WATER QUALITY, STORMWATER MANAGEMENT, AND DEVELOPMENT PLANNING ON THE URBAN FRINGE

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I. INTRODUCTION

Congress formalized the concept of environmental impact assessment in the National Environmental Policy Act of 1969 (NEPA). For nearly two decades NEPA has had a profound influence on thought and policy at all levels of government in the United States. It has also had a strong influence on environmental planning as a technical process; that is, with respect to the procedures and methodologies used to generate data and forecast impacts. NEPA requires environmental impact statements (EIS), an area of professional activity which, in many quarters, has become tantamount to environmental planning itself. The methodology employed in conventional EIS is based principally on an inventory process which calls for field surveys, data generation, mapping, and systematic description of the environment in which the proposed action is to take place.[1] Because time and resources seriously

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1. *See generally* R. ANDREWS & M. WAITE, ENVIRONMENTAL VALUES IN PUBLIC DECISIONS: A RESEARCH AGENDA 22-25 (1978).

limit most environmental inventories, preparers can often do little more than record and describe things as they find them at the time of investigation, usually only those phenomena physically manifest in the field or phenomena reported in published maps, reports, and other secondary sources.[2] The potential for understanding environmental phenomena in terms of their dynamics — such as origins, nature of changes, and interrelations and roles in complex systems — is limited because inventories do not cover interactions over time, even short periods.

Given these limitations, our understanding of cause and effect relationships is often inadequate for forecasting environmental impacts beyond the obvious ones of physical disruption and spatial displacement. This obstacle has led practitioners in two directions: (i) toward the use of analogue studies and various forecasting models; and (ii) toward the use of indicators and surrogate measures. Analogue studies draw on the results of a similar study and/or established models. For example, in stormwater hydrology studies, researchers focus on those models which forecast changes in peak streamflow as a result of land development. With respect to indicators and surrogate measures, researchers earmark certain phenomena as environmental bellwethers. Instead of using analytic techniques to forecast change, researchers assess the level of impact according to the expected change in the indicator phenomena. With stormwater, instead of calculating flow levels, a set of indicators, each of which is a legitimate variable in stormwater runoff, is mapped and measured. Practitioners typically measure slope, amount of vegetative cover, soil type, and urban development density. Stormwater impact in turn is gauged according to the change the proposed action would cause in these indicators.

The use of indicators to assess environmental impact has several advantages. Mapping and measurement are fairly straight-forward activities, and data collected can be easily translated into ordinances and regulatory language. This process in turn simplifies application of the regulations to proposed development projects and generally makes enforcement and monitoring a simple process. Not surprisingly, communities have strong incentives to use indicators as the basis for local environmental ordinances. In practice, communities ask the developer to comply with rules that are easily checked against slope maps, aerial

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2. The exceptions are large and controversial projects such as some of those of the U.S. Army Corps of Engineers which involve major proposals for large dams and reservoirs.

photographs, soil maps, and other guides. Whether the net effect of the apparent changes in the indicators accurately forecasts changes in the systems and processes they represent is uncertain. Most planners would agree that land use regulations built on environmental indicators should be guidelines rather than strict rules.

This Article reports on a study to formulate an environmental plan for a large development project in Austin, Texas. The issue was stormwater quality, and the principal concern was the meaningfulness of Austin's environmental ordinance, which is based on environmental indicators. We present an alternative approach to planning for stormwater management: one based on the form and function of the runoff system. The development project, called Steiner Ranch, is a 4600-acre parcel in the Hill Country, fifteen miles west of Austin.

II. BACKGROUND

Austin, Texas is situated on one of the more striking physiographic boundaries in the south central United States. This boundary is the Balcones Escarpment, a fault line (or fault zone), that separates the Hill Country on the northwest from the Coastal Plain on the southeast (Figure 1). Physiographically, the Hill Country is a plateau of modest elevation, called the Edwards Plateau, which has been dissected by streams to form a moderately rugged upland with thin, dry soils on elevated surfaces. The Coastal Plain, by contrast, is gently rolling terrain with much shallower stream valleys and decidedly heavier soil covers.

Old Austin is situated in the narrow transition between the Hill Country and the Coastal Plain at a point where the Colorado River crosses the Balcones Escarpment. In the past decade the city has grown rapidly, with large tracts of residential development extending northwestward into the Hill Country.[3] Virtually all of this land drains to the Colorado River, which rises in the Llano Estacado several hundred miles to the north and flows southeastward to the Gulf of Mexico. Where it crosses the Hill Country, the Colorado River is dammed to form a series of reservoirs. Lake Austin, one of the smallest reservoirs in the system, is Austin's primary source of water and one of the urban region's most prized scenic and recreational resources (Figure 1).

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3. The city itself grew 27.8% (from 345,890 to 442,009) between 1980 and 1984. DEPARTMENT OF PLANNING AND GROWTH MANAGEMENT, AUSTIN TEXAS, 1985 GROWTH WATCH REPORT 3.

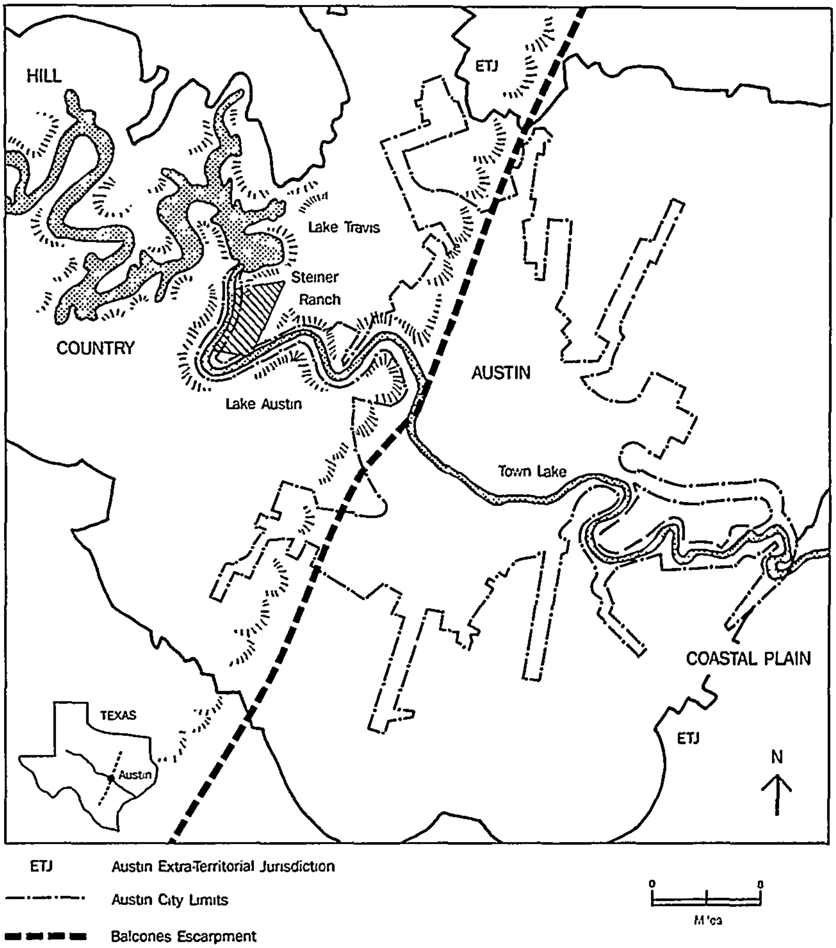

Figure 1. The Study Area: Austin's Extra-Territorial Jurisdiction in Relation to the Colorado River and the Balcones Escarpment

The Hill Country landscape has been seriously degraded in the past century or so. Marginal at best compared to the richer agricultural land of the Coastal Plain, the Hill Country has not benefitted from good land stewardship over the years, despite the value popularly ascribed to it as traditional Texas "cowboy country." Deforestation, fires, and overgrazing have increased runoff, soil erosion, and sparse vegetative covers. Coupled with the steep hillslopes and a marked tendency in this region for high-intensity rainstorms,[4] it follows that stormwater runoff rates are high. Development sites, if not carefully managed, are prone to rapid deterioration. Located downstream of this landscape, Austin sees itself as somewhat vulnerable. In response, the city has through annexation extended its jurisdiction well into the Hill Country. Proposals for new development in the Hill Country are carefully scrutinized, and over the past decade, Austin enacted a series of watershed ordinances aimed primarily at the protection of water quality.[5]

The latest of these ordinances, the Comprehensive Watersheds Ordinance,[6] is designed to control water quality through limits on the development of hillslopes, mandated setbacks from streams, and control of impervious ground cover by limiting overall development density. The Ordinance's planning approach is essentially an extended version of the inventory approach, including (i) mapping of slopes, waterways, and critical environmental features (ii) delineation of water quality zones, and (iii) review and evaluation of the proposed development plan. In spite of the apparent significance of water management to Austin,[7] the Ordinance fails to address directly hydrologic parameters — such as the location of drainage divides, basin size and order, and stream networks — as part of the environmental documentation and analysis.

