5. SUMMARY, CONCLUSIONS, IMPLICATIONS AND FUTURE RESEARCH NEEDS

5.1 Summary

Soil morphologic and physical properties were studied on three suburban and two rural sites dominated by Cecil (Typic Hapludult, clayey, kaolinitic, thermic) soils to investigate the role of suburban soil surfaces in infiltration and stormwater runoff. Significant proportions of the suburban sites (44.6 to 67.3%) were composed of disturbed soil profiles. Some soils had been excessively disturbed, thus often taxonomically yielding a new soil.

The suburban landscape is dominated by soil surfaces. Soil surfaces comprised 58.1 to 72.9% of the suburban sites studied, while impervious surfaces accounted for 27.1 to 39.1%. County soil surveys of metropolitan areas by the National Cooperative Soil Survey do not provide a sagacious assessment of the soils, nor the relative percent of impervious cover. The "urban complex" mapping units of the National Cooperative Soil Survey provides limited useful information for urban watershed planning and engineering. The nature and extent of excessively disturbed urban soils is normally not included in county soil surveys.

Typic Hapludult soil series are probably too broadly defined to allow for meaningful soil classification for urban purposes. Fine and very fine (clayey) family soil texture criteria should be established in the Ultisol order. Innovative use of soil phases can provide for more meaningful urban soil maps. Mapping, classification and characterization of disturbed urban soils is necessary for accurate assessments of suburban watershed hydrology.

Laboratory soil-water data were determined for 365 undisturbed soil cores. The volume of macroporosity (60-cm^{-1} tension) is closely correlated to the saturated hydraulic conductivity of the soil cores. Disturbed soil profiles had greater bulk densities, lower volume of macroporosity and slower saturated hydraulic conductivities than undisturbed soil profiles. These trends were most notable in subsoil core samples.

Soil-water characteristics of disturbed soil profiles were significantly different from undisturbed soil profiles. Data for the Sudbury Suburban Watershed indicate that the volume of macropores in subsoils of disturbed sites was 15.7 to 72.3% of that for forested sites, while the saturated hydraulic conductivity was 0.5 to 24.2% of that for forest subsoils. The conversion of forest to suburban soil conditions produces a markedly different soil-water environment. The saturated hydraulic conductivity of disturbed subsoils on the Mine Valley Subdivision was 7.9 to 41.1% of that of forest subsoils. The saturated hydraulic conductivity of disturbed subsoils on the Meredith Townes Subdivision was 11.7 to 15.7% of that of forest subsoils.

The laboratory soil-water physical data for the Schenck Pasture and Schenck Forest watersheds illustrate highly structured porous soils that have mean saturated hydraulic conductivities in the subsoil of greater than 5 cm/hour.

The macro and micromorphology of selected soils were studied to evaluate the soil pore system. The extent of tubular transpedal pore development in the argillic horizon strongly governs the soil-water and infiltration characteristics of the profiles. Tubular transpedal pores were generally well developed in forest soil profiles, but were lacking in samples studied from old cultivated fields with dense plow pans and disturbed suburban subsoils. Man-made disturbance of argillic horizons can produce significant alteration to the soil fabric producing a collapse and filling most notably of the larger pores and, or blockage of their continuity.

Man-made disruption, transport and deposition of clayey soil material produces a resultant soil with distinctive micromorphological characteristics. Pedorelicts and remnants of diagnostic argillic horizons were commonly found in the "man-made" soils studied. Both the cutting and filling of soil material create distinct macro and micro-morphologic characteristics in the resultant soils, that can serve as diagnostic criteria in the recognition and classification of these soils. Loamy and clayey "man-made" fill soils were found to invariably contain remnants of argillic diagnostic horizons. These soils would normally be classified as Arents.

Man-made cutting into an argillic horizon was found to produce a resultant soil with a thin fill or mixed layer with pedorelicts or remnants of the argillic horizon over the remainder of the previous profile. Depending upon the amount of or lack of a remaining argillic horizon, these soils would normally be classified as Typic Hapludults ($\geq$25 cm of argillic), Ochreptic Hapludults (<25 cm of argillic) or Typic Udorthents (no argillic).

