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Maximum Utilization of Water Resources within a Planned Community

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Synopsis

The hydrologic impact of urban development on a watershed can be described in terms of changes in quality of volume of runoff, base flow, peak discharge, time response, surface drainage patterns, groundwater recharge, and sediment production. These factors suggest the possibility that proper land development might not only result in control, but also maximum utilization of a scarce resource---water---and conservation of natural conditions. It is possible, by using the natural environment, to control storm runoff and minimize sediment transport and degradation of the water quality while at the same time retaining and enhancing the natural state and beauty of the land.

A management strategy for the utilization of water resources within the community was developed. This plan includes the use of stormwater, groundwater and treated wastewater in a manner compatible with the natural environment and existing "natural drainage" network. The purpose of the plan was to maximize the use of water resources within the community. While the plan reflects the entirety of water resources activities, the emphasis was on the reuse of urban runoff for recreational and aesthetic purposes.

The study site was The Woodlands, which is a new community being developed in Montgomery County, Texas. The community is situated in a heavily forested area encompassing 7,200 hectares. A total of 33,000 dwelling units are programmed with a projected population of 112,000 in 1992. A concern for nature and convenience for man were two of the major criteria used in the development of the General Plan for The Woodlands. The basis for all aspects of development in The Woodlands was a unique ecological inventory conducted from 1971 to 1973.

Data has been collected to quantify the characteristics of overland runoff within The Woodlands site. Temporal and spatial distribution of key water quality parameters are defined at selected sites on the major drainage network. The data is used to define natural conditions and development changes in the runoff.

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Résumé

L'impact hydrologique du développement urbain sur un bassin versant peut être décrit en termes du changement de qualité du volume de débit, de l'écoulement de base, du débit de pointe, du temps de réaction, des modes du drainage de surface, de la recharge de la nappe phréatique et de la production de sédiment. Ces facteurs suggèrent la possibilité que le propre développement de terrain peut aboutir au contrôle et à l'utilisation maximum d'une rare ressource, l'eau, et à la conservation des conditions naturelles.

Il est possible, par l'emploi de l'environnement naturel, de contrôler le débit de tempêtes, de réduire au minimum le transport de sédiments et la dégradation de la qualité d'eau et, en même temps, de maintenir et d'intensifier l'état naturel et le beauté du terrain.

Une stratégie d'exploitation pour l'utilisation des ressources d'eau disponibles dans la communanté a été developpée. Le plan comprenait l'emploi de l'eau des tempêtes, de l'eau phréatique et de l'eau résiduaire traitée d'une manière convenable à l'environnement naturel et au réseau actuel du "drainage naturel". Le but du plan était de porter au maximum l'emploi des ressources d'eau disponibles dans la communanté.

Bien que le plan reflètait la totalité des activités des ressources d'eau, l'attention était portee, au réemploi du débit urbain dans des utilités d'esthétique et de divertissement.

Le site d'étude était les Woodlands, une nouvelle communanté en état de développement dans le chef-lieu de Montgomery, Texas. La communanté se situe dans une région de forêts touffues de 7200 hectares. Un total de 33,000 unités d'habitation englobant 112,000 habitants en 1992 est projeté.

Le nature et la convenance aux habitants étaient deux des principaux critères dans le développement du plan général pour les Woodlands. La base pour tous les aspects du développement aux Woodlands était un unique inventaire ecologique mené de l'année 1971 à 1973.

Des données ont été rassemblées pour quantifier les caractéristiques du débit de surface dans le site des Woodlands. Les distributions temporales et spatiales des paramètres de qualité de l'eau clef sont définies à des sites choisis sur le réseau principal de drainage. Les données sont employées pour définir les conditions naturelles et les changements de développement dans le débit.

The natural hydrological characteristics of a forested watershed change with the advent of urbanization. Replacement of flow-retarding vegetation with impervious surfaces, such as roads and buildings, increases the amount of stormwater runoff. Removal of the water is traditionally implemented by the use of an urban drainage system consisting of storm sewers and deep, concrete-lined drainage ditches, designed specifically for prompt drainage. Increased runoff volumes and peak flow rates result, creating problems of downstream flooding and channel erosion.