Our research indicates that for this landscape, consideration of these hydrologic parameters is crucial to achieving overall water quality objectives. Strict application of the 1986 Watersheds Ordinance can, in some situations, allow development that meets all the ordinance criteria, but still poses a serious threat to water quality. In other situations, a development plan may exceed the ordinance limits in overall density without compromising water quality. Some instances of high development density apparently allow the developer sufficient economic margin to incorporate measures that will enhance the overall environmental performance of a project. Recognizing this potential, we formulated an approach in conjunction with the development of the

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4. Round Rock, Texas, located about 15 miles north of Austin, recorded a record 36 inches of rain in one 24-hour period in May 1937.

5. Caudill & George, *The Town Lake Manifesto: Zoning on the Ragged Edge of Texas Law and of Texas Cities*, 29 S. TEX. L. REV. 83, 90 n.26 (1987).

6. Austin, Tex., Comprehensive Watersheds Ordinance (1986).

7. For the past decade city council elections have been fought primarily over environmental versus growth/development issues.

Steiner Ranch master plan that utilizes basic hydrographic concepts and techniques to help guide development planning.

III. The Project and Problem

Steiner Ranch is a large tract of typical Hill Country terrain. The property borders the Colorado River, lying inside a large meander loop of the river. A drainage divide, corresponding roughly to the axis of the meander, separates the property into a northern and a southern zone. Each of these zones is subdivided into many small drainage areas which discharge directly into the Colorado River. Here the river takes the form of the narrow Lake Austin reservoir, the main target of Austin's concern for water quality protection. Most of the drainage areas are simple basins consisting of two main parts: a central canyon or valley surrounded by relatively flat upland. The valleys are forested; the uplands are mostly rangeland with thin, stony soil and light tree cover mixed with grassy open areas.

The Steiner Ranch development program proposed approximately 6,000 units of single-family residences with a full complement of commercial, institutional, and recreational uses. Given the balance of uses, the size of the project, and self-contained character of the site, the project qualifies by most criteria as a new town with a population capacity of nearly 20,000. The development will have its own sewer and water systems. Water will be drawn from Lake Austin and sewage disposal will rely on land application (irrigation) of effluent over 700 acres of the property.

The Comprehensive Watersheds Ordinance slope requirements limit development principally to the upland surfaces, given that the prescribed setbacks from waterways are also observed. Beyond these requirements, however, the Ordinance neither offers nor suggests guidelines as to how land uses should be arranged to promote the best possible performance in the drainage system. By default the Ordinance implies that all ground in the proper slope class (mainly 0-15 percent) and at the proper distance from a stream (up to 400 feet from center channel for large streams) is equally suited for development at density levels up to a rigid maximum allowable limit.

The rationale behind the density limitation is that urban development is the major source of stormwater pollution, and the denser the development, the heavier the pollutant loading. Studies conducted in various parts of the United States verify that overall stormwater quality declines with development density (Table 1). The data in Table 1 are from a comprehensive study conducted in the Washington, D.C., region and they illustrate striking differences, for example, between de-

TABLE 1
STORMWATER POLLUTION LOADING, DENSITY, AND IMPERVIOUS COVER FOR SELECTED URBAN LAND USES

Land Use	Density	Impervious Cover	Pollutant P**	Pollutant N***	Pollutant Pb****
Single Family Residential	0.10 DU/ac*	3%	0.3	3.9	0.06
	1.0 DU/ac	12%	0.8	6.7	0.17
	4.0 DU/ac	25%	1.1	8.8	0.40
Townhouse Apartment	8 - 10 DU/ac	40%	1.5	12.1	0.88
High Rise Apartment	30 DU/ac	60%	1.2	10.3	1.42
Shopping Center	—	90%	1.6	13.2	2.58
Central Business District	—	95%	2.7	24.6	5.42

Source: Northern Virginia Planning District Commission, *Guidebook for screening Urban Nonpoint Pollution Management Strategies,* Metropolitan Washington Council of Governments, 1979

* DU/ac = dwelling units per acre
** P = total phosphorus, lbs/acre per year
*** N = total nitrogen, lbs/acre per year
**** Pb = extractable lead, lbs/acre per year

tached single-family and commercial land use in stormwater loading of three representative contaminants.[8] The land use parameter that shows the strongest correlation with stormwater quality is impervious cover.[9]

In Austin's case, however, there are at least four significant problems with using land use density as the primary planning mechanism to

8. NORTHERN VIRGINIA PLANNING DISTRICT COMMISSION, GUIDEBOOK FOR SCREENING URBAN NONPOINT POLLUTION MANAGEMENT STRATEGIES 11-15 (1979) [hereinafter GUIDEBOOK].

9. CITY OF AUSTIN, TEX., DEPARTMENT OF PUBLIC WORKS, STORMWATER QUALITY MODELING STUDY FOR AUSTIN CREEKS 8 (1984).

manage runoff quality. The first involves the use of per capita, as opposed to dwelling unit, measure of density. The Washington, D.C. study above also showed that the land use having the greatest impact on stormwater quality *measured on a per capita basis* is the large lot single-family use. This impact is related to the size of homes, area of impervious surface, number of automobiles, and the larger infrastructure associated with widely spaced residences occupied by relatively few people. In its quest to maintain low densities, Austin is promoting its own urban sprawl by pushing large lot development, project by project, over a large geographic area. Translated into stormwater loading, the city is succeeding in holding loadings from individual development projects to acceptable levels, while increasing the total impact on runoff quality over the urban region for each increment of population growth. The alternative is cluster development, where relatively small areas of higher densities are assigned to selected locations surrounded by relatively large areas of open space.

The second problem is related to the quantitative validity of the density/water quality correlation for density differences *within* a single land use class. Austin officials have consistently argued that fractional differences in residential density, such as between 2.0 and 2.2 units per acre, are meaningful in forecasting stormwater loadings. Available data do not support that argument.[10] For detached single-family units, the increase in loadings associated with each increment of density is relatively small (Table 2). For small fractions of increments, the increase in loadings probably exceeds the level of significance of the data. For example, the increase in total annual phosphorous loading for a density increase from 1.0 unit to 2.0 units per acre is only 12.5 percent. For lead and zinc, the increase in loading with a density change from 2.0 to 3.0 units per acre is 36 percent and 8 percent respectively. Clearly, the reliability of forecasts of increases in these parameters for the density variances proposed by developers, such as an additional 0.2 units per acre on Austin's 2.0 units per acre allowable maximum on net density, is very poor. The calculated percentage increase in each parameter would be two percent for phosphorus, seven percent for lead and two percent for zinc. One possible explanation for these small increases in stormwater loadings is that the size of the development area and the magnitude of general infrastructure (streets, sidewalks and related impervious surfaces) are basically the same at 2.0 and 2.2 units per acre.

10. *See* GUIDEBOOK, *supra* note 8, at 11-15.

TABLE 2
LOADING RATES FOR SINGLE FAMILY RESIDENTIAL DEVELOPMENT*

Density	Phosphorus	Nitrogen	Lead	Zinc	Sediment**
0.5 unit/acre	0.8	6.2	0.14	0.17	0.09
1.0 unit/acre	0.8	6.7	0.17	0.20	0.11
2.0 unit/acre	0.9	7.7	0.25	0.25	0.14
3.0 unit/acre	1.0	8.0	0.34	0.27	0.15

* (values expressed in lbs/acre per year representing conditions associated with loam soils)

** tons/acre per year

Source: Northern Virginia Planning District Commission, *Guidebook for Screening Urban Nonpoint Pollution Management Strategies*, Metropolitan Washington Council of Governments, 1979.

The third problem is the relationship of land use density to stormwater runoff as a flow system. Under the Comprehensive Watersheds Ordinance, land use density is distributed according to slope and setback from drainageways, not according to the flow network, its sensitivity to stormwater loading, and its capacity to transmit contaminants to the target water bodies. A critical problem with the Ordinance is that it fails to recognize the drainage basin as the basic functional unit of stormwater runoff, and, therefore, the logical organizational entity for land use planning that is ostensibly stormwater driven. Thus, the Ordinance fails to provide a reliable means for distinguishing differences in carrying capacities among basins or parts of basins or for allocating stormwater loadings. Additionally, without understanding the relationship of land use to the runoff system, it is difficult to define (i) stormwater mitigation needs and (ii) management strategies for basins occupied by several independent projects.

