Case Study 6 Big Bear Creek, Lycoming County, Pennsylvania

Issued August 2007

Cover photo: Cross vane on Big Bear Creek in Pennsylvania

Advisory Note

Techniques and approaches contained in this handbook are not all-inclusive, nor universally applicable. Designing stream restorations requires appropriate training and experience, especially to identify conditions where various approaches, tools, and techniques are most applicable, as well as their limitations for design. Note also that product names are included only to show type and availability and do not constitute endorsement for their specific use.

Case Study 6 Big Bear Creek, Lycoming County, Pennsylvania

By Dr. Larry K. Brannaka, U.S. Fish and Wildlife Service (USFWS); David B. Putnam, USFWS; William Worobec, Dunwoody-Big Bear Hunting and Fishing Club, Lycoming County, Pennsylvania; and Donald Stover. (All are members of the Keystone Stream Team.)

Introduction

Big Bear Creek is a mountain stream in Lycoming County, Pennsylvania, that has been classified as a B3 stream using the Rosgen stream classification system (Rosgen 1992). The stream is in a moderately steep valley with sides of relatively gentle slope, matching the Rosgen Valley Type II classification. The location is indicated on a U.S. Geological Survey (USGS) 7.5-minute topographic quadrangle map (figs. CS6–1 and CS6–2). The stream is characterized by moderate slopes and cobble and gravel-bed materials. The riparian lands are mostly wooded. Big Bear Creek is a perennial stream with a significant ground water derived baseflow. Several springs occur along the treatment reach that contribute to the baseflow. The streamflow responds directly to surface runoff from precipitation events. Originally, one dam created a relatively small backwater pond in the project area. The dam has since been removed.

Project description

The restoration project on Bear Creek commenced in the summer of 1999. It was performed as a phased project ending in late summer of 2001. The overall project treated 3.7 miles of stream and included more than 200 instream structures, making it the second largest demonstration project of its kind in the eastern United States at that time. It also was the first project of its kind done by the U.S. Fish and Wildlife Service (USFWS) Pennsylvania Field Office and served as a demonstration project, classroom, and experimental lab.

Over the course of the 3 years it took to complete the project, many lessons were learned, some of which are related in this case study. Bear Creek is classified as a high quality cold-water fishery and has a long history of providing quality trout fishing. The Dunwoody-Big Bear Hunting Club has owned or controlled access to the creek for more than 100 years. The club has detailed records documenting the quality of the fishery, primarily native brook trout, over that time period.

Three bridges that act as constriction points for the flood plain cross the stream. The uppermost bridge, known as the Red Ridge Bridge, was built by the Dunwoody-Big Bear Hunting Club (fig. CS6–3). The

Figure CS6–1 Upper reach of Big Bear Creek restored in phase I

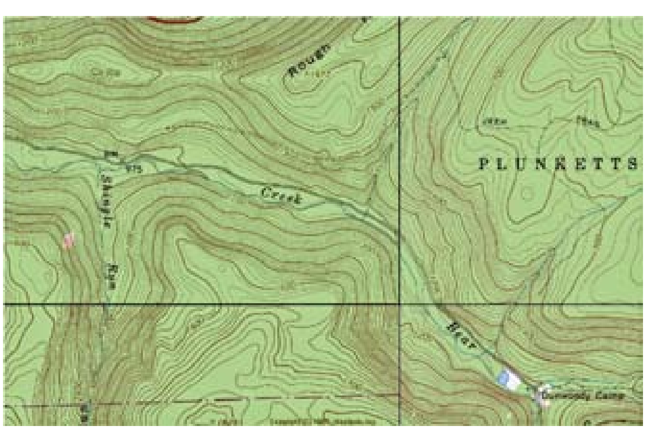
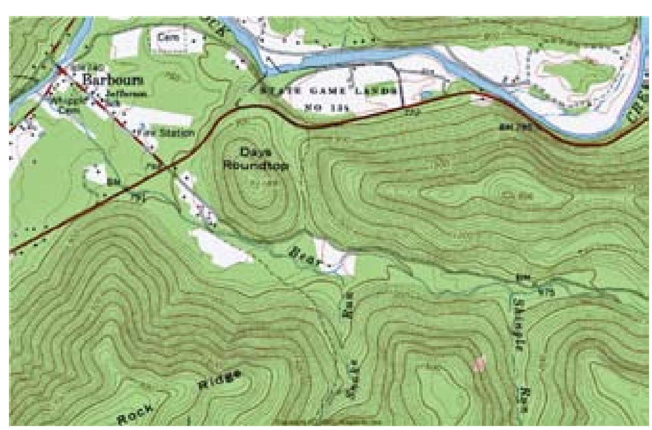


Figure CS6–2 Lower reach of Big Bear Creek restored in phases II and III



lower two bridges were built by the Pennsylvania Department of Transportation (PennDOT). The farthest downstream bridge just above the confluence of Big Bear Creek with Loyalsock Creek (fig. CS6–4), frequently filled with sediment—mostly gravel, cobble, and boulders.