Infiltration of stormwater is a major groundwater recharge source, however the urban emphasis on surface removal minimizes the infiltration rate, resulting in a lowered water table and possible urban land subsidence problems. Water quality in the area becomes generally poorer because the natural purification which infiltration provides is compromised.

The urban environment typified by industry, highways, solid waste and high population density provides a pollutant source for runoff waters. Recent investigations recognize the significance and magnitude of pollution problems from urban stormwater runoff. In terms of specific pollutants, the sediment yield problem is the most dramatic. Due primarily to urban construction, urban sediment loads were found to be as much as 75 times greater than loads in agricultural regions (1-3). Other runoff pollutants which are also higher in the urban regions include dissolved solids (4), coliforms (5), BOD and COD (6), polychlorinated biphenyls, heavy metals, pesticides, and fertilizers (6-9). The combined results of these studies emphasize the significance of the problem.

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1 Wolman, M. G., and A. P. Schick. Effects of Construction on Fluvial Sediment, Urban and Suburban Areas of Maryland. Water Resources Research. 3, p 451. 1967.

2 Guy, H. P., and G. E. Ferguson. Sediment in Small Reservoirs Due to Urbanization. J. Hydraulic Div. ASCE 88, HY2, p 27. 1962.

3 York, T. H., and W. J. Davis. Sediment Yields of Urban Construction Sources, Montgomery County, Maryland. U.S.G.S. Open File Report. 1972.

4 Changes in Quality of Water in the Passaic River at Little Falls, New Jersey. U.S.G.S. Professional Paper 525-D. 1965.

5 Geldreich, E. E., L. C. Best, B. A. Keener, and O. J. Van Donsel. The Bacteriological Aspects of Storm Water Pollution. JWPCF 40, p 1861. 1968.

6 Environmental Impact of Highway Deicing. 11040 Qkk Storm and Combined Sewer Overflows Section, Edison Water Quality Lab, U. S. Environmental Protection Agency. 1971.

7 Bryan, E. H. Quality of Stormwater Drainage from Urban Land. Presented at 7th American Water Resources Conference. Washington, D. C. 1971.

8 Heaney, J. P., and R. H. Sullivan. Source Control of Urban Water Pollution. JWPCF 43, p 571. 1971.

9 Water Pollution Effects of Street Surface Contaminants. EPA Contract No. 14-12-921. URS Research Corp. 1972.

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A unique drainage plan, termed "the natural drainage system", has been proposed to alleviate urban stormwater runoff problems. The "natural drainage" concepts are envisioned as a method of providing adequate drainage and yet minimizing the disruption of natural processes. The primary objectives of the drainage approach are to impede the movement of surface runoff and to recharge stormwater runoff into the ground where feasible. Impediment and storage is provided by modifying the existing drainageways, where necessary, with check dams, storage lakes, wet weather ponds and drainage easements known as swales. Swales are analogous to lateral storm sewers for providing primary drainage. Swales can be described as extremely shallow drainage ditches, less than one meter deep and 30 to 100 meters wide, containing the natural vegetation of the area. The swales and other retention devices are planned where possible, to coincide with areas of maximum soil permeability for high infiltration. A novel feature of the scheme is the provision for small wet weather ponds on individual lots (10).

The water retaining characteristics of "the natural drainage system" will reduce the sediment loads of stormwater runoff. Lower runoff velocities, intrinsic to the system, minimize the sediment transport capabilities of stormwater, while the wet weather storage ponds will serve as sedimentation basins (11).

In southeastern Texas a new town, The Woodlands, is being constructed to incorporate "the natural drainage system" as part of its water management scheme and overall environmental quality plan. In contrast to a residential subdivision, The Woodlands, will contain all services of a modern city, including facilities for social, recreational, educational, commercial, institutional, business and industrial pursuits. The community concept is committed to high standards for environmental and lifestyle quality. The planned, long range development places priority on ecological preservation and balance, as well as social and habitational quality. The objective is to be accomplished through a comprehensive environmental preservation and management program, including planning and design controls.

