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SPECTRAL MEASUREMENT OF WATERSHED COEFFICIENTS IN THE SOUTHERN GREAT PLAINS

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September 1976
Type II Report for Period
June 1, 1976 — August 31, 1976

Prepared for:
Goddard Space Flight Center
Greenbelt, Maryland 20771

Contract No. NAS5-22534

TEXAS A&M UNIVERSITY
REMOTE SENSING CENTER
COLLEGE STATION, TEXAS

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1.0 BACKGROUND & SUMMARY

1.1 Background

This investigation is directed toward testing and modifying a technique developed in a previous study (Contract #5-70251-AG TASK #5) where a linear combination of Landsat data was related to watershed runoff coefficients. The relationship was developed and tested in a region of central Oklahoma where extensive rainfall and runoff data were available for research watersheds.

In this study the technique will be tested in two regions; one in central and east central Texas having more dense vegetation than Oklahoma and the other in arid regions of Arizona and New Mexico where vegetation is less dense. In each region twenty watersheds will be selected on a basis of the most adequate records of rainfall and runoff. The technique will be tested in each region by developing a relationship between spectral response and runoff coefficients based on ten watersheds and then testing the prediction capability of the relationship on the remaining watersheds in that region.

It is expected that by testing the technique in regions having more dense and more sparse vegetation on the watershed surfaces, an estimate can be made of the area where the technique is applicable. At the same time, the influence of the quality of rainfall and runoff data used to calibrate the prediction scheme should indicate whether the technique can be useful to practicing hydrologists.

1.2 Summary

Rainfall and runoff data for the available experimental watersheds in Arizona and New Mexico were processed. Hawkins k and curve number (CN) were calculated for each watershed and the results tabulated.

An initial attempt to analyze the Texas watershed data indicated a poor correlation between measured CN and spectral reflectance. Several physical characteristics of the watersheds were determined to give an explanation for the data scatter. Characteristics attained for each watershed were its geology, soil type, amount of timber cover, average permeability of the soil, and antecedent precipitation index (API) on the date of Landsat coverage. A summary of this information was presented in tabular form. Basic data used to develop the summary are located in the Appendix.

2.0 ACCOMPLISHMENTS AND PROBLEM AREAS

2.1 Accomplishments During the Reporting Period

Topographic maps for the areas of interest in Arizona and New Mexico were received. Watershed boundaries were outlined on these maps in order to delineate the watersheds.

Rainfall and runoff data were processed for the experimental watersheds in Arizona and New Mexico. Approximately 15 to 20 storms were picked during the length of record for each watershed. For some watersheds every runoff producing event was selected. Two watersheds were deleted due to insufficient amounts of runoff.

Hawkins k, the Soil Conservation Service (SCS) curve number (CN) and CN_0, a curve number for a given precipitation (P) below which there is no runoff (Hawkins, 1973) were calculated for each of the selected storm events. The SCS storm runoff equation can be written:

$$Q = \frac{\left(P - \frac{200}{CN} + 2\right)^2}{P + \frac{800}{CN} - 8} \qquad [1]$$

where

Q = runoff in inches

P = precipitation in inches

CN = dimensionless coefficient

Hawkins suggested a modification of this equation such that the curve number can vary with the size of the storm. He defines a coefficient k that accounts for a decline of the curve number not accounted for in the original SCS equation.

$$k = \frac{CN_p - CN_o}{100 - CN_o} \qquad [2]$$

where

k = dimensionless coefficient

CN_p = curve number of a specific storm

CN_o = curve number when Q=0.0 for the precipitation for a specific storm

An average Hawkins k value for each watershed was calculated by a weighting procedure.

$$k_{ave} = \frac{\sum_{i=1}^{i=n} P^2 ki}{\sum_{i=1}^{i=n} P^2}$$

The k determined in this manner was then used to determine Hawkins CN for a precipitation of five inches. Table 2.1.1 lists the watersheds, their areas, and Hawkins k and CN.