Double-ring constant head flooding infiltrometers were used to conduct 136 infiltration tests on various soil conditions (land types) on the five research sites. Infiltration tests were made under both moist and wet antecedent soil moisture conditions. Suburban infiltration curves had such an early and sharp transition from the early falling limb to the slower constant rate of decline or steady state rate, that it was necessary to make semi-log plots of the curves. The transition to a steady state rate or a slow constant rate of decline generally occurred within 5 minutes for wet antecedent suburban soil conditions.

Significant differences occurred among the final constant infiltration rates. Land types that consisted of disturbed soil profiles had significantly lower infiltration rates than land types of undisturbed soils. Final constant infiltration rates of excessively disturbed soils of the Sudbury Suburban Watershed were 1 to 5% of those of forest soil profiles, and 3 to 16% of those for the least disturbed urban soil profiles. Significantly lower final constant infiltration rates were measured for disturbed soil profiles (cut and fill land types) than undisturbed soil profiles on all sites. The mean final constant infiltration rates for Schenck Forest and Schenck Pasture Watersheds were sufficiently high (>8 cm/hour) to only rarely produce appreciable runoff.

The final constant infiltration rates measured for the various soils do not agree with USDA soil hydrologic groups. Cecil Series soils are rated by the USDA to have a final constant infiltration rate of 0.38 to 0.76 cm/hour. Essentially the only measured final constant infiltration rates less than 1.00 cm/hour occurred for disturbed soil conditions. Forest, pasture and relatively undisturbed suburban soils generally had final constant infiltration rates significantly greater than 1.00 cm/hour.

Estimates of percent runoff from the various soil surfaces were calculated from wet antecedent infiltration data with an infiltration excess method. Estimated percent of runoff for short duration rainstorms was found not to agree with traditional runoff coefficients used in the rational method of runoff estimation.

Infiltration rates were compared to rainfall-runoff records for the Sudbury Suburban, Schenck Pasture and Schenck Forest Watersheds. Total runoff for short duration convective rainstorms varied between 17.5 and 80.4% for Sudbury Suburban Watershed, 0.1 and 24.6% for Schenck Pasture Watershed and 0.7 and 21.5% for Schenck Forest Watershed. Percent total runoff was most sensitive to 1-day antecedent rainfall (r2= 0.931) for Sudbury Suburban Watershed. While, percent total runoff was most sensitive to 5-day antecedent rainfall (r^2 = 0.691) for Schenck Forest Watershed and to 10-day antecedent rainfall (r^2 = 0.560) for Schenck Pasture Watershed.

Estimates of direct runoff were calculated from infiltration data with an infiltration excess method for the Sudbury Suburban Watershed. Estimates of direct runoff for three rainfall-runoff events were found to closely agree with the actual direct runoff by hydrograph separation. Runoff from soil surfaces was estimated to represent 40 to 50% of the direct runoff for the most severe rainstorm events on record for the Sudbury Suburban Watershed. Runoff from soil surfaces appears to sufficiently coincide in space and time with runoff from impervious surfaces to produce the record flooding. Runoff from excessively disturbed soils appears to be an important to dominant factor in the generation of mean maximum annual and larger floods.

5.2 Conclusions

Suburban soils and soil conditions were found to be substantially different than that for analogous undisturbed soils. Suburban and urban soils have been sufficiently disturbed to create significantly different soil-water environments than for undisturbed soils.

The soil conditions on suburban Piedmont watersheds greatly affect the watershed hydrology. Infiltration rates for suburban disturbed soils can have one to two orders of magnitude lower final constant rates. Although suburban infiltration rates are extremely heterogeneous, they appear to correlate with recognizable land types occurring across the suburban landscape. Significant soil disturbance appears to occur on a minority of suburban soil surfaces, but is a major factor in the generation of stormwater runoff.

Use of the USDA soil hydrologic group rating for the Cecil series is inappropriate for suburban conditions. USDA soil hydrologic groups consistently under-estimated the final constant infiltration rates for undisturbed forest, pasture and suburban soils that were studied.