The community is situated in 7200 hectares of pine-oak forest and will be developed over a twenty year period which began in September, 1972. A total of 33,000 dwelling units are programmed. Housing units planned include single family detached, townhouses and patio, and apartments. The projected population in 1992 is 112,000. At the present time, facilities completed or under construction include: a country club, conference center, golf course, manmade lake, 300 dwelling units and various swales and water retention areas of the "natural drainage system".

The Woodlands water management scheme was developed, after extensive ecological planning, to preserve the present watershed biota, minimize urban

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10 Ecological Analysis and Environmental Management Program - Revised General Plan - The Woodlands, November 16, 1973.

11 Winslow, D. E. and W. H. Espey, Jr. Storm Water Quality Analysis - Phase I - The Woodlands. Prepared for J. A. Veltman, Manager, Design Services, The Woodlands Development Corporation. May 1, 1973.

runoff problems, and maximize the beneficial use of water resources within the community. The management scheme can be simplified by detailing an hydrologic budget or an account of water use in a specific watershed. Figure 1 depicts the water budget for the undeveloped Woodlands site. Inflow to the system by precipitation and artesian flow is balanced with losses through streamflow, runoff, evapotranspiration, evaporation and artesian outflow. The completed city will have a water budget schematically presented in Figure 2. Water losses due to consumptive uses and surface runoff will be balanced by recycling waste water, impounding stormwaters, and groundwater withdrawals (12)

In order to have a total water management package, it is essential that stormwater be handled properly so that water reuse becomes economically attractive and aesthetically beneficial. Present research effort is directed toward characterizing stormwater runoff and quantifying detrimental effects of The Woodlands development.

Runoff from The Woodlands is measured by two streamflow monitoring stations located on Panther Branch, an ephemeral stream draining the area. An upstream station measures runoff from 64.4 km^2 (15,909 acres) forest drainage area, while a downstream station records additional runoff originating from the construction area, 23.05 km^2 (3,697 acres). Differences between the two drainage areas are attributed to the development activities of The Woodlands.

Stormwater samples are collected from the monitoring stations at discrete time intervals during runoff in order to assess changes in water quality as a function of flow rate. Samples are analyzed for suspended solids, total Kjeldahl nitrogen, chemical oxygen demand and total phosphorus, as well as other chemical and physical parameters. Total pollutant loads during runoff are obtained by numerical integration of the chemical concentrations with discharge data.

Although several storm events have been analyzed, a single event will suffice to illustrate the research effort. In December 1974, runoff associated with a short intense thunderstorm was sampled and analyzed. Rainfall, recorded at 4 area rain gauges, was determined by the Theissen method (13) to be 4.64 cm (1.83 inches) and 3.86 cm (1.52 inches) at the construction and forest areas respectively. Runoff from the thunderstorm lasted three days. Streamflow measurements indicated 42% of precipitation in the forest ended up as runoff, while 45% ran off the construction site. Due to the variation in precipitation, it cannot be determined whether the percentage difference is a result of urbanization activities.

Water quality parameters are summarized in Table 1. For comparison purposes, raw sewage and urban runoff characteristics are also presented. The urban

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12 Woodlands - New Community - An Ecological Plan. Prepared for The Woodlands Development Corporation by Wallace, McHarg, Roberts and Todd.

13 Linsley, R. K., et al. Hydrology for Engineers. McGraw Hill Book Co., Inc. 1958. pp 35 & 36.

36.6 runoff data represents a residential, light commercial drainage area. The sewage data are generalized characterizations (14).

Suspended solids concentration of the natural forest runoff has dramatically changed due to construction activities of The Woodlands. The average concentration has increased more than 8 times, 26 versus 218 mg/l, and now exceeds the concentration in raw sewage. The increase is attributable to excess soil washed off the construction site. As shown in Figures 3 and 4, both streamflow monitoring stations recorded a peak concentration or "flush" of suspended solids with the first runoff. The "flush" occurred a full day before the peak discharge and is thought to be a result of streambed sediment transported with an initial increase in stream velocity. Sediment erosion is The Woodlands' greatest problem, with suspended solids having been measured as high as 2,000 mg/l.

