

HYDROLOGIC ASPECTS OF LAND-USE PLANNING AT TUMAMOC HILL, TUCSON, ARIZONA

by

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ABSTRACT

Tumamoc Hill, an 869-acre (352 ha) desert area near Tucson, Arizona, is being considered as a controlled-access environmental site. Water affects the site's geology, soils, vegetation, wildlife, and archaeology. The Hill is drained by three small watersheds. The largest is rapidly urbanizing upstream. Hydrologic aspects include potential flooding and erosion hazards. These may be reduced simply, economically, and wisely in a land-use plan.

Upstream development increases storm runoff volumes, and flood peaks, and frequencies routed through the site, and threatens existing downstream urban development. Return periods of channel-overflow floods become shorter with urbanization. The region may be managed to reduce hydrologic hazards by three procedures: widen channels, install low checkdams, and vegetate drainageways. These methods will slow down runoff velocities, and increase cross-sectional area of flow and roughness coefficient. More water would also be available for vegetation and wildlife.

The land-use plan should include environmental education programs. These would present important effects of water on the natural ecology, and hydrologic aspects of watershed urbanization.

INTRODUCTION

The University of Arizona's Tumamoc Hill is a desert habitat. Part of the long-term research preserve is being considered as a controlled-access environmental study center for the public (Negri, 1974). An illustrated report by the Tumamoc Hill Committee outlined suggestions and recommendations for the region's development and management as an "environmental study area" (Baldwin, Brickler, Dumond and Skibinski, 1974). The need for hydrologic data is then justified. A resource inventory includes geology, soils, vegetation, wildlife, and archaeology. Important water-management and land-use issues are involved.

Rapid upstream urbanization is occurring on gentle slopes to the site's west, as housing developments, schools, and businesses attract residents, students and workers. Urbanization increases demands for energy supply, water supply, sewage disposal, roads, and culverts.

Hydrologic aspects present potential flooding and erosion hazards. Upstream development decreases local infiltration. Thus the storm runoff volumes, and food peaks and frequencies increase. These flows are routed through the University site and threaten existing downstream development. Storm runoff increases in organic matter, sediment, and bacterial

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concentrations. Water costs consequently increase. Numerous urban hydrology studies at the University and elsewhere confirm these findings. Relevant investigations are summarized in Water Resources Research Center (1969), Resnick and DeCook (1970), and U.S. Office of Water Resources Research (1974).

This article reviews hydrologic aspects of land-use planning at Tumamoc Hill. Emphasis is on the importance of water, and urbanization effects on runoff quantity and quality. Suggestions pertaining to land-use planning and environmental education are evaluated. It is my belief that environmental education should include water-resources considerations. These notes are preliminary because scant data exist.

GEOGRAPHICAL ASPECTS

Location, drainage, and land use comprise this report's geographical aspects.

LOCATION

Tumamoc Hill is in eastern Pima County, southwest of St. Mary's Hospital in western Tucson, Arizona, three miles (5 km) west of downtown Tucson, Arizona (Figure 1). It rises about 800 ft (244 m) above the Santa Cruz Valley floor to a 3108-ft (946-m) elevation, and stands as a prominent landmark. The University site contains 869 ac (352 ha) bounded by Anklam Road to the north, West 22nd Street to the South, Greasewood Road to the west, and a natural ravine and arbitrary line to the east, which divides the site from Sentinel Peak ("A" Mountain) to the southeast.

DRAINAGE

Surface drainage is rapid and radial from the steep Hill, and moderate to the northwest from the gently sloping western foothills and valley. Slopes range from 0 to 3 percent in the valley, to greater than 45 percent in the Hill proper (Barbarick, Clark and Popkin, 1973, p. 3). Three small watersheds occur in the University site. The largest watershed drains 73 percent, or 635 ac (257 ha), to the northwest by Silvercroft (St. Mary's) Wash; the second largest drains 15 percent, or 130 ac (53 ha), to the northeast by an Unnamed Northeastern Wash; and the smallest drains 12 percent, or 104 ac (42 ha), to the south by an Unnamed Southern Wash (see Figure 1). All the washes are ephemeral arroyos, and flow only when there is storm-generated runoff.

