lands found in the study area.................. 38
22. Aerial photograph of the watershed.................................................. 39
23. Water budget for the 1994-95 monitoring period................................ 41
24. Monthly precipitation totals for the 1994-95 monitoring period........... 42
25. Comparison of monthly precipitation totals....................................... 44
26. Graph illustrating the spatial variability of precipitation.................. 45
27. Tributary hydrograph from 11/22/94 to 2/24/95................................. 47
28. Comparison of the characteristic signatures associated with the tributary hydrograph........................................ 51
29. Summary of the mechanisms of preferential flow.............................. 54
30. Diagram of the amount of water attributed to overland flow.............. 57
31. Incipient runoff curve........................................................................ 59
32. Comparison of rainfall volumes to runoff volumes............................ 60
33. Graph illustrating the spatial variability of runoff production............ 61
34. Diagram of the amount of water that infiltrated the soil zone.............. 63

vii
35. Graph illustrating the spatial variability of infiltration into the soil zone..........................64

36. Water levels recorded in the mini-piezometers during two different storms...........................................65

37. Comparison of Type A storms to Type B storms..........................66

38. Water levels recorded in the mini-piezometers on 10/7/94..........................67

39. Water levels recorded in the mini-piezometers on 12/10/94........................................69

40. Diagram of the amount of water attributed to shallow fracture flow and deep flow...............................................70

41. Water levels recorded in the lower weir well (LWW)..........................71

42. Comparison of precipitation to water levels recorded in the hydro-deep well (HDW)........................................73

43. Flow chart illustrating the water budget for the 1994-95 monitoring period..........................75

44. Comparison of (44B) through (44F) illustrates the gradual recharge of the system during the monitoring period..........................78

45. Comparison of runoff production along the hillslope..........................84

46. Photograph of water ponding at the soil/bedrock interface after a Type A storm..........................86

47. Photograph of the inner tube of the mini-piezometers after a storm..........................88

48. Photograph of the soil zone after a Type B storm..........................85
Table 1. Summary of the hydrograph analysis........................................................................50
ACKNOWLEDGMENTS

I would like to sincerely thank Dr. Peter Allen, my advisor, for his expertise, continual support, advice, and his genuine interest and dedication to my graduate work at Baylor. His enthusiasm and love of hydrology and geology had a big influence on where I am today. I would also like to thank Dr. Joe Yelderman, my second reader, for his input as well as his support and expertise during my graduate work at Baylor. Thank you to my third reader, Dr. Lucille Brigham, for editing the final draft of my thesis. I would also like to thank all of the professors in the geology department for their contributions to my education at Baylor. To Paulette Penney and Karen Pate, I am forever indebted to you for your vast knowledge and your never-ending willingness (and good attitude!) to answer any and all of my many questions. In addition to the Baylor faculty, I would like to thank Dr. Robert Laury, my undergraduate advisor at Southern Methodist University. He had a big part in my decision to come to Baylor and I will always be grateful to him for that as well as for expertise and support while I was at SMU.

A special thank you to Amy Harrison, Troy Meinen, and Fred Nawrocki, as well as everyone else in the geology department, for their emotional support during my few first weeks at Baylor. You will never know how much it meant to me to have such good friends during that time. Thanks again to Troy and Todd Fritch for going to Childress Creek when I couldn’t be there. I know it was a
pain! Thanks to anyone else I unintentionally forgot who made a special trip to Childress to help me. Thanks to the many before me, especially Gib Bernhardt, who have done research at Childress Creek. Without their valuable research, I would have no thesis.

To Kim Head and Mary McLaughlin (in alphabetical order), y’all are the two best friends anyone could have. You definitely made graduate school bearable with all the late night three-way phone calls, the e-mails, the Lion Kings, and everything else. I would also like to thank Pat Carrigan, a very special person whom I have not known very long. However, your support and help during the last month of writing was a very important part of this thesis.

I want to thank my family, Chuck, Carol, and Mary for everything. I owe a lot to them and I hope they know how much I appreciate and love them. I also want to thank my grandparents, Hazel and Dan Peterson, and the Sholtz’s, Sylvia, Kent, Amy, and Christian, for their unending support. I wish you all lived closer.

Finally, I would like to dedicate my thesis to my grandfather, Daniel Peterson. He was the first geologist I ever knew and his love for rocks must have rubbed off on me over the years. My grandpa is truly one of the nicest and most genuine people I have ever known. I hope that I can live up to his example.
CHAPTER 1

INTRODUCTION

Purpose

The hydrologic response of a watershed is the driving force behind the transport of sediment and pollution in both the surface and the subsurface systems (Grayson, and others, 1992), yet little is understood about the preferential flow paths taken by this water through its drainage basin to the stream or to deeper aquifer systems. With the advent of more powerful computers which allow for the development of more complex hydrologic models, attempts have been made to try to improve forecasts of water yield, sediment yield, and pollutant loads from watersheds. However, all physically based models rely on assumptions regarding the flow paths of water. Routing of such flow involves various calibration parameters or assumptions regarding storage and flow velocities. The objectives of this research project were: (1) to better define individual surface and subsurface flow processes, (2) to determine the thresholds regulating these processes, and (3) to provide a more realistic basis for the appraisal of current assumptions within physically based and empirical models.
used to predict flow through such systems. The importance of this research was based on three major issues: (1) most of the larger communities in Central Texas, like Waco and Dallas, rely on surface water supplies as their sole source of water, (2) surface waters and shallow groundwaters are extremely sensitive to pollution from both urban and agricultural sources, and (3) the watershed in this study is similar in geology, topography, and vegetation to the Hill Country, which is a major source of recharge waters for the Edwards Aquifer in the Austin and San Antonio area.

