(This information was developed by the Colorado Division of Wildlife.)

Habitat restoration actions, in tandem with further remediation efforts, will significantly contribute to restoring the brown trout population in metals-impacted stream reaches of the upper Arkansas River below California Gulch. Historical placer mining within the river and grazing in the riparian areas of the river have reduced the amount of quality habitat for the brown trout fishery (Industrial Economics, 2006). Much of the 11-mile reach is over-width and aggraded, and presents as a continuous run or riffle with little deep pool or undercut bank habitat for over-wintering refugia. In addition, the banks are highly erodible due to lack of strong establishment of riparian shrubs such as native high-elevation willow species. Mine tailings and spoils are largely responsible for the poor vegetative growth, as well as a history of grazing and railroad activity in the area.

Physical habitat improvements within the 11-mile reach (including habitat and geomorphology improvements, bank stabilization, and riparian improvements) are expected to improve the fishery (density, biomass, spawning, and/or the number of large adult fish) up to 40% higher than current conditions. In-stream habitat restoration treatments are generally designed to perform one of the following functions, all of which directly or indirectly improve trout habitat: (1) improve natural river processes and connection between the river and the floodplain and riparian zone; (2) stabilize banks in a way which also creates winter habitat and cover for trout; and (3) enhance mid-stream habitats for trout and their prey base (forage fish or invertebrates). Photographs of in-stream restoration activities are included in Section A.3, bank erosion treatments in Section A.4, and aquatic habitat treatments in Section A.5.

Potential treatments for the entire 11-mile reach (Figure A.1) were identified and evaluated for the Preliminary Estimate of Damages (Industrial Economics, 2006). Table A.1 describes the general nature of the habitat restoration treatments that serve these functions and that will be considered for the reaches in the 11-mile segment. Stream reaches will be prioritized to develop an in-stream restoration timeline based on the (1) status of the brown trout population, (2) level of current and future contamination, (3) ease of access for heavy equipment, (4) public access after restoration, and (5) presence/absence of confounding factors such as water rights, ditches, agricultural practices, etc. With this prioritization scheme, Reach 3 between Highway 24 and Kobe was ranked as Phase I. EPA has conducted recent work in this reach and thus there are access roads that will facilitate in-stream restoration activities. In addition, the brown trout populations in this reach have not recovered to reference levels, and since metals contamination is lower in this reach compared to directly below California Gulch, we hypothesize that habitat is the limiting factor. Phase II of the project will be on the Moyer easement and Reach 2, which also shows severely degraded habitat and will have public access. Phase III includes private property from California Gulch to the confluence of the Lake Fork in Reach 1. There are issues in Reach 1 that must be addressed, including the maintenance of ditch access and agricultural practices, and protection of grazing land and physical structures. These issues may be best addressed with assistance from the National Resource Conservation Service. Work with private landowners was described in Section 3.3.1. Phase IV will include any point in Reach 4 where access and permission is granted.

Proposed treatment regimes for in-stream habitat restoration

Treatment regimes were proposed for the 11-mile reach of the upper Arkansas River based on initial inventory and survey techniques (Table A.1). These techniques include qualitative assessments of bank stability and riparian vegetation, counts of riffle to pool ratios, width to depth ratio measurements, aerial imagery at high and/or low flows, investigation of stream flow data from gauges, and determination of access logistics and private versus public property issues. Treatments for each reach are described in further detail below. These treatments will be further evaluated and adjusted or deleted when engineering models are applied to develop the final treatment plans for each reach. Nothing is currently proposed for the reference stream reach above California Gulch (Reach 0).

A.1 Engineering and Design

To assist with evaluating the size of material (boulders, cobbles, etc.) to use in various habitat treatments, a two-dimensional computer model will be developed. The United States Army Corps of Engineers' HEC-RAS computer program will be used to model each reach. This program is one of the industry standards for evaluating rivers in their current state as well as how planned improvements will affect the system. HEC-RAS utilizes river cross-section geometry, length of channel between cross-sections, channel roughness (amount of vegetation in the channel and overflow banks, size and shape of rock in the channel, etc.), and flow to determine water surface elevations, width of the water, and water velocity (impacts bank and channel bottom stability). The program will also help predict the ability of the river to transport sediment though the reach. This is important to design the river so there is neither agradation (deposit) nor degradation (erosion) at the structures.

The HEC-RAS computer model will evaluate river reaches as a system but is limited in its capability to predict how individual treatments/structures will affect the river at a particular location. To help evaluate the potential impacts that a particular treatment may have on the river in critical locations, it may be prudent to develop a three-dimensional model. There are several good three-dimensional hydraulic computer programs currently in use, such as the USGS MD-SWMM program.