Average spectral reflectance for multispectral scanner (MSS) bands four, five, six, and seven have been determined for the Texas test watersheds. These values as well as Hawkins k and CN and Williams CN for each watershed are tabulated in Table 2.1.2. In a preliminary examination of the data, a poor correlation was found between measured CN and spectral reflectance. These data may be influenced by a difference in one or more surface conditions

Table 2.1.1

Hawkins CN for Arizona and New Mexico Watersheds

Watershed	Area (ac)	Hawkins k	Hawkins CN for 5" rain
W. Fk. Sycamore Cr.	2931.2	.27	47.78
E. Fk. Sycamore Cr.	2873.6	.28	48.62
Whitespar A-3	302.89	.17	40.75
Beaver Cr. W-4	346	.52	65.69
Beaver Cr. W-8	1802	.48	62.90
Beaver Cr. W-10	571	.48	62.95
Beaver Cr. W-13	910	.43	59.23
Beaver Cr. W-18	242	.65	74.75
Atterbury W-2	2944	.25	46.53
Atterbury W-3	300.8	.30	49.66
Walnut Gulch W-3	2220	.39	56.60
Walnut Gulch W-4	560	.55	67.85
Walnut Gulch W-11	2035	.52	65.80
Safford W-1	519	.47	62.18
Safford W-2	682	.48	63.19
Safford W-4	764	.37	54.98
Safford W-5	723	.32	51.59
Willow Cr.	298	.22	44.64
E. Fk. Castle Cr.	1163.19	.38	55.57
N. Fk. Thomas Cr.	467	.19	41.84
S. Fk. Thomas Cr.	562	.18	41.59
E. Fk. Seven Springs	748	.14	38.79
Albuquerque W-1	97.2	.52	65.90
Albuquerque W-2	40.5	.57	69.38
Albuquerque W-3	168	.46	61.75

Table 2.1.2 Texas Watersheds Ranked Based on CN for 7" Rainfall (Hawkins)

	Area (mi^2)	Hawkins k	Hawkins CN	Williams CN	u_4	u_5	u_6	u_7	u_5-u_4	$(u_5-u_6)-(u_4-2u_7)$
Little Pond Cr.	22.2	.69	75.89	75.45	27.16	22.34	22.49	10.23	-4.82	-2.85
Bois d Arc Cr.	72.0	.67	74.33	80.80	30.64	26.78	37.33	19.46	-3.86	-5.45
North Elm Cr.	48.6	.62	70.44	75.87	23.86	20.25	21.25	10.74	-3.61	-3.84
Honey Cr.	39.0	.59	68.11	82.17	30.89	27.45	35.84	18.22	-3.44	-4.04
Lavaca R.	108.0	.53	63.44	76.06	22.37	19.79	23.47	13.50	-2.58	-6.11
Elm Fork	46.0	.44	56.44	77.96	26.75	24.25	31.50	14.65	-2.50	-0.30
Cibolo Cr.	68.4	.42	54.89	74.08	20.44	17.89	23.49	13.14	-2.55	-5.34
S. Fork San Gabriel	127.0	.37	51.00	79.27	20.69	18.64	23.30	12.84	-2.05	-4.43
Green Cr.	46.1	.34	48.67	64.82	31.64	29.45	38.80	19.64	-2.19	-2.67
Mukewater Cr.	70.0	.34	48.67	69.56	32.39	31.41	36.72	17.76	-0.98	+0.22
S. Fork Rocky Cr.	34.2	.28	44.00	76.08	21.50	20.11	23.82	12.89	-1.39	-3.35
Pecan Bayou	100.0	.68	75.11	78.81	26.68	22.32	35.51	19.46	-4.36	-7.77
Little Elm Cr.	75.5	.65	72.78	78.06	31.90	28.41	39.69	20.35	-2.49	-3.50
Tehuacana Cr.	142.0	.60	68.87	71.82	22.40	19.53	25.60	13.64	-2.87	-4.55
Big Bear Cr.	29.6	.53	63.44	73.50	28.02	25.71	34.39	16.08	-2.31	-0.08
North Cr.	21.6	.45	57.22	69.69	29.41	25.86	32.78	16.29	-3.55	-3.35
Middle Bosque R.	182.0	.42	54.89	75.63	25.36	21.57	24.73	11.86	-3.79	-2.78
Cow Bayou	85.0	.41	54.11	75.98	26.27	22.35	26.37	12.69	-3.92	-2.93
N. Fork Hubbard Cr.	38.4	.36	50.22	64.98	31.05	26.53	36.40	18.29	-4.52	-4.70
Berry Cr.	81.8	.34	48.67	77.64	20.52	18.52	23.67	13.05	-2.00	-4.43
Deep Cr.	43.9	.34	48.67	64.77	31.14	27.48	35.99	17.98	-3.66	-3.63
Calaveras Cr.	77.2	.27	43.42	60.86	26.86	26.00	31.31	16.77	-0.86	-3.09

