Solstice Canyon Creek

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Development of Bankfull Regional Relationships in the Los Angeles Area for Application in Local Stream Restoration Projects

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Widespread alterations to streams in the Santa Monica Bay and Los Angeles region have resulted in a loss of physical and ecological function that has recently been recognized. Attempts to restore these functions are confounded by the lack of knowledge about pre-disturbance conditions and a method for determining the present-day potential for the restoration of the altered streams. Developing a regional understanding of how the processes of sediment and hydrologic transport are expressed in the morphology of streams facilitates stream protection and water quality policies, flood management practices, and restoration. The most basic expression of regional stream morphology is a regional curve for estimating stream dimensions (cross-sectional area, width, and depth) from watershed size. The Los Angeles Regional Curve was developed as a geomorphic tool for estimating channel dimensions in stream assessments and restorations. The curve derived from measurements of local channel morphology is similar to other curves derived from the southwestern U.S. and indicates that the extremely altered environment of the Los Angeles region still supports the processes that build and maintain natural stream channels. Additional work is still necessary, as additional stream assessments in coastal, urban, and suburban watersheds are likely to create distinct sub-regional curves. Additional surveys need to be tied to sites with stream gauges to improve our understanding of the frequency of channel forming flows and mean velocities experienced during these flows.

IT ISN'T NEWS THAT STREAMS in the Santa Monica Bay watershed, as in the Los Angeles region, have been heavily impacted by development. Over the past 250 years, watershed alterations have changed runoff and sedimentation rates, while agencies and individuals also straightened, leveed, and ultimately culverted or armored waterways to increase developable land area and to decrease the associated flood hazards.

Today, approximately 90% of both perennial and intermittent streams in Los Angeles' urban areas are encased in concrete (Figure 1). Wetlands and backwaters are also mostly drained, although in some sensitive cases, they are now supported with either reclaimed or imported potable water. In today's watershed, paving and storm drains ensure that groundwater no longer receives annual recharging; this contributes to a regional deficit in groundwater resources while streams themselves are no longer recognizable as such to the average resident. Aquatic and stream-side (riparian) flora and fauna have mostly disappeared with the streams; the complex relationship between sediment, water, stream geometry, flood regimes, and vegetation that provided the matrix for now endangered fish is isolated to a few streams through state park lands – when not disturbed by gabions, rip rap, Arizona crossings, check dams, debris dams, irrigation, or flood control dams.

Also lost with these waterways is an understanding of a stream's structure and processes. Today, we may see a habitat restoration project that focuses on structures or conditions, such as trees, ponds, gravel beds, and soon for target species, but this does not allow the natural processes of a stream to rebuild the habitat through its own channel-forming processes, and thus we are missing the opportunity of a more resilient, self sustaining project. Additionally, water quality managers who seek to capture and infiltrate all runoff from small storms may ultimately undermine the processes that build and maintain stream channels if they do not also provide for the channel-maintaining function of sediment transport. Throughout the region, we have observed planning authorities routinely demonstrating a lack of understanding of the function of floodplains to safely dissipate and detain large volumes of water, a feature that benefits local water supplies, agriculture, and wildlife. This misunderstanding has led to permitting development in the floodplain, confining river channels to ever-narrower rights-of-way. Better integration of urbanization and streams will require advances in local understanding of how streams function and maintain their channels. An understanding of how stream dimensions and form support increased flood capacity, sediment transport, and aquatic and riparian ecological function will be a major step toward improving water quality, flood control, and habitat issues in the Los Angeles region.

The form of a stream channel is directly related to its ability to transport flow and sediment and dissipate energy. Channel slope, width, depth, sinuosity, and other characteristics regulate how sediment and flow are carried. Understanding channel form and dimension will give us an understanding of channel function. Rebuilding this knowledge base is rooted in empirical observations of natural stream morphological dimensions throughout the Los Angeles basin.

