A CASE HISTORY: RECONSTRUCTION OF THE EAST FORK OF THE ARKANSAS RIVER AT THE CLIMAX MINE[1]

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Abstract. The East Fork of the Arkansas River was diverted into a 2,000-foot long 7-foot diameter concrete pipe at Climax Molybdenum Company's Climax Mine near Leadville, CO, at an elevation of 11,150 feet asl (3.400 m). The pipeline was then buried under a waste rock valley fill during the course of mining operations. The mine initiated an ambitious project in 2006 to relocate the river channel on top of the development rock fill. The channel design incorporated hydrologic and hydraulic engineering design principles coupled with level II Rosgen methodology. Geomorphic parameters observed in adjacent undisturbed stream reaches became design criteria. Geomorphic design criteria were also applied to the reclaimed landforms adjacent to the channel to promote equilibrium between sediment production and riverine sediment transport mechanics. The primary channel and adjacent floodplain were designed to pass the full range of flows predicted for the river while maintaining fish passage.

Excavated materials were screened, stockpiled and incorporated during construction as required by the design specifications. Large boulders were used to anchor riffle-pool sequences and channel meanders. Smaller rocks and a soil-rock mixture modeled on the diverse substrate in adjacent undisturbed stream reaches were strategically placed as source material for redistribution during high flow periods. Cobbled armoring at cut banks and sandy deposits at point bars have formed as expected without significant loss of material. Floodplains and wetlands were constructed adjacent to the channel, providing habitat for riparian and wet meadow species. The completed project maintains floodplain connectivity, mimics natural topography, passes stormwater runoff through a dynamically stable and aesthetically pleasing restored stream reach and includes habitat for aquatic and wetland biota creating a viable, self-sustaining ecosystem.

Additional Key Words: geomorphic design, channel restoration, mine reclamation

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Introduction and Project Description

Relocation and restoration of the East Fork of the Arkansas River was completed at Climax Molybdenum Company's Climax Mine, located near the top of Fremont Pass (elevation 11,318 feet) in Lake County, Colorado. The river had been diverted in 1980 through a 7-foot diameter concrete pipe constructed in the valley bottom that was buried under coarse mine waste in an area known as the Storke Yard (Figure 1). Upon exiting the Storke Yard the river was returned to its native channel and allowed to flow downstream unimpeded. This project entailed the design and construction of approximately 2,000 feet of stream channel and adjacent landform. Stream channel restoration, habitat construction and revegetation activities are particularly difficult at this site as a result of the high altitude, short growing season, harsh winters, heavy snow pack, intense summer thunderstorms, periodic flood events and poor soils. The growing season averages 6 weeks and annual snowfall averages 23 feet (HMI, 2010).

Water & Earth Technologies, Inc. was responsible for engineering analysis and design and provided engineering construction supervision for this design-build project. Habitat Management, Inc. provided construction oversight and reclamation services including erosion and sediment control planning, soil analysis, development of amendment and seeding schedules and revegetation design. Information about the reclamation and revegetation phase of this project is available in these proceedings, in Bay et al. (2011). Fieldwork to support the design was conducted in the summer of 2006. Final design documentation was submitted to Climax in March, 2007. The project was built between May 28 and October 14, 2007. The following season, maintenance and fine-tuning activities including monitoring channel geometry and integrity, biosolids amendment placement, final revegetation and vegetation maintenance, and the placement of permanent monitoring transects and photo points were completed. In the spring of 2009 the full snowmelt runoff was first routed through the restored channel. An as-built survey was conducted in the fall of 2009 and documented in an as-built report (HMI, 2010).

The immediate goals of the construction project were to engineer a hydraulically stable and aesthetically pleasing stream channel. Ultimate goals include the establishment of self sustaining and diverse riparian and wet meadow plant communities and the creation of viable aquatic habitats.