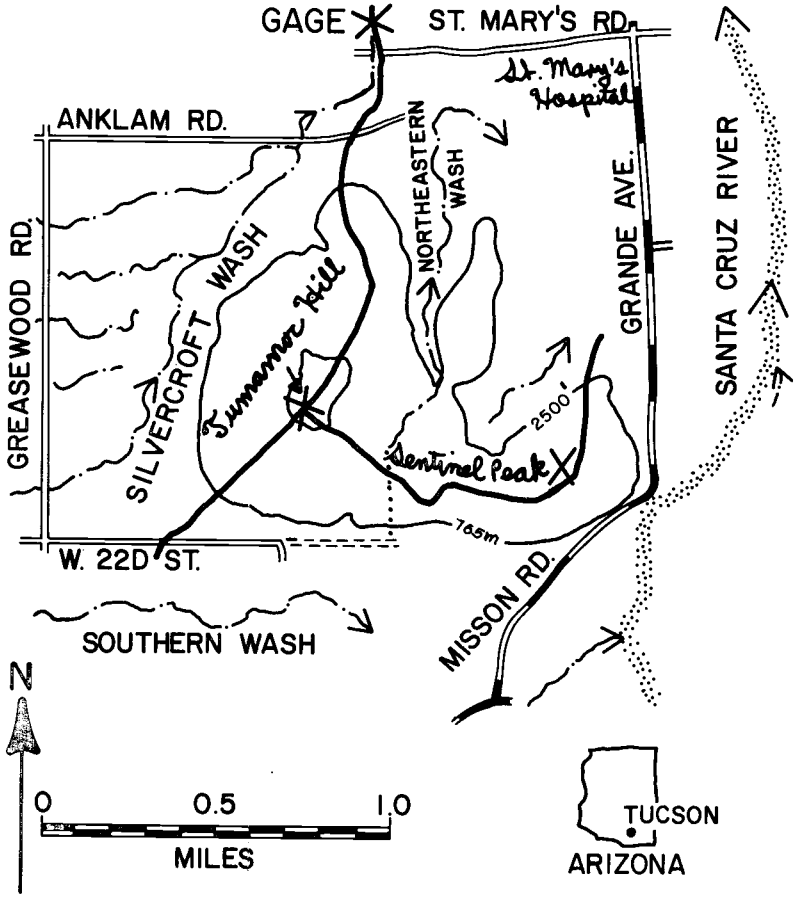


Figure 1. LOCATION AND DRAINAGE OF TUMAMOC HILL, TUCSON, ARIZONA

Silvercroft Wash also catches runoff west and southwest of the site, merges with Anklam (El Rio) Wash 1.5 mi (2.4 km) north, and enters the Santa Cruz River 2 mi (3.2 km) north of that junction. The watershed's total drainage area at the U.S. Geological Survey gage is 2.74 mi² (7.10 km²). New subdivisions, townhouses, and the Andy Tolson Elementary School lie to the site's west. This area is rapidly urbanizing, and may induce potential runoff problems downstream.

The Unnamed Northeastern Wash (the eastern ravine) also catches runoff from Sentinel Peak to the southeast and the Menlo Park area to the east, and enters the Santa Cruz River to the north. Menlo Park School and the older homes in the Manzo Improvement District lie to the site's east. Potential runoff problems may be induced by the Hill's steep eastern slope, and urbanization around St. Mary's Hospital.

The Unnamed Southern Wash also catches runoff directly south of the site, merges with other washes, and enters the Santa Cruz River within a mile (1.6 km) to the east. Older adobe and wooden houses, Cholla High School, trailer homes, and ranch-style subdivisions lie to the site's south. Potential runoff problems may be induced by the Hill's steep southern slope.

LAND USE

The University site once contained Hohokum Indian cultures (1200 A.D.), building-stone quarries (late 1880's), clay and brick foundries (early 1900's), Carnegie Institute's Desert Laboratory (1903 to 1937), U.S. Forest Service's headquarters for the Southwest Forest and Range Experiment Station (since 1940), and a sanitary landfill (early 1960's). The University of Arizona purchased about 42 percent of the site from the Forest Service in 1961, and leases the remaining western percentage from the State of Arizona.