Runoff from disturbed soils appears to sufficiently coincide in time and space with runoff from impervious surfaces to contribute to the peak of the flood hydrograph. The antecedent rainfall dramatically governs runoff production from the soil surfaces. Critical stormwater runoff discharges appear to only occur with 1 to 2-day wet antecedent rainfall conditions. An average infiltration value for a suburban watershed does not reflect the soil variability and thus does not provide for the multiplicity of infiltration and runoff rates. Suburban soil runoff appears to occur primarily from partial source areas consisting of disturbed soils. Reasonably accurate metropolitan stormwater modelling for the Piedmont region requires deterministic soil hydrologic evaluations rather than use of USDA soil hydrologic groups and more detailed soil maps than county soil surveys.

Metropolitan stormwater modelling can be improved by the accurate use of soil-water and infiltration data. Accurate soil hydrologic data

should be obtained for the major soils and soil conditions in the urban area. Soil hydrologic data should be carefully scrutinized with detailed rainfall-runoff records for locally monitored small suburban and urban watersheds.

The use of the various infiltration equations will not necessarily improve runoff prediction without the proper selection or estimate of final constant infiltration rates which are so all determining. Infiltration equations, e.g., Horton's equation, with a negative exponent should produce the best results, because a more rapid decay to the final constant infiltration rate can be achieved.

The amount of impervious surfaces, disturbed soil surfaces and relatively undisturbed soil surfaces should be determined or estimated for the watershed in question. Final constant infiltration rates should be determined or estimated for various soil conditions; at least disturbed and undisturbed soil surfaces. Runoff should be modelled for impervious, disturbed soil surfaces and undisturbed soil surfaces separately. This can be theoretically accomplished by modelling these three areas as separate flows, i.e., partial source areas, until they reach a common conduit or channel. The timing of these flows is critical; therefore, averages of distinctly different final constant values should not be made. The time of travel of soil-generated runoff must be considered in reference to the average distance before runoff waters are intercepted by impervious surfaces or conduits.

5.3 Implications and Future Research Needs

One of the most disturbing general conclusions that can be drawn from this research is that most currently available soils data and techniques for estimating suburban infiltration and runoff are inappropriate. This might be expected since there has been a virtual lack of soil hydrologic research in urban areas. Hopefully, the findings in this research effort will (1) provide a more precise understanding of the problem(s), (2) provide useful typical soil-water data of clayey kaolinitic Piedmont suburban soils and (3) stimulate academic and professional interest in suburban soil and hydrologic studies.

The focus of this research was aimed at developing a more precise understanding of suburban soils and their influence on watershed hydrology. The research findings tend to disagree with many perceptions and professional practices in current use. The lack of agreement between the author's data and the USDA soil hydrologic group ratings suggests that fundamental problems exist in runoff estimation.

The practice of runoff estimation needs to be more closely related to actual discharge data from small suburban watersheds. The largest source of such data which is available for the North Carolina Piedmont was collected by the USCS for Putnam's (1972) study. Further analysis and study of Putnam's rainfall-runoff data is recommended. Correlations between the rainfall-runoff data and antecedent rainfall, soils and watershed conditions should be investigated.

Control of the rate and velocity of stormwater runoff in suburban areas can theoretically be accomplished by reducing the volume of runoff production. Increased detention of rainfall in suburban soils will necessitate improved soil and agronomic management. Research will be necessary to determine effective and efficient soil and agronomic techniques. The effectiveness of soil management techniques should be evaluated from hydrologic measurement of watershed experimentation.

Suburban soil hydrologic management may provide one of the more reasonable means of reducing stormwater runoff, controlling downstream streambank degradation, reducing urban soil erosion and improving water quality.

Minimizing soil disturbance during urbanization will reduce runoff production. Although runoff reduction can be accomplished by lower development densities, this practice only redistributes rather than solves the problem. Fundamental changes to reduce the volume of runoff can occur by (1) planning suburban development to more closely fit the natural terrain, i.e., reducing cutting and filling; (2) increasing common open space by clustering development; (3) transferring stormwater runoff from impervious surfaces onto adjacent open space and (4) reducing the amount of impervious surfaces.

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