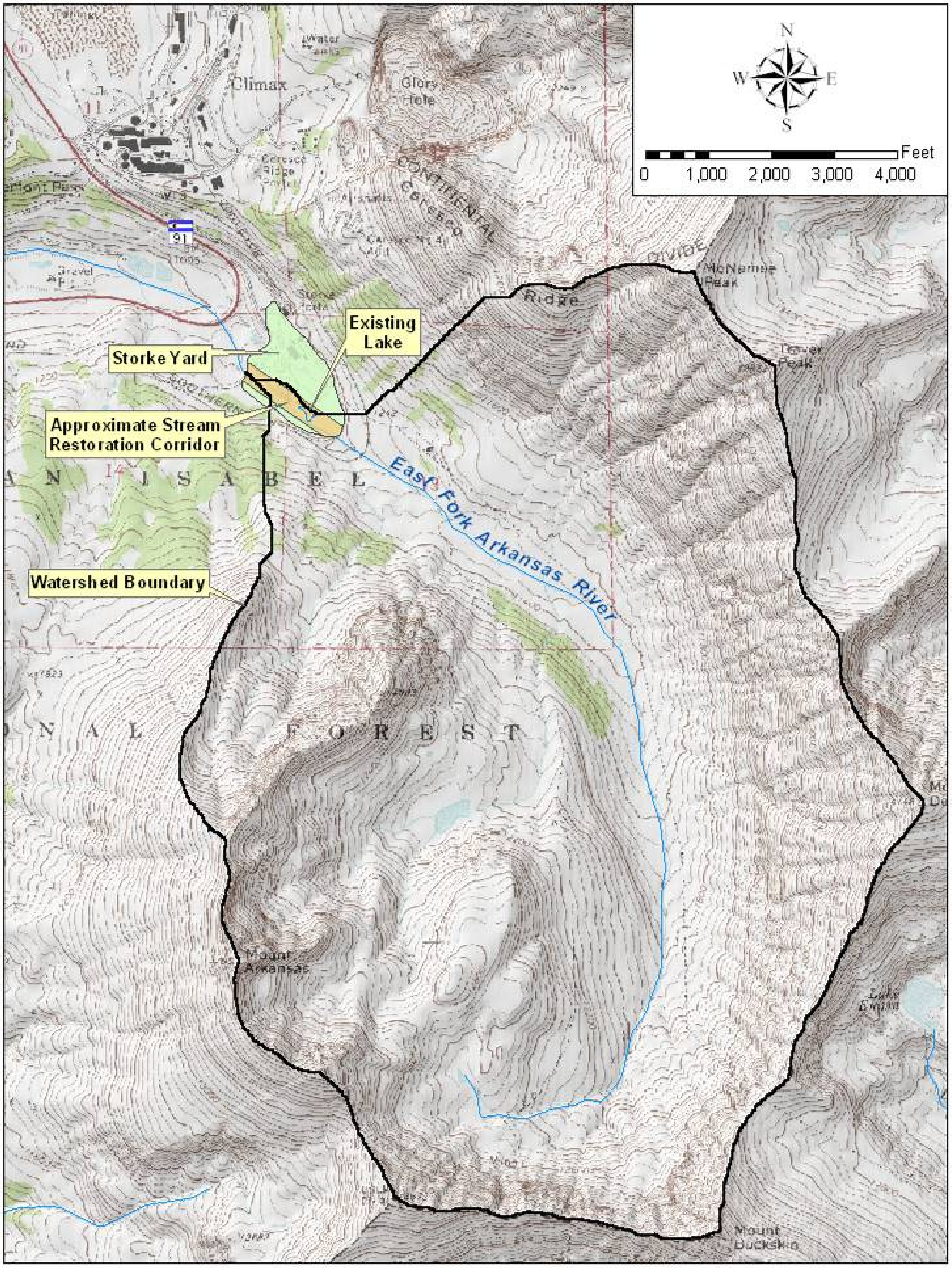
Existing Lake
Storke Yard
Approximate Stream Restoration Corridor
Watershed Boundary
East Fork Arkansas River
Climax
Glory Hole
CONTINENTAL DIVIDE
Ridge
McNamee Peak
Mount Arkansas
Mount Buckskin
N
S
E
W
Feet
0
1,000
2,000
3,000
4,000

Figure 1. Project site location and watershed delineation.

<u>Design Constraints</u>

Restoration of the river required that the piped reach be replaced with a new stream channel that would be built on top of an unengineered valley fill composed of mine development rock ranging from 10 feet to over 30 feet thick at the bottom of the valley (Figure 2). During seismic refraction surveys, the fill layer produced wave velocities typical of loose to moderately dense, unsaturated soils. A major project challenge was to seal the channel and prevent infiltration of water into the fill beneath the channel.

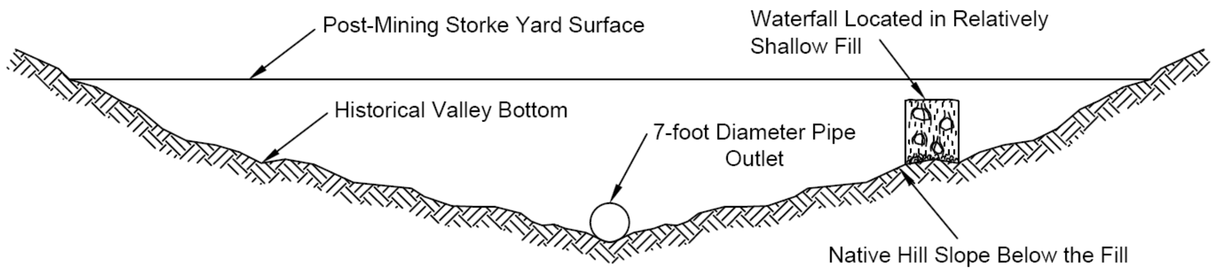

Figure 2. Storke Yard cutaway view.

