BENDWAY WEIRS AND SOIL BIOENGINEERING FOR CALIFORNIA BURN DUMP REMEDIATION

John McCullah, CPESC
Salix Applied Earthcare
3141 Bechelli Lane
Redding, CA 96002
Tel. (530) 224-0878
Fax (530) 224-0879
john@salixaec.com

Doug Hanford, CPESC
Hanford Company
23195 Maffel Road
Sonoma, CA 95476-9259
Tel. (707) 996-6633
Fax (707) 996-6641

BIOGRAPHICAL SKETCHES

John McCullah is a Certified Professional in Erosion and Sediment Control since 1986. He received a BS degree from Humboldt State University in Watershed Management, with an emphasis in Watershed Geology. John is president of Salix Applied Earthcare, a natural resource consulting firm in Redding, California. He is the author of Erosion Draw 3.0 and several other BMP and Biotechnical Soil Stabilization manuals and curriculum. He is a co-founder and executive director of Sacramento Watersheds Action Group (SWAG), a community-based, non-profit watershed action group. John is also a part-time instructor at Shasta College, teaching Watershed Restoration, and he is an instructor for IECA Professional Development Courses

Doug Hanford is the founder of Hanford Company, a general engineering and landscaping company, which specializes in erosion control revegetation and wetland and stream construction and rehabilitation. Doug is a licensed Landscape Architect, a licensed Landscape and Engineering Contractor, and a Certified Soil Erosion and Sediment Control Specialist. He has a BA in landscape architecture from the University of CA, Berkley.

ABSTRACT

This paper describes the first Bendway Weir project to be implemented in California. The Bendway Weir concept was developed by the Waterways Experiment Station (WES) in 1988 as a solution to a number of environmental and navigational problems caused by river bends (bendways) along two reaches of the Mississippi River. Performance there has been impressive. Since 1992, Bendway Weirs have been used on various sized rivers and streams in several areas of the country. The Bendway Weir and Longitudinal Peaked Stone Toe Protection (LPSTP) system was chosen for Buckeye Creek because of its proven efficacy in similar situations. John McCullah, erosion control consultant, David Derrick, hydraulic engineer, and Doug Hanford, soil bioengineering contractor, designed the streambank stabilization and erosion control components of this project.

Buckeye Creek is an ephemeral stream in Northern California that abuts a closed disposal site, the Dunnigan Burn Dump. Due to high flows in Buckeye Creek and extreme erosion from winter storms, burn ash and solid waste were being exposed along approximately 500 feet of the creek and carried downstream during periods of high water. Bendway Weirs were utilized in this remediation project to deflect the high-energy streamflows away from the exposed streambanks.

Thirteen weirs and over 700 meters (2,300 ft) of LPSTP was installed along the exposed bank to reduce the possibility of undercutting and future exposure of the waste material. Construction and material costs were significantly less than more traditional methods such as gabions and rock riprap. Concern for wildlife habitat and other environmental issues prompted the use of soil bioengineering techniques. One of the traditional benchmarks of soil bioengineering is to use the resources that the site provides you. This project site had severe limitations, with lack of moisture in the soil to successfully vegetate with live materials collected on site at the time of construction, and lack of funds to provide water or maintenance for container plants. However, native and indigenous plant materials were available immediately adjacent to the site, and these were used to construct Composite Brush Siltation Weirs (CBSW's), a suitable biotechnical practice for this site. This practice utilizes non-living material to initially dissipate the force of water until live plants can establish within this matrix.