not identified in the previous study on the Chickasha watersheds in Oklahoma (Blanchard, 1974).

In an attempt to explain the poor correlation between measured CN and space data, several physical characteristics of the watersheds were determined. Geologic formations, soil type, portion of the watershed in timber, average permeability of the soil in each watershed, and antecedent precipitation index (API) for the date of Landsat coverage were some of the characteristics considered. The information in Table 2.1.3 summarizes the physical characteristics of the Texas watersheds. The geology of each watershed is denoted by a symbol (Geological Highway Map of Texas, 1974), and area extent of the formation in that particular watershed is given. Table A.1 in the Appendix gives a description of each symbol representation by era, system, series, group, formation, and type of rock or mixtures of rock. Soil type and area extent (General Soil Map of Texas, 1973) in each watershed is the second column of information in Table 2.1.3. Here again, symbol representation is defined in the Appendix, Table A.2. Names of soil series that make up the particular symbol and the extent of their occurrence are listed in this table. A short description of the soils is given as well as the major land use and permanent vegetation on these soils. Timber cover, presented as percent

Table 2.1.3 Physical Characteristics of the Texas Test Watersheds

Watershed	Geologic Symbol and Area Extent (%)	Soil Type and Area Extent (%)	Timber Cover (%)	Average Permeability (in/hr)	API for Date of Landsat Scene
Honey Cr.	Kul_c - 100	14V - 100	2.1	0.11	0.30
S. Fork San Gabriel	Kl_a - 50	53M - 100	23.3	.19	.17
	Kl_b - 50				
Little Elm Cr.	Kul_b - 100	15A - 30	2.4	.34	.37
		14V - 50			
		17M - 20			
Berry Cr.	Kl_a - 5	53M - 100	25.7	.19	.21
	Kl_b - 95				
Lavaca R.	Tm - 100	16V - 90	3.6	.40	.61
		15A - 10			
N. Elm Cr.	Kuu_1 - 100	14V - 100	4.6	.11	.92
Little Pond Cr.	Kuu_1 - 100	14V - 100	1.2	.11	1.06
Big Bear Cr.	Kul_a - 95	22A - 100	11.9	1.86	.06
	Kul_b - 5				
North Cr.	IPv - 100	41A - 95	40.0	.97	.12
		42A - 5			
N. Fork Hubbard Cr.	Pl_1 - 100	48M - 100	32.3	.24	.52
Deep Cr.	Kl_a - 5	41A - 95		.87	.45
	IPd - 5	48M - 5			
	IPmi - 90				
Bois d' Arc Cr.	Kul_c - 100	14V - 100	2.3	.11	.30

Physical Characteristics of the Texas Test Watersheds (Continued)