Starting with Hurricane Agnes in 1972, Bear Creek has endured three significant natural flood events and several anthropogenic events. These natural flood events were a direct result of the arrival of Hurricane Agnes and, in 1975, Hurricane Eloise. On January 19, 1996, a 100-year rainfall event on frozen ground with a significant snowpack resulted in a flood event that moved significant amounts of sediment into and down the channel. The floods caused severe erosion and moved vast amounts of sediment into the stream channel. The primary anthropogenic event that further degraded the stream was the removal of a 100-year-old dam declared unsafe by inspectors in 1996. The short-term removal of the dam released 100 years worth of accumulated sediment and debris into the downstream channel. This sediment was comprised of not only silt, fine sand and gravel but also relatively large materials such as coarse gravel and cobbles. This large slug of coarse sediment washed downstream and overwhelmed the sediment transport capacity of the stream. Aggradation in the stream filled in pools, created mid-channel bars, transverse bars, and in some instances, channel avulsions. The aggradation split channel flows and put stress on the channel banks, which in turn began to erode, adding more sediment to the system. The result was a domino effect of erosion, channel migration, and elimination of aquatic habitat.

An aerial view of the stream before this project began (fig. CS6–5) provides an illustration of the condition of the stream. Following this flood event, some stream channel work was performed by the U.S. Army Corps of Engineers (USACE) and Federal Emergency Management Agency (FEMA) in Plunketts Creek Township, but this channel work ultimately contributed to the further degradation of fish habitat in the creek. The hurricane flood events put stress on the ecology of the Big Bear Creek system. However, the ecology of the system was more severely affected by the forced removal of the dam on the Dunwoody-Big Bear Hunting Cub property that had fallen into critical disrepair.

Figure CS6–3 Author Bill Worobec at the Red Ridge Bridge on Big Bear Creek

Figure CS6–4 Most downstream PennDOT bridge on Big Bear Creek

Figure CS6–5 Aerial view of phase II treatment reach of Big Bear Creek prior to restoration

Project objectives

The original goal of this project was to stabilize and improve aquatic habitat on approximately 3.7 miles of stream and restore the stream to a high-quality, coldwater (class A) fishery dominated by native brook trout. Subobjectives of the project included arresting and preventing further scour at the Red Ridge Bridge and transporting sediment efficiently through the two downstream PennDOT bridges.

Stakeholders

The primary stakeholder for the project was the Dunwoody-Big Bear Hunting Club, a private group that initiated the project. The dam that was removed was situated on their grounds. Other stakeholders included the USFWS, which provided technical assistance, equipment, training, and services for the restoration project, along with construction monitoring; and the Lycoming County Conservation District, which administered the Pennsylvania Department of Environmental Protection (PADEP) Growing Greener Grant that funded the restoration activities.

Project design and construction

The project was designed using natural stream channel design techniques. After an initial assessment survey, a contractor was hired to perform a geomorphic assessment survey of the treatment reach. This included a total station survey for topographic features, as well as geomorphic features such as the stream thalweg, edge of water, and bankfull indicators. Physiographic features were also included. Streambed substrate was sampled using pebble counts and bar samples. In addition, stable reaches of Big Bear Creek were identified and surveyed as reference reaches for the restoration design. One such reference reach is shown in figure CS6–6.

The watershed drainage area ranged from 10.1 to 12.6 square miles. Regional curves of fluvial geomorphic relationships showed the bankfull width to be in the range of 38 to 42 feet, cross-sectional area ranging from 90 to 100 square feet, and bankfull depth to be from 2.1 feet to 3.2 feet. The reference reach information yielded a bankfull width of 39 feet and bankfull depth of 2.3 feet. The restoration design was performed by the USFWS Pennsylvania Field Office. The design included channel relocation and realignment, construction of flood-prone benches, bank sloping and bank stabilization, and installation of rock vane structures for grade control and bank stabilization.