A framework for understanding form and dimension was developed starting in the 1950s, when United States Geological Survey (USGS) scientists, led by Luna Leopold, systematically surveyed natural streams throughout the United States and consistently found relationships between stream form (morphology), such as bankfull channel features, and discharge (rainfall-related flow) or the size of the watershed area. Their geomorphic approach quantified the physical characteristics of stream channels and identified patterns common to a watershed or region, developing an objective, standardized system of stream assessment in which the consistent identification of common reference points among the variety of natural channels within a region became possible. They found that, generally, low-gradient alluvial channels are composed of two important physical components: a low-flow "bankfull" channel and an adjacent floodplain. The bankfull stage is described as the point of incipient flooding, the point at which flow overtops the natural channel and spreads across the floodplain (Leopold et al. 1964). Empirical evidence from a large number of rivers in the other regions of the United States suggests that these flows are frequent, moderate events with a typical return interval of one to two years and that they represent a channel forming or maintenance flow (Dunne and Leopold, 1978). The channel features observed are depositional; sediment deposited by these moderate events forms the stream's flood plain and can be visually differentiated from the erosive cutting of a bank.

Figure 1. Concrete Channel

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In stable channels, the dynamics of sediment input (deposition) and output (erosion) are in balance, reflected in the stream's channel form. Streams that experience changes to sediment flows adjust through variations of channel form, pattern, and/or slope, which often disturbs the development of bankfull channels. Bankfull is a widely accepted feature from which to observe and understand stream processes and illustrates equilibrium conditions that can serve as a starting point for restoration. If channel processes maintain bankfull flows in identifiable ways, they can serve as a common point of reference across a variety of streams. Earlier studies have identified relationships between bankfull channel geometries and drainage area (Leopold et al. 1964; Emmet 1975; Jackson 1994; Castro 1997; Moody and Odem 1999; Knight et al. 1999). These relationships have been termed regional curves.

Perennial and ephemeral streams in arid regions pose special challenges in assessment, classification, and restoration. Southern California is dominated by winter rain events that produce infrequent, short-duration, high-discharge stream flows. In the southwestern United States, hydrologic processes influenced by varied topography, geology, soils, and vegetation produce a wide range of channel forms. With a general awareness of the braided, shallow Los Angeles and San Gabriel Rivers, and much theorizing as to the level of instability of many headwater streams, stream restoration advocates were left to wonder if the streams of Los Angeles were exceptional or likely to develop observable and consistent channel features that indicate channel forming flows in other regions of the world. Despite the challenges presented by the urban setting of the Los Angeles area, the quantification of a regional curve for bankfull dimensions would indicate

Figure 2. Survey Sites

that this region could approach stream assessment and restoration in a similar manner to other regions.

In 2006, Natural Channel Design, Inc. and staff from the Santa Monica Bay Restoration Commission surveyed 29 stream reaches. The goal was to identify at least 10 sites representing a range in watershed sizes within a homogenous hydrophysiographic region. Sites that were not surveyed were bypassed for several reasons. In some cases, the bankfull features were not clear – the stream was in the process of reestablishing itself after major disturbances such as flooding or debris flows, was influenced by flow regulation such as diversions or dams, or was restricted as private property and rugged topography. On the other hand, the dearth of natural channels in the lower elevations of the Santa Monica Bay watershed limited the team's ability to use entirely local references. For this reason, the 15 stream sites ultimately surveyed ranged across several major Southern California watersheds including the Santa Clara River (San Francisquito and Santa Paula Creeks), the San Gabriel River (East Fork and Graveyard Creeks), the Los Angeles River (Devil's Canyon, Brown's Canyon, Aliso Canyon, and Limekiln Creek), Ballona Creek (Stone Canyon), and smaller coastal watersheds (Topanga Creek, Las Virgenes Creek, Arroyo Sequit, Peck Park Creek, and Miraleste Creek) (Figure 2). The elevations ranged from sea level to over 1,300 feet above mean sea level. Watershed area for each site ranged from 0.3 to 58 square miles, with varying watershed characteristics including average annual rainfall amounts. Sites furthest inland were generally highest in elevation and were the least impacted, although northern coastal sites (Arroyo Sequit and Topanga Creek) had less developed watersheds in state park lands. Southern coastal sites (Peck Park, Miraleste, and Stone Canyon) were in suburban and urban areas and tended to represent the smaller watershed sizes. The streams surveyed represented a range of channel slopes, entrenchment, meander patterns, and sediment sizes. The presence or absence of base flow was not considered relevant, and streams representing both conditions were surveyed.