Watershed	Geologic Symbol and Area Extent (%)	Soil Type and Area Extent (%)	Timber Cover (%)	Average Permeability (in/hr)	API for Date of Landsat Scene
Pecan Bayou	Kul_c - 100	15A - 40	57.6	.47	.61
		19A - 60			
Elm Fork	Kl_a - 15	52M - 95	4.2	.46	.13
	Kl_b - 85	21A - 5			
S. Fork Rocky Cr.	Kl_a - 100	53M - 100	6.7	.19	.09
Cow Bayou	Kuu_1 - 75	14V - 97	3.8	.12	1.81
	Kul_2 - 15	17M - 3			
	Kul_c - 10				
Middle Bosque R.	Kl_b - 30	52M - 100	9.8	.27	1.14
	Kl_c - 70				
Cibolo Cr.	Kl_a - 60	55M - 100	34.3	.21	.05
	Kl_b - 40				
Tehuacana Cr.	Te_1 - 50	18A - 70	12.8	1.12	1.02
	Te_2 - 50	15A - 30			
Mukewater Cr.	IPv - 100	41A - 85	13.6	.81	.28
		48M - 15			
Green Cr.	Kl_a - 90	21A - 100	5.7	4.10	.22
	Kl_b - 10				
Calaveras Cr.	Te_1 - 10	14V - 40	14.0	1.58	.07
	Te_2 - 90	24A - 60			

of total watershed area, Table 2.1.3, was estimated from United States Geological Survey (USGS) topographic maps by measuring the green shaded area inside the watershed boundaries. Average permeability of the soil in each watershed was determined from the surface layer infiltration rate for the different soils in the watershed. Appendix Table A.3 shows the permeability for the different soil series encountered in the Texas watersheds (Soil Conservation Service, 1976). The last column of Table 2.1.3 lists the actual API value for the watershed on the date of Landsat coverage. Landsat scenes were ordered on the basis of low regional API values with the assumption that the antecedent moisture conditions were not very much different throughout the area of coverage. However, as shown by the API values, this was not the case for a number of watersheds.

2.2 Problem Areas

None.

2.3 Recommendations

None.

2.4 Accomplishments Expected During the Next Quarter

Rainfall and runoff data will be processed for the USGS gauged watersheds that were selected in Arizona.

These watersheds will also be outlined on USGS topographic maps.

Landsat scenes will be selected that have the best coverage for the test watersheds in Arizona and New Mexico. Computer compatible tapes corresponding to these scenes will be ordered.

Watershed boundary points in latitude and longitude will be taken from topographic maps of the watersheds and tabulated. These points will be converted into records and pixels, respectively, so that watershed boundaries can be outlined on greymaps of the area of interest.

A more detailed analysis of the spectral data for the Texas watersheds will be undertaken. Hopefully, the physical data gathered on these watersheds will explain the scattering of data points.

3.0 SIGNIFICANT RESULTS

3.1 Significant Results

None.

3.2 Presentations

None.

REFERENCES

1. Blanchard, Bruce J. 1974. Investigation of use of space data in watershed hydrology. USDA Southern Great Plains Research Watershed Chickasha, Oklahoma.

2. General Soil Map of Texas. 1973. Published by Texas Agricultural Experiment Station, Texas A&M University in cooperation with Soil Conservation Service. U. S. Department of Agriculture.

3. Geological Highway Map of Texas. 1973. United States Geological Highway Map Series, Map No. 7. Published by the American Association of Petroleum Geologists with the cooperation of the United States Geological Survey.

4. Hawkins, Richard H. 1973. Improved prediction of storm runoff in mountain watersheds. Journal of the Irrigation and Drainage Division, Proceedings of the ASCE 99(IR4).