Four flow zones exist in the study area: the overland flow zone, the shallow soil flow zone, the shallow fracture flow zone, and the deep flow zone (Bernhardt, 1991). The focus of this study is to quantify water movement through the preferential flow paths in a juniper/oak dominated watershed in McLennan County, Texas.

Location

The study watershed is located approximately one mile northwest of the intersection of Childress Creek Drive and FM 2490, 12 miles northwest of Waco, McLennan County, Texas (fig. 1). The major tributary in the 76 acre watershed is approximately 6000 feet long. The tributary drains into Childress Creek, which has a drainage area of 87 square miles. Childress Creek is a subbasin of the Brazos River System. The watershed lies in the Washita Prairie, a physiographic subprovince of the Grand Prairies of Central Texas (Hill, 1901). The study area lies in the northern
Figure 1: Location map of the study area. The study site is located in McLennan County in Central Texas, approximately one mile northwest of FM 2490, twelve miles northwest of Waco, Texas. From Bernhardt, 1991.
reaches of the humid subtropical belt which extends inland from the Gulf of Mexico (Flawn and Burkett, 1965, p. 14). Average seasonal temperatures range from 78°F to 56°F in McLennan County, with a mean annual temperature of 67°F. The summer months, June through August, are generally very hot and humid with temperatures ranging from the mid- to upper-nineties. The winters are mild, with temperatures dropping to freezing or below fewer than 4 days out of 10. Average annual precipitation is 31 inches (Bomar, 1983), but is described in greater detail for this study area later in the paper.

Methods

This study extended for a one year period, from 2/24/94 to 2/24/95. A slope representative of the watershed was chosen for monitoring rainfall, runoff, and shallow soil flow. Eight stations (S1 through S8) were chosen along the slope, based on factors such as soil cover, soil depth, vegetation, degree of slope, and location along the slope in order to obtain a representative sample of flow through and over the hillslope. A site map indicating the location and type of monitoring equipment at each station is shown in figures 2 and 3. In addition to the eight stations, the discharge of the tributary and the water levels in four piezometers were monitored throughout the study period.
Figure 2: Location map of the monitoring equipment used for this study. Eight monitoring stations were chosen along a slope (G) representative of the basin. At each station, precipitation, the overland flow zone, and the shallow soil flow zone were monitored. Four piezometers (A-D) monitored the shallow fracture flow and deep flow zones. A 120° V-notched weir (F) monitored the discharge of the tributary. No scale intended.
Figure 3: Cross-sectional view of the location of the eight monitoring stations. At each station, precipitation, the overland flow zone, and the shallow soil flow zone were monitored.
Precipitation

A total of thirteen conventional rain gages (RG1 through RG13) were monitored on a storm by storm basis. The large number of rain gages allowed for inferences to be made regarding spatial variations in precipitation beneath the juniper/oak canopy. Two of the gages (RG1 and RG13) were placed outside of the vegetative canopy. Each of the eight hillslope monitoring stations had a gage, RG2 through RG9. The remaining three gages, R10 through R12, were placed beneath a tree to monitor throughfall. A tipping-bucket rain gage, located outside the vegetative canopy, recorded the volume and duration of each event. The tipping-bucket rain gage was connected to an analog data recorder.

Overland Flow

Runoff plots were installed at each of the eight stations in order to measure overland flow (runoff). The runoff plot consists of a steel runoff pan, a catchment area (615.75 square inches in area), a garden hose, and a 5-gallon plastic receptacle (fig. 4). The precipitation that falls into the catchment area infiltrates the ground surface or forms runoff. The runoff flows through the runoff pan, down the hose, and is collected in the receptacle where it is stored until it is removed and measured. The runoff plots are installed on top of the ground surface (fig. 5). The hose was extended downslope to ease the flow of runoff into the storage tanks (figs. 4, 5). The plots included runoff from the layer of leaf litter.
Figure 4: Diagram of the runoff plot. The runoff plot consisted of four main components: (A) is the catchment area; (B) is the runoff pan; (C) is a garden hose; and (D) is the runoff receptacle. Any rain that falls in (A) and forms runoff will flow through (B). The water flows down (C) and is stored in (D) until it is measured. The catchment area (A) is placed upslope from the runoff receptacle (D) to allow for a natural gradient.
Photograph of the runoff plot. Any rain that falls in the catchment area (A) flows through the runoff pan (B) and down the hose (C) where it stored in the runoff receptacle (D) until it is measured. The catchment area (A) is located upslope from the runoff receptacle in order to create a natural gradient.
Shallow Soil Flow