A.2 Project Management and Construction

The preferred alternative of in-stream habitat restoration will require detailed engineering for each designated stream reach and associated construction and heavy equipment operations along the banks and within the streambed. While engineering plans will be adhered to as much as possible, there may be a need or opportunity for design-build activities beyond the engineering plans. Access roads previously developed by EPA for reclamation and restoration activities will be used, although additional access points may be required. Project management will require both knowledge of heavy equipment operations, placement of in-stream restoration treatment types, and fish behavior and ecology.

TABLE A.1. PROPOSED RESTORATION TREATMENTS FOR THE 11-MILE REACH OF THE UPPER ARKANSAS RIVER

A. Descriptions of treatments used to improve natural river process

River channel treatments	*Restoration treatment descriptions*
Reduce Channel Width	Excavated channel substrate material, imported gravel, and cobble or riparian vegetation sod blocks can be used to reduce river channel width.
Pool Excavation	Pool habitats should be excavated at a spacing of about 5–7 channel widths along either outside river curves or in straight channel reaches. Excavated substrate materials can be used to create point bars and reduce channel width.
Elevate Riffle Substrate	Riffle substrates can be elevated using gravel or cobble so it will not be transported during high-stream flow events. This treatment can be used to increase channel substrate elevation in a high-flow braided channel reach. During low-river discharge this treatment confines the river flow into a single low-flow channel. During high flows the elevated riffle channel becomes an over-flow channel and reduces the erosion potential along riverbanks in the low-flow channel. An elevated riffle placed in a low-gradient river channel creates additional channel roughness, increases trout habitat diversity, and provides excellent juvenile trout habitat.
Riparian Bench	A bench is constructed using river channel substrate, riverbank materials, or imported soil materials. The top elevation of the constructed bench should be slightly below bankfull elevation. Blocks of riparian vegetation sod scooped up in a bucket of an excavator or front-end loader are placed on top of the constructed bench. Buckets are rinsed before digging up the sod. After loading the sod block, it is soaked in water before being placed on the prepared bench. The soaking helps the vegetation block slide from the bucket. The top elevation of the placed riparian sod should be slightly above bankfull elevation. Depending upon the material size used to construct the bench and the river gradient, it may be necessary to line the front of the riparian bench with appropriately sized cobble to lessen riverbank erosion.
Increase Overhead Trout Cover Under Woody Vegetation	Sites best adapted for this treatment have woody vegetation creating overhead cover in river reaches located along outside river curves where trout habitat is limited by shallow water. Additional trout habitat is created using an excavator by extending the boom and carefully removing river channel substrate material under the woody vegetation. The increased water depth creates more useable overhead cover for trout.
Riparian Vegetation	Moving willow clumps during the dormant season maximizes success of survival. Survival of bare root willow stock and dormant stub plantings, planted deep enough to remain in permanent soil moisture, should exceed 80%. Seeding appropriate riparian grass species along stream banks disturbed during restoration increases the recovery of riparian vegetation.

B. Descriptions of woody materials treatments used to reduce riverbank erosion

Bank erosion treatments	*Restoration treatment descriptions*
Log Spur	Logs for this treatment should exceed 1 ft in diameter. In locations where stream banks are composed of alluvial material, a trench should be dug into the top of the riverbank. The angle of the trench facing upstream should be 15–25 degrees from the tangent line where the log intercepts the riverbank and have a downward slope of 2–7 degrees. The top elevation of the log where it meets the stream bank should be at or slightly above bankfull elevation. About one-half the length of the log should be placed into the riverbank. The upstream end of the log should be below the water surface at low flow and buried into the channel substrate. For additional anchoring and trout habitat, a boulder can be placed on the upstream end of the log that is buried in the river substrate. A boulder placed next to the riverbank on the downstream side of the log provides an additional anchor. Rather than excavating a trench, if stream banks contain moist clay or silt, the log may be pushed or pulled into the riverbank.
Log Vane	This treatment is installed the same as a log spur. Log length should exceed 20 ft and the log angle should be 15–20 degrees from the tangent line where the vane intercepts the riverbank and have a downward slope of 2–7 degrees. Fabric material should be placed between the riverbank and the log. The fabric should be attached at the top of the log and covered with excavated substrate material. Unlike a log spur that passes water under the log, the fabric material covered with substrate materials forces water to pass over the log directing it toward the center of the river.
Riverbank Root Wad	A root wad fan should exceed 3 ft in diameter having at least a 12 ft attached trunk. The trunk should be buried in a trench or pushed into a soft clay/silt bank so the root fan is upstream at an angle that slightly defects surface water currents toward the center of the stream. The top of the root wad should be about 1 ft above bankfull discharge and placed flush against the stream bank.
Horizontal Parallel Log/ Root Wad	Horizontal logs are best suited for riffle and run habitats. The log should be at least 2 ft in diameter and exceed about 12 ft in length. Depending upon riverbank stability, it may be necessary to place an appropriate fabric material extending from the river substrate up to about bankfull elevation. The top of the horizontal log is placed against the fabric at about bankfull elevation and parallel to the stream flow. The space between the bottom of the log and the river substrate creates overhead trout cover. The support system for the horizontal log is site specific. If the log has an attached root wad this supports one end of the log. On the other end of the log, small flat boulders or another log placed perpendicular to the river flow and secured into the riverbank supports the log. It is important that the horizontal log is suspended only on each end. This helps maintain water velocities high enough to keep river-transported sediments from accumulating along the underside of the horizontal log and reducing areas trout use as overhead cover. In over width river channels or where the log does not fit snug against the bank, a second, usually smaller diameter, log is placed behind the horizontal log at a slightly lower elevation. The area between the channel substrate at the base of the riverbank, over the lower elevation log to the top of the horizontal log, is covered with fabric material and backfilled using soils capable of supporting riparian vegetation. If available, riparian grass/willow sod is placed on the fill material out to the front edge of the horizontal log. This results in a natural appearing structure that creates overhead trout cover under both logs.