Unprecedented surrounding growth threatens to impinge upon the property for commercial and urban expansion. Already there are powerlines, access roads, easements, gaslines, petroleum pipelines, radio towers, telephone lines, and sewer and water lines (Baldwin and others, 1974, p. 40-41). There is a 43-ac (17-ha) abandoned landfill in the site's southwest.

Population growth in the Tucson Metropolitan Area results in alteration of the character and composition of many natural areas. Concern for uncontrolled growth is expressed (Boster, Davis, Dutt, Mizlek, and others, 1973; City of Tucson Planning Division, 1973; City of Tucson Planning Division and others, 1973; Baldwin and others, 1974; Wilson, 1974).

Brown and Caldwell (1973a, p. 40) summarize Tucson's recent dramatic growth. The urban area of 39.8 mi² (103 km²) contained 121,000 people in 1950. Within ten years, population doubled to 243,000, and the area covered 77.7 mi² (202 km²). In 1973, the urban area of 129.5 mi² (338 km²) contained 397,000 people. This is a 228.1-percent increase in population since 1950, and a 63.4-percent increase since 1960.

Figure 2 shows current area land use in Silvercroft Watershed. Note the population pattern. Commercial, high density, medium density, low density, suburban, and desert uses occupy 4.8, 6.9, 7.8, 19.4, 23.1, and 38.0 percent of the Watershed, respectively (Brown and Caldwell, 1973a,b).

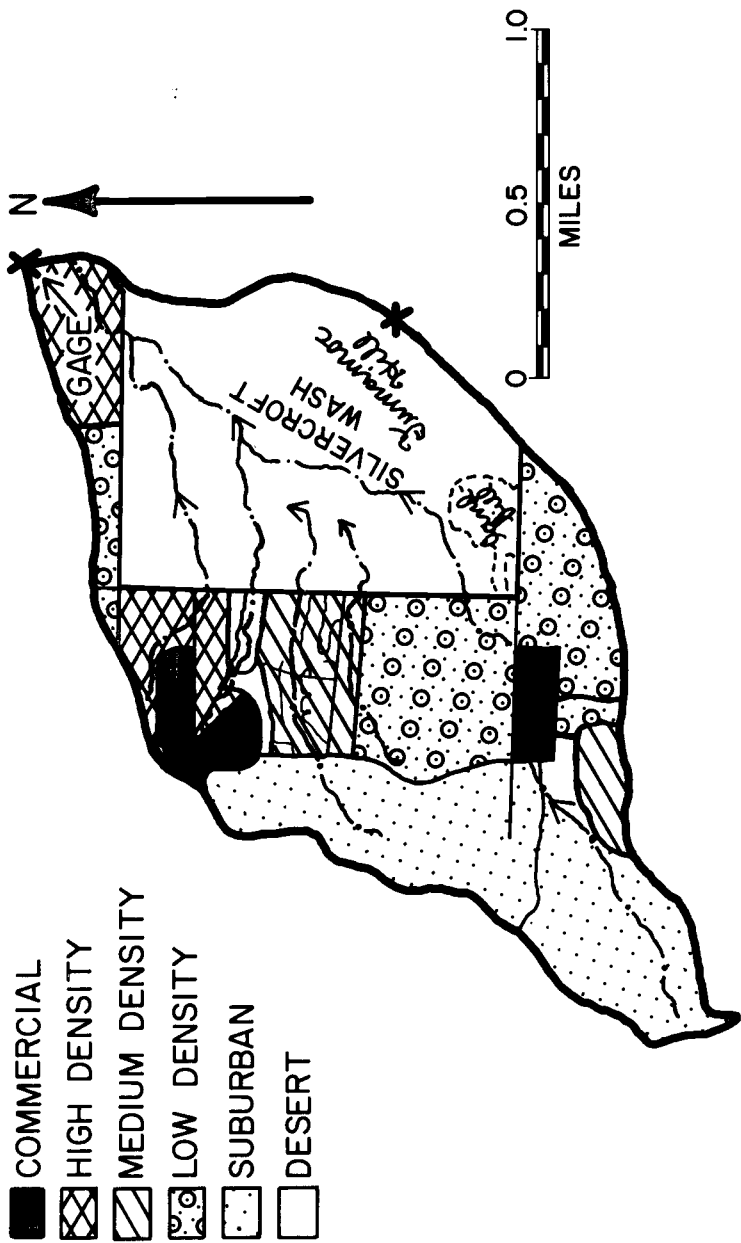


Figure 2. LAND USE OF SILVERCROCK WATERSHED, TUCSON, ARIZONA

High, medium, and low densities are currently 15 to 20, 10 to 15, and 5 to 10 persons/acre, respectively. These will nearly double in the next 50 years when the urban fringe here will accommodate over 48,000 people (Brown and Caldwell, 1973a, p. 13, 15). Silvercroft Wash drains part of Tucson's western fringe, moving storm runoff through the University site into the urban core. The University controls 36 percent of the watershed.

