RELATIONSHIP OF FOREST DESTRUCTION AND SOIL DISTURBANCE TO INCREASED FLOODING IN THE SUBURBAN NORTH CAROLINA PIEDMONT[1]

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ABSTRACT. A research study was conducted to determine the significance of soil disturbance, urban vegetation and infiltration in suburban stormwater management. A considerable amount of suburban land is commonly denuded and soil sufficiently disturbed to produce a marked increase in downstream flooding. Sensitive land use planning can significantly reduce the amount of tree destruction and soil disturbance during urban development. Reclamation of disturbed sites through urban soil and tree management has the potential to significantly increase the low infiltration conditions thereby reducing the volume of stormwater runoff.

Urban areas have always been plagued by drainage problems and flooding due to the impact of intense rainstorms, while forests and managed landscapes generally have sufficiently intact trees and soil conditions to avoid significant stormwater runoff problems (Dunne, et al 1975; Hewlett and Nutter 1970). Management of trees and soils in urban and suburban areas offers a means to minimize stormwater runoff, to maintain a base flow in streams and to improve water quality. Unnecessary destruction of trees and disturbance of soils during metropolitan development creates increased water management problems.

The hydrology of suburban watersheds is greatly dependent upon the amount and condition of vegetation and soils present after urbanization (Leopold 1968). It has been well recognized that water runoff increases with construction of buildings, roads, etc. in the watershed (Carter 1961; Putnam 1972). However, little thought has been given to actually reducing water management problems by carefully managing trees and soils during and after urbanization (Felton and Lull 1963; Kelling and Peterson 1975). The intent of this paper is to illustrate some tree and soil management approaches that

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[1] Metro. Tree Impr. Alliance (METRIA) Proc. 3:118-125, 1980.

have been developed through a research study in the suburban Piedmont province of North Carolina (Kays 1979). Although the research study was primarily directed towards soil-water management, vegetation is the principle strategy. The Sudbury Watershed in Charlotte, North Carolina will be used to illustrate this suburban water, tree and soil management approach.

We all know that trees and soil will aid in the retention of rainfall and thus will decrease and slow runoff to the stream. In order for the natural system to aid in urban stormwater engineering, the natural processes must work under most adverse climatic conditions; that is, short duration high intensity rainstorms that follow wet antecedent conditions. In other words, a sudden torrential rainstorm that occurs after at least one day of antecedent rain. How do we make the natural system work for these rare events . . . rain events that occur once every five to ten years in which severe flood damage may occur?

Historically the Sudbury Watershed (150 ha) in Charlotte, North Carolina had agricultural and forest land uses (Figure I). By 1968 (Figure II) the watershed had become completely urbanized. This study area was selected to measure infiltration and runoff. The dominant soul conditions on the watershed are given in Table I. These clayey subsoils are naturally quite infertile.

TABLE I

Dominant Upland Soil on Sudbury Watershed
Charlotte, NC

Soil Classification:	Typic Hapludult , Clayey, Kaolinitic, Thermic, Cecil Series
Subsoul Properties:	
Particle size –	Sand 20 – 30% Silt 15 – 20% Clay 50 – 60%
Base saturation –	12 – 16%
Cation exchange capacity, pH 7 –	7-8 Meg / 100 g
Clay mineralogy –	57 – 58% Kaolinite