APPENDIX

Table A.1 Geology of the Texas Test Watersheds

Kul_a	ERA	Mesozoic
	SYSTEM	Upper Cretaceous
	SERIES	Gulfian
	GROUP	Woodbine
	FORMATIONS	Woodbine - sandstone, shale, sandstone Pepper - shale
Kul_b	ERA	Mesozoic
	SYSTEM	Upper Cretaceous
	WERIES	Gulfian
	GROUP	Eagle Ford
	FORMATION	Eagle Ford - shale, limestone, shale South Bosque - shale Lake Waco - shale, limestone, shale
Kul_c	ERA	Mesozoic
	SYSTEM	Upper Cretaceous
	SERIES	Gulfian
	GROUP	Austin
	FORMATIONS	Austin - limestone Tokio - sandstone, shale, conglomerate Gober - limestone Brownstown - marl Blossom - sandstone Bonham - marl
Kl_a	ERA	Mesozoic
	SYSTEM	Lower Cretaceous
	SERIES	Comanchean
	GROUP	Trinity
	FORMATIONS	Paluxy - sandstone
	Subsurface	Rusk - limestone, shale, anhydrite Ferry Lake - anhydrite Rodessa - limestone Pearsall - shale, limestone, shale Sligo - limestone Hosston - sandstone, shale, sandstone Glen Rose - limestone, dolomite, limestone, dolomite, limestone Twin Mountains/Travis Peak - sandstone, shale, sandstone, shale, sandstone
Kl_b	ERA	Mesozoic
	SYSTEM	Lower Cretaceous
	SERIES	Comanchean
	GROUP	Fredericksburg
	FORMATIONS	Goodland - mixture of limestone & shale Edwards - limestone Comanche Peak - mixture of limestone & shale Walnut - mixture of limestone & shale, limestone, marl

Kl_c	ERA	Mesozoic
	SYSTEM	Cretaceous
	SERIES	Comanchean
	GROUP	Washita
	FORMATIONS	Buda - limestone
		Grayson - shale
		Del Rio - shale
		Main Street - limestone
		Pawpaw - sandstone, mixture of sandstone & shale
		Weno - limestone
		Denton - shale
		Fort Worth - limestone
		Duck Creek - limestone & shale mixture, limestone
		Kiamichi - shale, limestone, shale
		Georgetown - limestone, shale, limestone, shale, limestone
Kul_2	ERA	Mesozoic
	SYSTEM	Upper Cretaceous
	SERIES	Gulfian
	GROUP	Austin
	FORMATIONS	Austin - limestone
		Gober - limestone
		Brownstown - marl
		Blossom - sandstone
		Bonham - marl
		Tokio - sandstone, shale, sandstone, shale, sandstone, conclomerate
	GROUP	Eagle Ford
	FORMATIONS	Eagle Ford - shale, limestone, shale
		South Bosque - shale
		Lake Waco - shale, limestone, shale
Kuu_1	ERA	Mesozoic
	SYSTEM	Upper Cretaceous
	SERIES	Gulfian
	GROUP	Taylor
	FORMATIONS	Taylor - shale
		Annona - limestone
		Marlbrook - marl
		Pecan Gap - marl
		Wolfe City - sandstone
		Ozan - marl

Te_1	ERA	Cenozoic
	SYSTEM	Tertiary
	SERIES	Paleocene
	GROUP	Midway
	FORMATIONS	Wills Point - shale Kincaid - shale & sandstone, sandstone with conglomerate
Te_2	ERA	Cenozoic
	SYSTEM	Tertiary
	SERIES	Eocene
	GROUP	Wilcox
	FORMATIONS	Calvert Bluff-Sabinetown - shale Simaboro-Rockdale-Pendleton - sandstone, shale, sandstone Hooper-Seguin - sandstone, shale, sandstone, shale, sandstone, shale
Tm	ERA	Cenozoic
	SYSTEM	Tertiary
	SERIES	Miocene
	GROUP	Fleming
	FORMATIONS	Fleming - sandstone & shale mixture Lagarto - shale Oakville - shale & sandstone mixture, sandstone
	GROUP	Catahoula
	FORMATIONS	Catahoula - sandstone with shale outcrops & shale mixture Anahuac - shale (subsurface) Frio - shale with sandstone outcrops
ℙd	ERA	Paleozoic
	SYSTEM	Pennsylvanian
	SERIES	Desmoinesian
	GROUP	Lone Camp
	FORMATIONS	Capps - limestone Ricker - sandstone, sandstone & conglomerate mixture Ricker Station - limestone East Mountain - shale Garner - sandstone & conglomerate mixture, shale
	GROUP	Millsap Lake
	FORMATIONS	Grindstone Creek - shale, sandstone, limestone Lazy Bend - limestone

