The Role of Landscapes in Stormwater Management

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Abstract

This paper presents evidence that many existing streams did not have conspicuous channels and were not identified during presettlent times (prior to 1830s in the Midwestern United States). Many currently identified first, second, and third-order streams were identified as vegetated swales, wetlands, wet prairies, and swamps in the original land survey records of the U.S. General Land Office.

The data presented show that significant increases in discharge for low, medium, and high flows have occurred since settlement. Stream channels have formed inadvertently or were created to drain land for development and agricultural land uses. Currently, discharges may be 200 to 400 times greater than historical levels, based on data from 1886 to the present for the Des Plaines River in Illinois, a 620-square-mile watershed. Historic data document how this river had no measurable discharge or very low flow conditions for over 60 percent of each year during the period from 1886 to 1904.

This study suggests that land-use changes in the previous upland/prairie watershed have resulted in a change from a diffuse and slow overland flow to increased runoff, concentrated flows, and significantly reduced lag time. Preliminary modeling suggests the following results: reduced infiltration, reduced evaporation and evapotranspiration, greatly increased runoff and hydraulic volatility, and increased sediment yields and instream water quality problems caused by destabilization of streambanks.

The opportunity to emulate historical stormwater behavior by integrating upland landscape features in urban developments and agricultural lands offers stormwater management options that are easier to maintain, less expensive over time, attractive, and possible more efficient compared with many conventional stormwater management solutions and the use of biofiltration wetlands.

Introduction

Diverse and productive prairies, wetlands, savannas, and other ecological systems occupied hundreds of millions of acres in presettlement North America. These ecological systems have been replaced by a vast acreage of tilled and developed lands. Land-use changes have modified the capability of the upland systems and small depressional wetlands in the uplands to retain water and assimilate nutrients and other materials that now flow from the land into aquatic systems, streams, and wetlands. The historical plant communities that were dominated by deep-rooted, long-lived, and productive species have been primarily replaced by annual species (corn, soybeans, wheat) or shallow rooted non-native species (bluegrass lawns, brome grass fields). The native vegetation was efficient at using water and nutrients, and consequently maintained very high levels of carbon fixation and primary productivity. Modern communities, in turn, are productive but primarily above ground, in contrast to the prairie ecosystem where perhaps 70 percent of the biomass was actually created below ground in highly developed root systems. These changes in the landscape and vegetation coupled with intentional stormwater management have changed the lag time for water to remain in uplands and consequently increased the rate and volume of water leaving the landscape.

The Des Plaines River

Changes that have occurred on the uplands and how these changes have affected the hydrology of wetlands and aquatic systems can be illustrated using historical and more recent data to illustrate trends in discharge of major river systems. The Des Plaines River was chosen as a study watershed because of available historical data and trackable changes in watershed land uses.

The Des Plaines River originates southeast of Burlington in southeastern Wisconsin, flows for over 90 river miles through agricultural, urban, and suburban landscape through northeastern Illinois and the Chicago region, then flows west and south, meeting with another river and becoming the Illinois River. The historical data presented are from a case before the Illinois Supreme Court and a circuit court (U.S. Department of War vs. Economy Power and Light, 1904) that dealt with the navigability of the Des Plaines River. The data were derived from a gauge station installed and operated at present-day Riverside, Illinois, from 1886 to 1904. The U.S. Geological Survey has maintained this same station since 1943. Historical data from 1886 to 1904 including a single-stage measurement per day and weekly discharge measurements (rating curves). For our studies, duration flow curves were created for the years 1886 to 1904 and 1943 to 1990. The data were compared using median values of discharge (50 percent) and also using low and high levels of discharge s indicated by the 75 percent and 10 percent values derived from the annual duration flow curves 1886 to 1904 and 1943 to 1990. The watershed area gauged at Riverside is approximately 620 square miles (400,000 acres).