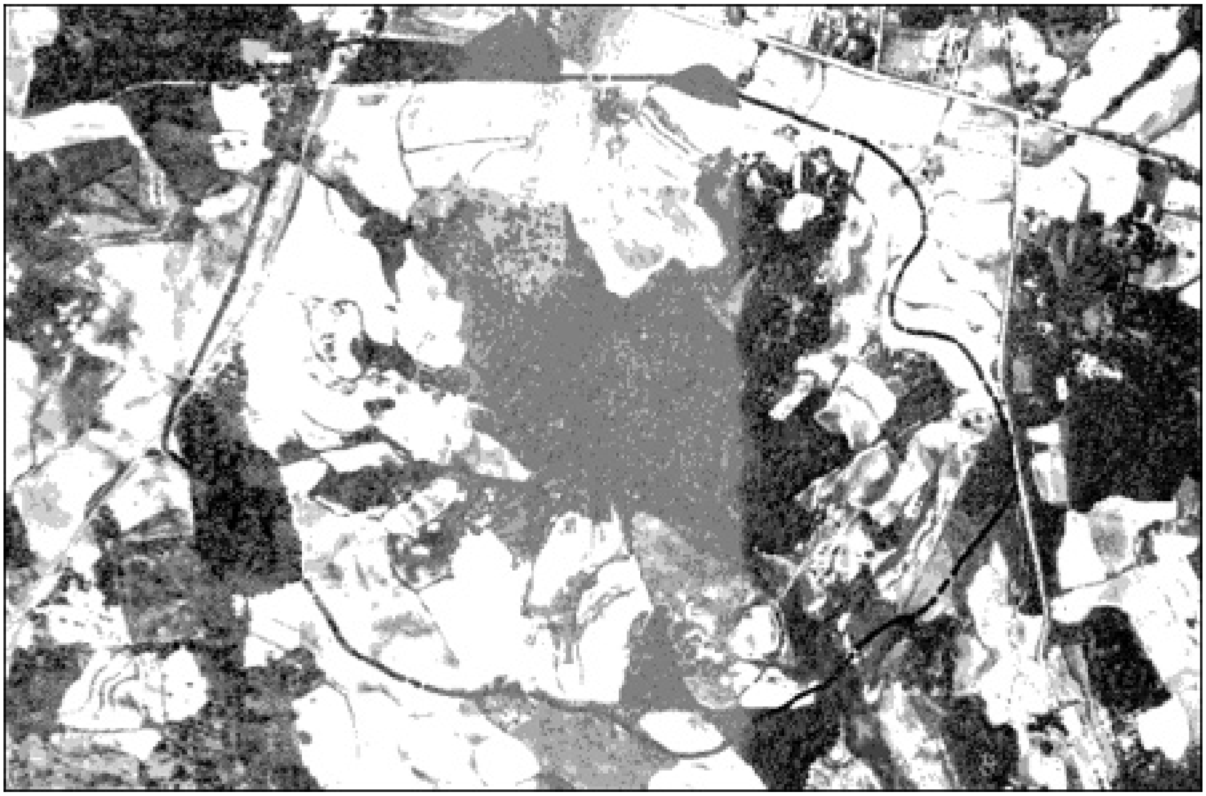

FIGURE I – 1938 airphotograph of Sudbury Watershed, Charlotte, NC

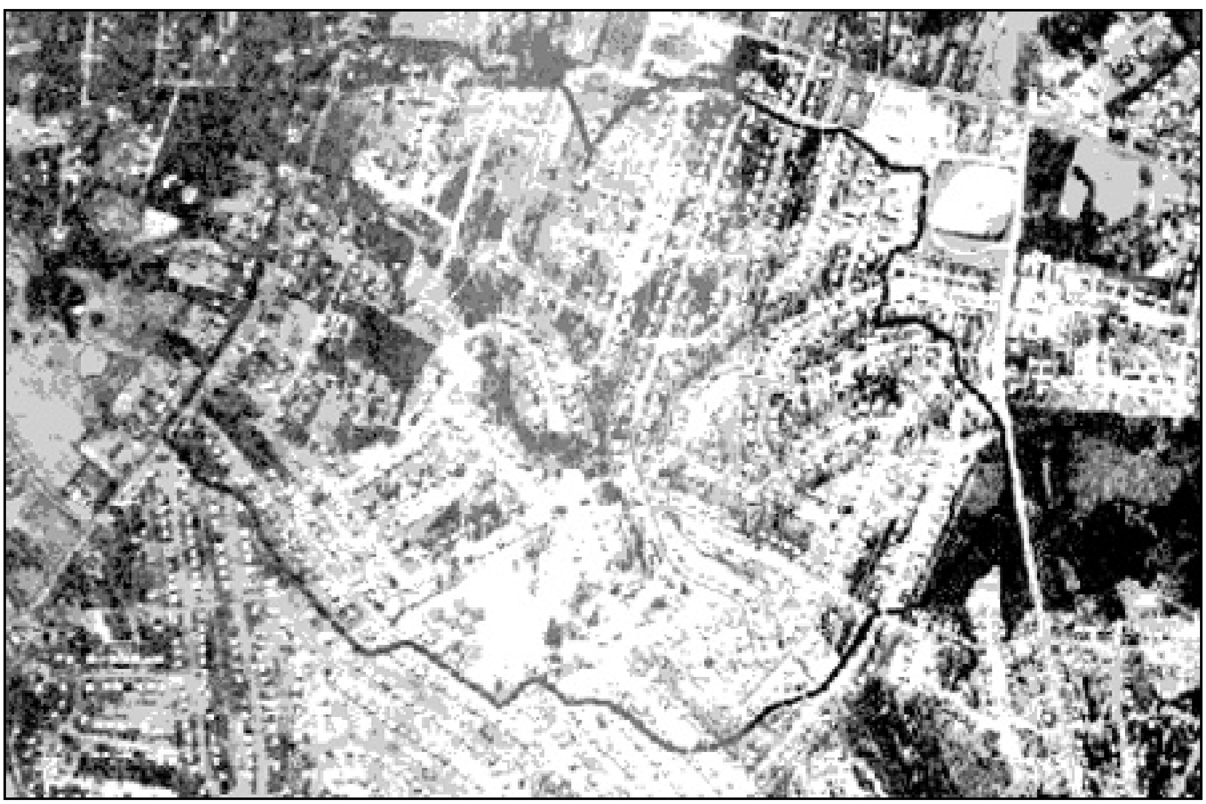

FIGURE II – 1968 airphotograph of Sudbury Watershed, Charlotte, NC

The United States Geological Survey monitored the watershed from 1966 through 1970 (Putnam 1972). Short duration rainstorms of less that 60 minutes produced from 18 to 80% runoff depending upon the antecedent rainfall conditions. Although 27.1% of the watershed is covered by impervious surfaces, only about 18% runoff occurred with dry antecedent conditions. Up to 80% runoff was produced with wet antecedent conditions.

TABLE II

Selected Rainfall Runoff Events
Sudbury Watershed, Charlotte, NC
United States Geological Survey Data

Storm Rainfall cm	One-Day Amt. Rain cm	Peak Runoff cms	Volume Runoff ha-m	Percent Watershed Runoff
4.67	4.85	9.68	5.63	80.4
4.34	6.50	12.72	5.12	78.9
3.51	2.01	6.85	2.15	40.6
3.15	1.04	3.28	1.20	25.4
4.72	0.00	4.08	1.34	18.8
5.00	0.25	3.76	1.39	18.2

Infiltration tests were conducted across the watershed on various land types (Table III), which were defined by different soul and vegetation conditions. The medium aged pine-mixed hardwood forest conditions had a mean final constant infiltration rate of 31.56 cm / hr. When the forest understory and leaf litter was removed, the resultant residential lawns had a mean infiltration rate of 11.20 cm / hr. Suburban development on old cultivated fields produced a 4.78 cm / hr. mean rate. Four land types of disturbed conditions all had infiltration values less than two orders of magnitude less than that for the native forest conditions. Infiltration rates less than 2.00 cm / hr. accounted for about 36% of the watershed. By adding the 27% impervious surfaces, the watershed is essentially 63% “impervious’.

The most immediate and economical way to have high infiltration rates after urbanization is to retain as much undisturbed forest and undisturbed soul areas as possible. This can be done during urbanization through sensitive land planning. The Atlanta Regional Commission is attempting to accomplish this in addition to regulating the amount of impervious surfaces on a large urbanizing watershed in Atlanta.