The fourth problem is the lack of performance standards in the Comprehensive Watersheds Ordinance. While the *quality* of stormwater can be gauged according to indicators such as total phosphorus, total nitrogen, extractable lead, extractable zinc, sediments, and fecal coliform, there is no general agreement on the acceptable *levels* of loading. Austin's expressed rationale for stormwater management in new development projects is the protection of its primary source of drinking water, Lake Austin. Because stormwater is only one of the many areawide sources of pollution (the others being agriculture, atmospheric fallout, groundwater and existing urban stormwaters), it is very difficult to define how much loading from new development can be allowed without disrupting the quality of Austin's water supply. The determination of permissible loading levels is also difficult because stormwater from most development sites is mitigated in the course of delivery (via swales and streams) to Lake Austin.

In the end, the selection of performance standards for complex systems such as runoff is, at least in part, arbitrary. For example, with respect to stormwater discharge, many communities use the predevelopment peak discharge for the ten-year or one-hundred-year storm as the performance standard. This discharge magnitude is used to fix the maximum rate of allowable stormwater release from the developed site as measured at the heads of streams or at the outlets of small basins. The assumption is that the magnitude of predevelopment peak discharge is an acceptable level of performance. This, however, is clearly not the case for many sites because such predevelopment activities as agriculture, lumbering, and mining may have degraded the original performance. Nonetheless, the use of a predevelopment standard solves the problem of selecting a point in the history of a site when performance can be understandably and noncapriciously defined. Applied to stormwater quality problems, this approach is equally workable, but it requires field measurement and/or forecasting of predevelopment runoff quality in proposed development areas. As with stormwater discharge, predevelopment stormwater quality is not the same everywhere, especially in the Texas Hill Country where ranching, cropping and other land uses vary radically. On Steiner Ranch, predevelopment water quality is unknown, but the poorly managed land indicates that it may not be good. In the opinion of Austin City Council member Mark Rose, Steiner Ranch is an overgrazed cattle ranch, not a pristine environmental treasure.[11]

In developing the Steiner environmental plan, our main objective was to respond specifically to the natural drainage system on the site, using individual drainage areas as the principal organizational element. These units form the functional link between the problem, namely, land uses in the terrestrial environment, and the performance target, namely, water quality in Lake Austin. We designed the planning scheme to achieve (i) a land use loading for each drainage unit proportional to its carrying capacity, (ii) a land use layout which would respond to the local stormwater flow system, and (iii) a widespread and

11. *Water Quality Ordinance Meant to Curb Growth*, Austin American Statesman, Apr. 12, 1987, at J2, col. 1.

relatively even distribution of stormwater discharges into Lake Austin.[12] In addition, the planning scheme proposed various mitigation measures which were intended to reduce the total contaminant loading released by the stormwater system in each basin.

IV. Analysis

The Steiner Ranch site is covered by 26 drainage units which range from 32 to 1,177 acres (Figure 2). Nineteen units qualify as drainage basins in the strict sense of the term because they are integrated into a central channel or trunk stream that discharges into Lake Austin at a single point. These basins occupy more than ninety percent of the site. Seven drainage units are classed as nonbasins; that is, they are not drained by an integrated network of channels, and instead of discharging at one point, they discharge at many small ones. Nonbasin units lie between the mouths of adjacent basins, and unlike basins which are linked to Lake Austin at a single discharge point, they form a border fringe of shoreland along the Lake (Figure 2). The distinction between basins and nonbasins is important: the nonbasins, though small, have extensive frontage on the lake; the basins with little lake frontage contribute the most discharge and carry the vast majority of the land use (Figure 2 inset).

The analysis of these drainage areas involved a three-step process that narrowed the focus of the problem with each step. The first step involved the development of a ratio of developed space to open space in each basin. Uneven distributions in several basins suggested a need for reallocating land uses. As a mitigative measure, however, land use redistribution among drainage areas represents only an elementary and probably minor alteration. A measure more reflective of the flow system was needed. Travel time (or time of concentration) of stormwater was proposed as the parameter.

Travel time analysis showed that flow rates differ radically among different parts of the basins and that small basins are particularly vulnerable to large increases in runoff rates when development occurs. To convert such data into a planning tool involved two steps: (1) identifying divergent and convergent flow zones which correspond to slow and

12. This follows one of the management practices for nonpoint sources of water pollution recommended by the EPA as a part of the 208 program, namely, to diffuse stream pollution from stormwater as much as possible by releasing manageable-sized outfalls of many points along a segment of channel rather than concentrating it in a few massive outfalls.

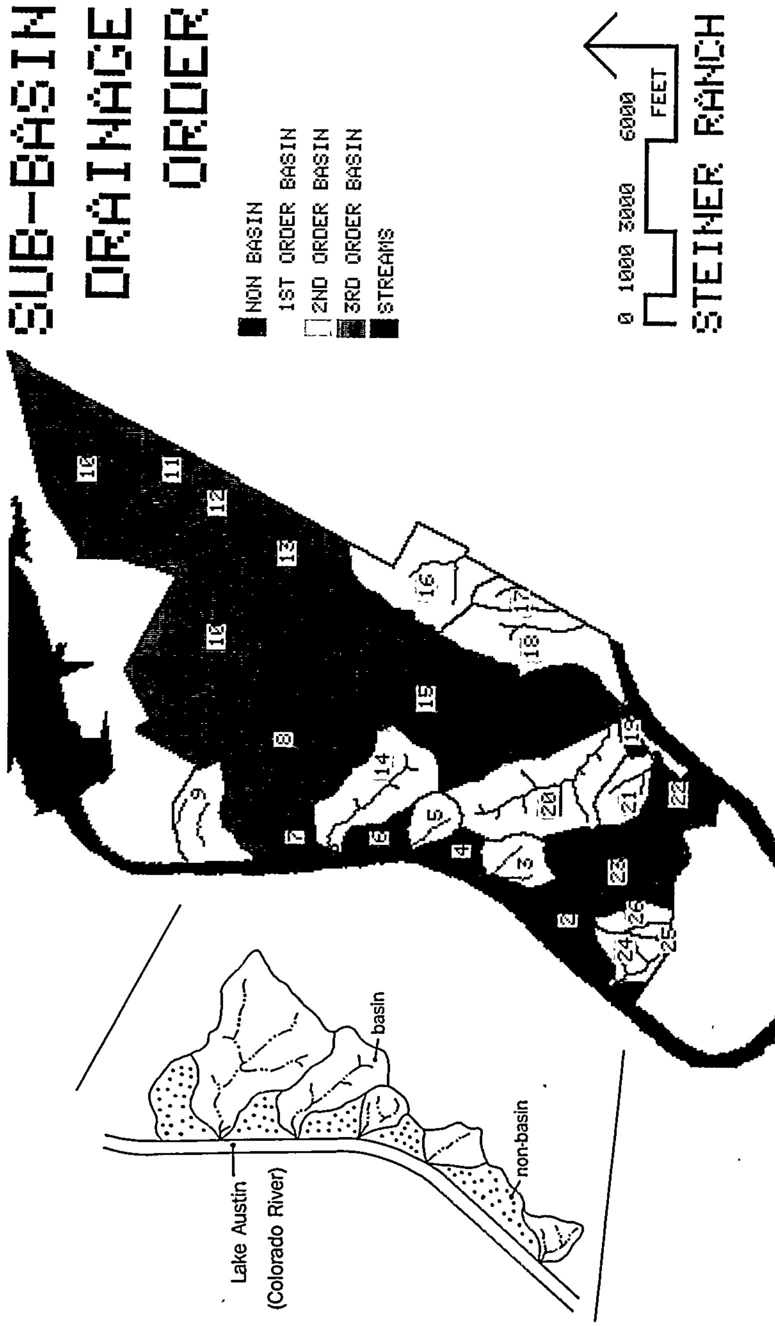

Figure 2. Drainage Units in the Steiner Area. Inset map distinguishes units of basin and non-basin drainage.

fast runoff areas, respectively; and (2) transforming travel-time data into isochronal maps which illustrate the spatial pattern of the runoff system in individual basins. This information made it possible to present a spatial framework and rationale for various planning and mitigative alternatives for stormwater management.

A. *Balancing Land Use Density*

A simple test of land use loading and potential stormwater distribution is the ratio of developed space to open space. Using data files developed in the preliminary phases of the project,[13] we analyzed the proposed land use and open space plans for a sample set of five drainage units, numbers 5, 6, 13, 14, and 15 (Figure 3). Four units showed a favorable balance with open space occupying thirty-five percent to fifty percent of each unit. Unit 13, however, showed serious imbalance with no open space. Because the land use allocation proposed for each basin was compiled in accordance with ordinance slope and setback requirements,[14] it appears that the ordinance fell short of its goals in drainage area 13. Thus, some adjustments in the land use plan seemed to be in order. These adjustments could follow two basic strategies: (i) shifting land uses among all the basins to achieve a better overall balance, say, thirty to forty percent open space in each basin; and/or (ii) introducing mitigation measures to offset the imbalance in unit 13. Mitigation measures would require facilities such as detention basins to help reduce peak flows and contaminant levels, a topic addressed later in this Article.

