# 2000 ASLA ANNUAL MEETING PROCEEDINGS

COMPILED BY DIANE L. SCHEU

AMERICAN SOCIETY OF
LANDSCAPE ARCHITECTS
WASHINGTON, DC

ASLA

# PROCESS VS. FORM IN RESTORATION OF RIVERS AND STREAMS

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## INTRODUCTION

Interest and investment in river and stream restoration are at an all-time high, driven by public demand for environmental enhancement, legal requirements to protect endangered species, and mitigation requirements. True "restoration" is rarely possible, due to the profound changes in processes of runoff, sediment yield, invasion of floodplains by human settlements, invasion of exotic species, and other such factors (e.g., NRC 1992, Cairns 1991). Brookes and Shields (1996) use "rehabilitation" for a partial return to a pre-disturbance condition, "enhancement" for any improvement in environmental quality, and "creation" for making habitats where they did not previously exist. In common practice, all three are casually referred to as "restoration". Restoration projects may involve a wide range of activities, from removing dams and other barriers to fish migration, creating of artificial gravel riffles for salmon spawning habitat, installing log or boulder structures in the bank or bed to create cover and complex channel conditions, to regarding the channel and floodplain into a configuration deemed more suitable for habitat (Kondolf 1996). Many river and stream restoration projects attempt to physically create forms seen as suitable for habitat, more stable, or more aesthetically pleasing, without consideration of geomorphic processes operating at the site.

The vast majority of stream restoration projects have not been objectively evaluated (Kondolf 1995, Kondolf and Micheli 1995), but for those that have, the success rates are not encouraging. For example, Frissell and Nawa (1992) evaluated the performance of fish habitat enhancement projects in fifteen streams in western Oregon and Washington and found the median success rate to be 40%. Miles (1998) evaluated enhancement projects after 8-14 years on the high-energy Coquihalla River in British Columbia and found 41% of structures were washed away or buried, and 87% of the structures were at least 50% eroded away (as defined by loss of their material).

In the report, "Restoration of aquatic ecosystems" the National Research Council (NRC) noted the frequency of failure for river and stream restoration projects and concluded that these failures commonly resulted from not taking hydrology and natural processes into account in project design (NRC 1992). The NRC committee writing this report then recommended that geomorphology be taken into account in river restoration projects by applying a popular channel classification scheme (Rosgen 1994) and a table indicating what types of artificial habitat enhancement structures to use for different types of channels (NRC 1992:236-243). This "cookbook" approach requires only that the current state of the stream reach be determined and expressed in terms of this classification system, that analyzes historical changes leading up to the present condition, influences of upstream land uses on the study reach, and complex interactions in the river system. The appeal (to managers and other non-geomorphologists) of this approach is understandable, as it holds the promise that one can account for geomorphic influences without protracted studies of the river system, and staff can easily be trained to apply the classification system, after which use of the table is a simple job.

## COMMON FALLACIES IN STREAM RESTORATION

**Fallacy 1: There is an inherently stable channel geometry for every stream, and if we can only get the channel dimensions "just right" the channel will not change.** Channels change. Change can be imperceptibly slow in most years or in low-energy systems, or unnervingly fast during large floods or in high-energy channels. Many channels, especially in drier climates or steeper, high-energy settings, are inherently unstable and influenced by infrequent, high-magnitude events more than humid climate streams (Wolman and Gerson 1978). For example, in Mediterranean climates, stream channels may undergo cyclic changes in width: abruptly widening in response to floods, followed by gradual narrowing over subsequent low-flow years.

**Fallacy 2: A stable channel is ecologically preferable to an unstable one.** The native flora and fauna of most stream systems are adapted to the periodic disturbances of floods and even channel change. (Exceptions include spring-fed streams, which may exhibit true long-term stability.) The role of disturbance is increasingly recognized (e.g., Resh et al. 1988, Sparks et al. 1990), and according to the 'intermediate disturbance hypothesis', an intermediate level of disturbance tends to produce the greatest species richness (Connell 1978, Picket and White 1985). When dams eliminate floods and substitute steady, regulated flows, this may favor establishment of exotic fish species (Baltz and Moyle 1993). Actively migrating meandering rivers have very high ecological diversity, and if meander migration rate decreases because of dam reduced-highflows or rip-rapping banks, ecological diversity declines. (Johnson 1992) Ecologically, there is nothing inherently desirable about a stable channel, but in urban areas we are usually constrained by infrastructure and must restrict channel movement for human reasons.