The pipeline that conveyed the river beneath the Storke Yard was to be retained during construction and at least throughout a 3-year reclamation and monitoring phase after construction. In the long-term the pipe can be sealed or preserved to allow Climax to divert flows from the river during flood events or to regulate stream flow during spawning to promote recovery of the fishery. Given the short growing season at the project altitude, retaining the pipeline provided an opportunity to moderate extreme flows during the crucial early years of revegetation establishment before reintroducing the river's full flow into the restored reach. The berm and retaining wall that served to divert the river into the pipe (Figure 3) had to be retrofitted to safeguard the pipe entrance and to allow flow to be diverted to the new channel. An inlet box with Waterman slide gates was designed to govern flow between the restored river channel and the 7-foot diameter pipe. A similar Waterman slide gate was fitted to the culvert that conveys the river beneath the berm and into the restored channel, allowing flows to be diverted completely into either conveyance or split between them (Figure 4). The layout of the restored reach was required to accommodate a perpendicular cut through the berm for the culvert, and to avoid the inundation of the retaining wall in the berm at the peak design flow.

Figure 3. Uncontrolled entrance to the Storke Yard pipeline.

Figure 4. Finished pipe and channel inlet structures.

An opportunity existed to incorporate a small lake (Figure 5) that had formed at the location of an excavation for a reclaim conveyor into the restored channel reach. The ultimate design expanded the lake's surface area by raising its water surface elevation (Figure 6), and shallow areas and benches along the perimeter of the lake were constructed to expand aquatic habitat, specifically trout-spawning habitat. Retaining the lake divided the restored alignment into two channel reaches, one Upstream and one Downstream of the lake. Given the water surface elevation at the lake, a 5.6% average gradient was required for the Upstream reach above the lake. A step-pool bed form design for this reach was designed to facilitate Climax's desire to maintain fish passage through the Upstream reach and into the undisturbed watershed upstream of the project area.

In addition, Climax wished to locate a waterfall feature at the bottom of the Storke Yard to enhance the view from nearby Highway 91 and to facilitate the future management of fisheries by allowing the Mine to isolate the restored reach. A waterfall drop structure was engineered to transition the restored channel from the fill material in the Storke Yard to the native hill slope below the fill embankment. To avoid areas of deep fill, only one location for the drop structure was feasible. An average gradient of 2.8% was therefore required for the Downstream reach that would lie between the lake and the drop structure. To promote the long-term stability of the drop structure, the Downstream reach was required to include a relatively straight approach section with side slopes no steeper than 3:1 approximately 100 feet in length.

Additional important design constraints impacted the feasibility of various channel layouts. Challenges for the final realignment design included:

1. Minimizing crossings of the underground pipe by the restored channel, to avoid the potential for seepage to be intercepted by the pipe or its bedding;
2. Avoiding costly excavation of remnant building foundations located throughout the Storke Yard by selecting a channel layout clear of these obstacles;
3. Avoiding the inundation of surface level inlets to historic drainage structures even during the design flood;
4. Establishing channel geometry for the restored stream channel that would provide consistency with undisturbed stream reaches in the immediate project vicinity;

Figure 5. Lake prior to restoration.

Figure 6. Lake after restoration.

5. Creating channel and overbank geometry hydraulically capable of passing the 100-year, 24-hour peak flood flow while protecting the stability of the incised channel;
6. Creating a longitudinal low flow channel, including adequate riffle-pool or step-pool spacing and depths, capable of supporting trout even during low flow conditions, with discharges of 3 to 7 cubic feet per second (cfs);
7. Creating a restored channel and surrounding landform that ties into the surrounding valley, is stable over the entire range of design flows and supports the runoff of precipitation to created wetlands in the project area while minimizing disturbance area to the extent possible; and
8. Constructing a restored stream that looks natural and is visually pleasing.

An alignment along the south side of the yard was chosen, which also reduced the number of times the buried culvert was crossed. A three dimensional digital surface model of the existing, post-mining Storke Yard landform was developed from topographic survey data and used to model proposed river realignments, balance cut and fill, minimize haul distances and confirm post-construction as-built topography.

Test Pit Investigations

A test pit investigation was undertaken to determine the composition of the fill material along the proposed river alignment and characterize its suitability for sealing the channel base. Eight 3 to 4.5 feet-deep test pits were excavated and the material was analyzed with a tape measure and a gravelometer to estimate the incidence and size distribution of rocks (Figure 7). Samples of the finer (less than 3-inch diameter) material from each test pit were collected to conduct sieve analysis and determine particle size distribution. The investigation supported the conclusion that the excavated material, when properly placed and compacted, could be used to seal the channel. Even in the uncompacted state that existed in the Storke Yard, the test pits provided evidence of a relatively low permeability for the material in the valley. After excavation, a significant storm event filled the test pits with water, and the water remained for many days (Figure 8).

Figure 7. Material encountered in a test pit excavation.

Figure 8. Test Pit 8 filled with rain water.