A simple comparison of individual drainage areas for the percentage of open space, however, fails to consider inherent differences in the land use capacity of drainage units based on hydrophysical factors. Put another way, it is entirely possible that drainage area 13 has a high capacity for development and that the proposed land use loading is entirely appropriate for it. This raises the question of what measures

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13. The environmental inventory and certain parts of the analysis for this project were completed with the aid of an ERDAS system. ERDAS is a microcomputer-based geographic information system that allows users to prepare multiple geo-referenced map files, such as land use, drainage basins, and soils, that can then be analyzed in association with one another to develop complex planning information.

14. Because of the submission date for the preliminary plan (1985), this part of the site was covered by the Lake Austin Watershed Ordinance, a forerunner of the Comprehensive Watersheds Ordinance. Application of the Comprehensive Watersheds Ordinance to this basin would result in some open space along streams, but the amount (less than 20%) would still be small compared to the other basins.

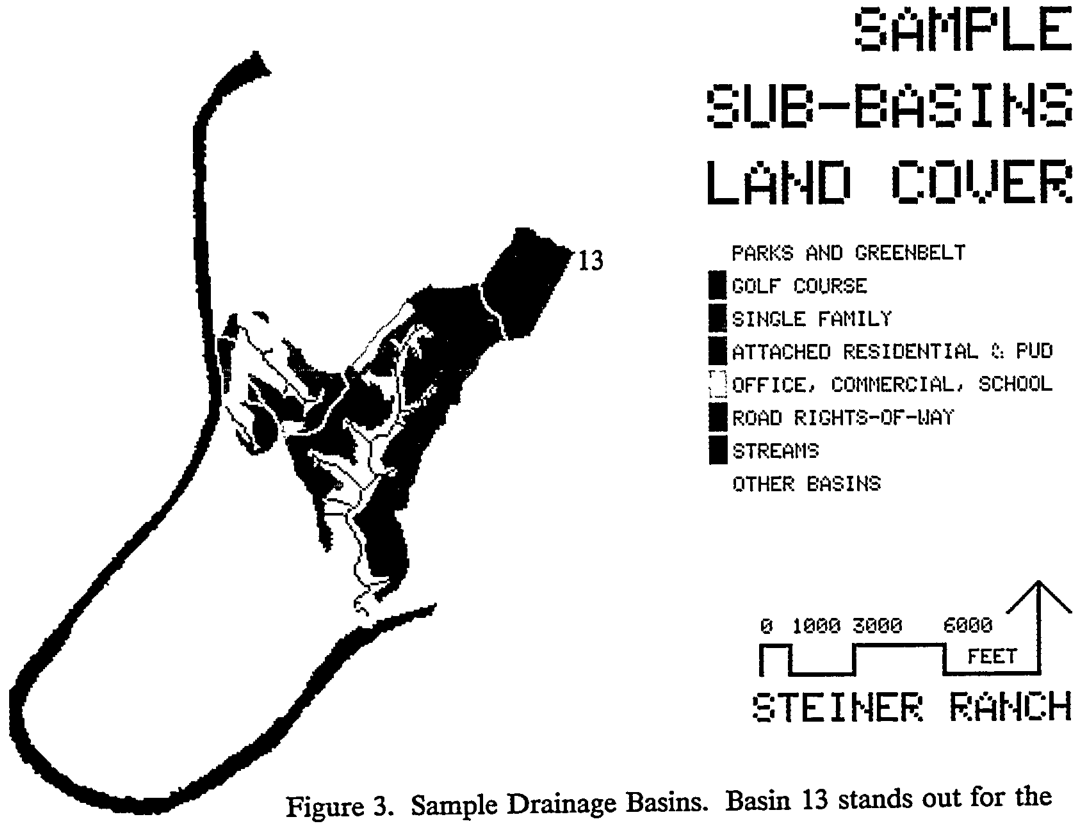

Figure 3. Sample Drainage Basins. Basin 13 stands out for the absence of Open Space.

can be used to determine land use capacities of individual basins.[15] The traditional measures are slope, forest cover, and soil type because they all influence infiltration capacities, runoff rates, and related factors, and can in combination serve as indicators of appropriate and inappropriate locations for various land uses. A good deal of uncertainity exists, however, in assigning quantitative limits to these measures for the purposes of land use planning. In other words, how steep is too steep for residential development when different soils or different landscape design schemes are involved? Or, what combination of slope, soil type, and vegatative cover is suitable for which land uses at which densities? The convential interpretation holds that the area suitable for development is the residual after the areas of steep slopes, forest cover, and poor soils, or some combination thereof, have been extracted. Presumably, drainage basins comprised of flat ground, no forest, and good soils (i.e., soils that drain well and will support structures) can be fully developed.[16] Of course, most planners would intuitively advise against full development, which is one of the reasons cities such as Austin require setbacks from streams and related drainageways. But what quantitative thresholds of slope, vegetation, and soils are appropriate with respect to the basin's environmental performance is largely guesswork in environmental planning.

In an attempt to find hydrologic measures more directly reflective of a basin's capacity for development, we decided to examine three parameters of the flow system: stormwater travel distance, runoff rates, and types of flow. This decision was based on the observation that, in general, the quality of stormwater from developed surfaces improves with longer travel distances (excluding artificial channels), slower flow rates, and higher friction surfaces with shallower flows.[17]

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15. Gilliland & Clark, *The Lake Tahoe Basin: A Systems Analysis of Its Characteristics and Human Carrying Capacity*, 5 ENVTL. MGMT. 397 (1981); *see also* Godschalk & Parker, *Carrying Capacity, a Key to Environmental Planning?*, 30 J. SOIL & WATER CONSERVATION 160 (1975).

16. Here we take "fully developed" to mean all that is assigned some use, such as residential, commercial, or institutional, rather than designated as open space or park.

17. *See* D. KAO, DETERMINATION OF SEDIMENT FILTRATION EFFICIENCY OF GRASS MEDIA (Kentucky Water Resources Research Institute Report No. 124, 1980); *see also* S. WONG & R. MCCUEN, DESIGN OF VEGETATIVE BUFFER STRIPS FOR RUNOFF AND SEDIMENT CONTROL (1981) (available from Maryland Coastal Zone Management Program, University of Maryland).

B. *Runoff Travel Time Within Basins*

Travel distance and flow rate can be combined to form a single expression, called *travel time* or *time of concentration*, which is a measure of a basin's response time in transmitting runoff from head to mouth. This is a standard variable used in making stream discharge computations for high magnitude rainstorms. Travel time is made up of two components, overland flow travel time and channel flow travel time.

Overland flow is the runoff first released from a surface in response to a rainstorm. The water moves in shallow sheets and small trickles which concentrate downslope, eventually leading to stream channels. Overland flow is very slow compared to channel flow, on the order of twenty-five times slower. Streams at bankfull levels typically flow at velocities of four to six feet per second, whereas overland flow velocities range from less than 0.10 foot per second for rangeland[18] to 0.25 foot per second for turf.[19]

Among the various sized basins on Steiner Ranch, there are, predictably, significant differences in travel time. The largest basin (1,177 acres) has a travel time of 44 minutes, and the smallest (32 acres) has a travel time of 10 minutes.[20] The ratio between basin size and travel time, however, is not constant.

In contrast to what the raw travel times might suggest, small basins are actually much slower per acre than large basins because the overland flow/channel flow ratios are so much greater in small basins (Figure 4). This implies that under conventional development, small basins are more susceptible to dramatic increases in travel time than large ones because flow is changed from the slowest mode (overland flow) to the fastest mode (stormsewers and related channels). The overall response time of small basins can be increased as much as tenfold with development and stormsewer construction. Moreover, the average gradients in small basins are greater than large basins which, in the Hill Country near Austin, induces stormsewer velocities of the highest order, fifteen to twenty feet per second. In short, water which took sixty minutes or more to pass through a basin under predevelopment conditions may take only ten minutes after the basin is developed. This

18. W. EMMETT, THE HYDRAULICS OF OVERLAND FLOW ON HILLSLOPES A-13 (U.S. Geological Survey Professional Paper 662A, 1970).