Construction began in the summer of 1999. The cost of construction for the initial phase of the Big Bear Creek restoration was approximately $160,000 for treatment of 4,000 linear feet of stream. The treatment included 38 rock structures (J-hook and cross vanes) with seeding, mulch, and geotextile fabric stabilization for impacted streambanks and other disturbed areas. An example of a J-hook rock vane is shown in figure CS6–7. Dimension rock, cut from a quarry, commonly known as wall rock, was used to construct rock vanes, an example of which is shown in figure CS6–8. The approximately 500 tons of wall rock used for the structures in the first phase of the project, valued at $12 per ton, was donated by a local quarry. The rock was transported to the site at a cost of about $6,000, paid for with a Watershed Restoration and Assistance Program (WRAP) grant from the PADEP. The equipment used to set the rock cost $17,000 which included an excavator with a Balderson™ progressive link thumb and a 3.5-cubic-yard, rubber-tired loader. Approximate-

Figure CS6–6 A stable reach of Big Bear Creek, a B3 stream

ly $20,000 was spent for the preliminary stream survey, design, and preparation of permits. Onsite supervision and construction labor was estimated to be $60,000. Miscellaneous construction materials, such as seed, mulch, and geotextile material, cost about $2,000. The total cost broke down to $40 per linear foot of treated stream. However, caution must be exercised when using unit costs for estimating or comparing stream projects, as each project has its own level of preparatory effort and construction intensity. This project was performed when the natural stream channel design approach was still, for this region, in its infancy. Today, costs can be much higher and typically include performing a watershed assessment, as well as addressing more detailed and rigorous permitting requirements.

Another way to examine the project costs for the first phase of the Big Bear Creek restoration project is to divide the cost among the structures installed in the treatment reach. For the Big Bear treatment reach, the estimated actual construction cost for the rock vanes was about $650 each for the J-hook vanes and $1,300 for each cross vane. These figures are only for the construction phase of the structures and do not include the preparatory work such as stream analyses, survey, design work, and permitting, nor does it include the stream channel work needed to construct flood-prone benches and to bring the channel itself to within proper and appropriate channel dimensions and geometry.

Rootwads were not used in the project design or the construction phase of the project, but it was estimated that they could be installed for approximately $400 each.

Rock vane performance

For the most part, the rock vanes performed well. However, problems were encountered with some of the vanes. Some of the vanes had to be tweaked, some needed to be rebuilt after being damaged by high flow, and some vanes were torn out and relocated to achieve the objective for each vane. Two construction crews worked in the phase II and phase III of the project. One crew had very good luck with their structures, but the other did not. Unfortunately, communication between crews was lacking, especially with regard to procedures, construction techniques, and expectations. Consequently, the good luck was not always shared. When the construction operator paid attention to detail and maintained the patience required in fitting the rocks securely together, the structures held up against bankfull events. Attention to detail in the construction resulted in a stable structure.

Figure CS6–7 J-hook rock vane on Big Bear Creek

Figure CS6–8 Cross vane on Big Bear Creek

Problems encountered with rock vanes

Problems were encountered when the construction crew was rushed to complete the vane installation. Early problems were a product of inexperience on the part of both construction crews, each experiencing a learning curve for developing the most efficient procedures to use in these types of projects. Initially, for example, the rock vanes were laid out in great detail with rebars driven into the streambed (fig. CS6–9). Later, a technique was developed where the butt rock was laid to specifications, and then a target rock was placed out in the stream along the line of the vane. It became the job of the person on the bank to sight along the butt rock and target rock during the installation of the other footer and vane rocks to direct the operator in aligning the vane rocks to that line. The vane was then built by checking the elevation every 10 feet and holding the vane rocks to a 0.1 feet tolerance.

Typically, the problems encountered were related either to the alignment and design of the structure and its effect on the streamflow or the problems related to the construction of the structure itself, where one or more of the vane rocks (and sometimes the footer rocks) would be washed out of position, compromising the function of the vane.

Problems related to the alignment and design of the structure also appeared in the effect the structure had on the flow lines of the stream. Early designs consisted of only a plan view. The structures would be built and then field evaluated. Sometimes subtle adjustments were required to align the streamflow properly, and other times, the structures were relocated or removed. In the subsequent phase of the restoration project, a different approach was tried where all structures were designed in great detail and constructed exactly to the design specifications. Again, several structures had to be relocated or reconstructed due to the inability of the designer to anticipate every aspect of the design in three dimensions and the lack of appropriate field adjustments. The only way this approach would be viable is when the designer also stakes out the structures in the field. The designer can then see what design adjustments may be necessary. The designer can return to the office to draft a final, revised design that can be handed off to build. While a detailed design is valuable, some flexibility in adjustment of the structure design to the site must be allowed, as well as to be able to adjust the implementation of the design to unforeseen elements in the field.

Some structures were found to be out of spec with the design drawings. Some of the vane slopes were steeper than the 10 percent maximum recommended in the design specifications, based on Rosgen's experience. Since the time of this project, the recommended maximum slope has been reduced to 7 percent. In some cases, the slope of the structure, although within range, was actually too steep for the particular setting. The steep slopes reduced the effectiveness of the vane in providing a gradual reduction in the fall energy of the water flowing near the banks. Further information on these structures is provided in NEH654 TS14H and NEH654.11.