Keywords: bendway weir, soil bioengineering, streambank stabilization, longitudinal peaked stone toe protection (LPSTP), and composite brush siltation weirs (CBSW's)

INTRODUCTION

Severe channel aggradation combined with high stream flow velocities resulted in accelerated streambank erosion and channel migration within Buckeye Creek, which is an intermittent tributary to the Sacramento River. The Buckeye Creek watershed is located within the western Sacramento Valley region of Northern California, and drains an area of approximately 100 km^2, primarily rangeland. The largest land uses in the basin are primarily dryland ranching and irrigated almond orchards. The region receives approximately 750 mm of precipitation annually, typically between November and June. Buckeye Creek along this project reach is primarily a "dry" riparian area, and the most abundant xeric species include chamise, toyon and buckeye. There are a few cottonwood trees on-site. The highly eroded outer banks are generally devoid of vegetation and the toe of the vertical banks are composed of consolidated gravely clay loam and poorly consolidated gravely alluvium. The few places along the banks where cottonwoods or the random almond tree have established show reduced streambank recession.

Between 1940 and 1976 Yolo County owned and operated a waste disposal site adjacent to Buckeye Creek, approximately 5 miles NW of Dunnigan. During this period the 2 ha dump received primarily household waste that was periodically burned and buried to consolidate the landfill. The Dunnigan Burn Dump is typical of many abandoned landfills throughout the State and these burn dumps require remediation when erosion exposes the waste and burn ash. Burn ash is toxic and must be handled carefully, usually by in-situ burying, to ensure the ash does not become airborne. The California Integrated Waste Management Board (CIWMB) has an AB 2136 Solid Waste Disposal and Codisposal Site Cleanup Program to assists with remediation of burn dumps. The CIWMB can provide cost-share funding, project design and project administration to qualifying applicants.

In recent years, streambank erosion exposed the waste and burn ash at the Dunnigan Bun Dump. In one winter alone, 1997/98, the accelerated erosion resulted in approximately 7 to 10 meters (20-30 feet) of lateral bank erosion which allowed the toxic waste to be washed into Buckeye Creek. The Yolo County Public Works Department requested the assistance of the CIWMB to manage the cleanup and remediation of the site. Subsequently, CIWMB engineers developed plans and specifications for the remediation. The remediation plans involved: (1) the removal of exposed waste from the landfill, streambank, and creek channel; (2) regrading the streambanks to the desired slope; (3) capping the areas of exposes waste; (4) constructing deflectors to

Figure 1. Erosion on the banks of Buckeye Creek was exposing waste and burn ash at the Dunnigan Burn Dump.

divert flow away from the bank; and (5) install biotechnical erosion control along the streambank.

The CIWMB hired John McCullah, Salix Applied Earthcare, to provide design and specifications for the erosion control aspects of this project. The erosion control consultant enlisted the services of David Derrick, River Research and Design, to provide more detailed designs for the Bendway Weirs and Longitudinal Peaked Stone Toe Protection. All non-Mississippi River Bendway Weir projects in the U.S. (25 projects at this time) were designed or co-designed by Mr. Derrick. Doug Hanford, Hanford and Company provided designs and implementation for post-construction soil bioengineering elements.

Project Design

The goals for this project was to prevent the exposed waste, car bodies, glass and burn ash from further contaminating the area. The waste would be pulled back from the streambank, re-consolidated, and capped with topsoil. The long-term goals would be achieved with effective erosion control. The topsoil cover would be protected from future erosion with appropriate native grass species while the streambank erosion and lateral migration would be arrested with a combination of structural and vegetative methods.

Both gabions and rock riprap were initially considered for this project. The large rock for riprap and angular stone for the gabions was not locally available and would have to be delivered great distances. The gabions and rock riprap were ultimately rejected for several reasons: In sand and gravel streambeds, the anticipated or calculated scour on the streamside of a gabion structure, even with a good foundation, can result in stability problems, undermining and failure. Pullback and stabilization with rock riprap would be expensive because significant quantities of large rock would be required. There was no guarantee that rock riprap would solve the problems of streambank scour and erosion, and the use of riprap alone was rejected for this project. Additionally, some state resource agencies had recently voiced concerns over long-term loss of habitat from the use of gabions and riprap along streambanks in California. It was determined that the construction of rock weirs to deflect flows away from the eroding outer bank would require less rock material.