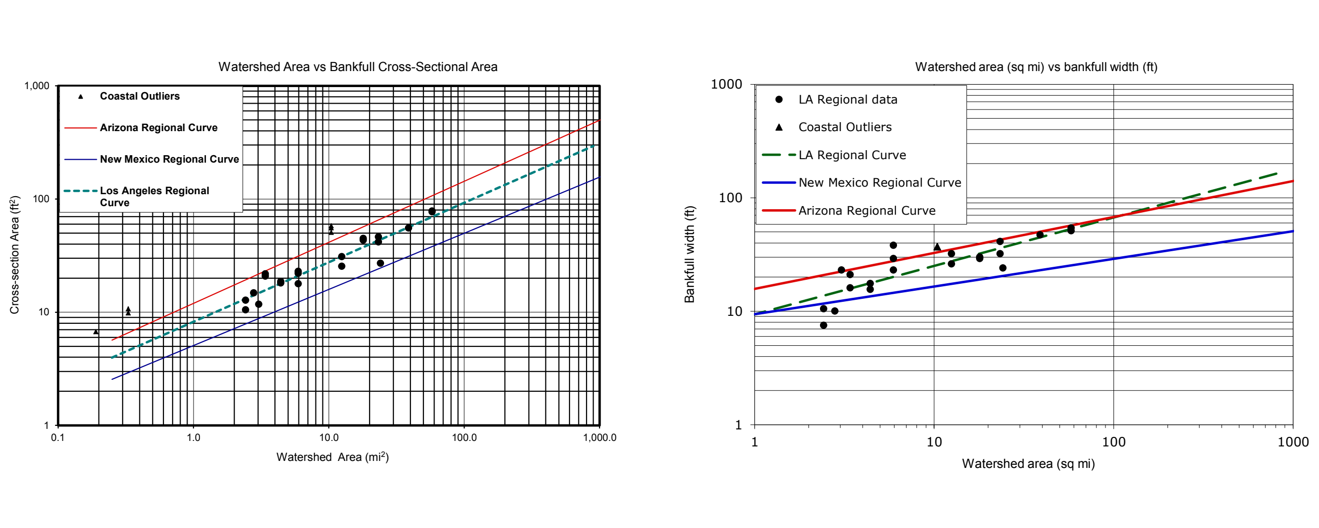
Bankfull features were clearly identified at the 15 surveyed sites. Bankfull stage was identified using procedures described by Dunne and Leopold (1978). Walking the channel, depositional features indicative of bankfull stage, such as floodplains, point bars, changes in bank slope, and changes in particle size, were noted. Vegetation served as a secondary indicator. These features were surveyed and described for analysis. High and low terraces as well as consistent vegetation were included in the surveys. A longitudinal profile equal to a distance of 20 to 40 channel widths was surveyed using a tape and laser level. One to three cross-sections were surveyed at riffle sections within the reach. Channel thalweg (lowest point of the flow line), water surface, and alluvial features were included in each profile and cross-section. Bed and bank materials were characterized using the Wolman Pebble Count Method (Harrelson et al. 1994) (Figure 3).

Data was analyzed for channel slope, bankfull width, bankfull cross-section area, mean depth, maximum depth, flood prone width (width at twice maximum bankfull depth), and super flood prone width (width at three times maximum bankfull depth). Watershed areas were delineated with topographic maps. After initial analyses, cross-sections that were affected by disturbances caused by logs, culverts, or other flow disruptions were eliminated. Reliable cross-sectional areas were plotted against watershed area on a log-log scale. A slope was fitted to the line using regression techniques.

Figure 3. Channel Surveys

PHOTOS: JESSICA HALL

Figures 4&5. Los Angeles Area Regional Curve Superimposed Over New Mexico & Arizona Regional Curves



There was a strong relationship between watershed size and bankfull cross-sectional area, where R^2 (0.89, n = 10) showed little scatter in the data (Figure 4). The data was then compared to regional curves that previously have been developed for other southwestern regions. The Los Angeles regional curve was found to fall within the New Mexico and Arizona regional curves, with a similar slope, confirming the team's hypothesis that the rainfall patterns and watershed conditions produce similar stream channels throughout much of the Southwest.

When watershed size and bankfull width were compared, R^2 (0.69) also indicated a fairly strong relationship (Figure 5). Width varied among the different channel shapes, thereby weakening the correlation. However, other regional curves have found similar strength of correlation for bankfull width. Given more data points, the relationship could be stratified by channel type and provide a more useful, predictive relationship.