Occasionally, a vane was constructed at too great an angle from the bank. Vanes with an angle greater than 30 degrees with respect to the bank were found to be less effective. In some cases, this larger angle resulted in significant backwater eddy currents that served to scour the bank behind the structure. In other cases, the design specifications showed the correct alignment, but the layout of the structure during construction was not accurate. On occasion, the operator

Figure CS6–9 Staking out a cross vane

built the structure using the eyeball technique. That is, the structure was built by an operator substituting a trained operator eye for the use of a construction transit or laser level. Consequently, the slope along some of the problem structures measured greater than 7 percent (or even 10%), as constructed.

Working with contractors

The construction crew must be aware of allowable tolerances and know the importance of adhering to the design specifications. If the construction supervisor is either inexperienced or not insistent enough to maintain the proper tolerance with the rest of the construction crew, problems can occur. In rock vane construction, strict attention to detail is critical for the structure to maintain its physical integrity during high-flow events and maintain its design functionality. Ultimately, the construction supervisor must ensure that the structures are built according to the design specifications and that the construction crew understands and complies with the project procedures, specifications, and objectives. The supervisor must insist that the contractor build the structures according to design and use the proper techniques. The supervisor should be experienced enough with natural stream channel design procedures to make field adjustments, if required.

Construction of natural stream channel design structures should be contracted on a time and expense basis. This ensures that the contractor will be justly compensated for taking the time to construct the structures correctly; hence, the contractor is more willing to make adjustments (or rebuild a structure, if necessary). The authors note that the success of the project largely depends on the disposition of the operator. Patience, persistence, and secure self-esteem are qualities to look for in an operator. The setting of rock in difficult conditions requires both patience and persistence. Operators must also have enough self-esteem not to take it personally when asked to rip out and rebuild their work if it is out of specification or the structure alignment or location does not produce the desired effect on the streamflow.

Allowances must be made in the design and permitting procedures for in-the-field changes or adjustments to the restoration design. The experienced supervisor or designer must have the latitude to make adjustments according to observed flows through the structures in the field. Having this latitude can make the difference between a successful project and one that must later be adjusted or rebuilt.

Additional lessons learned

Rock—Wall rock (fig. CS6–10) is preferred over smaller R5–R7 size rock. Vanes constructed of the smaller rock give the appearance of being simply piled, and it is much harder to plug the holes between the rocks. The wall rock is more massive and lends itself to placement with an excavator. The wall rock also provides good footer rocks. Size specifications for the wall rock for this project indicated rock dimensions should be between 3 and 6 feet, with no dimension less than 3 feet and no dimension greater than 6 feet. The rock was to be of hard sandstone with an alkaline pH, or limestone. One of the biggest challenges is transporting rock of this size. Large steel-bed dump trucks were used to deliver 8 to 10 rocks at a time. Depending on the truck tailgate configuration, it was sometimes necessary for the excavator to unload the rock from the truck. Typically the rock was stored at a staging area near the construction site and delivered

Figure CS6–10 Loading a typical wall rock used for vane construction

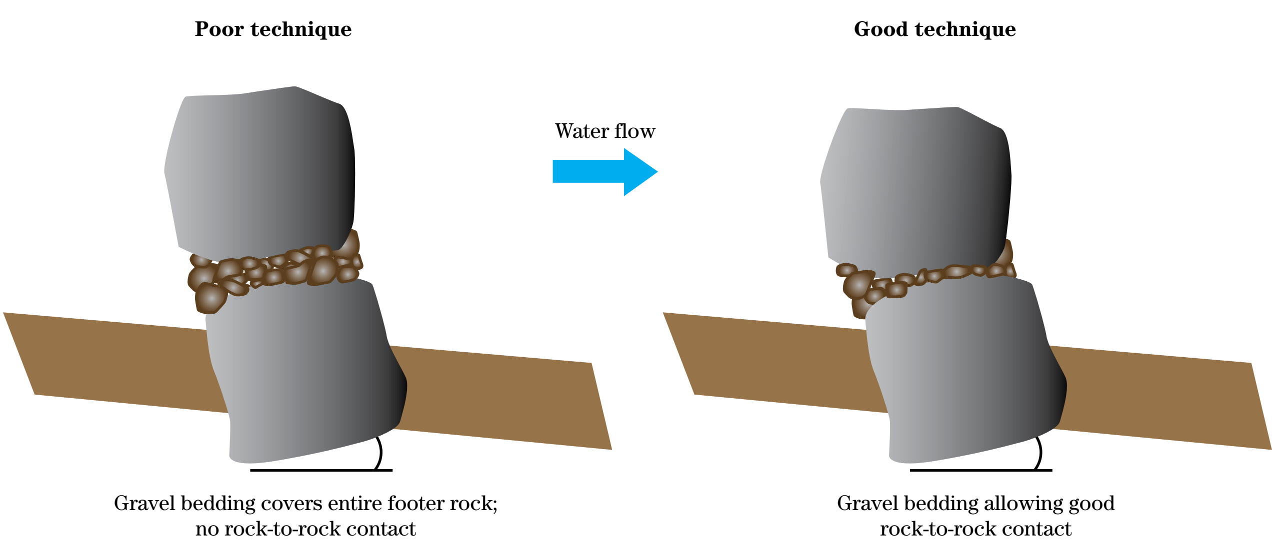
to the excavator using a rubber-tired front end loader (fig. CS6–10).