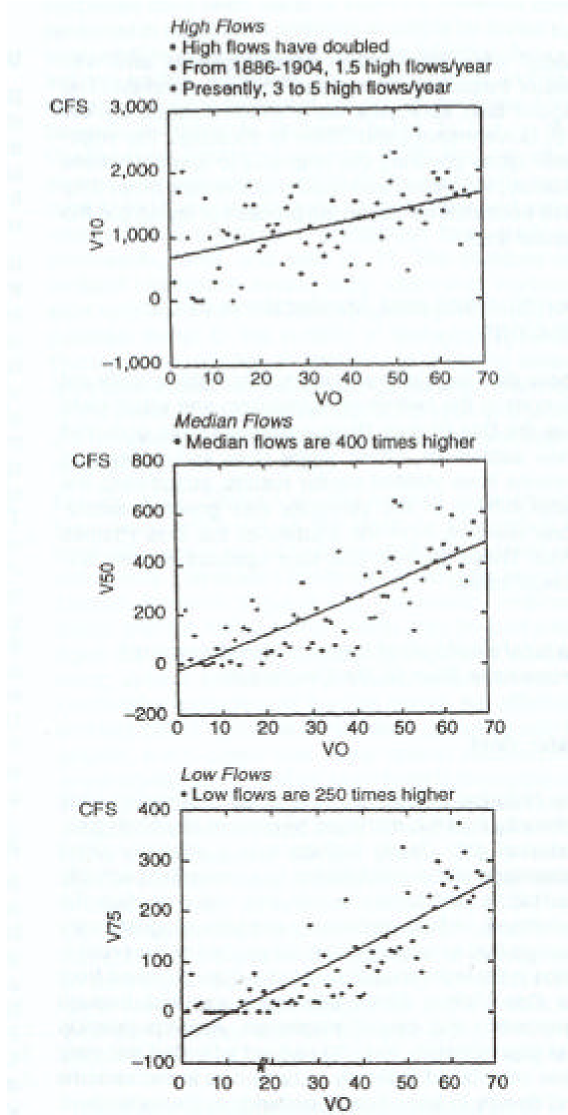

Figure 1. Linear regression analysis and raw data plots of Des Plaines River discharge at Riverside, Illinois, 1886 to 1988. Low, median, and high flow data were derived from duration-flow curves for 75, 50, and 10 percentile annual flow levels (1).

In the late 1800s, about 40 percent of the watershed had been tilled and/or was developed. In contrast, approximately 70 to 80 percent of the watershed is now developed or under annually tilled agriculture land uses. Annual duration flow curve values based on linear regression analysis suggested very significant increased in discharge since 1886; perhaps 250 to 400 times (Figure 1). In 1886, the median discharge was 4 ft^3/sec. In contrast, in recent years the median discharge has been 700 to 800 ft^3/sec. Trends in low, medium, and high flow values for the Des Plaines River have undergone very significant increases.

Preliminary watershed hydrologic modeling suggests that the watershed and discharge data for 1886 to 1904 had already been modified by development and agricultural land uses; the Des Plaines River watershed was settled in the late 1830s, and thus 50 years of land use and development had passed before the 1886 data were collected. Other data resulting from the litigation suggested very clearly that the discharge of water from the Des Plaines River was significantly less between 1886 to 1904 compared with present day discharge. Because the litigation contested navigability, evidence was presented using daily stage, discharge, and water depth data on the opportunity for commercial navigation on the river. The data suggested that between 1886 and 1904, for an average 92 days per year, the river had no measurable discharge. An additional 117 days per year, the river had 60 ft^3/sec or less discharge, which was equal to a depth of less than 3 in. at Riverside. Based on these statistics, over 60 percent of the year the 400,000 acre watershed yielded no water or such low flows that navigation was not possible or reliable. Another 10 to 25 percent of the year the river was covered with ice.

Additional supporting evidence of the significance of changes in the watershed and river is available. The original land survey records for parts of the Des Plaines River where section lines were surveyed identified that reaches of the river had no discernable channels. Where channels now occur, in the 1830s surveyors found wet prairies, swamps, and swales but usually no conspicuous or measurable channel widths. Channels and "pools" were identified in some locations and with greater frequency downstream in the watershed. The original land surveyors were under contract by the U.S. Government Land Office to document the vegetation types covering the land and to identify, where possible, the widths and depths of streams when they were encountered during the process of laying out the section lines.

Conclusions and Applications of the Findings

These data suggest very clearly that highly significant changes in the hydrology, hydraulics, and water yield from the Des Plaines River watershed have occurred since settlement. Other major river and watershed systems have yielded similar results, suggesting the transferability of the concepts and general conclusions reached from the studies of the Des Plaines River. These findings and their applications are discussed below.