19. Jens & McPherson, *Hydrology of Urban Areas*, in HANDBOOK OF APPLIED HYDROLOGY 20-8 (V.T. Chow ed. 1964).

20. The basic computations of basin travel times were made by Espey Huston, Inc. of Austin, Texas.

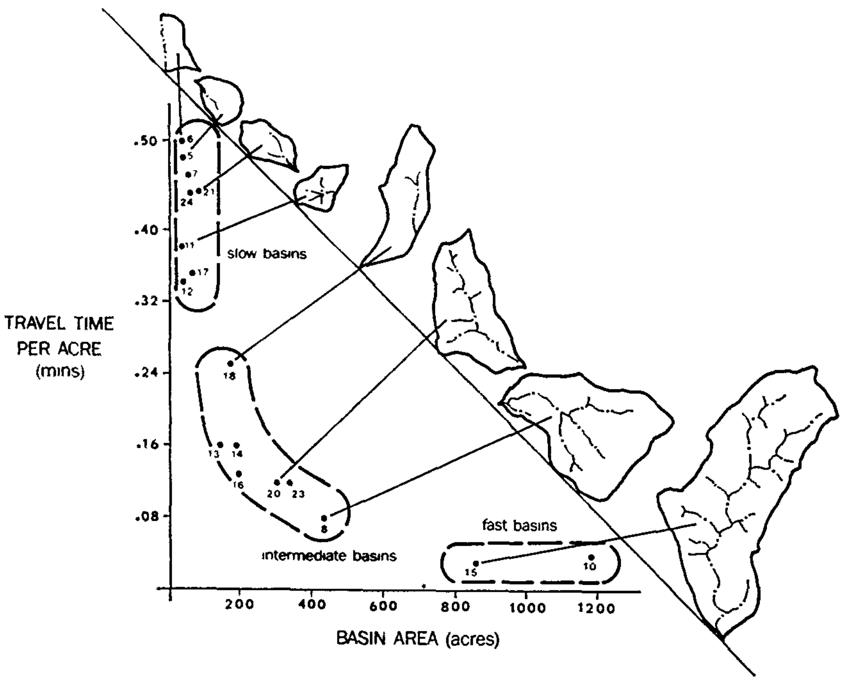

Figure 4. Travel Time Per Acre of Drainage Area. Small basins where a large part of the runoff is made up of overland flow are much slower per acre than large basins where channel flow is the primary mode of conveyance.

change means that less water will be lost to infiltration; less sedimentation will occur in depressions, swales, and pools; fewer contaminants such as phosphorus will be filtered out in soil or settle out with sediment; and the magnitude and frequency of peak flows will be greater.

C. *Travel Time Mapping*

The next level of investigation focused on the individual drainage areas and the distribution of runoff within them. Runoff was defined according to flow zones and travel time. The procedure involved first mapping the flow zones into two classes: divergent and convergent. The convex slopes generate much lighter overland flows than the concave slopes and therefore tend to be slower and dryer than their concave counterparts (Figure 5). Engineers favor concave slopes for stormsewer construction because these zones are natural runoff collection areas with relatively smooth gradients leading to the heads of stream channels.

After mapping the flow zones, we calculated the runoff travel time for the various flow zones and transformed the point data into an isochronal map (Figure 5). Our objective was to produce a travel time surface for the entire drainage area so that the spatial pattern of slow zones and fast zones would be apparent to land use planners and landscape designers. Moreover, such a map would serve as a means of testing proposed land use layouts and recommending (i) plan modifications to achieve better performance in the runoff system, and/or (ii) mitigation measures, such as detention basins and filter berms, to slow runoff delivery. The travel time maps also established a first-level performance standard inasmuch as they set a measurable quantitative target—predevelopment travel times—for planners and engineers to work toward in designing land use and drainage schemes.

We then set up a test for drainage area 14 in which the planners[21] were asked to formulate a land use layout by their conventional methods, that is, without the benefit of travel times or related information. This layout was then overlaid with the travel time/flow zone map to identify the areas of potential difficulty between runoff and proposed land uses. Two types of problem areas appeared: (i) where runoff-accelerating land uses were proposed for fast runoff zones or close to fast zones; and (ii) where, on the other extreme, slow runoff zones were not appropriately used in the plan (Figure 6). In particular, we found that park space was assigned to a convex slope, where travel times were relatively slow and the pattern of runoff divergent over the slope, because the site met park and recreation criteria. In addition, residential facilities and roads were assigned to an area adjacent to one of the fastest zones of convergent flow near the valley head.

Although the proposed plan was perfectly acceptable from a land use design perspective, it presented glaring inadequacies from a water management standpoint. First, the park in its proposed location offered no opportunity to also use the space for stormwater management, so we recommended shifting the uses around and placing the park next to the fast zone where it could serve as buffer and runoff mitigation space (Figure 7). The original park site, on the other hand, was more appropriate for residential development not only because of modest travel times but also because of the divergent runoff pattern on convex

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21. Land use planning was done by Richardson Verdoorn, Inc., of Austin, Texas.

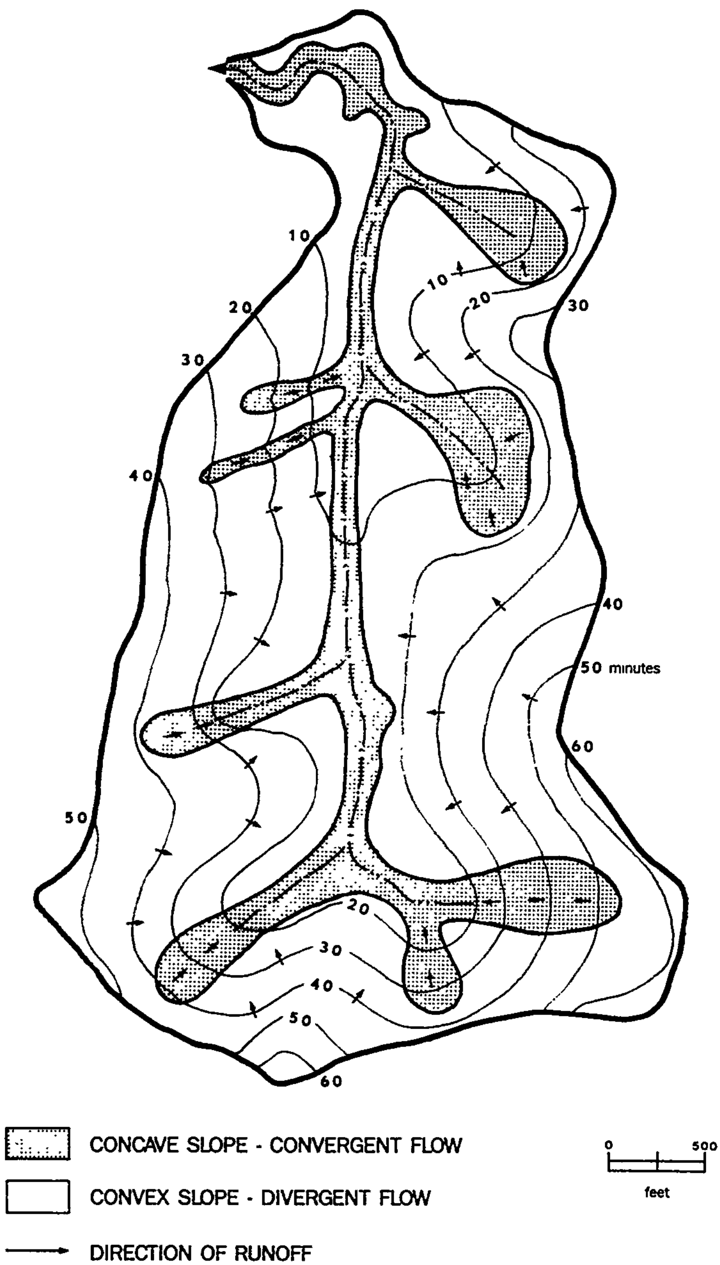

Figure 5. Flow Zones and Runoff Travel Times.