Use of Bendway Weirs and Longitudinal Peaked Stone Toe Protection

Bendway Weirs combined with Longitudinal Peaked Stone Toe Protection (LPSTP) were chosen as the protection structures for this project. The Bendway Weirs designed for this project were intended to reduce erosion on the outer banks by reducing velocities near the bank and reducing the concentration of currents on the outer bank, while producing a better current alignment through the bend. Additionally, the LPSTP is a protection method that allows stone to self-adjust or "self-launch" into any scour hole that may form on the stream side of the structure. The lengths of the weirs were designed to intercept a large percentage of the flow and move the thalwag (the deepest section of the channel) away from the toe of the eroding bank and into a smoothed alignment streamward of the ends of the weirs.

Bendway Weirs are environmentally desirable as they improve aquatic habitat diversity and complexity (Shields et al., 1995). The weirs will enhance the overall aquatic quality by increasing available habitat in this stream, in which rocky habitat is limited. Some areas on the Mississippi River stabilized with Bendway Weirs have yielded anywhere from 2 to 13 times as many fish compared to similar sites using other types of bank protection (Davinroy et al., 1998).

Combining vegetation with the strength of the rock enhances the structural integrity of the weirs. Once the high velocity flow vectors have been deflected away from the bank, less intensive and less costly biotechnical erosion control practices were used on the streambank areas between weirs. Incorporating appropriate and naturally occurring vegetation (poplar, willow, buckeye, native grass, etc.) with structural components (rock, turf reinforcement mats, geotextile materials, coir material, etc.) results in a more naturally maintaining system which enhances the aquatic and terrestrial ecosystem. Some scour should be anticipated at the weir ends, immediately upstream and downstream. The resulting scour pools will provide additional stream habitat and dissipate some of the erosive stream energy.

Construction

Construction began in October of 1998, and the contractor began by clearing, grubbing and reconsolidating the surface debris. The stream was still dry at this time. The equipment mobilized for this job included a dozer, scraper, loader, excavator and water truck. The waste and eroding streambanks in the area of the exposed dump were "pulled back" and relocated in designated fill areas away from the stream. The contractor then placed a 0.6 meter (two-foot) thick soil layer over the reconsolidated material and graded the area to drain. A mid-channel island was also removed. The erosion control consultant directed the contractor to salvage existing woody vegetation, when feasible, for future transplanting and stabilization of the completed streambank. A mature toyon was subsequently re-established by transplanting with the loader landward of the LPSTP and "watered in" with the water truck.

The first phase of the streambank protection began with the construction of the peaked stone toe wall. The alignment of the LPSTP was grade checked as per the plans to provide a smooth radius of curvature along this outer bend. The LPSTP and Bendway Weirs were constructed using ½ T class rock. The median rock size was approximately 0.6-1.0 meter (24"-36") boulders. The crest of the toe wall was 1.3 meters (4 feet) above the existing streambed. LPSTP constructed 1 meter high requires about 3 tons per meter (1 ton per foot). LPSTP applied at 6 tons per meter (2 tons per foot) would be about 2 meters tall. The LPSTP was easily constructed by using the loader to smooth the streambed prior to placement. Keying into the bed was not required, but keying into the banks was important. The loader was the primary piece of equipment used to build the LPSTP, while the excavator was only necessary to help "set" the rock and smooth the alignment. Backfill, 3-4 meters wide, was placed immediately landward of the LPSTP in the immediate vicinity of the dump, from Weir 5 downstream to Weir 13, a distance of approximately 300 meters.

Figure 4. Buckeye Creek, before Bendway Weirs.

Figure 5. Bendway Weirs, during completion of the keyways landward of the LPSTP.

The backfill was compacted with water and 4 passes with the dozer, except for the last 0.6 meters, which were left uncompacted for future biotechnical plantings.

Biotechnical plantings are generally more successful, especially in harsh areas, if the plantings are done in conjunction with the construction instead of after. Planting during construction often allows the cuttings to be placed deep into the soil, thus increasing survivability and geotechnical stability (McCullah, 1998). It should be noted here that biotechnical plantings, such as pole cuttings of cottonwood and willow, should have been done prior to backfilling in the zone just landward of the LPSTP. Use of the water truck and slightly compacted backfill would result in deeply planted cuttings. However, because of scheduling problems and inexperience, the contractor was averse to incorporating planting during construction of the LPSTP.