Excavator—The key to efficient and successful placement of rocks for the rock vanes was finding an excavator with a Balderson progressive link thumb, coaxially mounted on the bucket pin (axle) (fig. CS6–10). The progressive link connection shares the same pivot axle as the bucket, thereby allowing the thumb to follow the bucket along its entire pivotal swing. In other words, the thumb can grasp a rock and hold it, no matter how high the operator swings his bucket up. Other thumbs not coaxially mounted and without the progressive link have a limited range of radial motion, so that when the operator rotates the bucket back upwards, the thumb cannot follow. Consequently, the bucket pulls away from the thumb, and whatever is in its grasp falls out. The Balderson™ thumb is not the only thumb assembly that will work for rock vane installations, but it is the most efficient.

Rock vane installation—Installation of the rock vane usually begins with keying a footer rock into the bank and a vane rock that constitutes the butt rock of the vane. Footer rocks should be of comparable size to the vane rocks. Typically, a target rock is then placed in the stream for sighting alignment purposes. A second person with a two-way radio to talk directly to the operator is usually needed to guide the operator in aligning the vane rocks. Another lesson learned is to angle the footer rock slightly, tipping it in the upstream direction as shown in figure CS6–11. The vane rock is less likely to be pushed downstream off of its footer rock. Tipping the footer rock also facilitates fine adjustments in the vane rock elevation. Simply by moving the vane rock a bit laterally (perpendicular to the vane line), the vane rock elevation is adjusted slightly up or down. Most of the vanes on Big Bear Creek have the vane rocks set to the design elevation with a tolerance of ±0.1 feet. A laser level was typically used to check elevations, usually at a 10-foot interval along the vane.

In the second year of the project, a second crew was brought in to help with the construction. This crew was experienced, having just completed another similar project. However, this team had slightly different approaches to constructing rock vanes. Perhaps the most significant difference was that many of the vanes were constructed of large rocks with either no footer rocks for the throat rocks of the cross vanes or relatively small and flat footer rocks. This technique

Figure CS6–11 Schematic of vane rock installation



resulted in less excavation into the stream subbase to set the throat rocks at or near the streambed level. Over the long term, it was found that these structures were much more susceptible to washouts and displacement of the throat rocks than those where all the vane rocks were carefully placed on footer rocks of comparable size. High velocity flows moving over the vanes scoured out the downstream pavement and subbase of the streambed, tipping or causing settling of the footer rock, which in turn caused the vane rock to fall into the scour hole. The process repeated itself, eroding a scour hole downstream of the tipped rock until it rolled into the hole, thereby moving the rock downstream. An example of this is shown in figure CS6–12.

Footer rocks of the proper size are typically embedded into the streambed to a depth greater than the scour depth and, thus, resist washout. Figure CS6–13 shows a footer rock being set. Two other features of a properly footed vane rock also help to resist tip-outs of the vane rock. First, the vane rock is typically offset to the upstream side of the footer rock (fig. CS6–11) leaving a small sill at the base of the vane rock. This sill sometimes acts as an energy dissipater for water pouring over the vane rock. The second feature is that a properly installed footer rock is tilted slightly upstream. For the vane rock to move downstream, it must also move uphill (fig. CS6–11).

Once the footer rock is set, leaning slightly upstream, gravel bedding may be dribbled on top of the footer rock. The vane rock is then placed on top and scrunched back and forth until there is direct contact between the vane and footer rock at least at one point (fig. CS6–11). For a time, one construction crew ignored this tenet and just placed vane rocks on top of bedding gravel. Without the rock-to-rock contact, it is relatively easy to displace the vane rock and roll it off of the footer rock. Some of the vane rocks observed had most of the gravel bedding scoured out from beneath the vane rock. Patience and persistence are required. If the vane rock is not set at the proper elevation, the footer rock must be raised and some streambed material moved underneath to support it. If the vane rock must be lowered, a deeper hole should be dug before replacing the footer rock.