Design

The project design sought to blend the naturally existing undisturbed topography, including the upland, riparian and aquatic ecosystems of the upper watershed, with the newly designed terrain. Measures were taken throughout the design process to maintain floodplain connectivity, mimic undisturbed topography and include aquatic habitat, even at base flow levels. The technical design approach incorporated empirical geomorphic criteria with sound hydrologic analysis and hydraulic engineering principles.

Geomorphic Design Criteria

A complete survey to quantify parameters characterizing the fluvial geomorphology in potential reference reaches was conducted in August 2006 (Figure 9). Channel slope, sinuosity, meander frequency and other characteristics were compiled for representative reaches of the undisturbed river in the project area using standard methods for geomorphic field investigation (Rosgen, 1996 and 2006). Data collected from the reference reaches were used as a template to design moderate- to low-gradient plan and cross-sectional bed form and river bank geometry. Design for the Upstream reach was modeled on a 5.6% step-pool reach of the East Fork of the Arkansas River upstream of the Storke yard. The Downstream reach was similarly modeled on an upstream 2.8% riffle-pool reach. Target values for geomorphic parameters, especially the meander length and width, were modified to allow the realignment to fit onto the Storke Yard topography in an aesthetic arrangement that could be made to work with the other layout criteria. Riffle-pool or step-pool sequencing, rock placement and substrate composition were analyzed in the reference reaches. A summary of the geomorphic parameters measured in the reference reaches is provided in Table 1.

Design Hydrology

The watershed that generates runoff in the design river reach is approximately five square miles. Precipitation runoff conveyance throughout the watershed and in the design channel was modeled using SEDCAD 4.0 and the estimated 100-year, 24-hour design storm, resulting in a design peak discharge of 550 cfs. Rainfall values were obtained from the NOAA Atlas 2 Colorado Isohyetal map and the Natural Resources Conservation Service (NRCS) type II design storm criteria were used (Mockus, 1985). Hydrographs in SEDCAD are developed on a subwatershed basis, with inputs including the design storm, area, time of concentration, NRCS curve number and one of three dimensionless double triangle unit hydrograph shapes. Routing of hydrographs is accomplished by Muskingum's method. SEDCAD 4.0 modeling procedures and inputs conformed to standard program protocol and industry standards as detailed in the user manual (Warner et al., 1998).

Table 1. Geomorphic Design Criteria Measured in Reference Reaches

	Upstream Reach	**Downstream Reach**
Gradient	5.6%	2.8%
Morphology	Step-pool	Riffle-pool
Meander Length	210 feet	160 feet
Meander Width	35 feet	35 feet
Pool length range	8 to 13 feet, average 12 feet	20 feet to 60 feet
Pool width range	8 to 15 feet, average 12 feet	10 to 23 feet *
Pool Depth range	2 to 3 feet	2 to 2.7 feet
Pool Boulder Dimensions	1 to 3 feet	1 to 3 feet
Pool Boulder Embeddedness	5 to 25 %	25 to 50%
Riffle length range	N/A	30 to 50 feet
Riffle width range	N/A	15 to 20 feet *
Riffle Boulder Dimensions	N/A	0.5 to 3 feet
Riffle Boulder Embeddedness	N/A	5 to 25%

* Pools in riffle-pool sequences were typically wider than the preceding riffle.

Figure 9. Surveying fluvial geomorphic characteristics of reference reaches.

Base flow was estimated from measurements taken in August 2006 and ranged between 5 and 6 cfs. Data were collected and reduced using the mid-section (Schultz, 1974). These values were used to calibrate the HEC-RAS model for low-flow simulation. Literature reviewed at the mine site indicated that low flow estimates historically fell within the same range. Historic peak snowmelt runoff estimates of river discharge were between 100 and 200 cfs (HMI, 2010. Because bankfull flows are about 100 cfs, bank overtopping would typically be expected during spring runoff, and localized overtopping was observed in subsequent springs.

<u>Hydraulics</u>

Incised channel geometry measured in the reference reaches was used to inform the cross section geometry of the design reaches. Bankful stage calculated from the survey measurements taken in the reference reaches was confirmed by modeling the reference reaches in HEC-RAS (COE, 2002), and the results of this hydraulic analysis were used to ensure reasonable consistency between the reference and design reaches' computed average depth, width, maximum flow area, velocity and water surface elevation at various discharges through an iterative hydraulic design process. Cross sectional geometry was developed as a compromise between potential damages from flood overtopping, fish passage at low flow, and fluvial geomorphic processes occurring in the river, as characterized by the reference reaches. The primary channel and adjacent flood plain were designed to pass the full range of flows predicted for the river while maintaining fish passage. A defined low flow channel was designed to concentrate low flows and thereby facilitate the survival of fish at low stages. Rock structures within the riffle-pool or step-pool sequences are intended to accommodate fish passage at moderate flows. Plan and bed forms for these features were developed from aerial photography and ground surveys of the reference reaches.