One exception, however, was when a very large cottonwood tree was cleared from the streambed, upstream from Weir 1. The tree had been deflecting flows into the eroding banks and would compromise the ability of the Bendway Weirs to control the flows through the reach. The tree was cut up and the large limbs and branches were thrown behind the LPSTP with the terminal bud ends pointing up. The excavator then removed the rootwad, with 2 meters of trunk attached, and also placed it behind the LPSTP. Soil was placed over the branches and the rootwad, and then the backfill was moistened with the water applied by the water truck.

Thirteen Bendway Weirs were constructed at locations and angles designated on the plans using careful onsite analysis. The onsite lay out, utilizing the advice of a Bendway Weir expert, is necessary because they have tremendous potential to affect stream processes and direction. The most important weirs are the first two or three - where the flows enter the weir field and are thereby “captured”. Also significant is the angle and length of the exit weir because it directs the flow downstream. The Bendway Weirs were designed between 12-17 meters (35-50 feet) long (from the LPSTP out into the stream) and angled 10-20 degrees upstream from their radii. Each weir was keyed into the bank to ensure the stream does not migrate or scour behind the structures. The keys were of various length such that they extended through and landward of the LPSTP, into the bank until the crest of the key was 4 meters above the streambed, and the keyways were a uniform 1 meter thick.

The weirs were constructed at a level elevation, 1 meter above the streambed, with a crest width of 1.3 meters (4 feet). Once again, the streambed was simply smoothed before placement of the stone. The weirs were placed approximately 20-30 meters apart and angled upstream. While the loader facilitated rapid construction of the weirs, the excavator was necessary to excavate the keyways and place the keystones. As an additional precaution the LPSTP was extended for almost 100 meters above the first weir and 40 meters below the last downstream weir (Weir 13). Another precaution was taken to ensure the opposite bank was protected: a 150-meter long LPSTP was built along the left descending bank. This LPSTP was also keyed into the bank at 35-meter intervals. The upper end of the LPSTPs were keyed into the point bars by digging trenches 1.2 meters wide by 1.2 meters deep and filling those with sufficient stone to ensure the flows do not go around the LPSTP.

Cost of Construction

The Bendway Weir system combined with the LPSTP proved to be the most cost-effective stabilization technology considered for this site. The project was completed ahead of schedule and about 30% under budget.

Construction costs for these stabilization techniques were approximately $200 per meter ($67 per foot) of streambank protected. The entire project required almost 3600 tons of rock. Over 600 meters of LPSTP was placed to protect the right bank adjacent to the weirs and the descending left bank. The 13 Bendway Weirs and accompanying keyways required the placement of 260 meters (780 feet) of rock. Therefore, the actual cost of building the weirs and LPSTP was only about $150 per meter ($50 per foot).

Surface Cover and Erosion Control

Direct seeding of a specially formulated native seed blend was specified for this 3 ha (6+ acre) site. A soil test indicated that some areas to be seeded were low in nitrogen. A slow release, polyurethane-coated fertilizer was to be incorporated into the soil. Slow release fertilizers are believed to aid the establishment native perennial grasses while ammonium phosphate fertilizers are quick release and thereby provide nutrients to the annuals and invasive types of vegetation. Hydraulic planting was the specified method of application. The seeding was not completed until December, which was very late in the year for California. Straw mulch, applied at a rate of 0.7-0.9 tons per ha (1.5-2.0 tons per acre) was also applied with the intention of preventing raindrop and sheet erosion until the grasses became established. The straw mulch was "punched in" using a straw punch on the flat areas and tackifier was used to anchor the straw onto the steeper streambanks.