Nitrogen and phosphorus concentrations at the construction site are twice that of the forest, although both are at low levels. The downstream increase in nutrients is thought to be a result of intense fertilization at The Woodlands golf course. The nutrients did not exhibit a "flush", rather, fluctuations in concentrations coincided with changes in discharge rates. It is possible that the solubility of these nutrients is enhanced by greater discharge rates.

The forest region has higher COD values than the construction site, reflecting the loss of the organically rich forest carpet in the developing area. The carpet, consisting of pine needles and decomposing plant material is replaced in urban development by sod and pavement.

Because The Woodlands will be developed over the next twenty years, the viability of its water management scheme will not be immediately known. The data presently collected will be used as baseline information for examination of the community's success in controlling water resources.

ACKNOWLEDGEMENT

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14 Weibel, S. R. Urban Drainage as a Factor in Eutrophication. In: Eutrophication: Causes, Consequences, Correctives. Anon (ed.). Proc. NAS-NRC Symposium, Washington, D.C. pp 383-403, 1969.

Table 1. Constituents of Stormwater Runoff at The Woodlands Compared with Urban Runoff and Raw Sewage

	The Woodlands					
	Forest		Construction Area			
Constituent	Mean	Range	Mean	Range	Urban[b]	Raw Sewage[c]
Suspended Solids	26.5[a]	11-130	218	19.5-719	227	200
Total Kjeldahl N	0.82	0.57-1.25	1.08	0.75-2.19	3.1	40
Total Phosphorus	0.07	0.016-0.2	0.16	0.001-0.53	0.36[d]	10
Total COD	59.7	45.6-68.9	51.25	48.4-72.9	111	350

[a]Data are expressed in milligram/liter

[b]Weibel (1969). Residential, Light Commercial Area, Separate Storm Sewer.

[c]Weibel (1969). Generalized Composition of Domestic Sewage.