Natural Ecological System Functions and Processes Should be Emulated

Water Yield

The historical landscapes "managed" stormwater very differently than it is managed by present-day strategies. Historical data clearly indicate that a relatively small percentage of the precipitation in a watershed actually resulted in measurable runoff and water leaving the watershed. In fact, preliminary analysis suggests very strongly that an average 60 to 70 percent of the precipitation in the watershed did not leave the watershed from the Des Plaines River; this water was lost through evaporation and evapotranspiration. Analysis predicts that approximately 20 to 30 percent infiltrated and may have contributed indirectly to base flow in the streams and directly to base flow in wetlands in the watershed. During a full year, the balance of the water directly contributed to flow in the "river," where an identifiable river channel now occurs.

Present-day water management strategies involve collection, concentration, and managed release of water. These activities are generally performed in developed parcels in the lower topographic positions. Historically, a greater percentage of water was lost through evaporation and evapotranspiration from upland systems. In these situations, microdepressional storage and dispersed rather than concentrated storage occurred. Weaver (1) documented the ability of the foliage of native perennial grassland vegetation to intercept over an inch of rain with no runoff generated.

Sediment and Pollutant Management

Because many pollutants in stormwater require water to dislodge and translocate the suspended solids to which they are absorbed, there is a great opportunity to emulate historical functions by using upland systems to perform biofiltration functions, increase lag time, and reduce total volume and rate of runoff.

Increased discharge and velocity of water moving through channels has been documented to greatly affect instream water quality. Perhaps as much as 70 percent of instream sediment loads come from channel and bank destabilization associated with the higher velocity waters and with solufluction and mass wasting of banks after flood waters recede (2). Stabilizing (or at least reducing) hydraulic pulsing in streams can best be accomplished by desynchronization and reduction of tributary stormwater volumes and runoff rates from uplands. This can be accomplished by integrating substantial upland perennial vegetated buffers throughout developments and agricultural land uses. Buffers are designed not only to convey water and minimize erosion (i.e.grassy waterways) but also to attenuate hydraulic pulsing, settle solids and adsorbed nutrients, and reduce and diffuse the velocity, energy, and quantity of water entering rivers, wetlands, and other lowland habitats. Using upland microdepressional storage, perhaps in the form of ephemeral wetland systems and swales in the uplands, would also emulate the historical landscape conditions and functions.

Applications

Several example projects of “conservation developments” are now being completed, which integrate up to 50 to 60 percent of the urban development as open space planted to perennial native prairie, wet swales, and other upland communities (as site amenities). Hybernia is a 132-acre residential development in Highland Park, Illinois, designed and constructed by Red Seal Development Corporation, Northbrook, Illinois. Empirical date from Hybernia suggest that the use of upland vegetation systems in combination with ponded areas has resulted in the rate and volume of discharge being essentially unchanged before and after development. Another project, Prairie Crossing, is a 677-acre residential project designed to offer comprehensive onsite stormwater management in uplands and created lake systems. Extensive upland prairie and wet swale systems biofilter runoff and enhance the quality and reduce the quantity of water reaching wetlands and lakes in the development.

In these types of projects, upland vegetation takes several years to fully offer stormwater management benefits. In planted prairies, surface soil structure develops a three-dimensional aspect in 3 to 5 years. The development of this structure seems to have an important role both in offering microdepressional storage and increasing the lag time of retained water in upland systems.

Restoration and native species plants also have provided benefits where ecological system degradation has led to increased water and sediment yields. Where ecological degradation is occurring indirectly-because human activities on the landscape have reduced or eliminated major processes (such as natural wildfires),--restoration can provide vegetation and stormwater management benefits.

Wildfires have been all but eliminated since human settlement has occurred, especially in areas that contain forests, savanna, or oak woods. In the absence of fires in many oak woods and savannas, a dense shading develops caused by increased tree canopy and dense shrub development. Where this has occurred, ground cover and soil stabilizing vegetation is reduced due to the low-light conditions. Consequently, highly erodible topsoils (containing the seeds, roots, and tubers of the soil stabilizing vegetation) and higher volumes and rates of water run off from these degraded savanna sites. The process of savanna deterioration has been documented; restoration has used prescribed burning and other strategies (3-5). Reestablishment of ground cover vegetation is key to reducing runoff, improving water quality, and reestablishing an infiltration component in degraded, timbered systems.

Should Wetlands Be Used for Sediment Management, or Should This Occur on the Uplands?

Because wetlands often provide what little wildlife habitat remains in developed landscapes, and because they are attractive to wildlife, their use for stormwater management must be carefully considered. Currently, a national movement is afoot to use created (and often natural) wetlands for stormwater management and biofiltration. Many studies of existing high-quality wetlands, however, provide little or no evidence that they historically served important biological filtration and sediment management functions. Sediment deposition was generally episodic (e.g., after wildfires), was of short duration, and yielded small sediment loads compared with loads from present-day agricultural and developed lands.