On similar state-managed projects in the past, loose and vague seeding specifications has allowed hydroseeding contractors to provide seed that cost much less. However, these seeds were often not native to the area and did not produce the desired results, which was to re-establish stands of native perennial grasses while also providing the necessary erosion control. The seeds specified for this project were required to be native to California. The seed must have been grown and collected in California only. The seed was required to have a minimum of 80 percent pure live seed (PLS). The percentage of seed germination was to include the germination percentage of any hard seed rate for approval.

The seed blend developed for this site was developed after consulting with reputable California seed producers familiar with the area. The application rate was 13 kg per ha (65 pound per acre).

To ensure that the proper seed was applied, it was specified that the Inspector and/or Engineer must approve the seed before application. Additionally, the Inspector was to be present onsite during application, and the hydroseeding contractor was to show the seed invoice (proof of purchase) to the Inspector and/or Engineer prior to application of seed.

The area was hydroseeded with a native grass blend.

Species	PLS (lb./acre)	% of Mix
Hordeum californica sp. californica	13	20%
Stipa pulchra (Purple Needlegrass)	9.8	15%
Elymus glaucus (Blue Wildrye) var. Anderson	9.8	15%
Bromus carinatus (California brome)	9.8	15%
Lotus purshianus	6.5	10%
Mellica californica (California Mellic)	6.5	10%
Vulpia microstachys (Six Weeks Fescue)	6.5	10%
Poa secunda Secunda	3.1	5%
Total	65 #	100%

Soil Bioengineering

The construction of the new Bendway Weirs made this stretch of Buckeye Creek more stable. This stability was enhanced with the addition of non-living brushy materials (Composite Brush Siltation Weirs or CBSW's) which help to increase the probability of successful vegetation establishment at this site. The new Bendway Weirs slow and direct water towards the center of the stream, while the LPSTP will help prevent scour along the outer bank. Landward of the LPSTP was a benched slope which needed to be vegetated to further slow potentially erosive water during higher flows.

Traditional methods of revegetation for a dryland riparian site such as this included:

- planting of container grown stock;
- direct seeding of site collected materials and seeding for successive seasons;
- planting pole cuttings of site-collected live materials; and
- installation of fascines or wattles constructed of live plant materials.

The early weather pattern of the winter of 1998-1999 was very cold and very dry. This pattern was contradictory for successful establishment of container grown plant materials, which needed initial soil moisture and subsequent natural or supplemental water in order to grow.

Composite Brush Siltation Weirs (CBSW's) were placed on the bench landward of the LPSTP, and live pole cuttings were placed around the keystones. This configuration combined rough vegetative materials on the bench that will help to slow down the water and allow sediment to settle out. This new sediment drop out zone will become a seedbed for new plants. As soils gradually build up adjacent to these brush bundles, there will be enhanced opportunity for native plants to establish on their own.

The CBSW's are designed to decompose over time, with this decomposition being an investment in future vegetative colonization. The decomposition of the brush weirs will result in an enhanced microflora community within the soil, creating the right conditions for native plant regeneration in a more favorable growing season. It is important to get native plants established as soon as possible, however, in order to avoid aggressive weed intrusion. Brush Weirs are very cost effective compared to higher impact systems and more closely mimic the processes which encourage natural plant succession.

Installation of Biotechnical Methods

Following is a description of the installation methods and materials used to construct the Composite Brush Siltation Weirs:

Weir construction materials consisted of brushy vegetation collected on site (using thinnings of selected existing woody plants) and lashed together with heavy sisal or coir twine. Plenty of brushy materials were available immediately adjacent to the site. Brushy materials consisted of the following: (1) Heteromeles arbutifolia (toyon); (2) Adenostoma fasiculatum (chamise); (3) Baccharispilularis consanguinea (coyote brush); (4) Aesculus californica (California buckeye); (5) Populus fremontii (cottonwood); and Rhomnus californica (coffeeberry).

In this dryland, riparian site, there is an ebb and flow of water from year to year with corresponding flushes or die-back in plant growth. Consequently, brushy plant material has grown up over wet seasons and then died back when water was lacking. Thinning these plants encourages new growth if conditions are favorable, and reduces total leaf area of the plants so that they are more capable of surviving droughty periods.