C. Descriptions of boulder treatments used to reduce riverbank erosion

Bank erosion treatments	*Restoration treatment descriptions*
Cross Vane	Usually a cross vane is placed at the upper end of an excavated pool to create a diversity of trout habitats and direct river flows toward the center of the channel. This structure helps reduce riverbank erosion along the outside curve. The first few boulders forming each side of the structure upstream are placed on a 20°–30° angle from the riverbank. The rest of the boulders are placed across the channel resembling an upstream facing arch across the river. Embed the first boulder into the riverbank at about 1 ft above bankfull elevation. A fabric material placed behind this boulder helps reduce future riverbank erosion. This first boulder keys the structure and directs the water current away from the eroding riverbank. Depending on boulder shapes and the way the water is directed from the bank, each succeeding boulder is placed lower in the water column than the previous one. The lowest elevation boulder is located near mid-channel at about 25% of bankfull elevation. The hydraulic jump, the difference in water surface elevation between the upstream and downstream side of a boulder, is usually no more than 12–15 inches. Boulder elevations near mid-channel are then gradually increased until reaching the opposite side of the river. The final boulder is embedded and blended into the top elevation of the constructed point bar, which is usually less than bankfull discharge. Erosion is seldom an issue on the point bar side of the river channel because point bars are usually depositional areas.
Single Boulder Deflector	Single boulder deflectors should have a somewhat flat side and be tall enough to extend from a shallow pocket in the channel substrate to about 12–15 inches above bankfull elevation. This treatment is best suited for eroding riverbanks still containing clumps of riparian vegetation and having a bank top elevation near bankfull elevation. Single boulder deflectors can be used to divert river flows away from tall eroding riverbanks but does not help the riverbank healing process if void of vegetation.During installation, excavate a depression to fit the shape of the bottom side of the boulder and remove riverbank soil to match the shape of the boulder side to be embedded into the eroding riverbank. Place an appropriate fabric material into the depression and along the riverbank where the boulder will be placed. The upstream end of the boulder is embedded deeper into the riverbank while the downstream end extends slightly into the river. The single boulder deflector gently deflects surface water currents toward the center of the river. The boulder deflector reduces riverbank erosion a short distance downstream, depending on the deflection angle and the curvature of the riverbank. After the first single boulder defector has been installed, the location for the second is obvious by observing the river surface flows. The distance where the river surface current returns to the riverbank becomes the site for the next boulder deflector. This treatment works best where riverbank erosion is not so severe and enough riverbank vegetation remains to protect the riverbank between boulder deflectors. If riverbanks are severely eroded, revegetation may be necessary between boulder deflectors.
Hard Point	This treatment mimics a stable riverbank between the low river flow and bankfull elevation. It is best suited for a riffle reach on an outside curve. The treatment requires substrate material or imported material sized so it will not be easily eroded when placed on the slope of the riverbank. The material is placed from about the river substrate near the low-flow water surface up the riverbank to slightly below bankfull elevation. When placed on the non-vegetated channel substrate below bankfull elevation it protects the toe of the exposed riverbank and helps reduce future riverbank erosion. This treatment helps reduce erosion by decreasing the riverbank angle. This treatment can be shaped to deflect high water from the riverbank toward the center of the river. The treatment normally extends the length of an eroding riverbank where additional riverbank protection is necessary. When installed properly this treatment has a natural appearance.