TABLE III

Infiltration Rates by Land Type
For Sudbury Watershed, Charlotte, NC

Land Type	Percent of Watershed	Mean Final Constant Infiltration Rate cm / hr.
Medium aged pine-mixed hardwood forest with leaf litter	2.6	31.56
Slightly disturbed soils with lawns and large trees preserved	23.8	11.20
Slightly disturbed soils, previously cultivated field, lawns and few young trees	9.1	4.78
Slightly disturbed souls, previously cultivated field with plow pan, lawns and few trees	8.7	0.70
Highly disturbed fill soils, lawns and few young trees	7.1	1.25
Highly disturbed cut soils, lawns and few young trees	15.1	0.67
Highly disturbed cut and compacted soils, sparse grass, no trees	4.7	0.45
Wet drainage ways, bottom-land hardwoods	1.7	—
Impervious surfaces	27.1	—

The difficult question is how to regain high infiltration rates on those areas inevitably disturbed during development. There are two primary methods to increase infiltration. First is to simply add topsoil. However the addition o f topsoil can be extremely expensive. For example, to add an average of 15 cm of topsoil across the soil surfaces on the Sudbury Watershed (see Table IV) it would cost in excess of 2.1 million dollars. The second method recognizes the fact that the critical rainstorm occurs with wet antecedent conditions of antecedent rainfall. Therefore it is necessary to achieve more rapid downward movement of the antecedent rainfall so that a greater infiltration capacity is developed prior to the critical intense rainstorm. More rapid soil drainage will require deep root development of vegetation, especially trees. Planting of trees species that will root deep into these infertile clayey subsoils would be required.

TABLE IV

Estimated Topsoil, Drainage and / or Rooting Depths Required to Increase Infiltration of Hypothetical 5 cm, 30-Minute Duration Rainstorm with Wet Antecedent Condition, Sudbury Watershed, Charlotte NC[a]

Increased Infiltration cm	Percent Runoff	Required Topsoil Addition[b] cm	Required Topsoil Addition[b] meters^3 x 104	Required 24 hr. Drainage Depth[c] cm	Required Rooting Depth[d] cm
0	80	-	-	-	-
0.5	70	2.5	2.7	10	20
1.0	60	5.0	5.5	20	40
1.5	50	7.5	8.2	30	60
2.0	40	10.0	10.1	40	80
2.5	30	12.5	13.6	50	100
3.0	20	15.0	16.4	60	120

[a] Watershed is 149.9 ha with 109.3 ha of soil surfaces (72.9%).
[b] Topsoil is assumed to have 20% macroporosity.
[c] Required drainage depth assuming subsoil to have 5% macroporosity.
[d] Rooting depth is assumed to be twice the drainage depth.

Most of the common lawn grasses require high levels of fertility to root deeply in these clayey soils. Analysis of soil fertility data on suburban lawns across the watershed indicates extremely infertile conditions. Low levels of P_2O_5 and K_2O and high buffer acidity appear to have severely limited rooting depth. Low phosphorous levels were measured at every sampling location across the watershed and even within 2.5 cm of the soil surface. This rooting depth soil fertility relationship is thought to occur for many of the trees planted across the watershed. This is not to imply that the other factors do not control rooting depth, but rather that the soil fertility was so extremely low that it is assumed to be the most limiting factor. Because of the need to deeply incorporate lime and fertilizer, reclamation of these sites would amount to a major and expensive proposition. Merely adding lime and fertilizer to a tree-planting hole will not suffice. The best recommendation is the use of native trees and cultivars that are adapted to these relatively infertile soil conditions.

Summary. Sensitive land planning controls and incentives that minimize the destruction of the forests and disturbance of the soils should be considered for inclusion in local urban tree, stormwater management and land planning ordinances. Local recommendations should be developed for the reclamation of disturbed sites. The use of deep-rooting trees and grasses that are adapted to the native unamended soils should be recommended.

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