Brush trimmings were cut with chain saws and stacked alternating the butt ends of the brush in both directions. The stacks were tightly bundled and secured with twine made of natural sisal. The finished bundles were approximately 2.6 meters (8 feet) long and 0.5-0.6 meters (18 inches-2 feet) in diameter. Trenches were dug into the graded bench area on the landward side of the LPSTP, perpendicular to the stream

Figure 7. Composite Brush Siltation Weirs (CBSW's) were installed on the bench landward of the LPSTP in order to reduce overbank flow velocities and encourage siltation and natural revegetation.

channel, in preparation for placement of the CBSW's.

Direct Seeding:

Prior to placement of the Brush Weirs, the trenches were direct seeded with toyon, coffeeberry, and California buckeye. Buckeyes should be direct seeded when they are fresh or have been stored in a cool and moist area, as they germinate and grow most successfully when gathered and planted in the same season they have fallen from the trees.

The composite brush bundles were then installed into these trenches with the lower half of the bundle buried and secured in place with pole cuttings and stakes cut from 2 x 4's.

Live Pole Planting:

Live pole planting refers to planting a cut section of an easily rootable plant directly into the ground. Cottonwood was chosen for this site. The cottonwood poles ranged from 20 mm to 37 mm (3/4" to 1 1/2") in diameter and are approximately 0.6 m (2') long. It is vitally important to keep the top/bottom orientation of the plant correct. To keep this orientation correct, the bottom end of the pole cutting is cut at an angle and the top end is cut straight across.

Pole cuttings were taken from dormant, healthy specimens of cottonwood and planted within 24 hours of cutting. Poles were planted so that no more than 75-100 mm (3-4") of the cutting protruded above the ground, again to prevent desiccation. The 75-100 mm (3-4") sections of the cuttings above ground level had at least 2 nodes where dormant buds could break and grow. The pole cuttings were firmly tamped and watered in so that there were no air pockets around the stem, assuring good plant to soil contact.

Results and Discussion

PROJECT SCHEDULE

The vegetative components of this project were installed during the month of March, 1999. Weather patterns for this area at this time of year were such that temperatures were beginning to warm up and there was not a great deal of rain fall that occurred after the construction window. Ideally, the revegetation for this project should have been implemented in

Figure 8. Even the highest flows in the winter after construction did not overtop the Bendway Weirs. Note the LPSTP is protecting the high bank in the foreground, allowing it to naturally repose.

December or early January, when there was more moisture to give a greater opportunity for establishment. This was particularly critical on this site due to the long, hot dry summers.

CONCLUSION

Subsequent visits to the site have shown about 50% of the live pole plantings to be sprouting. None of the direct seeded areas within the Composite Brush Siltation Weirs have shown any signs of seedling emergence. The CBSW's did not experience any periods of inundation from high flows during the spring of 1999. The desired revegetation is expected to occur during the next few years as the CBSW's trap sediment, creating a more hospitable medium for native plant colonization, and as a percentage of the direct seeding and seeds naturally found in the CBSW's begin to germinate. This process is already beginning to occur in the silt deposits left in the backwater zones of the bendway weirs.

REFERENCES

Davinroy, R.D., Rapp, R.J., and R.E. Myhre 1998. "Hydroacoustic Study of Fishes in Bendway Weir Fields of the Middle Mississippi River". Proceedings of the ASCE conference Wetlands Engineering and River Restoration Conference 1998.

Derrick, D.L., 1995. Case Study: Harland Creek Bendway Weir/Willow Post Bank Stabilization Demonstration Project. In *Water Resources Engineering*, Proceedings, First International Conference on Water Resources Engineering, ASCE, New York.

McCullah, J., 1998. Biotechnical Soil Stabilization. Training Manual for Caltrans, California.

Shields, Jr. F.D., Knight, S.S., and Cooper, C.M. 1995. "Streambank Protection and Habitat Restoration". Volume 1 of the ASCE conference, The First International Conference on Water Resources Engineering, San Antonio, TX. p. 721-725