There was no significant relationship between watershed size and mean depth due to the range of channel shapes encountered. However, the ratios of mean depth to maximum depth were consistent with values found for cross-sections taken at stream riffles in sites in Arizona, New Mexico, and Utah, indicating that Los Angeles area streams had a similar range of variation compared to other southwestern regions.

Five plotted cross-sections were found to be obvious outliers and eliminated from the fitted regression curve (Figure 4). They showed significantly larger cross-sectional areas per watershed size than the other channels surveyed, indicating watersheds that may have different runoff yields or receive larger amounts of rainfall. Those outliers came from three low elevation coastal sites (Miraleste, Peck Park, and Arroyo Sequit), and quite possibly could be the beginning of a different regional curve for the specific conditions they represented. Additional data collected in similar watersheds will be needed to show if they represent a single additional regional curve or several. The Los Angeles area represents a variety of elevations, watershed types, and rainfall types. Several curves may be needed to reflect this regional variety accurately.

These regional curves provide a starting point for inventory and analysis of Los Angeles area streams. This initial project, to construct regional curves for the area, indicates that morphological features can be reliably utilized to construct regional curves. We recommend additional surveys to gather more data points throughout Southern California. More data points would improve the curve, and may start to break out subregional curves, as is suggested by the coastal outliers. Additional data will also allow stratification of data by stream type, allowing for reliable construction of dimensionless ratios that can be utilized for stream restoration design. Importantly, morphological information tied to stream gauges is lacking from this analysis. Suitable sites with reliable periods of record were not found for this survey. Surveys associated with gauging stations allow for the validation of flood frequency estimates of bankfull discharge and an estimation of stream velocities during bankfull events. This is important data that should be understood if the regional curves are to be validated and utilized. Collection and analysis of additional data should become a priority for agencies charged with assessing stream conditions and the restoration or enhancement of streams.

The Los Angeles Regional Curves Assessment demonstrated a clear relationship between the sediment transport process of a watershed, the watershed's size, and bankfull channel formation. It confirms that, despite common perception, the streams of the region have observable, consistent features, patterns, and profiles, much like streams elsewhere in the southwest. Currently, the regional curve provides a baseline for the assessment of stream conditions and a comparison for additional geomorphic studies. It provides an important starting point for restoration and enhancement activities.

BIBLIOGRAPHY

Andrews, E. D., 1980. "Effective and Bankfull Discharges of Streams in the Yampa River Basin, Colorado and Wyoming." J. Hydrol., (1980): 46.

Castro, Janine M., "Bankfull Flow Recurrence Intervals: Patterns in the Pacific Northwest." PhD diss., Oregon State University, 1997.

Chow, V. T., Open Channel Hydraulics. Boston, MA: McGraw-Hill, 1959.

Dunne, T., and L. B. Leopold. Water in Environmental Planning. San Francisco: W. H. Freeman Co., 1978.

Emmett, W. E., Hydrologic Evaluation of the Upper Salmon River Area, Idaho. U.S. 1975.

"Geological Survey," Professional Paper 870-A, U.S. Govt. Printing Office, Washington, DC.

Harrelson, Cheryl C, C. L. Rawlins, and John P. Potyondy, "Stream Channel Reference Sites: An Illustrated Guide to Field Technique." Gen. Tech. Report RM-245. Ft. Collins, CO: U.S. Forest Service, 1994.

Jackson, F., "Plotting Bankfull Dimensions of a New Mexico Stream on Leopold's Regional Curves," In Stream Notes. Stream Systems Technical Center, , Fort Collins, CO: USDA Forest Service, 1984.

Knight, K., T. Moody, W. Odem, and M. Wirtanen. "Stream Channel Morphology in New Mexico: Regional Relationships." Surface Water Branch, New Mexico Environment Department, Santa Fe, NM. & Rocky Mt. Research Station, USDA Forest Service, Flagstaff, AZ, 1999.

Leopold, L. B., M.G. Wolman, and J.P. Miller, 1964. Fluvial processes in geomorphology. Freeman, San Francisco, CA.

Leopold, L. B., A View of the River. Cambridge, MA: Harvard Press, 1994.