**Fallacy 3: We can restore streams by creating the appropriate channel form and floodplain elevations.** Restorations based on form are unlikely to be sustainable, because form follows function. The form and dimensions of alluvial river channels (i.e., channels whose bed and banks are composed of river sediments) reflect their flow and sediment transport regimes, the independent variables to which the dependent variables of channel geometry adjust. If flow or sediment load change, we can expect to see a corresponding change in channel form. For example, an increase in peak flows through an alluvial channel will typically cause an increase in channel dimensions through erosion of bed and banks. To restore requires that we first understand the processes: this requires looking upstream at a watershed scale, and looking back at historical changes that have led us to current conditions.

**Fallacy 4: We can design restoration projects based on a channel classification system.** Many projects are designed by applying a stream channel classification system, as noted above. These projects have experienced many failures, but few have been documented, in part because most agencies prefer to spend their funds on building projects rather than post-project performance evaluation. The cookbook approach remains popular among agency managers and other non-geomorphologists because it offers an easy shortcut to river restoration design.

## CASE STUDIES

### *Uvas Creek*

Uvas Creek drains 71 mi$^2$ (184 km$^2$) in the Coast Range, about 30 mi (50 km) south of San Jose. The Uvas Creek watershed experiences a Mediterranean climate and is underlain largely by the erodible Franciscan Formation, conditions which together produce a large supply of sand and gravel to the channel. As a result, like most other streams in this setting, Uvas Creek was historically braided and unstable. In November 1995, a 0.5-mi (0.9-km) long reach of the stream in city of Gilroy was reconstructed as a meandering channel with symmetrical meander bends, based on predictions of stable channel configuration using the Rosgen (1994) classification scheme. The channel washed out in February 1996, returning to a braided form (Figure 1)(Kondolf et al. in press). The stated objectives of the project were to improve fish habitat by creating a deeper, narrower channel, and to reduce sediment supplied from bank erosion by creating a stable channel geometry.

Examination of the project design and environmental permitting documents show the basis of the design was application of the stream classification system and some assumptions about past channel conditions, but no historical geomorphological analysis (Kondolf and Larsen 1995) of changes in flow regime, sediment supply, or channel form over the preceding decades. Uvas Creek was only one of at least six restoration projects in California built between 1990 and 1996, all of which created idealized, meandering channels based on the same classification scheme, and all of which promptly washed out.

These projects were designed based on a belief that if the form was imposed on the stream, it would be stable. They failed to account for dynamic fluvial processes, which if allowed to operate unhindered, could eventually create the favorable habitat conditions as a matter of course. The fact that these projects have all sought to create idealized, symmetrical meanders in reaches where such channels may never have existed (or could no longer exist because of changed runoff or sediment load), suggests that these meandering forms may have an aesthetic appeal, and the notion that they would be inherently stable was attractive to the project proponents.

### *Clear Creek*

Clear Creek drains 228 mi$^2$ (590 km$^2$) in the Klamath

Mountains and northern Coast Range, the joining Sacramento River south of Redding. Its headwaters are impounded by Whiskeytown Reservoir, which has reduced flaws and sand and gravel supply to downstream reach. A 100-year old dam about 7 mi (10 km) upstream of the Sacramento River confluence is only 20 ft (6 m) high, but blocks upstream migration of salmon to the best spawning and rearing habitats (Figure 2). In the alluvial reach of Clear Creek, downstream gravel mining in the 1950s through 1980s completely disrupted channel form, leaving large pits, in which the stream channel confinement is lost and fish migration interrupted. Most of the Clear Creek floodplain is in public ownership, offering a potential opportunity to restore dynamic fluvial processes.

Ecosystem restoration on Clear Creek is being funded by the US Bureau of Reclamation, US Fish and Wildlife Service, and the Calfed Bay-Delta program, and implemented by a local team and their geomorphological consultants. Their approach is to restore ecosystem processes, by removing the dam to permit salmon to access upstream habitats, by seeking to increase the controlled release capacity of Whiskeytown Dam, by adding large quantities of gravel to the stream (Figure 3) to compensate for upstream trapping by the dam and losses to mining pits downstream, by purchasing private land or easements along the creek, and by rebuilding a floodplain in the reach severely affected by gravel mining. Rebuilding the floodplain requires importing large quantities of gravel from piles left by gold dredgers nearby, to provide confinement to the channel. However, the precise dimensions of the channel are not to be designed, rather high flows (when they occur) are expected to sculpt the channel. Channel migration is expected to occur, and indeed desired.