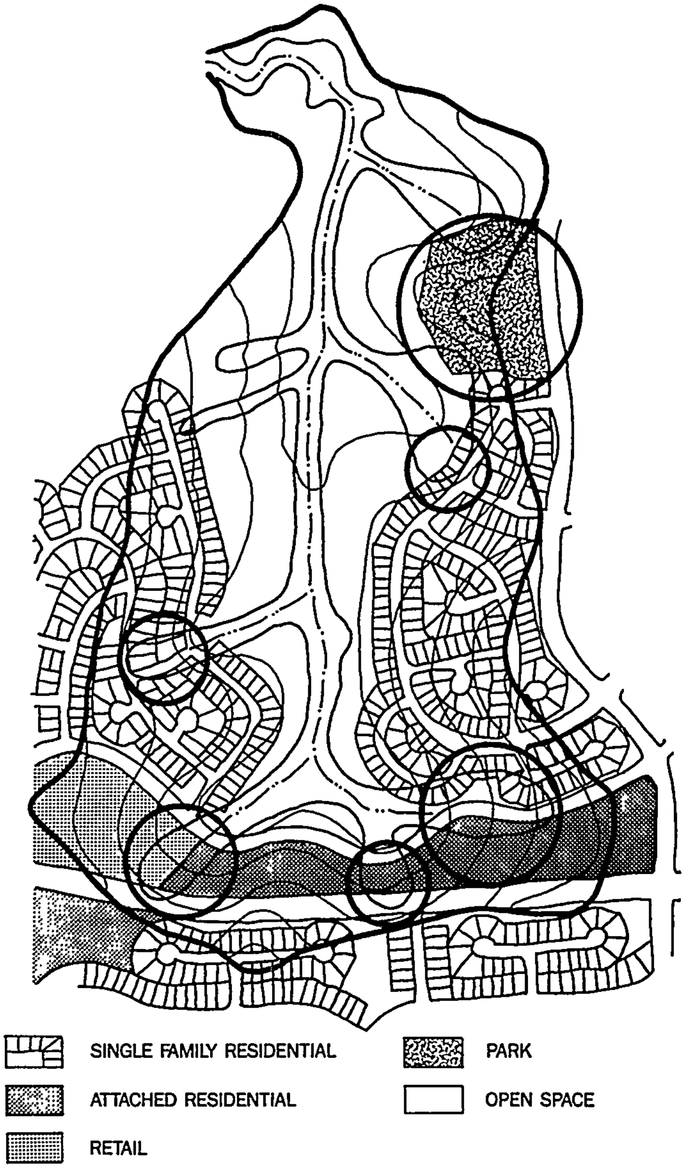

Figure 6. Inappropriate Land Uses Relative to Flow Zones (circled areas). An example in the upper right shows high density land uses in areas of convergent flow and open space (park) in an area of divergent flow.

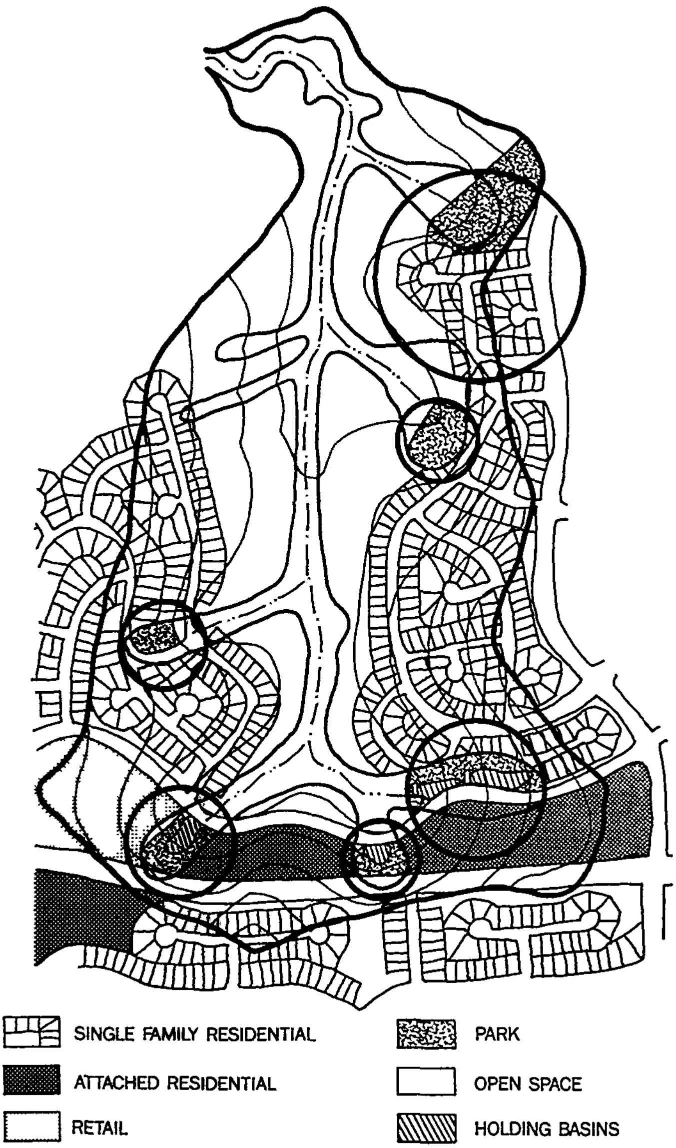

Figure 7. Modified Land Use Plan Integrating Park/Open Space and Stormwater Management. Each zone of convergent flow is used for water management. The overall balance between park and single-family residential acreage remains the same. The area taken from attached residential and retail would total about three acres.

slopes. Such landforms tend to diffuse rather than to concentrate runoff downslope, which makes mitigation with terraces, filter berms, and vegetated belts a somewhat easier matter than in zones of fast, concentrated flows. Second, two of the land uses that generate the greatest runoff, retail and attached residential, were placed at the very head of the ravine in a zone of concentrated flow and short travel times. Not only would this result in large, fast stormflows, but the quality of the water would be the poorest in the basin (Table 1).

The test also revealed where stormsewers should not be used and where stormflow mitigation measures such as detention basins should be added to achieve net travel times approximating those of the predevelopment surface. This, in turn, forced decisions about on-site detention and filtration, stormwater routing, and the type, size, and location of basinwide and neighborhood mitigation facilities. Conflicting stormwater policies also came to light: for example, the city's requirements for curb, gutter, and storm drains for paved streets were shown to be contrary to stormwater management and water quality objectives.

In summary, the test showed that:

1) Given a trend surface map of runoff travel times for a drainage area, the land use planner can design layouts and adjust land use configurations to achieve a better initial response to the runoff system than would otherwise be likely in conventional land use planning.
2) The travel times map allows planners and drainage engineers to pinpoint problem areas and to define options to improve performance by drawing on both land use design and engineering alternatives.[22]
3) The travel times map provides a simple, first-level performance standard against which proposed land use and engineering schemes can be tested and evaluated quantitatively.

D. *Mitigating Stormwater Quality*

The question now arises as to what extent stormwater quality will be improved by longer travel times. Slowing down the overall rate of flow will induce greater infiltration, more sedimentation, and less channel erosion, but we have no data on the net improvement. There are, how-

22. This contrasts with traditional practice in development planning, which at this stage in the project, turns the problem of stormwater management exclusively over to the engineers. The traditional method largely eliminates opportunities to use land use planning and landscape design measures in the stormwater plan.

ever, data on the effectiveness of the individual mitigation measures in stormwater quality control in areas of residential and urban land use. Three levels of mitigation are generally recognized: (i) control of on-site pollutant production; (ii) control of pollutant removal from the site; and (iii) control of pollutant transfer through the delivery system. The first level involves mainly the selection of land uses, their densities, and behavioral controls such as lawn fertilizing, street cleaning, and garbage burning. Austin's efforts at this level, as discussed earlier, centered on density controls based on the established relationships among density, impervious cover, and stormwater quality (Table 1).

Measures for controlling transfer of pollutants from the site are aimed largely at regulating the volume of runoff. The most common strategy relies on increasing soil absorption through, for example, increasing the ratio of vegetated to impervious ground cover, using porous pavers, and diverting runoff into infiltration trenches and dry wells. According to the Washington, D.C., study cited earlier, soil absorption measures are the most effective means of removing pollutants from stormwater. This study found that for soil with average permeability (three-day drawdown), expected removal capacities are in the range of 35% to 65% for total annual phosphorus; 40% to 85% for annual biochemical oxygen demand (BOD); and 80% to 90% for annual lead, depending upon urban land use.[23]

The City of Austin favors two types of soil medium filtering and absorption measures: filter berms and filtration basins. Filter berms are elongated earth mounds constructed along the contour of a slope. They are usually constructed of soil containing different grades of sand and a filter fabric and are designed to function in the same fashion as soil infiltration trenches, which have been shown to be highly effective in contaminant removal. The main reason for using berms instead of trenches is that the soil cover in the Hill Country is generally not thick enough to excavate suitably deep trenches. With both berms and trenches, treatment is limited to small flows. This limitation restricts their application to individual lots or small groups of lots.[24] Soil filtering efficiency is very high according to tests of effluent application to soil in various parts of the United States (Table 3).

Filtration basins — also called water quality basins or filtering ponds in Austin — are concrete structures floored with several grades of sand

23. *See* GUIDEBOOK, *supra* note 8, at VI.