In soft, fine material, it is sometimes extremely difficult to achieve the proper elevation and alignment between adjacent rocks. Where one rock is properly set according to grade and alignment but repeated

Figure CS6–12 Example of vane rocks with small footer rocks and inadequate long-term performance

Figure CS6–13 Setting a footer rock (upstream direction is to the right)

attempts to set the adjacent rock fail, it was found to be advantageous to set the troublesome rock close to proper position and then set the next rock down. Once this next rock is set, the operator can go back to the troublesome rock and complete its positioning according to proper grade and alignment. The adjacent rocks on either side of the troublesome rock help to hold it in place during minor adjustments. This procedure may be repeated down the vane.

Subtle adjustments to the vane rocks during placement or judicious selection and orientation of the vane rocks offer opportunities to be creative. One example noted during the construction of this project was that angling the top surface of the throat vane rock toward the upstream side tended to increase the hydraulic jump downstream of the vane and promoted better scour in the structure pocket pools. The use of dished rocks for throat rocks and pour-overs to concentrate flow can create an aesthetically pleasing effect.

The most prevalent problem—Most of the problems observed with structure meltdowns where the vane rocks washout or are displaced during a high-flow event are a result of inattention to detail during construction. There must not be any open spaces between the structure rocks (fig. CS6–14). Open spaces result in the formation of suck holes during high-flow events. The water becomes accelerated as it passes through the hole between the rocks resulting in a high-velocity water jet. This jet will have much more localized power than the stream in general and can dislodge and cause the erosion of the bed material around and behind the footer rock. If the erosion persists, it can result in the movement or tip-outs of the footer rock, which in turn dislodges the top vane rock. It was noted that filling the gap holes with tightly packed coarse gravel is **not** a sustainable solution or practice. Where the streambed material is of fine material and there is a shortage of delivered cobble rock, grout bags can be used to fill the holes. The grout bags used in this case were sand bags filled approximately one-half to two-thirds of a mixture of sand and Portland Cement. Another method is to use a geotextile fabric (filter fabric) as a barrier to keep finer material from washing through the holes. The fabric is placed on the upstream side with the top of the fabric kept even with the fill line. The upstream side of the rock vane should be filled in with bed material up against the filter fabric. This procedure is labor intensive and may present challenges working in moving water.

Figure CS6–14 Gap holes, which in high flow, become suck holes

Evidence of this process was observed in many of the failures that occurred in the second year of construction in Big Bear Creek (figs. CS6–15 and CS6–16). The spaces between the rocks must be filled and preferably barricaded on the upstream side using large rocks that will span the hole. In later projects, the authors found that it is advantageous to have smaller rock delivered along with the wall rock for this purpose if the streambed material does not contain sizable cobbles.

In many cases, filling the gap holes makes the difference between a successful and sustained structure and one that will have to be rebuilt following a high-flow event.

Pool construction—Each structure should have a scour pool associated with it. Over the long term, this scour pool will develop naturally by eroding the streambed materials. The problem with this approach is that the system remains relatively unstable until the scour pools develop, and the potential fish habitat is not fully realized until that time. Since it requires several bankfull events to complete the pool scour, it could be years before the pools fully develop. The natural scour of the pools also adds to the sediment load of the system. The sediment removed from the pools may be deposited in a riffle section below the structure resulting in a splitting of flow. This behavior can increase the shear stress near the banks and, in turn, may increase bank erosion. Any disproportionate input of sediment at one location can set off a series of impacts downstream—the domino effect.

A much better approach is to give nature a hand, and excavate the scour pools during construction. The pools for cross vanes should be excavated so that the pool starts about halfway through the structure, with the deepest part of the pool roughly across from the butt rock of the structure. The glide- (tail-out slope) out of the pool on the downstream side of pool should have a slope based on the analyses of pool characteristic dimensions from stable stream reaches (reference reaches).

For J-hook vanes, pools should begin two-thirds of the way into the structure with the deepest part roughly across from the butt rock. As a rule of thumb, the glide should extend approximately one vane length downstream from the butt rock.

Fill from the pool excavation may be used to fill in against the rock structure on the upstream side of the vane rocks. In some cases, it may also be used in the construction of flood-prone benches, a technique used to stabilize a steep, eroding bank. For improved fish habitat, make riffles at low flow half the pool width for deeper riffle flow.

It was found that rounded throats for cross vanes were more effective than straight throats. Similarly, the J-hook vanes needed to retain the shape of a “J,” rather than an “L.” The more pointed throats concentrated flow better than those that were blunt. By concentrating the energy more efficiently, sediment was more readily transported. Consequently, the scour pools are more likely to be maintained without aggradation.