[d]Ortho-phosphate

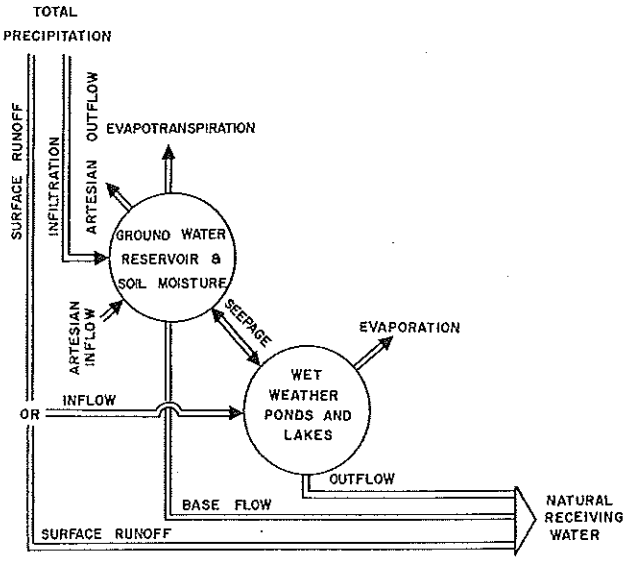

Fig. 1. Water budget for an undeveloped watershed

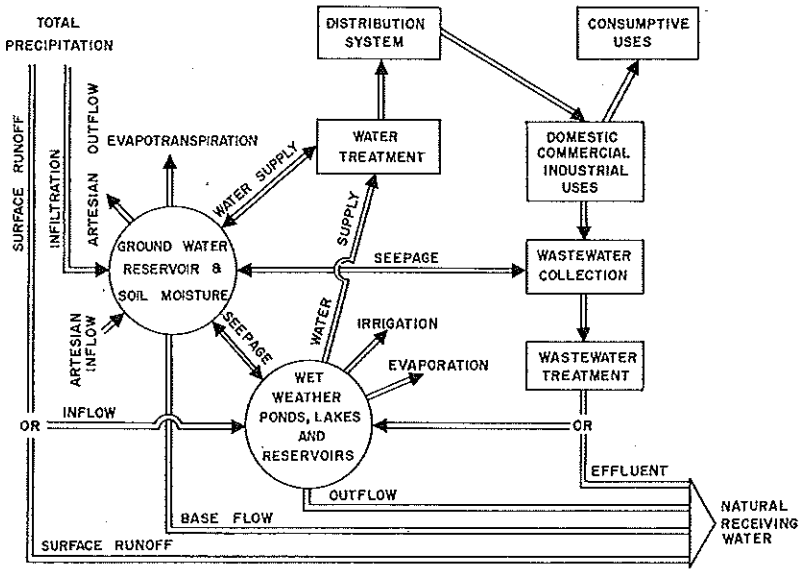

Fig. 2. The Woodlands water budget

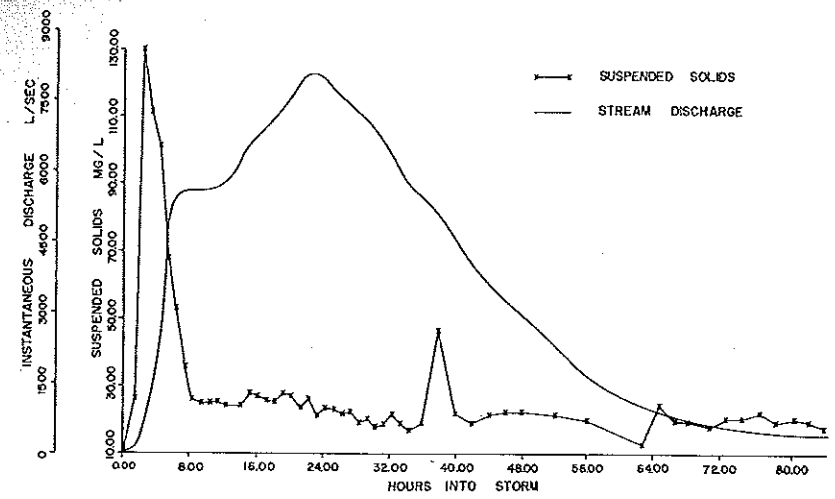

Fig. 3. Temporal distribution of streamflow and suspended solids at the uppper Panther Branch monitoring station

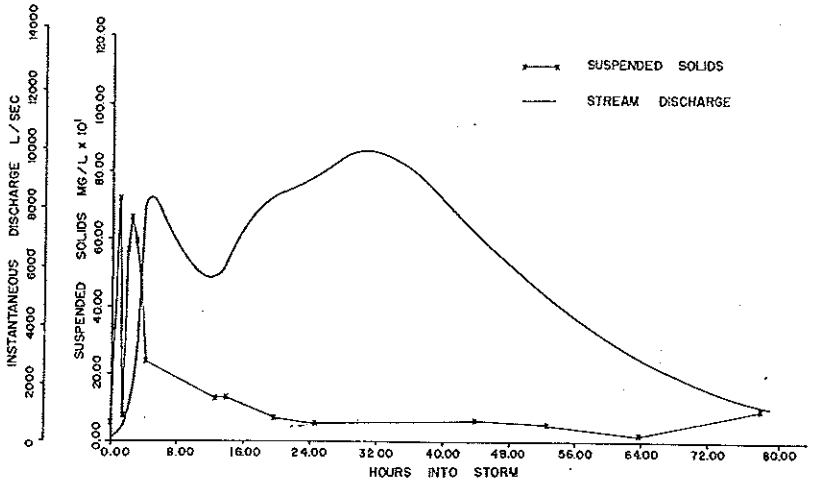

Fig. 4. Temporal distribution of streamflow and suspended solids at the lower Panther Branch monitoring station