# Take the plunge

## Spend less on rip-rap by transitioning culverts into natural streams.

**By: Chris Estes**

**Water quality best management practices, such as wet ponds, typically have forebays with culvert inputs. Incorporating correctly sized natural plunge pools can enable a more compact design for velocity attenuation. This allows a greater "stilling" effect for more efficient pollutant removal.**
Photos: Estes Design Inc.

Naturally formed plunge pools, or scour holes, are common in urban stream systems where the transition between a pipe and a natural stream channel occurs. Contrary to common perception, these pools provide critical benefits to the hydraulic and biological integrity of the stream.

In 2004, the University of North Carolina – Charlotte completed research on naturally formed plunge pools in urban stream systems. The results, published in the February 2005 issue of the *Journal of American Water Resources Association*, concluded that existing methods for designing "stilling basins" and energy dissipating pools failed to predict naturally formed pool geometry seen in the field. Naturally designed pools also cost significantly less than rip-rap aprons.

Pools occur naturally in a stream as part of the "riffle-pool sequence," which provides a dynamic checks and balances system for regulating velocity and reducing erosion. Correctly sized pools are self-regulating and improve habitat diversity while serving as refuge for aquatic species during low flow periods. The study found that every natural plunge pool presented itself as a safe haven for aquatic species, especially during droughts or low flows. In many cases, the pools were the only place fish were observed.

Rip-rap aprons are designed to protect the outlet from scour for a determined distance downstream until hydraulic velocities decrease to a "non-erosive" level. Yet in urban areas even a correctly designed rip-rap apron may need a significant amount of area and length before the velocities fall to non-erosive levels. This practice also impedes natural riffle-pool sequencing. Aprons are also vulnerable to storms larger than the specified design storm and require periodic maintenance.

Increasing urbanization upstream of many culvert crossings typically results in the simultaneous erosion of the original rip-rap apron, channel incision, and channel widening as flows become more frequent and intense. Without armoring, a scour hole typically forms as a transitional feature from the accelerated velocity of an enclosed system to that of an open natural stream system. Essentially, the culvert is acting as a higher efficiency riffle, and the pool forms to complete the natural sequence.

The researchers examined the morphologic characteristics of naturally formed plunge pools associated with road crossing culvert outlets owned by the Charlotte, N.C., DOT. The development of stable plunge pools at outlets is common where maintenance frequency is low and the naturally formed plunge pools in built-out urban watersheds haven't been modified for at least 10 years.

Researched field comparisons concluded that previous design equations for hydraulic dissipation developed from flume studies generally failed to predict the naturally formed plunge pool dimensions. Based on the study, the researchers recommended a modification to the existing design equations and a modified methodology. The research also estimated construction costs for designed plunge pools, which exhibited significant cost savings compared to construction costs of traditional rip-rap aprons. Of the 12 sites surveyed, the estimated cost of the pools was 60% lower than the cost of rip-rap aprons.

**Culvert outlets with submerged tailwater conditions typically exhibit a variation in designed pool geometry from their counterparts with free-falling jets or supported jets.**

Typically, due to a public perception that pools are a nuisance, the common maintenance practice is to simply fill such pools with rip-rap. All this does is cause significant localized bank erosion and channel incision. Within a relatively short period of time — in many cases less than a year — this practice destabilizes downstream channels, accelerates bank erosion, and initiates a larger cycle of stream instability in an otherwise stable built-out watershed.

A precursor to the 2004 research included conducting a thorough literature review and a national survey of public municipalities around the country. The survey identified specific concerns for public safety and liability related to pools. Concerns were fear of drowning and proliferation of mosquitoes. The research concluded that pool depth was the least sensitive dimension to scouring flow and that, for this study, the average pool depth was 3.5 feet. Of the 18 pools surveyed in the Charlotte area, half displayed depths of less than 3 feet.

The advantage to using this methodology is that it requires minimum hard revetment. Armoring the streambed and banks is an "impact" that is detrimental to aquatic habitat. Typical structures utilized for hydraulic energy dissipation, such as rip-rap aprons and baffles, may impede "aquatic passage" or "safe passage of fish and other aquatic species" especially during low flow or drought conditions. Therefore, the preferred solution is one that reduces ecological impacts.

The initial applications where natural plunge pool design was utilized were municipal culvert replacement projects in Charlotte. Additionally, the research found advantages — such as maintaining riffle pool sequencing and eliminating the regulated stream impacts — for commercial and residential developments, stream restoration projects, wet ponds, and incorrectly designed/constructed culvert crossings.

One of the first applications was a municipal culvert upsizing project in Charlotte. The arch culvert was upsized from 42 inches to 90 inches. Designed and built according to the recommended methodology, the plunge pool quickly exhibited the natural morphological characteristics of a stable pool with no downstream erosion observed five years later.

**The natural plunge pool design methodology can also be used to transition steep grades by incorporating the methodology into step pool design.**

Some of the ecological impacts related to development are typically attributed to the armoring of outlets. Designed plunge pools, in lieu of rip-rap aprons, can reduce these regulated ecological impacts. Many new culvert crossings in urban areas have successfully incorporated natural plunge pools. The majority of these have been monitored for more than five years with no apparent downstream erosion due to the installed culvert.

Stream restoration projects in urban areas typically have many culvert outfalls and crossings associated with them. When culverts are part of the restored stream they should be considered as riffles and incorporated into the riffle-pool sequence. A natural plunge pool facilitates the sequencing.

Occasionally, new culvert crossings are designed or built incorrectly, conflicting with conditions of Clean Water Act Section 404 permits. This issue is typically due to culverts placed too high above the channel bed to meet the “aquatic passage” condition or to unanticipated additional impacts from armoring the culvert inlets and outlets. In many cases, a natural plunge pool can mitigate these ecological problems by restoring natural aquatic function while also providing more efficient energy dissipation.

Designing pools to provide aquatic passage for culverts that are inadvertently installed above the stream bed require the base flow of the stream to be raised to pass through the culvert. Culverts greater than 48 inches in diameter must be buried at least 1 foot below the stream bed. Smaller pipes must be placed as practicable and appropriate to maintain water flow. This requires designing the pool to raise the tailwater elevation of the culvert outlet, creating a submerged tailwater condition.

Design based in nature's process is inherently more efficient. Understanding natural processes and replicating them by design is the essence of science.

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