Growth requires new roads, schools, water supplies, sewerage lines, and storm drains. A new southwest sewage-collection interceptor (Brown and Caldwell, 1973a,b), check dams and storm sewers (Cella, Barr, Evans and Assoc., 1974) are proposed to serve the area.

RESOURCE INVENTORY

Geology, soils, vegetation, wildlife, and archaeology constitute the University site's resources. These are summarized below, and appropriately related to hydrologic influences.

GEOLOGY

Tumamoc Hill, Sentinel Park, and smaller hills and ridges are the result of Paleocene and earlier volcanic activity (Baldwin and others, 1974, p. 28). The area is within the down-dropped structural Santa Cruz basin. Tucson Mountains to the northwest are a source of igneous-origin alluvium. Safford Peak to the northwest is the likely source of andesite, rhyolite, and tuff which form the fairly symmetrical, elongated, north-south trending Hill. The summit is flanked on all sides by Holocene (Recent) alluvial and colluvial fans, terrace deposits, and flood-plain alluvium. Observable geologic processes include frost and root wedging, chemical and biochemical weathering, and water and wind erosion and deposition. Erosion is more extensive in the gently sloping western part of Silvercroft Watershed.

Water has an important role in the area's geology, effecting rock type and distribution, and landforms. Caliche, metallic dendrites, and alluvium are common sediments in the vicinity. Caliche conglomerate, and silicious precipitates are also present. Water is the major agent of chemical and mechanical weathering and erosion. Weathering is in-place rock decomposition, and erosion is rock decomposition caused by movement. Chemical weathering includes calcium, manganese, and silica solution from the plagioclase-rich basalts on the Hill. Mechanical weathering includes fracturing of high-elevation rocks due to frost wedging of occasional ice. Chemical erosion includes downslope movement of calcium, manganese and silica in solution to lower elevations, and precipitation as caliche, dendrites, and chert. Mechanical erosion includes the downstream movement of clay, silt, sand, and gravel to lower elevations, and deposition of alluvium.

SOILS

Major soil associations at the Tumamoc Hill site are:

1. Soils-of-the-Hill-proper and Rock Outcrop -- gently sloping to steep, very gravelly sandy loamy to cobbly clayey soils and bedrock on residual upland;

2. Pinaleno-Palos Verdes -- deep, nearly level or level to gently sloping, gravelly to very gravelly sandy loamy to sandy clay loamy soils on old alluvial-colluvial fans and stream terraces;
3. Nickel -- gently to strongly sloping, very gravelly, calcareous, moderately coarse sandy loamy soils on sloping old stream terraces and alluvial-colluvial fans; and
4. Anthony-Arizo -- deep, nearly level or level to gently sloping coarse sandy loamy to gravelly sandy soils on alluvial flood plains.

These associations occupy about 50, 20, 15 and 10 percent, respectively, of the site's 850 western acres (344 ha) surveyed (Barbarick and others, 1973, p. 15). Runoff is rapid in Soils-of-the-Hill-proper and Rock Outcrop. Permeability is moderate to rapid in Anthony and Arizo soils, which provide good recharge potential when not underlain by clay or caliche. Arizo soils are suitable gravel sources. Road fill is fair to good in Anthony, Arizo, Palos Verdes, and Pinaleno soils. Palos Verdes and Pinaleno soils make good reservoirs. All these soils have slight to severe sewage disposal properties, and none are good as low-building foundations. Earth blasting is necessary for septic-tank installation in the upstream area in Silvercroft Watershed. These soils and their properties are similar to those throughout Silvercroft Watershed.