Habitat rocks—The installation of habitat rocks is an advanced technique for fish habitat enhancement. In several instances, habitat rocks were placed in the stream and found to be a detriment, rather than an enhancement. Habitat rocks placed in glides resulted in aggradation on the downstream side. In-line placement of habitat rocks parallel to the streamflow caused aggradation between rocks. A better technique was to use a cluster alignment of three rocks, one upstream and two downstream, but offset from the first with respect to the streamflow lines. Adequate spacing is also needed between structures to incorporate habitat rocks; otherwise, the habitat rocks promote aggradation. The authors suggest placing the habitat rock cluster no closer to the butt rocks of the upstream structure than one bankfull width. The downstream extent of the habitat cluster should be no closer to the downstream vane than half of the distance between

Figure CS6–15 Vane with a tip-out vane rock due to the scour from a gap hole

Figure CS6–16 Tip-out due to scour from a suck hole

the vanes. If these dimensions cannot be met, the habitat rocks should not be installed at that location.

Habitat rocks must also be installed with footer rocks of comparable size. For habitat purposes, biologists suggest that the habitat rocks be set at an elevation to be just submerged during normal spring flows. This rule of thumb was supported by trial and error on this project.

Maintaining cross section—It is important that the cross-sectional area be maintained through the structure. If the structure is too wide, there is a chance that the flow will spread out across the downstream portion of the structure with a subsequent reduction in velocity. With the velocity reduction comes a reduction in the power of the water and in the capacity for sediment transport. This ultimately leads to aggradation downstream of the structure. A structure which constricts the flow may promote additional scour as the velocity of the stream accelerates through the structure, also promoting erosion of the banks upstream of the constriction. In fact, the installation of an undersized structure may defeat the purpose for which it was installed.

One significant lesson learned was related to the gravel and streambed fill material that is placed between the structure and the bank (representing the acute angle of the structure). In several cases, the fill placed by one of the construction crews ran from the upstream edge of the vane rock to the top of the bank (at the bankfull level) all along the leg of the vane. So, instead of a relatively flat, tapering ramp extending horizontally to the bank bordered on the downstream side by the vane rock (fig. CS6–17), the fill in these cases ran from the vane rock to the top of the bank all along the leg of the vane. The bank then extended to the edge of the vane (now at a different slope), illustrated schematically in figure CS6–18. The result of this mistaken practice was a reduction in the cross-sectional area and an increase in flow depth and high-flow velocities. The structures could not function as designed since there were no ramps for the water to run up on and expend its energy on. Rather, the flow was deflected away from the vane rocks and maintained much of its velocity as it was channeled to the center. The vane functioned as a channel constriction. Once discovered, the construction crew was required to dig out the fill along these structures until flat ramps were formed.

Machine tracks—The tracks of the excavator were visible in the reworked streambed, and it was noticed that these tracks acted as energy dissipaters. While it was probable that the tracks would have been filled in by the stream over time, the tracks were dusted out before the machine left the stream to minimize effects on flow patterns in the stream.

Figure CS6–17 Cross vane illustrating the proper upstream fill along the vanes, leaving a flat horizontal ramp along the vane

Figure CS6–18 Schematic representation of the improper fill technique on the upstream side of the vane

Working instream

Perhaps one of the most potentially controversial issues in the construction of the restoration project was working in the stream channel, in the wet, with heavy construction equipment (fig. CS6–19). The USFWS personnel practiced a no tolerance policy regarding equipment malfunction and leaking fluids. If equipment leaked or dripped any nonaqueous fluid, it was immediately removed from the channel area and repaired.

Typically, the biggest concern over working in the wet channel is the amount of sediment stirred up by the equipment and allowed to migrate downstream. Allowing the construction equipment in the stream actually minimizes the construction time (and, therefore, the disturbance time) over other options designed to arrest some of the stirred-up sediment. Where equipment is working in the stream, the sediment that moves downstream is predominantly sediment that is already in the stream system and does not represent a new sediment input into the system. Construction activities are performed during low flow so that the sediment mobilized during the construction is mostly fine sand, silt, and clay. The release of this fine sediment is episodic for usually less than 10 hours per day and many days less than 8 hours. The streams usually clear up between construction events.

Two of the authors of this case study, Putnam and Worobec, studied the sediment transport characteristics of Big Bear Creek and its unstable reaches prior to this project. Their estimates ran as high as 10,000 tons per year released into the system prior to construction. This sediment included coarse and very fine sediment. The amount of fine sediment released during construction activities pales in comparison to this estimate. Consequently, this construction technique was deemed the most cost-effective method with relatively low risk of ecological impact. The authors' evaluation was supported by the postconstruction monitoring data. Results of ecological monitoring, both pre- and postconstruction, indicate that equipment working in the channel during construction caused no long-term adverse effects. In fact, monitoring showed that macroinvertebrates made a healthy rebound within 2 months of the cessation of construction activities in the channel. Monitoring also showed a significant increase in trout populations the following season.