## DISCUSSION

The case studies presented here include the relatively small Uvas Creek project whose design was based on assumptions about channel stability and did not involve a longer-term or broader spatial perspective, and the more ambitious Clear Creek restoration program, which attempts to restore ecosystem processes on a larger scale. However, this does not imply that restoration projects must be big to be good. Small-scale projects can be designed with an understanding of their larger context and the processes now ongoing. This suggests that restoration planning first evaluate how and the degree to which watershed processes have been altered, and develop an approach accordingly.

### *Restoration of Reaches with Watershed Processes Intact.*

In cases where the watershed processes are essentially intact, but the channel has been physically modified, we could expect that we could do nothing and eventually the processes would drive the channel back to its pre-disturbance condition. However, the time scale for this would depend on the energetics of the river, and for a lower-energy system we may not want to wait. Here, the "carbon copy" (Brookes and Shields 1996) approach can be applied: the channel form and dimensions of the pre-disturbance channel can be reconstructed, based on historical evidence or a "reference reach", as exemplified by a restoration project on the Blanco River, Colorado (NRC 1992).

### *Restoration of Reaches with Watershed Processes Modified.*

Where (more commonly) watershed processes have been modified by human alterations such as urbanization, timber harvest, roads, mining, dams, levees, and floodplain conversion, the problem becomes more complex. The most sustainable approach is to restore processes where possible, as now being attempted on Clear Creek. Another example of restoring river processes is levee breaching or set-back. Levees have prevented floodwaters from inundating their historical floodplains, so to restore natural flooding of floodplains, levees are being breached, set-back, or removed along some rivers, such as the Cosumnes River in California, Missouri River in Missouri, and the Rhine in Germany and France (Dister et al. 1990)

If processes cannot be restored, the nature of historical geomorphic and ecological change should be documented, and realistic goals developed. For example, where runoff has increased (e.g., from urbanization), the channel can be sized to mimic natural features but scaled to accommodate increased peak flows, preferably utilizing a two-stage channel approach, in which floodwaters overflow onto a floodplain (Haltiner et al. 1996). However, predicting appropriate channel dimensions under altered hydrology involves considerable uncertainty, and (at least for higher energy systems) it may be best to "rough out" the channel with the expectation that subsequent high flows will adjust channel dimensions and sculpt the channel form, as being done in the gravel-mined reach of Clear Creek. Moreover, we should explicitly acknowledge the uncertainty and monitor and evaluate project performance to get feedback on the effectiveness of our interventions, as well as insights into the functioning of the stream (Kondolf 1995). These notions fall within the Adaptive Management approach, which emphasizes using each intervention as an experiment, from which more can be learned to inform future management decisions (Holling 1978).

## CONCLUSIONS

Many river and stream restoration projects attempt to physically create forms seen as suitable for habitat (or aesthetically pleasing) without consideration of geomorphic processes operating at the site. There have been many spectacular failures among such projects. The popular notion that there is an inherently stable channel geometry for every stream is not supported by geomorphic theory nor experience. Moreover, ecologically there is nothing inherently desirable about a stable channel, as native flora and fauna are adapted to periodic disturbance.

With an understanding that landforms reflect processes, it becomes clear that a more sustainable approach to river conservation and restoration is to maintain or restore the natural processes that would result in the desired landforms, whenever possible. This means restoration actions throughout the watershed, such as giving the stream as wide a corridor as possible, setting back levees, implementing on-site stormwater management in urbanizing areas, controlling artificially increased erosion, and restoring high flows and sediment supply below dams where possible. In urban channels it is often impossible to restore process, but it is still important that we understand how the watershed processes have changed and account for this in our restoration designs.

Experience with river and stream restoration to date suggests that restoration planning should prioritize first presevation of natural processes where they continue to function, and second, where natural processes can be restored, to restore these processes. As a third priority, where natural habitats exist, preserve them. The last priority should be to recreate natural habitats through restoration projects, because the forms these projects seek to recreate are often no longer maintained by dynamic river processes.