24. Bendixon, *Ridge and Furrow Waste Disposal in a Northern Latitude*, 94 J. SANITARY ENGINEERING DIVISION 147 (1968).

TABLE 3
POLLUTANT REMOVAL RATES USING SOIL FILTRATION

Pollutant	Removal Efficiency	Source
BOD*	88%	Bendixen, 1968
	99%	U.S. Army Corps of Engineers, 1972
Total Phosphorus	60 - 95%	Pound, 1975
	93%**	Bendixen, 1968
Total Nitrogen	75 - 80%	Lance, 1975
	90%	U.S. Environmental Protection Agency, 1977
	70%**	Bendixen, 1968
Lead	50 - 95%	Pound, 1975
	95 - 99%	U.S. Army Corps of Engineers, 1972
Zinc	50 - 95%	Pound, 1975
	95 - 99%	U.S. Army Corps of Engineers, 1972
Suspended Solids	98 - 99%	Pound, 1975 U.S. Army Corps of Engineers, 1972

* Biochemical Oxygen Demand
** with vegetation cover

and a filter fabric through which the stormwater is conducted. Filtration basins are generally used for larger drainage areas, such as shopping centers, than would be appropriate for filter berms. They are designed to filter the first 0.5 inch of runoff, the so-called first flush, which is heaviest in contaminants. The performance of filtration basins based on Austin's experience is good for small stormflows (less than 0.5 inch runoff). For first-flush flows the reported removal rates are: Fecal coliform 76%, total suspended solids 70%, total nitrogen 21%, total Kjeldahl nitrogen 46%, nitrate nitrogen 0, total phosphorus 33%, BOD 70%, total organic carbon (TOC) 48%, iron 45%, lead 45%, and zinc 45%.[25]

Another filtering measure strongly favored by Austin is the vege-

25. CITY OF AUSTIN, TEX., STORMWATER MONITORING PROGRAM: 1985 ANNUAL STATUS REPORT (1986).

tated buffer. Several experimental studies[26] show that vegetative buffers can be extremely efficient in sediment removal (up to ninety percent or more) if they meet the following design criteria: (i) continuous grass/turf cover, (ii) buffer widths generally greater than fifty to one hundred feet, (iii) gentle gradients, generally less than ten percent, and (iv) shallow runoff depths, generally not exceeding the height of the grass. In Austin's case, unfortunately, vegetated buffers are assigned to steep valley slopes and to stream setback zones, most of which exceed twenty-five to thirty-five percent slope, and lack continuous turf covers.

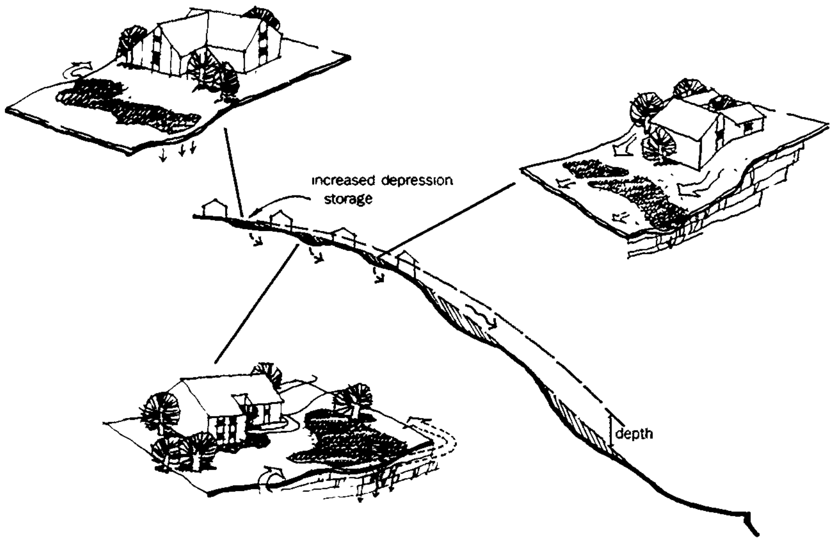

Figure 8. Vegetative Buffers Integrated with Depression Storage in Residential Areas on Upland Surfaces. Most lots of 0.25 acres or larger can easily detain the first 0.5 inches of runoff on site.

Such buffers probably are not very effective because, in addition to meeting the above criteria, overland flow is already concentrated into relatively deep, fast flows by the time it reaches midslope in hilly terrain. For the Steiner Ranch stormwater plan we therefore recommended that vegetative buffers should, to the greatest extent possible, be located on upland surfaces and integrated with depression storage

26. *See, e.g.*, B. Barfield, R. Warner & C. Haan, Applied Hydrology and Sedimentology for Disturbed Areas (1981); D. Kao, *supra* note 17.

(Figure 8). Building on a concept originally advanced by the hydrologist Robert E. Horton in the 1940s,[27] we recommended that depression storage be increased or at least maintained as a part of grading and landscaping residential, park, and road rights-of-way areas, rather than eliminated, as is the conventional practice. To hold the entire first-flush flow of runoff from a modest-sized residential parcel on the lot as depression storage is relatively simple. For a quarter-acre lot, the first-flush 0.5 inch of water amounts to 460 cubic feet. At a storage depth of 2.0 inches, this water would cover only 25 percent of the lot; at a 4-inch depth, only 12.5 percent of the lot. In Austin, rainfall events that yield a half inch or more of water occur on an average of about twenty times a year. The pollutant removal efficiency for infiltration water from depression storage depends principally on soil moisture storage capacity, drawdown time, and plant cover; in general, the removal values given in Table 3 are applicable.

The final class of mitigation measures are those placed in the delivery system. These measures are impoundments, usually detention ponds and retention basins. These basins are designed to withhold stormwater from the flow system at the time of peak flow to reduce peak discharge. Water quality can also be improved by holding stormwater, especially the early runoff from a storm. Investigators generally point to the importance of sediment settling in stormwater basins and its role in the overall removal of pollutants from the water. Table 4 offers representative removal values reported by various studies from retention basins and detention basins. Values tend to be higher for retention basins because they hold water on a permanent basis and have a correspondingly higher potential for sediment settling and biochemical synthesis than detention basins. Retention basins are often larger than detention basins; therefore, retention residence times are longer, which also improves their efficiencies. For example, Biggers[28] recommends twenty-four hour detention times and slow release rates to achieve high trap efficiencies for silt particles.

One inherent difficulty for all basins is mitigating the large flows, those large enough to sweep through the basin producing short resi-

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27. Horton, *Erosional Development of Streams and Their Drainage Basins; Hydrophysical Approach to Quantitative Morphology*, 56 BULL. GEOLOGICAL SOC'Y AM. 275 (1945).

28. Biggers, *Urban Best Management Practices (BMDs): Transition from Single Purpose to Multipurpose Stormwater Management*, INT'L. SYMP. URB. STORM RUNOFF 249 (1980) (available in the Office of Engineering Services, College of Engineering, University of Kentucky).

TABLE 4
REPRESENTATIVE REMOVAL EFFICIENCIES FOR DETENTION BASINS
PERCENTAGE REMOVAL

Source	Sd	Ph	BOD	Pn	N	HC	Z	Cu	FC	
1	~60	~45	~45	60		60				
2*	69	10	26	30	28		35			Detention Basins
3	44-89	25-63			15-22		12-44	58-83		
4	75	58	67	95	31					
5	50-95	10-20	50-90		10-30				90-95	Retention Basins
6	17-23	43			30		71			

* dual purpose basin

Source:

1. Whipple 42 (1993)
2. Northern Virginia Planning District 11-13 (1979)
3. Akeley 39 (1980)
4. Adams and Dove 5-7 (1981)
5. Hydroscience 202-203 (1979)
6. Northern Virginia Planning District 11-15 (1979)

Contaminant:

Sd = Suspended Sediment
Ph = Total Phosphorus
BOD = Biochemical Oxygen Demand
Pn = Lead
N = Total Nitrogen
HC = Hydrocarbons
Z = Zinc
Cu = Copper
FC = Fecal Coliforms

dence times. Water Resource Engineers[29] reported suspended sediment removal of 70 percent for small flows (discharge rate of 300 gallons per day per square foot of pond surface) but as low as 30 percent for large flow (discharge rate of 2,300 gallons per day per square foot of pond surface). One approach to this problem is to limit discharges into the basin to the first part of a storm, the part that usually contains the most contaminated water, and divert the remainder around the basin. Another is to direct flows from various contributing

29. WATER RESOURCE ENGINEERS, INC., MANAGEMENT OF URBAN STORM RUNOFF (American Society of Civil Engineers Resources Research Program Technical Memo No. 24, 1974).

surfaces according to the expected quality of stormwater with only the poorest quality runoff going to basins.

V. Application to the Land Use Plan

With the basic land use/runoff model in hand and a reasonably good understanding of the potential effectiveness of various stormwater mitigation measures, an application of these concepts to the Steiner Ranch land use plan was proposed. Working with the Austin City planning staff, an agreement was formulated giving the developer higher residential and commercial densities in return for a stormwater management program based on travel time and the stormwater quality performance. The agreement called for strict adherence to ordinance slope requirements but allowed a gross residential density of 1.14 units per acre[30] compared to 0.75 units per acre allowable under the ordinance. Because of compliance with the slope requirement, the total area subject to development and the magnitude of the infrastructure would therefore be the same under both the proposed plan and an ordinance-based plan.