Other options can be considered for doing construction in a stream (although not considered for this project), such as:

- working strictly from the bank
- diverting the stream to an alternate channel and doing construction in the dry channel
- pumping the water around the construction site
- diverting the water to one side of the construction activities

Several comments will be made on each in comparison to doing construction with the equipment in the channel. The amount of the sediment released for each scenario must be evaluated over the long term along with other effects on the stream.

Working strictly from the banks may be a viable option in an urban setting where the riparian vegetation has been removed or is minimal. On Big Bear Creek, this scenario would have destroyed large portions of riparian vegetation, which in turn would most likely have destabilized the banks and resulted in an increase in bank erosion, moving large quantities of coarse and fine sediment into the system.

Figure CS6–19 The open heart surgery approach, working with heavy equipment in the channel of Big Bear Creek

An alternate channel would also destroy riparian vegetation, and a significant amount of sediment would be released from this freshly constructed channel due to the recent disturbance of the soils during construction. The cost of this option rivals the cost of the restoration activities just on its own.

A pump around system is also very costly for the amount of flow that would need to be pumped. This option carries with it a distinct potential for erosion at the discharge of the pumping system, requiring the construction of energy dissipation structures. In addition, a stilling well would to be required for the upstream intake. Aquatic life would be either be prevented from passing the project reach or pulverized by the pumps. This option is also very energy intensive.

Diversions in the channel limit the mobility of the equipment and prevent the construction crew from evaluating the effect of the constructed structures on the streamflow lines. The velocity and volume of the streamflow is constricted to the remaining portion of the channel, which significantly increases the stress on the opposite bank, raising the potential for significant erosion during construction. Sediment will still be dislodged in the setting up and moving of the diversion barriers.

Project evaluation

Much has been said about the deficiencies and problems with the design and construction of this project. In some respects, it lends itself to discussing lessons learned, particularly since this was the first project of this type and scope built by the personnel of the USFWS Pennsylvania Field Office. There were many lessons to be learned in the process. It should be noted, however, that overall, the project was a large success. What was once a highly unstable stream contributing upwards of 10,000 tons per year of sediment to the stream system is now 3.7 miles of stable stream with a sediment load of approximately 2,100 tons per year.

Examples of successful restoration techniques are shown in figures CS6–20 and CS6–21. In figure CS6–20, a landslide area is shown before restoration. A flood-prone area was constructed along the eroding bank to move the main channel away from the bank, leaving only relatively slow moving water on the flood-prone bench next to the susceptible slope. The relocated and resized channel was stabilized with several cross vanes along the reach. A completely aggraded channel reach that resulted in the formation of a channel avulsion is depicted in figure CS6–21. The gravel was excavated from the original channel, and the banks were resloped. The channel avulsion was filled in. The newly excavated channel was stabilized with cross vanes. As vegetation fills in, the need for the vanes lessens.

Gravel bars

The effects of this project were evaluated based on the results of an extensive monitoring program that evaluated aquatic plants, macroinvertebrates, fish populations, and sediment transport before and after project completion. The aquatic life and macroinvertebrates showed signs of rebound 2 months after the completion of construction activities in the stream. A marked increase in the population of brook trout was found the following season. Aquatic plants are now thriving, as well as a diverse population of macroinvertebrates. The rocks in the streambed are now turning blackish indicating the streambed is now stable enough for moss and algae to grow on the cobbles that make up the streambed. Prior to construction the rocks were light gray, their native color, indicating active transport. Local fishermen noted that Loyalsock Creek used to run brown during an intense rain storm with a more noticeable, intense brown streak coming into the Loyalsock at the confluence with Big Bear Creek. Since the completion of the restoration project, fishermen observe the confluence waters of Big Bear Creek as it pours into the Loyalsock Creek and note that the waters from Big Bear Creek create a plume of clear water within the brown muddy waters of the Loyalsock.

There is now no evidence of continuing instability along the treatment reaches. Based on the parameters described above, the authors feel the objectives of the project have been met and that the project is a success.

Some of the most important lessons learned on the Big Bear Restoration project are:

- When using multiple construction crews, communication is one of the keys to success. Communication must start with making sure everyone is onboard with the project objectives, techniques to be used, and performance expectations.
- Attention to detail during construction is paramount.
- Review the second point.
- Re-review the second point.

Figure CS6–20 Treatment technique used for a landslide area

Resloping and stabilization of landslide, construction of a flood-prone bench, and construction of rock vane structures

Figure CS6–21 Treatment of a channel avulsion with rock structures