Riprap sizes required to withstand the velocities estimated by hydraulic modeling of the design channel at the peak 100-year rainfall event were determined using the utilities feature in SEDCAD 4.0. The D_{50} was determined to be 9 inches for the riffle-pool Downstream reach, and 15 inches for the step-pool Upstream reach. A well-graded mixture of material would be required to ensure adequate compaction of the riprap in the channel bed and to prevent interflow within the riprap. To develop bank stability, especially along the outer bends of the meanders, large rocks with up to 7-foot diameters, embedded into the side slopes of the outer banks, were specified in the design package. An estimate of the volume and sizes of rock needed from the channel was made by estimating the number of different sizes of rock in the existing template reaches.

Channel Construction

Construction of the channel began in late May 2007 with the installation of Best Management Practices (BMPs) to control onsite erosion and prevent offsite sediment transport. The construction area was then staked using high resolution survey grade GPS equipment and post-construction terrain models. Channel excavation, materials screening and channel construction were performed simultaneously at different locations within the project site. Channel construction started in the Downstream channel and worked upstream, with excavation of the Upstream channel beginning prior to completion of the lower channel to compress the construction schedule. Construction of the drop structure occurred in phases, causing minor delays in the completion of the lower channel. Construction of the inlet box to the existing pipeline and installation of the Waterman slide gates occurred after the majority of the stream channel had been built. The construction footprint totaled 15.6 acres (Table 2).

Table 2. 2007 Disturbance Areas

	Area (ft^2)	**Area (acres)**
In Bank River Channel	**29,900**	**0.7**
Upland and Riparian	**650,000**	**14.9**
Net Area	**680,000**	**15.6**

Best Management Practices (BMPs)

Silt fence was installed around the downstream perimeter of the project site and adjacent to fresh water bodies (Figure 10). Sediment logs were installed in swales to facilitate sediment deposition prior to stormwater discharge. Stormwater retention areas were also utilized to attenuate discharge and reduce offsite impacts. All BMPs were monitored and repaired as needed throughout the two-year project. BMPs were left in place at the end of the 2008 season to continue to protect waterways until the vegetation community established. All BMPs were removed in 2009.

Figure 10. Silt fence along the downstream perimeter of the project site.

Construction Staking

Construction staking (Figure 11) was performed using high resolution Leica survey grade GPS equipment. Transects were projected across the post-construction digital terrain model, loaded into the Leica GPS equipment and field located. Cut and fill depths were assigned to construction stakes based on the elevation of the existing ground surface relative to the proposed ground surface of the terrain model.

Figure 11. Construction staking in the upstream channel.

Initial Channel Excavation

Construction began on June 4, 2007. Initial excavation of the channel began at the downstream end and worked up the valley. Using a Caterpillar D-9 bulldozer, materials were pushed from the channel center line towards the edges (Figure 12) where they were stockpiled for later screening and terrain construction. Excavation for the drop structure was performed using a Komatsu 300 excavator and occurred contemporaneously with the material removal in the lower channel. Work began in the upper channel on August 16, 2007, once excavation in the lower channel and at the drop structure had been completed.

Over-excavation ranging from 1 to 3 feet was required in the bed and banks to allow for embedding riprap and other rock required for bank stabilization and/or the development of riffle-pool and step-pool sequences, and to allow for the placement of 1 to 3 feet of seal material. In addition, a toe trench was excavated to accommodate the placement of toe rock and to allow pool weirs to be adequately keyed. The Komatsu 300 was used to over-excavate the new channel.

Figure 12. Excavating materials from the downstream channel.

Materials Screening

The screening operation began on June 18, 2007 and continued through July 13, 2007. Screening activities were located along the north side of the lower stream channel in the pre-defined staging area. Screening started once an adequate stockpile of excavated material had been created. Boulders measuring 24 inches and greater in diameter along their widest axis were set aside during channel excavation. Materials measuring less than 24 inches in diameter were run through a grizzly mechanism (Figure 13) to acquire the 12- to 24-inch materials. Materials passing through the grizzly were run through a Clemro self-contained screen plant (Figure 14).

The screening plant produced four rock sizes including 2-inch minus, 2 to 5-inch cobble, 5 to 8-inch rock and 8 to 12-inch riprap. All sorted materials were stockpiled for later use in the construction of the channel seal, bed forms, banks, riprap armoring and the drop structure. Additional boulders were imported from an on-site limestone rock quarry located on the northwest side of the Climax Mine (Figure 15). Approximately 300 boulders measuring greater than four feet across their median axis were imported to the Storke yard for use in the stilling basin and in the face of the drop structure.

Figure 13. Grizzly operation sorting boulders and finer materials.

Figure 14. Clemro screening plant sorting 12-inch minus material.

Figure 15. Limestone boulders imported from the Climax quarry.