Two qualitative methods of monitoring shallow soil flow were installed at each of the 8 stations: gypsum blocks and mini-piezometers. The gypsum blocks are soil moisture blocks which measure the moisture content of the soil as a function of the resistance between two electrodes embedded in a porous medium (gypsum). The soil must be in equilibrium. The soil moisture content is determined from a rating curve correlating the electrical resistance reading and soil moisture content (Morrison, 1983, p. 13). The mini-piezometers recorded water height in the soil above the base of the piezometer (which rested at the soil/bedrock interface). The mini-piezometers were installed through the soil horizon to the top of the bedrock (figs. 6, 7). The gypsum blocks were buried approximately two inches beneath the top of the soil, with the wire running through the soil and connected at the ground surface to a marker (fig. 7).

Soil flow volumes were measured at Station 1 using a shallow soil flow interceptor. At the station, the shallow soil flow interceptor consisted of a pan, similar to the runoff pans, and a 2-gallon plastic receptacle. The pan was buried on top of the soil/bedrock boundary. The rain which falls in the catchment area and infiltrates the soil flows through the pan, down the hose, and is collected in the receptacle where it is stored until it is removed and measured.
Figure 6: Diagram of the mini-piezometer. It consists of two pieces of PVC pipe: an outer tube (A) and an inner tube (B). Both (A) and (B) were installed through the entire soil horizon, the base of each resting on top of the bedrock. The outer tube (A) was slotted the entire depth of the soil column. A water soluble pen was used to mark the inner tube, indicated by the dark line (B). The arrows indicate potential movement of water through the soil zone. Water movement through the mini-piezometer erases the water soluble pen from the inner tube.
Figure 7: Photograph of the mini-piezometer. Shallow soil flow was monitored at all eight stations on a storm by storm basis. In addition to the mini-piezometers, a gypsum block was installed at each station. It was placed two inches below the top of the soil.
Shallow Fracture Flow and Deep Flow

Four piezometers penetrated the unconfined flow system at the site: hydro-shallow well (HSW), hydro-deep well (HDW), upper weir well (UWW), and lower weir well (LWW). Hydro-shallow well, the lower weir well, and the upper weir well monitored the shallow fracture flow system and hydro-deep well monitored the deep flow system (Bernhardt, 1991). Figure 8 illustrates the design of the piezometer. All four piezometers are completed in a five-inch bore and consist of a two-inch diameter PVC pipe. A screened interval (8.5 feet) at the base of the piezometer was isolated with bentonite seals. The annulus around the screened interval was filled with sand packing (Bernhardt, 1991). Hydro-deep well is completed in the Edwards Limestone approximately 140 feet north of Childress Creek and 260 feet east of the weir.

Hydro-shallow well is completed in the Kiamichi Shale of the Georgetown Formation and is located approximately 300 feet north of Childress Creek and 290 feet east of the weir. Figure 9 illustrates the placement and location of hydro-deep well (HDW) and hydro-shallow well (HSW). The upper weir well is located approximately 220 feet north of Childress Creek and 85 feet east of the weir. The lower weir well is located approximately 200 feet north of Childress Creek and 23 feet east of the weir. Figure 10 illustrates the placement and location of hydro-shallow well, the upper weir well and the lower weir well. Hydro-shallow well and hydro-deep well were manually measured using an E-line water probe. Beginning in June, 1994, hydro-deep well was
Figure 8: Diagram of the piezometer design used to monitor the shallow fracture flow and deep flow zones. Each piezometer was completed in a five-inch bore and consists of a two-inch diameter PVC pipe followed by an 8.5 foot interval of slotted screen with sand packing. The screened interval was isolated from the ground surface with bentonite seals (After Bernhardt, 1991).
Figure 9: Diagram of the placement and location of hydro-deep well (HDW) and hydro-shallow well (HSW). HDW monitors the deep flow zone and HSW monitors the shallow fracture flow zone (After Bernhardt, 1991).
Figure 10: Diagram of the placement and location of hydro-shallow well (HSW), upper weir well (UWW) and lower weir well (LWW). HSW, UWW, and LWW monitor the shallow fracture flow zone.
measured at thirty minute intervals using a pressure transducer. The transducer was connected to an analog data recorder.

Discharge from the Tributary

The discharge of the tributary was determined using a 120° V-notched weir. A pressure transducer was connected to an analog data recorder from 11/22/94 to 2/24/95. The height of the water behind the weir was recorded by the data recorder, from which the discharge can be determined (fig 11). The approximate location of the weir is 200 feet from the mouth of the subbasin draining into Childress Creek. The weir was placed on the basal limestone bed of the Duck Creek Limestone (Bernhardt, 1991).
Photograph of the 120° V-notched weir used to monitor the discharge of the tributary. A pressure transducer connected to an analog data recorder was placed on the upstream side of the weir. The discharge of the tributary can be determined from the height of the water behind the weir. The weir is located approximately 200 feet upstream from the confluence of the tributary with Childress Creek.