Soils are the product of interaction between parent rock, topography, climate, organic matter, and time. Physical and chemical properties of soils are partially affected by the historical moisture regime. The Anthony-Arizo association owes its origin to upstream mechanical erosion and downstream deposition, where water is the primary agent. These arid-land soils have coarse textures and low cation-exchange capacities because of their hydrologic environment.

VEGETATION

Over 250 species and varieties of trees, shrubs, grasses, and cacti occur in the Tumamoc Hill area (Baldwin and others, 1974, p. 34-35). These plant communities are identified: Paloverde-Saguaro -- foothill paloverde, various shrubs, saguaro, several cacti; Creosote bush; and Riparian -- mesquite, blue paloverde, and catclaw.

Local moisture regime is an important control for the type and distribution of plants. Paloverde-Saguaro prefer well-drained, rocky hillsides or coarse-soil slopes, and typify the Sonoran Desert hill community. Creosote-bush communities prefer lower and more arid lands, and dry, more level, gravelly soils. Riparian vegetation prefers major drainages and associated terraces.

WILDLIFE

Tumamoc Hill is a suitable habitat for various wildlife species because of its terrain, vegetation, and proximity to the Tucson mountains (Baldwin and others, 1974, p. 36). Available water for the Hill's wildlife is important to type and distribution. Small animals are less common in dry years, and certain species, such as frogs, are found only during wet

periods. A few water holes help sustain wildlife through dry seasons.

ARCHAEOLOGY

The Hill contains remnants of "trincheras", petroglyphs, sleeping circles, mortar holes, and pottery of Hohokam origin (1200 A.D.; Baldwin and others, 1974, p. 18, 37-39). Water was important to Hohokam life. Settlement is near ancient streams or springs, from which water could be carried in pots to more defensive positions. Agriculture and food gathering was practiced in the once moisture-rich valleys. Hunting of animals at water holes was likely.

HYDROLOGIC ASPECTS

Rainfall and evaporation, runoff and floods, groundwater, and water quality comprise this report's hydrologic aspects.

Water resources are limited, and supply depends on rainfall, ephemeral storm-generated runoff, or importation. Rainfall data are long term and discontinuous. Streamflow records are few. Ground-water information is not extensive for the site. The "well" shown on Cat Mountain quadrangle is actually a City of Tucson booster pumping plant (Stein, 1974). Infiltration rates are high in the Anthony-Arizo soil association along major drainages. Consumptive use by vegetation is also high. There are a few water holes in clay pits and landfill in Silvercroft Watershed.

RAINFALL AND EVAPORATION

Winter and summer precipitation, and spring and fall drought describe Tucson's semiarid rainfall pattern. Winter precipitation is from cyclonic storms that originate to the northwest; it is widespread, and light to moderate. Summer rains are violent convective thunderstorms from moisture from the Gulf of Mexico. Occasionally late August and September tropical storms move inland from the Gulf of California and the Pacific Ocean, and produce large rainfall amounts (Davidson, 1973, p. 10). About 65 percent of the annual rainfall occurs between May and October. About 50 percent of the annual total occurs in summer months as localized, showery, and intense events over mountainous terrains, and normally light events over desert terrains (Green and Sellers, 1964, p. 13). Intensity is often high on an hourly basis in the Tucson Basin (Burkham, 1970; Condes de la Torre, 1970).

Average annual precipitation is 11.21 in. (286 mm) with a range of 5.34 in. (135.2 mm) to 42.25 in. (1080 mm) for a 40-year record (National Weather Service). The greatest average monthly rainfall occurs in the summer, when air temperature and potential evapotranspiration is highest (Davidson, 1973, p. 10). Average monthly temperature ranges from 50°F (10°C) in January to 86°F (30°C) in July (Green and Sellers, 1964, p. 435). Annual evaporation, computed by the Thornthwaite method (Thornthwaite, 1948), is about 42 in. (1070 mm; Buol, 1964, p. 8), or four times the average annual precipitation. Annual pan evaporation is 89.27 in. (2265 mm).