Use of wetlands for biofiltration can actually aggravate existing problems for many wetland wildlife species. For example, in the Chicago region it is not unusual to find 100 to 200 parts per million lead (and other contaminants) in tadpoles (especially in frog species with a 2-year tadpole stage, such as leopard frogs, bullfrogs, and green frogs) found in wetlands receiving highway stormwater. It is imperative to understand the potential long-term toxic effects on biological systems associated with Contaminant mobility and stormwater management in wetlands.

Proposals have been made to allow the materials concentrated in biofiltration wetlands to simply be buried by each additional sediment load or to be intentionally buried by adding additional soil. Contaminant mobility through biological pathways still occurs, however, from beneath considerable sediment burial. In fact, in the Great Lakes, contamination from PCBs that are often several feet below the surface of the sediments have contributed to major increased mortality rates and major morphological problems in predacious birds such as cormorants, terns, and gulls (6, 7). The literature on wetland biofiltration inadequately addresses contaminant mobility routes through biological systems and the potential threat to the viability of biological systems. Because wetlands are so attractive to biological organisms (and, in fact, the biological organisms are often key to the successful functions of the biofiltration wetlands), it is necessary to rethink and carefully design biofiltration wetland systems in the future.

Far too often, people view the lowland environments (i.e., rivers, wetlands) as the locations for treating or physically removing problems created in the upland environments. The studies briefly described in the previous section, however, suggest that stormwater, sediment loads, and the varied contaminants may be best managed on upland systems. Although the land cost for using upland rather than lowland environments for stormwater management may be higher, the efficiency and reduction in potential contaminant problems may be greater. A landscape with many upland microdepressional storage opportunities and a large buffering capacity might offer more efficient processing than would a single biofiltration wetland at the downstream end. Each buffer or depressional wetland would need to treat a smaller volume of water and contaminants. Also, upland or dispersed stormwater treatment facilities would have significantly reduced long-term maintenance costs and represent a more sustainable approach to management of stormwater. Centralized biofiltration wetlands, on the other hand, have high maintenance requirements and potential problems that include decreases in removal efficiency for some materials in the short and long term.

There Are No Controlled Year-Round (and Long-Term) Studies of Removal Efficiencies Comparing Uplands and Wetlands

The stormwater treatment literature indicates that use of wetlands and measurements of removal efficiencies have been based primarily on removal during storm events passing through the biofiltration wetlands. Year round contaminant mass-balance data are largely unavailable. Nongrowing season studies have documented the export of materials to be significant; consequently, removal efficiencies for some materials (e.g., metals, phosphorus) are not likely to be significantly reduced from what has been documented for storm event sampling. Wetland efficiencies need to be experimentally controlled and compared with upland removal efficiencies, which also have not been studied in detail (with the exception of removals for several key elements such as phosphorus). The ability of upland (soil colloids) systems to provide reliable and long-term binding and retention for many contaminants has been demonstrated (8).

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References

1. Weaver, J.E. 1968. Prairie plants and their environment, a 50-year study in the Midwest. Lincoln, NB: University of Nebraska Press.
2. Dunne, T., and L.B. Leopold. 1978. Water in environmental planning. San Francisco, CA: W.H. Freeman and Company.
3. Haney, A., and S. Apfelbaum. 1990. Structure and dynamics of Midwest oak savannas. In: Sweeney, J.M., ed. Management of dynamic ecosystems. West Lafayette, IN: The Wildlife Society, North Central Section. Pp. 19-30
4. Haney, A., and S. Apfelbaum. 1993. Characterization of Midwestern oak savannas. In: U.S. EPA. Proceedings of the Workshop on Oak Savannas, February. Chicago, IL. In press.
5. Apfelbaum, S.I., and A. Haney. 1991. Management of degraded oak savanna remnants in the upper Midwest: Preliminary results from 3 years of study. In: Ebinger, J., ed. Proceedings of the Oak Woods Management Workshop, Peoria, IL pp. 81-89.
6. Schneider, S., and R. Campbell. 1991. Cause-effect linkages Il. Abstract presented at the Michigan Audubon Society Symposium, Travers City, MI, September 27-28.
7. Gilbertson, M., and R.S. Schneider. 1991. J. Toxicol. Environ. Health 33(4).
8. Leeper, G.W. 1978. Managing the heavy metals on the land. New York, NY: Marcel Dekker.