Moody, T. O. and Wilbert Odem. "Regional Relationships for Bankfull Stage in Natural Channels of Central and Southern Arizona," Arizona Department of Environmental Quality, Phoenix, AZ. & Rocky Mt. Research Station, USDA Forest Service, Flagstaff, AZ, 1999.

Rosgen, D. L., "A Classification of Natural Rivers." Catena, Vol. 22 (1994): 169-199. Amsterdam: Elsivier Science, B.V.

Rosgen, D. L., "Applied river morphology. Wildlands Hydrology, Pagosa Springs, CO. USDA Soil Conservation Service, 1981. Land resource regions and major land resource areas of the United States." Agriculture Handbook 296, Washington, D.C.: Government Printing Office, 1996.

U.S. Geological Survey. "Guidelines for Determining Flood Flow Frequency," Bulletin # 17B, Hydrology Subcommittee, Interagency Advisory Committee on Water Data, Geological Survey, U.S. Department of the Interior, 1981.

Wolman, M. G., and J. P. Miller. Magnitude and Frequency of Forces in Geomorphic Processes, 1960.

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This work could not have been accomplished without the expertise and commitment of Tom Moody, P. E. Tom leaves a legacy of good works and potent ideas as a contribution to the evolving science of stream restoration in the southwest. His wit and intellect are sorely missed.

L.A. Streams: A Closer Look

Seven years ago, a resident on a small stream in Brentwood called environmental groups for help. A neighbor had dug out one bank of the creek and packed it up against his own – giving himself more room for his remodel. Permitting authorities missed the presence of the stream; it was not mapped nor indicated on a survey. Exempt from the California Environmental Quality Act (CEQA) as a single family residence, state and federal environmental agencies were not notified and hadn't permitted the impact to the stream. This was initially viewed as a NIMBY dispute.

A few years later a developer squeezing homes into confined lowlands between Mandeville Canyon Road and a steep canyon wall located septic seepage pits in the banks of a "swale" that is the physical remains of Mandeville Canyon stream – the high and continuous flows of the stream being directed into a box culvert beneath the swale. The fight that ensued wasn't even about whether the seepage pits should be 100' away, a Plumbing Code standard – the lots were too shallow for that – or about the soundness of developing lots that couldn't adequately accommodate seepage pits. The fight was over whether or not Mandeville Canyon even had a stream around which to apply the Plumbing Code setbacks.

A 1906 USGS map shows that the Los Angeles region had considerably more perennial and intermittent streams than today. By one estimate, there were almost 150 miles of watercourses just in the Ballona Creek watershed at that time. After a century of concrete channelization and culverting, about six miles of those same streams remain, and those precious six miles are being lost to piecemeal development and environmental laws that encourage, rather than enforce, environmental standards.

In 2006, motivated by a desire to address this loss, the City of Los Angeles invited state environmental agencies and local nonprofits to assist in the drafting stream protection measures. After reviewing myriad stream definitions, the committee agreed on a stream definition that incorporates an understanding of stream function. This definition was included in a policy for locating septic systems appropriately in new development and has advanced water quality protection at the local level.

While state and federal law mandates a process for reviewing impacts to streams and wetlands, it doesn't actually prohibit development in streams. Environmental protection is encouraged by assessing mitigation measures for impacts. This has not translated into "no net loss" of dynamic riparian or wetland systems. Actual stream protection – the prohibition of filling or armoring of a stream channel, and the prevention of impacts to the wooded riparian corridor that lines streams – has to be initiated at the local level. The City's committee took this on, studying examples of ordinances from around the country. The best of these models preserves a stream's ability to function dynamically – flooding within its riparian corridor, moving sediment, and rebuilding its channel over time – by creating a protected stream buffer setback zone. Finding the right formula of setbacks for LA's short lots led to lively discussions that remain unresolved. However, while still in consideration of an ordinance, the City, along with state regulators, has moved forward with limiting urban runoff.

This has long been desired by scientists who've observed the impacts of urbanization to degrading water quality, such as spiking stream flows and initiating channel instability. Yet, completely halting discharge for low and moderate storms – the storms that carry most of the bankfull-forming sediment – could have the unintended consequence of also disrupting the stream's ability to rebuild its channel. From a geomorphic standpoint, it would be preferable to mandate that runoff from a development mimics the rate and timing of discharge that would be found in a natural condition, and then manage water quality in other ways.