RUNOFF AND FLOODS

Runoff results when precipitation exceeds infiltration and surface-ponding capacity. In the Santa Cruz River basin upstream from Tucson, and in Rillito Creek, only 0.6 and 1.0 percent of the precipitation becomes streamflow (Schwalen, 1942, p. 468-469). This is because of high evapotranspiration in the desert soil-water system (Davidson, 1973, p. 11). Average annual runoff ranges from about 3 ac-ft/mi² (0.056 in. or 1.44mm) in the infiltration-high central basin, to more than 200 ac-ft/mi² (3.8 in. or 96 mm) in the infiltration-low mountainous areas (Burkham, 1970; Condes de la Torre, 1970). The standard deviation of annual streamflow at most basin gaging stations is as large, or larger, than the mean annual flow (Davidson, 1973, p. 12).

Streamflow Records and Floods. Table 1 shows streamflow records at Silvercroft Wash. The gage is located at latitude 32°13'53"N, longitude 111°00'10"W, in NW/4, Sec. 10, T.14S., R.13E., 0.1 mi (0.2 km) west of Silverbell Road, 0.3 mi (0.5 km) northwest of St. Mary's Hospital, and 0.4 mi (0.5 km) north of Anklam Road, at 2,350 ft (720 m) altitude. The crest-stage gage was established with the City of Tucson on December 12, 1972, on this 2.74 mi² (7.10 km²) drainage area. Channel at most stages is the control. Bedrock is exposed about 150 ft (46 m) downstream. Peak flows are calculated by a rating table based on a step-backwater curve, which balances the water-energy equation through a few sections of straightened reach. Other flow measurements were made by slope-area survey (roughness coefficients of 0.025 and 0.027) at and away from the gage, and by current meter, and by estimation.

These short-term data are not sufficient to project meaningful return periods, even if watershed properties were stable. Return-period floods are floods for which the time interval of recurrence is calculated from historical data. Nonetheless, order-of-magnitude estimates are shown in Table 2, where the Gumbel frequency distribution of return period gave the best graphical fit. The Rational method calculates discharge from the product of a watershed coefficient, rainfall intensity and drainage area (Chow, 1964a,b). Assumptions include a concentration time of 67 minutes, drainage length of 13,000 ft (3,960 m), a slope of 1.24 percent, and a coefficient of 0.35, chosen for urbanization, slope, and channel features.

Increasing urbanization increased runoff, so that the channel was straightened north of Anklam Road a number of times since the early 1960's. Flows over 2,500 cfs (71 cms) would probably overflow the channel at the gage, and smaller flows would overflow the channel at upstream reaches. The Gumbel frequency distribution indicates that these sizes floods have a ten-year return period, assuming watershed properties are constant.

No streamflow records are available for the two other washes draining Tumamoc Hill. Estimates are made for the flow of the Unnamed Northeastern Wash at Anklam Road (Cella and others, 1974). The Rational method yields annual, 10-, 25-, and 50-year return-period flows of 193, 297, 382, and 490 cfs (1 cfs = 0.0284 cms), respectively. These correspond to 190, 300, 380, and 450 cfs when calculated by water-energy balance or Puls method. Assumptions were based on information from the Arizona Highway Department.

Urbanization. Increasing runoff volumes, rates, and frequencies accompany urbanization, because covering undeveloped areas with pavement and structures prevents precipitation and storm runoff from infiltrating.

Table 1. Streamflow Records at Silvercrock Wash, Tucson, Arizona.*

Date of Measurement	Discharge in cfs (in cms)	Channel Depth in ft (in m)	Drainage Area in sq mi (in sq km)	Unit Area		Comments
				Discharge in cfs/sq mi (in cms/sq km)	Discharge in cfs/sq mi (in cms/sq km)	
08-22-69	365 (10.4)	2.5 (0.8)	2.44 (6.33)	150 (1.65)		Slope-area measurement at gas pipeline for peak flow.
07-20-70	1,500 (42.5)	4.0 (1.2)	2.83 (7.35)	430 (5.79)		Slope-area measurement at West Speedway for peak flow. Water level within 6 in. (15 cm) of top of channel.
08-17-71	1,400 (39.7)	4.2 (1.3)	2.74 (7.10)	510 (5.60)		Slope-area estimate at gage site for peak flow. Water level within 6 in. (15 cm) of top of channel.
08-15-72	100 (2.8)	1.0 (0.3)	2.74 (7.10)	36.7 (0.39)		Estimated peak flow.
03-14-73	7.67 (0.22)	0.2 (0.06)	2.74 (7.10)	2.7 (0.03)		Current-meter measurement of continuous flow.
08-10-73	115 (3.3)	3.5 (1.1)	2.74 (7.10)	42.0 (0.46)		Step-back water curve measurement of peak flow.