Channel Substrate

The channel substrate was constructed after the layout and over-excavation of the new channel alignment. A minimum 1-foot layer of the 2-inch minus material from the screening plant was used to create a seal bed which was compacted like road base to achieve maximum impermeability. This material was placed in 6-inch lifts in the bed, toe trenches and bank areas and wheel packed by the front end loaders and also compacted by vibrating compactors (Figure 16). Large boulders were then positioned in the channel at the cut banks and riffle-pool or step-pool structures, secured by toe rock keyed into the trenches. The overbank and bank fill material included a specified rock size distribution and percentage to provide erosion protection and seat riprap placed along the channel.

Data from the preconstruction survey of the reference reaches had been used to determine riffle-pool and step-pool spacing and locations along the meandering alignment of the river. The first riffle-pool sequence was built approximately 150 feet above the drop structure. Riffle-pool and step-pool location information was transferred to the center line shown in the post construction terrain model to guide the placement of rock as channel construction proceeded.

Figure 16. Compacted 2-inch minus material in the Downstream channel.

Bank Construction

Natural fluvial geomorphic processes create dynamically stable streams as a result of flow dynamics within meandering channel geometry. The sinuous alignment of the restored river was designed to encourage the development of point bars through these processes. Lower side slopes on the inside of meanders allow the river to access its floodplain, expanding and slowing flow and causing the deposition of sediments. On the opposite bank, at the outside of meanders, stockpiled material was used to provide armoring for steeper side slopes that are not overtopped during 100-year design storm. Boulder walls at these steep banks were configured specifically to prevent bank scour. Keystone boulders (Figure 17) were placed above footer rocks keyed into the toe trench and buried in the substrate. Additional boulders were set contiguous to the keystones for a distance of approximately 50 to 100 feet in both directions. These boulders were all placed in a manner to protect adjacent rocks from scour by tucking the upstream edge of the downstream boulder behind the next successive upstream boulder. This configuration deflects water away from the gaps between boulders which could be susceptible to infiltration or scour from flowing water. Once boulder placement was complete, areas behind the constructed banks were backfilled and bucket packed and smaller rip rap was installed along the length of the channel (Figure 18). Similar rock linings were observed in the reference reaches (Figure 19).

Figure 17. Keystone boulder and armoring at the outside of a meander.

Figure 18. Incised channel will be overtopped by high flows at the inside meander to encourage point bar formation.

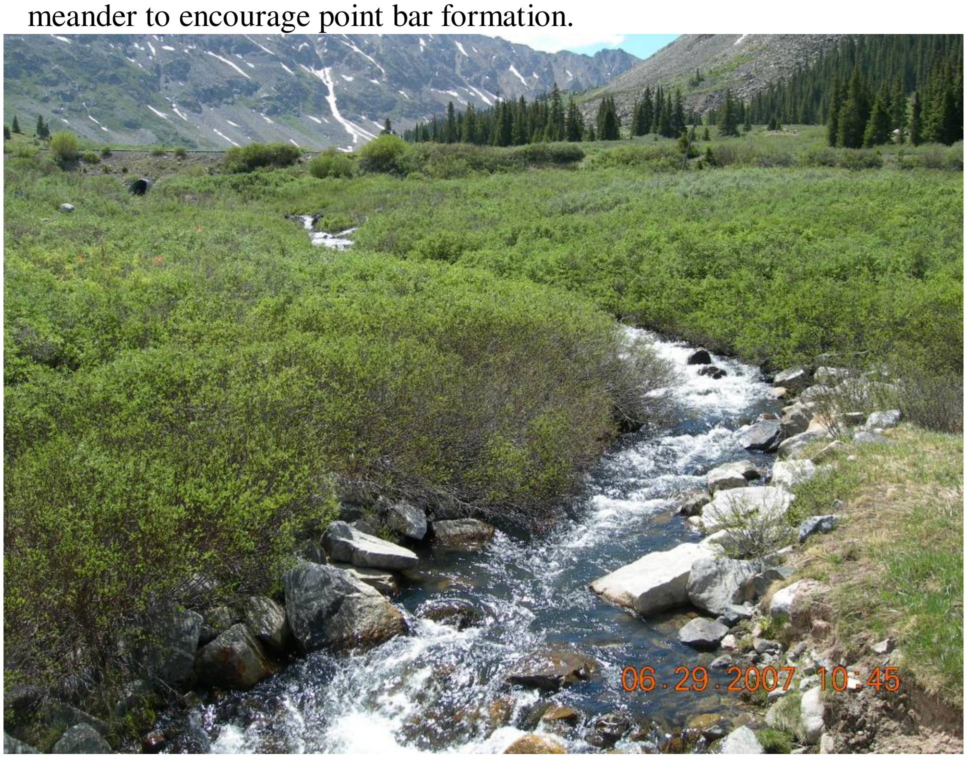

Figure 19. Reference reach incised channel geometry and rock armoring.