	GROUP	Kickapoo Creek
	FORMATIONS	Rayville - shale, sandstone, limestone Parks - shale with sandstone, limestone Caddo Pool - limestone & chert mexture, sandstone
Pv	ERA	Paleozoic
	SYSTEM	Pennsylvanian
	SERIES	Virgilian
	GROUP	Thrifty
	FORMATIONS	Obregon - shale Chaffin-Crystal Falls - limestone Quinn - shale Parks Mountain - sandstone Breckenridge - limestone Speck Mountain-Blach Ranch - limestone, shale, limestone Ivan - shale & limestone mixture Avis - sandstone & shale mixture with conglomerate sandstone mixture
	GROUP	Graham
	FORMATIONS	Wayland - shale with a little sandstone Gunsight - limestone, sandstone Bluff Creek - shale, limestone & shale, limestone, shale Bunger - limestone Gonzales - limestone & shale mixture, shale Salem School - limestone & shale mixture
Pl_1	ERA	Paleoxoic
	SYSTEM	Permian
	SERIES	Leonardian
	GROUP	Lueders
	FORMATIONS	Lake Kemp - dolomite & limestone Maybelle - dolomite & limestone
	GROUP	Clyde
	FORMATIONS	Talpa - dolomite, limestone, shale, limestone Grape Creek - dolomite, limestone & shale mixture Fulda - sandstone

GROUP	Belle Plains
FORMATIONS	Bead Mountain - dolomite, limestone & shale mixture
	Valera - mixture of shale & anhydrite
	Jagger Bend - limestone
	Voss - shale
	Elm Creek - limestone
	Jim Ned - shale

GROUP	Admiral
FORMATIONS	Fisk/Overall - limestone
	Wildcat Creek - shale
	Hords Creek - limestone
	Lost Creek - shale

Table A.2 Soils of the Texas Test Watersheds

15A Wilson - Crockett-Burleson (40-40-20)
Slightly acid soils with loamy surface layers and cracking clayey subsoils, and noncalcarious cracking clayey soils.

16V Burleson-Heiden-Crockett (40-35-25)
Noncalcarious and calcareous cracking clayey soils; and slightly acid soils with loamy surface layers and cracking clayey subsoils.
Major land uses and potentials: pasture, range, crops
Vegetation: tall grasses, mesquite, and other scrubby deciduous trees

18A Lufkin-Axtell-Tabor (60-30-10)
19A Wrightville-Susquehanna-Muskogee (60-25-15)
Soils with loamy surface layers and mottled gray and red or yellow cracking clayey subsoils.
Major land uses and potentials: pasture, recreation, wildlife, woodland grazing
Vegetation: post oak - tall grass savanna

21A Windthorst-Nimrod-Duffau (60-25-15)
22A Windthorst-Galey-Konawa (60-25-15)
Soils with loamy or sandy surface layers and red or mottled clayey or loamy subsoils.
Major land uses and potentials: residences, urban, crops, woodland grazing
Vegetation: post oak - tall grass savanna

24A Miguel-San Antonio (60-40)
Light colored soils with loamy surface layers and clayey subsoils.
Major land uses and potentials: range, crops, residences, wildlife
Vegetation: short and mid grasses, mesquite trees, thorny brush, cacti

41A Truce-Owens-Waurika (65-25-10)
42A Bonti-Truce-Vashti (35-35-30)
Moderately deep to deep soi's with loamy surface layers and clayey subsoils, and shallow clayey soils.
Major land uses and potentials: range, crops (Waurika), wildlife
Vegetation: mid grasses, short grasses (Owens), mesquite and post oak trees