*Based on records provided by the U.S. Geological Survey, Tucson, Arizona.

This adds to potential downstream watershed and street flooding, upstream erosion, downstream siltation, and downstream hazard to residents, unless storm drains or other flood-routing structures are provided. It is noteworthy that various Geological Survey reports (Burkham, 1970; Davidson, 1973) and engineering studies (Engineering Sciences, and Marum and Marum, 1972; Brown and Caldwell, 1973a,b; Cella and others, 1974) now consider hydrologic effects of urbanization.

An intense Tucson summer storm over an urban area may produce volume and peak-flow rates three or more times as high as runoff from undeveloped areas. To illustrate this impact, if half of the yearly storms occur in the summer on a watershed whose upstream sections double its impermeable area to 20 percent of the watershed, runoff contribution from that urbanized area would perhaps double or triple. Then the 2,500-cfs (71-cms) flow rate necessary to overflow the Silvercroft Wash channel would have a return period of perhaps five or seven years. In other words, urbanization will increase the downstream-flood frequency.

Table 2. Estimated Return-Period Floods at Silvercroft Wash, Based on 1969-1973 Peak Flows.*

Return Period (in years)	Semi-Logarithmic Analysis (cfs)**	Full-Logarithmic Analysis (cfs)**	Gumbel Analysis (cfs)**	Rational Method (cfs)**
Annual (2.33)	700	380	800	450
Ten	2,200	8,000	2,350	1,000
Twenty-five	3,050	50,000	3,300	1,300
Fifty	3,600	240,000	3,850	--

*Based on drainage-area adjustments from records provided by the U.S. Geological Survey, Tucson, Arizona.

**Note that 1 cfs = 0.0284 cms.

GROUNDWATER

There have been no groundwater studies on Tumamoc Hill, though information is available from the University's Soils, Water and Engineering Department on the peripheral area. Major drainageways are underlain by caliche and are not natural recharge routes. Alluvium, which forms the Tucson Basin aquifer, is less than 20-ft (6-m) thick.

According to nearby ground-water data, Schwalen (1942), Matlock and Davis (1972), and Davidson (1973), the Tumamoc Hill area lies in a hard-rock area out of the major Tucson basin aquifer. Section 22, south of the Hill, and the eastern quarter of section 10, east of the Hill, lie within Tucson's major ground-water system. Inhabitants of Silvercroft Watershed obtain water from the City of Tucson.

There are about 55 city, domestic, laundry, irrigation, nursery, standby-hospital, and inactive wells surrounding the Hill from 42 to 550 ft (14 to 180 m) deep. Most of these lie to the Hill's south, and are completed in 3 to 33 ft (1 to 100 m) of water-bearing sand, gravel, caliche, conglomerate, and fractured volcanic rock. Nearly all the wells were deepened as water-levels dropped as much as 60 ft (20 m) in 40 years because of excessive withdrawals. Current water levels generally exceed 90 ft (30 m). Reported discharge rates range from 0.1 to 1,200 gpm (0.4 to 4,800 lpm).

Downstream siltation due to upstream erosion caused by urbanization in Silvercroft Watershed reduces infiltration and ground-water recharge in the Santa Cruz River (Brown and Caldwell, 1973a, p. 74). Almost 75 percent of the main-channel streamflow infiltrates the basin (Davidson, 1973), but most of this water is lost to evapotranspiration. Water levels decline, the aquifer compacts, and land subsidence occurs since ground-water use exceeds recharge (Matlock and Davis, 1972; Brown and Caldwell, 1973a,b; Davidson, 1973).

WATER QUALITY

No water-quality data are available for Tumamoc Hill (Laney, 1972), but there are peripheral data (Department of Soils, Water and Engineering). Tucson's streamflow is moderately hard (Davidson, 1973, p. 58) with dissolved-solids concentration usually less than 400 mg/l, and commonly less than 200 mg/l. Groundwater is moderately hard to very hard, and contains less than 500 mg/l dissolved solids at depths of 1,000 ft (305 m) or more (Davidson, 1973, p. 57). Thus, groundwater is considerably more saline than surface water. This is because the long contact time between warm subsurface water and the rock environment encourages mineral solution.