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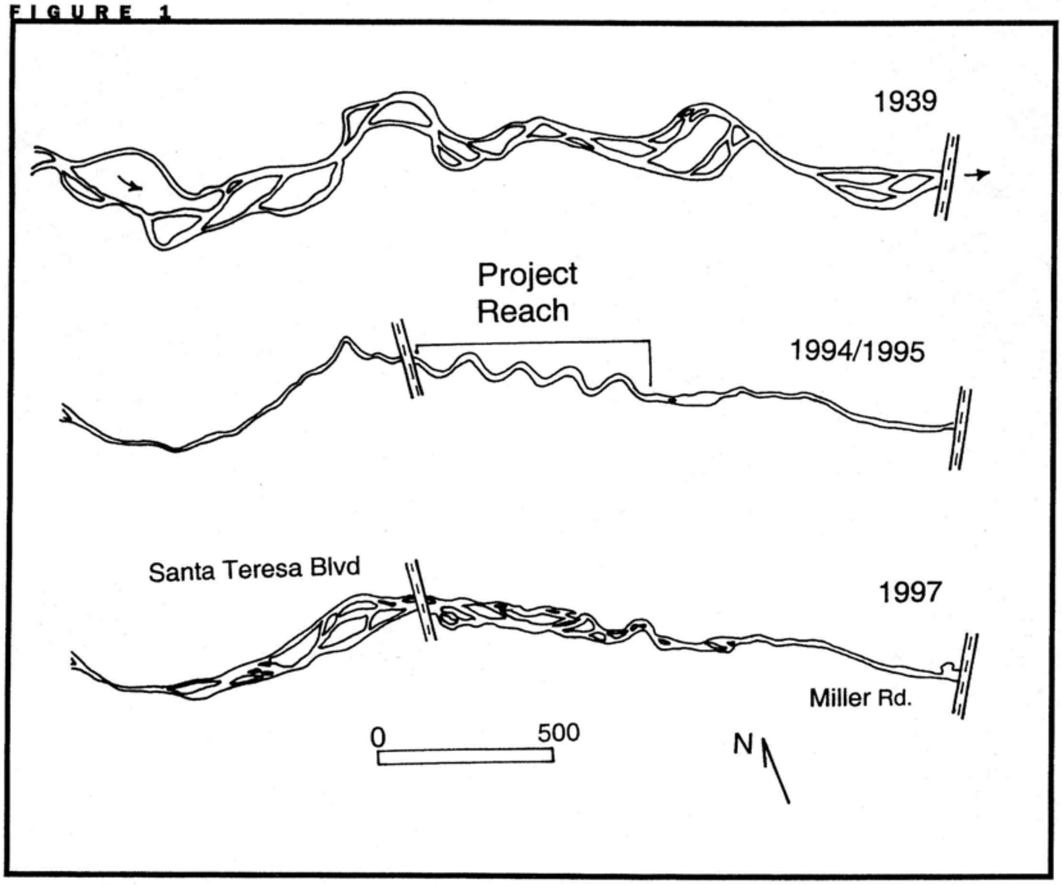
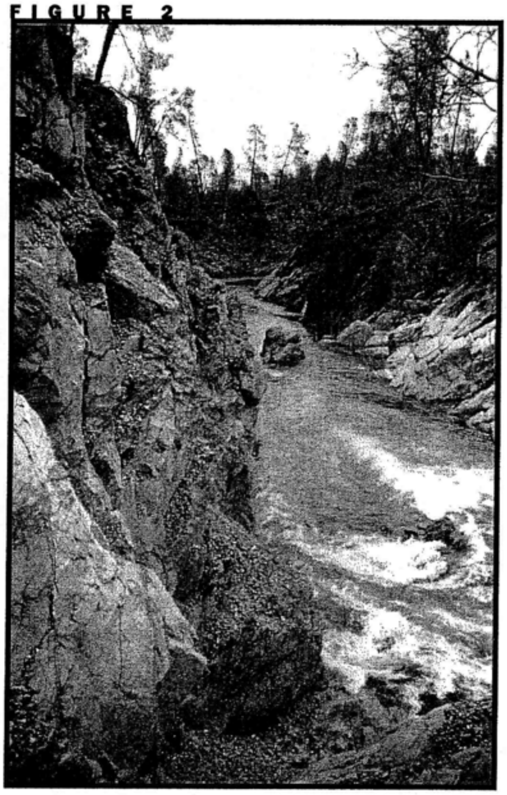
FIGURE 1




*Active channel planform of Uvas Creek near Gilroy, showing historically active braided condition and the contrast with the constructed meander bends. (Channels based on historical aerial photographs with constructed meandering channel (Nov 1995-Feb1996) superimposed on the 1994 aerial photograph.*

FIGURE 2



*View of gravel injection site on Clear Creek, in a bedrock gorge immediately downstream of Saeltzer Dam. (photo by author March 1999).*