14V Houston Black-Heiden-Austin (55-30-15)
Dark clacareous mostly cracking clayey soils
Major land uses and potentials: crops, pasture, range, urban
Vegetation: tall grasses

17M Austin-Stephen-Eddy (60-30-30)
Deep to shallow calcareous clayey soils over chalk
Major land uses and potentials: urban, residences, pasture, crops, range
Vegetation: tall grasses, juniper (Eddy)

48M Tarrant-Kavett-Rowena (60-20-20)
Mostly shallow and moderately deep soils over limy earths, red beds, or limestone; some deep soils with loamy surface layers and clayey subsoils
Major land uses and potentials: range, wildlife, crops (irrigated-Rowena)
Vegetation: short and mid grasses, tall grasses, mesquite trees, live oak trees (Tarrant)

52M Denton-Purves-Brackett (40-30-30)
53M Tarrant-Brackett-Denton (50-30-20)
Moderately deep cracking clayey soils, shallow clayey and loamy soils, some stony or gravelly
55M Tarrant-Brackett-Speck (60-30-10)
Shallow stony to gravelly clayey soils, shallow loamy soils, and deep cracking clayey soils
Major land uses and potentials: range, crops (Denton), wildlife, recreation
Vegetation: tall and mid grasses, live oak savanna, juniper (Brackett), mesquite trees

Table A.3 Infiltration Rates for the Various Soils in the Texas Test Watersheds

Soil Series	Depth (in)	Permeability (in/hr)
Wilson	0-06	0.2-0.6
	6-90	<0.06
Crockett	0-08	0.60-2.0
	8-57	<0.06
	57-73	0.06-0.2
Burleson	all depths	< .06
Heiden	all depths	<0.06
Lufkin	0-07	0.6-2.0
	7-46	<0.06
	46-65	<0.06
Axtell	0-08	0.6-2.0
	8-39	<0.06
	39-75	0.2-0.6
Tabor	0-14	0.6-2.0
	14-72	<0.06
Wrightsville	0-16	0.2-0.63
	16-50	0.2-0.06
	50-66	0.2-0.06
Susquehanna	all depths	<0.06

Soil Series	Depth (in)	Permeability (in/hr)
Muskogee	0-14	0.2-0.63
	14-26	0.2-0.63
	26-72	<0.2
Windthorst	0-10	2.0-6.3
	10-38	0.2-0.63
	38-72	0.63-2.0
Nimrod	0-06	2.0-6.3
	6-38	0.2-0.63
Duffau	0-08	2.0-6.3
	8-36	0.63-2.0
Galey	0-14	2.0-6.0
	14-72	0.6-2.0
Konawa	0-09	2.0-6.3
	9-34	0.63-2.0
	34-48	2.0-6.3
Miguel	0-10	2.0-6.0
	10-33	<0.06
	33-60	0.06-0.2
San Antonio	0-08	0.2-0.6
	8-28	0.06-0.2
	28-60	0.2-0.6

Soil Series	Depth (in)	Permeability (in/hr)
Truce	0-08	0.63-2.0
	8-45	0.06-0.2
Owens	all depths	<0.06
Waurika	0-12	0.2-0.63
	12-32	<0.06
	32-60	0.2-0.63
Bonti	0-10	0.63-2.0
Vashti	0-14	2.0-6.3
	14-36	0.63-2.0
Houston Black	all depths	<0.06
Austin	0-15	0.2-0.6
	15-30	0.2-0.6
Stephen	0-08	0.2-0.6
Eddy	0-06	0.2-0.6
	6-10	0.2-0.6
Tarrant	0-10	.06-0.2
Kavett	0-08	0.2-0.63

Soil Series	Depth (in)	Permeability (in/hr)
Rowena	0-08	0.2-0.63
Denton	0-09	0.06-0.2
Purves	0-20	0.2-0.6
Brackett	0-08	0.02-0.63
Speck	0-08	0.2-0.6
	8-18	0.06-0.2