Water to the Hill's immediate surroundings (sections 5 to 10, 17 to 22, 22) from 34 wells have total dissolved solids, nitrates, and hardness from 605 to 1050, 2.0 to 18.0, and 100 to 347 mg/l, respectively. Ground-water quality in the nearby Sentinel Peak-Tucson area is reported as follows for range and average: dissolved solids, 412 to 1,231, and 696 mg/l; nitrates, 6.4 to 15.0, and 11.3 mg/l; and hardness, 17 to 660, and 230 mg/l (Brown and Caldwell, 1973b, p. 32).

Urbanization degrades runoff and local ground-water quality, especially with regard to organic matter, sediment, turbidity, and bacterial concentrations. Tucson urban runoff is generally unsuitable for irrigation and recreation use without some treatment (Atala, 1969; Dharmadikari, 1970; Mische, 1971; Popkin, 1972, 1973). Upstream erosion, domestic sewer backup during storms, pesticide spraying, over-fertilizing, and watering of lawns contribute to this decline. Sewers are optimally located to follow natural drainage, and often cross washes in the Silvercroft Watershed. In arid lands, overirrigation of newly established landscapes produces saline drainage waters.

SUGGESTED MANAGEMENT POLICIES

The City of Tucson's Department of Public Works, the Pima County Highway Department, the Town of South Tucson, and the Arizona Highway Department bear the prime responsibility for Tucson's storm-water control structures (Brown and Caldwell, 1973a, p. 62). Erosion-damage control in

urban areas should be the responsibility of the contractor or developer who modifies the land, and the governmental agency which reviews proposed modifications (Brown and Caldwell, 1973a, p. 24). The Davis-Monthan Air Force Base in Tucson was built with a large concrete storage basin to divert its generated storm runoff. The University of Arizona controls the central portion of Silvercroft, and the upstream portion of the two other watersheds comprising Tumamoc Hill. The University should consider the Hill's hydrologic significance.

Widened channels, low check dams (as doodle dams for gully control), and vegetated drainageways would reduce runoff rates, downstream siltation and flood hazard (Schwab, Frevert, Edminster and Barnes, 1966; Cella and others, 1974). Grass and soil filtration has been used to upgrade Tucson urban runoff (Lehman, 1968; Popkin, 1972, 1973). Such a control plan can be designed to provide supplemental moisture for the Hill's wildlife and vegetation. Maintenance would be required to remove entrapped sediment, which perhaps could stabilize the landfill.

Diverting storm runoff from high-channel flow for storage, irrigation, recharge, or later release would be more expensive, but might provide favorable research results. No water-management scheme should be incorporated before detailed data analysis and watershed modeling. Stochastic watershed models are appropriate for arid-land urban hydrology.

Hydrologic and environmental interactions are suitable study disciplines for the controlled-access tours being considered by the Tumamoc Hill Committee. Booklets and school projects could accompany field survey into the hydrologic effects of urbanization on this desert region. Results of detailed hydrologic and environmental investigations could lead to a beneficial land-use plan for Tumamoc Hill.

SUMMARY

Water is an important factor in the geology, soils, vegetation, wildlife, archaeology of Tumamoc Hill. Water weathers, erodes, precipitates, and deposits rocks, drains and leaches soils, and provides moisture for vegetation and wildlife. Archaeological settlements and their preservation are determined by hydrologic circumstances. Research in natural settings relate to the water situation. All these disciplines are effected by water at Tumamoc Hill.

Hydrologic aspects of the Hill include potential flooding and erosion hazards because upstream urbanization reduces natural infiltration. This development increases storm runoff volumes, flood peaks and frequencies routed through the site, and threatens existing downstream urban projects. Return periods of channel-overflow floods become shorter with urbanization. The region may be managed to reduce hydrologic hazards by these procedures: widen channels, install low check dams, and vegetate drainageways. These methods will slow down runoff velocities, and increase cross-sectional area and roughness coefficient. More water would also be available for vegetation and wildlife.

A land-use plan should be developed. It should include environmental education programs which present important effects of water on the natural ecology, and hydrologic aspects of watershed urbanization.

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