Bed Form Construction

Riffle-pool and step-pool sequences were created by placing boulders, keyed into the banks 3 to 6 feet deep, across the new channel to define the upstream pool and stabilize the downstream riffle or create the drop (Figure 20 and Figure 21). Encounters with bedrock outcrops (Figure 22) throughout the upper channel required some modifications to the design bed form. However, the overall grade of the upper channel remained 5.6% from the inlet to the lake. The bedrock outcrops were incorporated into the channel design as much as possible by redistributing the step-pool sequences. In all instances modified profile was within 1 foot of the specified elevations on the design plan. At several locations within the upper channel, bedrock was used as the substrate in place of the mix material and is visibly integrated into the bed and banks (Figure 23). Individual large rocks were placed in riffle reaches to enhance the aquatic habitat.

Middle-sized rocks were interspersed throughout the riffle-pool stream reaches. A mix of smaller rocks and soil created specifically to mimic the material encountered within adjacent reference reaches (composed of approximately one part 2-inch minus, one part 2- to 5-inch material and one part 5- to 12-inch material) was dumped around the placed rocks in the upper section of each major riffle. This "launch rock" was intended to be redistributed through fluvial geomorphic processes by the river during subsequent high flows. Fine materials have been redistributed in the channel by fluvial processes as expected, without a significant loss of material from the reach. Substrate diversity can be seen throughout the channel (Figure 24, Figure 25 and Figure 26), with the deposition of fines in pools, the formation of sandy point bars and cobbled thalwegs all occurring at various stream locations.

To allow the river to grade substrate materials and create its own areas of aggradation and degradation, it was necessary to provide sands, gravels and cobbles to the restored river during construction. In the future, however, the geomorphic design criteria that were applied to the reclaimed landforms adjacent to the restored river are expected to allow the valley to reach equilibrium between sediment production from the adjacent and upgradient landforms and sediment transport mechanics in the river. These geomorphic design criteria utilized reference landforms in the same way that reference channel reaches were used to guide the design of the restored river.

Figure 20. Riffle structure during construction.

Figure 21. Completed riffle structure.

Figure 22. Bedrock outcrop encountered during construction.

Figure 23. Bedrock outcrop incorporated into river bed and bank.

Figure 24. Point bar deposition at an inside meander.

Figure 25. Deposition at an inside meander.

Figure 26. Deposition on the inside meander at a pool.

Drop Structure Construction

The drop structure was designed to transition the newly constructed river channel from the fill material in the Storke Yard to the native hill slope below the fill embankment and to fulfill a request by Climax for a waterfall feature visible from Highway 91. Construction of the waterfall included placement of a concrete cut-off wall to prevent seepage through the structure that would potentially winnow the fine material from the foundation. The horizontal alignment of the concrete cut-off wall was configured to focus the water conveyed over the crest to the center of the plunge pool. Conveyance of the 100-year discharge will be accommodated within the notch of the cut-off wall. To ensure stability during the 100-year discharge and potentially greater events, 4 feet of freeboard has been engineered into the design of the drop structure as a safety factor. Adjacent areas upstream of the drop structure have between 2 and 4 feet of freeboard.

Phase one of the cut-off wall construction required the removal of approximately 10,000 cubic yards of fill material to make space for the concrete wall. A structural engineer oversaw subgrade preparation due to the occurrence of organic materials in the substrate and the relatively fine textured footer materials (Figure 27). Starting on June 25, 2007, lifts of the subgrade, in 1 foot increments, were constructed to reach the desired elevation of 11,104.5 feet. Each lift was compacted with a mechanical sheep's foot and tested with a nuclear gauge to measure proctor densities. All measured densities were recorded at or above 98%.

Figure 27. Compacted sub-grade for retaining wall of drop structure.

Construction of the cut-off wall began on June 5, 2007 with the layout and erection of the rebar skeleton (Figure 28). Fabrication of the cut-off wall occurred simultaneously with the channel excavation and construction of the lower reach. The concrete footer was poured on July 3, 2007 and the upper portion of the retaining wall was poured on July 16, 2007. Both pours were conducted with concrete pump truck and a CDOT Class D highway mix intended to break at 4500 PSI in 28 days. Slump and air entrainment tests were performed during the cut-off wall pour to quantify concrete break strengths. Once completed, the cut-off wall was left to cure above ground for approximately 45 days (Figure 29).

Figure 28. Rebar skeleton of drop structure retaining wall.

Figure 29. Finished retaining wall during 45-day cure period.

The downstream side of the waterfall required the over-excavation of an additional several thousand cubic yards of fill material. Boulder placement began once these materials had been removed and the stream channel above the drop structure had been completed. The stilling basin was constructed from the bottom up with two layers of 4- to 7-foot diameter boulders placed over a layer of geotextile and bedding material. Boulders were then placed up the face of the drop structure with the same overlapping method used for the river banks, eventually tying into the top of the cut-off wall (Figure 30). The inlet to the cut-off wall and drop structure was constructed with 2-foot diameter riprap placed over an impermeable 12 mil (.012-inch) thick vinyl geomembrane anchored to the wall (Figure 31). Once all boulders and rock had been placed, a concrete pump truck was used to grout the structure (Figure 32). Approximately 118 cubic yards of a seven sack concrete grout were used to fill the voids on the face of the structure and the stilling basin. An additional 18 cubic yards of grout were used to cement in the inlet and to pour a 4-foot deep cut-off wall. The completed drop structure provides visual interest from Highway 91 (Figure 33) and makes a discontinuity between aquatic biota in the river upstream and downstream of the feature.