In exchange, the developer agreed to formulate, in conjunction with the City's Department of Environmental Protection, a land use and stormwater management plan for each drainage basin in which post-development net travel time would not be faster than the predevelopment travel time of runoff.[31] The developer further agreed to run a parallel analysis for each basin, comparing water quality performance (i) as it would be under a plan complying with the Comprehensive Watersheds Ordinance, and (ii) as it would be under the proposed plan using various structural and nonstructural mitigation measures to reduce pollution levels. Finally, the developer agreed to a field monitoring program of stormwater travel time and stormwater quality in the first basins developed under the proposed plan. The purpose of the monitoring program was to evaluate performance and make adjustments in the planning and design of subsequent basins. After joint evaluation by the City and developer, if the proposed stormwater program proved to be unacceptable, the developer would agree to comply with the Comprehensive Watersheds Ordinance for the remainder of the project.

30. Gross density is the unit density computed over the entire site area (or a subarea) rather than over the developable area alone.

31. Environmental Planning Agreement Regarding Steiner Ranch Waiver Area (presented to Austin, Texas, City Council).

VI. Epilogue

The Austin City Council received the Steiner Ranch plan following approval of the waiver proposal (the environmental planning agreement) by the City Planning Commission by a 5-4 vote and endorsement of the environmental planning agreement by city staff. Opposition by environmentalists and property owners was substantial, and the Council denied the waiver by a 4-3 vote. The process did, however, bring into sharper focus the question of whether the purpose behind the Comprehensive Watersheds Ordinance was environmental protection or growth control. The following excerpt is from a subsequent editorial in the Austin American Statesman:

> The City Council majority on Thursday demonstrated clearly that its idea of the purpose of the Comprehensive Watersheds Ordinance is not necessarily to assure water quality in the area west of Austin but to limit development.
>
> That had been the suspicion when the ordinance was adopted—in the hills west of Austin it does not allow, except by waiver, creative ways of making sure runoff is clean. Density appears to be the sole permissible method. In the area to the east, creative means are permitted. But there are not any actual water quality standards. It looks like a limit-growth ordinance.
>
> And sure enough, when the Steiner Ranch along Lake Austin came up before the council on Thursday with a request to use various non-density ways to assure water quality, the council majority said no. Even though the city staff approved the waiver. . . .
>
> If, as Council Members Charles Urdy and Mark Rose kept pointing out, the idea of the watershed ordinance is to keep the water clean (Lake Austin is the major source of our drinking water), and if the Steiner Ranch proposal would accomplish the same thing as relying on density, as the professional staff indicated it would, then there was no reason to deny the waiver. The developers said that the property would be developed in increments, and if the creative water-quality methods turned out not to work, it would either go back and retrofit to make them work, or develop the entire tract under the density requirements of the ordinance. Fair enough. . . .
>
> The council has spoken, and the message is hardly murky. But what the council—or a future one—should do is adopt some water quality standards and allow developers to use whatever valid means are available to meet those standards, and then make sure

the developments are monitored and the requirements met. That would qualify as a water quality ordinance."[32]

32. Austin American Statesman, Apr. 12, 1987, at J2, col. 1.

Appendix
ENVIRONMENTAL PLANNING AGREEMENT REGARDING STEINER RANCH WAIVER AREA

1. In addition to the substantive information required in the normal filing of a pre-preliminary plat application, the following information shall be filed as a part of any such pre-preliminary application for any parcel of the Steiner Ranch Waiver Area:
   A. Information indicating the computed predevelopment runoff travel times for each drainage basin and sub-basin within the property for which such pre-preliminary plat is being filed;
   B. Maps and other graphic data delineating creeks, runoff, and flow zone;
   C. A map showing all Critical Environmental Features as defined within the Comprehensive Watersheds Ordinance, and proposed setbacks around them;
   D. A map indicating the proposed land uses for such pre-preliminary plat including designation of all open spaces, recreational spaces, residential spaces, residential land, and other related or associated uses;
   E. Computer data showing a comparison of pre- and post-development data indicating the effects of all proposed mitigation measures;
   F. Calculations showing compliance with the impervious cover requirements of the Lake Austin Watershed Ordinance and showing a tabulation indicating compliance with the density calculations of this agreement.
   G. A reproducible overlay, at the same scale as the pre-preliminary plan, which shows a schematic development scenario achievable under the comprehensive Watersheds Ordinance. This schematic scenario will show land uses comparable with those shown on the pre-preliminary plan.
   H. A delineation of Critical Water Quality Zones, Water Quality Buffer Zones, and other required buffer zones as defined in the Comprehensive Watersheds Ordinance.
2. Each pre-preliminary plat application shall include the submission of a plan indicating all measures taken in an effort to control, manage, and mitigate any effect of the proposed development upon the water quality of the run-off from such developed areas. This control system will be specific to each hydrosystem. The Department

of Environmental Protection and the developer shall formulate a program for each drainage basin tributary to Lake Austin to provide for a postdevelopment net travel time which shall be not less than the projected predevelopment travel time of the runoff.

3. Each pre-preliminary plat submission shall include a construction phase environmental control plan which shall include but shall not be limited to:
   A. Proposed methods of preconstruction land preparation and postconstruction land restoration.
   B. Schedule indicating development phasing and land conversion activities updated annually. The schedule would outline the implementation of THE STEINER RANCH DEVELOPMENT CRITERIA (Copyright).
   C. Proposed erosion and sedimentation control measures which meet or exceed the performance of the measures outlined in the City's Erosion and Sedimentation Control Manual.
   D. Proposed timing and placement of all water quality control measures according to drainage distance and drainage area of basin.
   E. A specific program providing for the inspection and maintenance of all measures taken with regard to the control, management, and mitigation of development impact upon runoff water quality; such program shall include any proposed upgrading measures necessary to achieve the approved level of environmental performance in the event postdevelopment runoff travel times are less than projected in predevelopment analysis.
   F. A specific enforcement program for operating and maintenance of all water quality measures including warnings and fines to be levied in the event of failures to comply therewith.
   G. A two-part monitoring program shall be developed and agreed to by the developer and the Department of Environmental Protection and submitted within one year of the date of City Council approval of this Comprehensive Watersheds Ordinance waiver. This program will include: monitoring of land conversion and indicators specific to travel times computations using Thematic Mapper or comparable technology, and hydrologic and water quality monitoring for selected basins.
4. The "Curve Number" method of calculating run-off travel times from the Soil Conservation Service's National Engineering Hand-

book, Section 4, will be used. A comparison of pre- and post-development travel times will be made on a sub-area of sub-area basins and final evaluation of postdevelopment performance will be based on the sum of the net changes in travel times for all sub-areas within the watershed.

5. Evaluation matrices comparing the proposed pre-preliminary plan and CWO overlay shall be completed for each proposal submitted, and shall be retained as part of the permanent record for each phase of Steiner Ranch. These matrices will include comparisons of density, impervious cover, buffer zones and runoff travel times.
6. Target pollutants as well as modeling methodology will be those set forth in the "Guidebook for Screening Urban Nonpoint Pollution Management Strategies" (1979 version) prepared by the North Virginia District Planning Commission. Staff and applicant shall agree upon the unit area, unit volume or other appropriate removal efficiency measures to be employed based upon City of Austin monitoring data, the COA publication on vegetative filters, and mutually acceptable literature values.
7. Subwatersheds which are proposed with layouts showing densities and water quality control strategies achievable under strict compliance with the Comprehensive Watersheds Ordinance may not require additional analysis.
8. In addition to a modeling procedure to be carried out prior to approval of pre-preliminary plans and subsequent preliminary plans, a procedure to model and monitor the time of travel and water quality impacts of build-out of approved subdivisions is to be developed within one year of waiver approval. This program will include the establishment of water quality monitoring locations and a monitoring schedule addressing frequencies, parameters and sampling and analysis responsibilities.

   The primary objective of this build-out monitoring and modeling program is to adjust approved plans if adverse impacts are identified. The following process will be implemented by the applicant subject to City Staff review if adverse impacts are identified:

   A. Evaluate the adverse impact and identify its sources.
   B. Formulate mitigation alternatives and evaluate these alternatives in terms of pollutant reduction efficiency, cost and other criteria.
   C. Select the most appropriate mitigation alternative and design and implement mitigation measures.

D. Continue water quality monitoring with subsequent evaluation of performance in areas of adjustment.

9. A common Area Maintenance Association will be created and will be responsible for maintenance and repairs to the water quality management structures and areas. Regular inspection schedules will be established. The Association will keep written records which will be available for city review.