Figure 30. Placement of boulders over bedding materials and geotextile.

Figure 31. Geomembrane bolted to the retaining wall of the drop structure.

Figure 32. Concrete pump truck grouting drop structure.

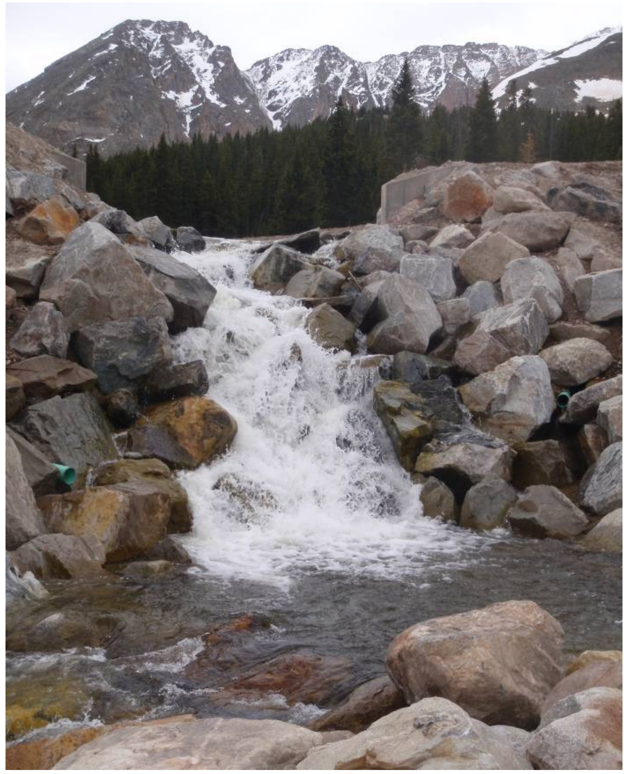

Figure 33. Completed waterfall feature.

Inlet Box Construction

An inlet box was attached to the 7-foot diameter pipe, building off the footer of the existing concrete headwall and doweling into the wall face. Once the inlet box was completed, a 36-inch diameter Waterman slide gate was bolted to the inlet box. A steel platform was built over the inlet box to allow access to the mechanism that raises and lowers the slide gate (Figure 34). The inlet box was left open at the top, allowing flood waters to overtop the wall and bypass the river.

In addition to the inlet box, a 48-inch diameter corrugated metal pipe, concrete headwall and 48-inch Waterman slide gate were installed just downstream in the newly constructed river channel. This structure was built perpendicular to the river channel and backs water up to the inlet box when closed. Stream flow can be regulated between the new channel and the existing pipeline, by altering the heights of the 36-inch and 48-inch slide gates relative to one another.

Figure 34. Inlet box with upper steel structure.

Topographic Shaping

Once channel reconstruction was completed, adjacent ridges and valleys were formed throughout the disturbed area of the Storke Yard and the reclaimed landform was tied to existing topographic features. Wetland areas were constructed in the floodplain adjacent to the channel and in drainage swales connected to the channel, providing habitat for riparian and wet meadow species. The D-9 and D-5 Caterpillars were primarily used to create these topographic features (Figure 35). In several instances, materials stockpiles were incorporated into topographic features to limit off-site hauling. Construction activities concluded at the site in early fall 2007

Conclusion

The design approach for the restoration of the East Fork of the Arkansas River used standard hydrologic and hydraulic analyses along with selected components of empirical geomorphic methodologies to establish baseline design criteria and create continuity between the undisturbed stream above and below the Storke Yard and the restored reach. Instead of restoring a degraded stream, the project required the development of an entirely new stream reach, a stable but dynamic system that allows the restored stream to approach its potential supported by the existing hydrology, climate and geology. The channel has experienced the full flow of the river for three seasons, with peak snowmelt flows typically occurring beneath heavy snowpack. Monitoring for ice jams during the peak snowmelt period is conducted using snowshoes to access the channel, and the channel is reassessed after snowmelt. The channel has maintained gross channel stability while responding to fluvial geomorphic forces by developing features observed in natural stream reaches. Areas of aggradation provide substrate diversity and will support further establishment of riparian vegetation and aquatic biota. The project has contributed to the understanding of high altitude stream and disturbed landform restoration through the integration of a wide range of innovative design technology and construction techniques. Information about the revegetation approach utilized for this high altitude site is provided separately in these proceedings in Bay et al. (2011)

Figure 35. Pushing a materials stockpile into final topography.

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