C. Descriptions of boulder treatments used to reduce riverbank erosion (continued)

Bank erosion treatments	*Restoration treatment descriptions*
Boulder J Hook	This structure is usually placed at the upper end of pool habitats. It is created using 3–5 ft boulders arranged in a partial upstream-facing semicircle. It also creates a diversity of water depths and water velocities, creates additional trout habitats, and helps maintain adequate pool depths. The first few boulders in a J hook structure reduce water velocities and riverbank erosion. Excavation of a pool habitat is usually necessary. The site for the first boulder is along the outside curve where the pool is excavated. The fabric material is placed where the first boulder is embedded into the riverbank. The fabric forms a seal between the boulder and the riverbank. The top of the boulder is set about 12 inches above bankfull elevation. This boulder is placed to deflect water surface current toward the center of the stream. Footer boulders are placed directly downstream of all boulders placed to form the J-hook structure. Footer boulders prevent the structure boulders from moving downstream during high river flows. Each boulder in the structure is placed to direct surface water flows toward the middle of the stream. The boulder structure starts at an angle of about 30–40 degrees from the riverbank for about 1/3 the distance across the stream, gently curves downstream for about 2/3 the distance across the stream, then curves sharply downstream into the center of the excavated pool. The top elevation of each boulder is decreased and the gap between each boulder increases as the structure is constructed across the river.
Boulder Vane (Half cross vane)	This structure uses three to four rectangular shaped boulders ranging in size from 4–6 ft and 2–3 feet in height. The boulder vane points upstream about 20–30 degrees from the riverbank and directs surface water currents toward the center of the river channel. The top elevation of each succeeding placed boulder decreases and the final boulder rests about 12–15 inches above the channel substrate. Boulder vanes rarely extend more than 20% across the river channel. The hydraulic jump between boulders normally should be less than 1 ft. On the downstream side of each boulder, a footer boulder is embedded into the channel substrate and placed tight against each vane boulder. The footer boulder provides stability to the boulder vane structure and creates additional trout habitat.

D. Description of treatments used to enhance mid-channel aquatic and trout habitats	
Aquatic habitat treatments	*Restoration treatment descriptions*
Random Boulders	Boulders exceeding about 3 ft in length and 3 ft in height, with at least one nearly flat surface and with an irregular rectangular shape, make excellent random boulders. First excavate an oversized oval-shaped pit for each boulder. Place the flattest side up. When a variety of random boulders are used in riffle or run reaches, boulder top elevations should range between about bankfull to slightly underwater during low stream flows. The different boulder elevations provide a diversity of water depth and water velocity habitats across a wide range of stream flows. Limited use of random boulders in pools creates additional trout cover. Rivers with high stream transported sediment loads tend to accumulate sediment on the downstream side of boulders and limit their value as trout habitat.
Boulder Cluster	Larger boulders > 5 ft in length and about 3 ft in height are recommended for boulder clusters. In riffle or run habitats, excavate a large oversized oval-shaped pit large enough to accommodate the number of boulders planned for the cluster. A boulder cluster normally contains three boulders but up to seven boulders have been used. The excavated pit should extend several feet beyond the planned size of the boulder cluster. Boulders placed in a cluster arrangement need different spacing and elevations to create a diversity of water depths and velocities. In the middle of the cluster downstream from the three or four most upstream boulders, excavate deeper into the channel substrate to provide additional deeper water trout habitat. If river transported sediment materials are minimal, a boulder can be placed into the deepest water pocket. Create a tail out in the lower end of the boulder cluster.
Rock Garden	A rock garden treatment involves embedding boulders less than 2 ft in diameter into a small/coarse gravel riffle substrate. This treatment is suited for secondary active channels lacking cover or other in-channel structures. Boulders are placed close enough together to create diversities of water velocities that provide habitat cover. This treatment creates additional channel roughness.
Stumps	Stumps are merely root wads with a short trunk. The root fan should exceed 3 ft in diameter and trunk length can be cut to fit the site. Sumps are placed upright in low-gradient runs and riffles or in pools with the root fan resting on the channel substrate. Stumps are anchored with large flat shaped boulders. This treatment is not suitable for high-gradient rivers of in-streams with high sediment loads.
Mid Channel Root Wads	This structure provides mid-channel overhead trout cover. Mid-channel root wads can be placed into low gradient riffle and run habitats or placed into existing or excavated mid-channel pools. Root wads with a root fan diameter greater than 3 ft and having attached trunks > 16 ft in length are placed parallel to the river flow facing the root fan upstream. This structure is anchored using flat-sided 3–6 ft boulders placed on the trunk or root wad. Wherever possible, two root wads should be placed beside each other for better anchoring. This also creates additional overhead trout cover. Depending upon the curvature of the root wad log, the downstream end of the trunk can be buried into the channel substrate and anchored using a large boulder.

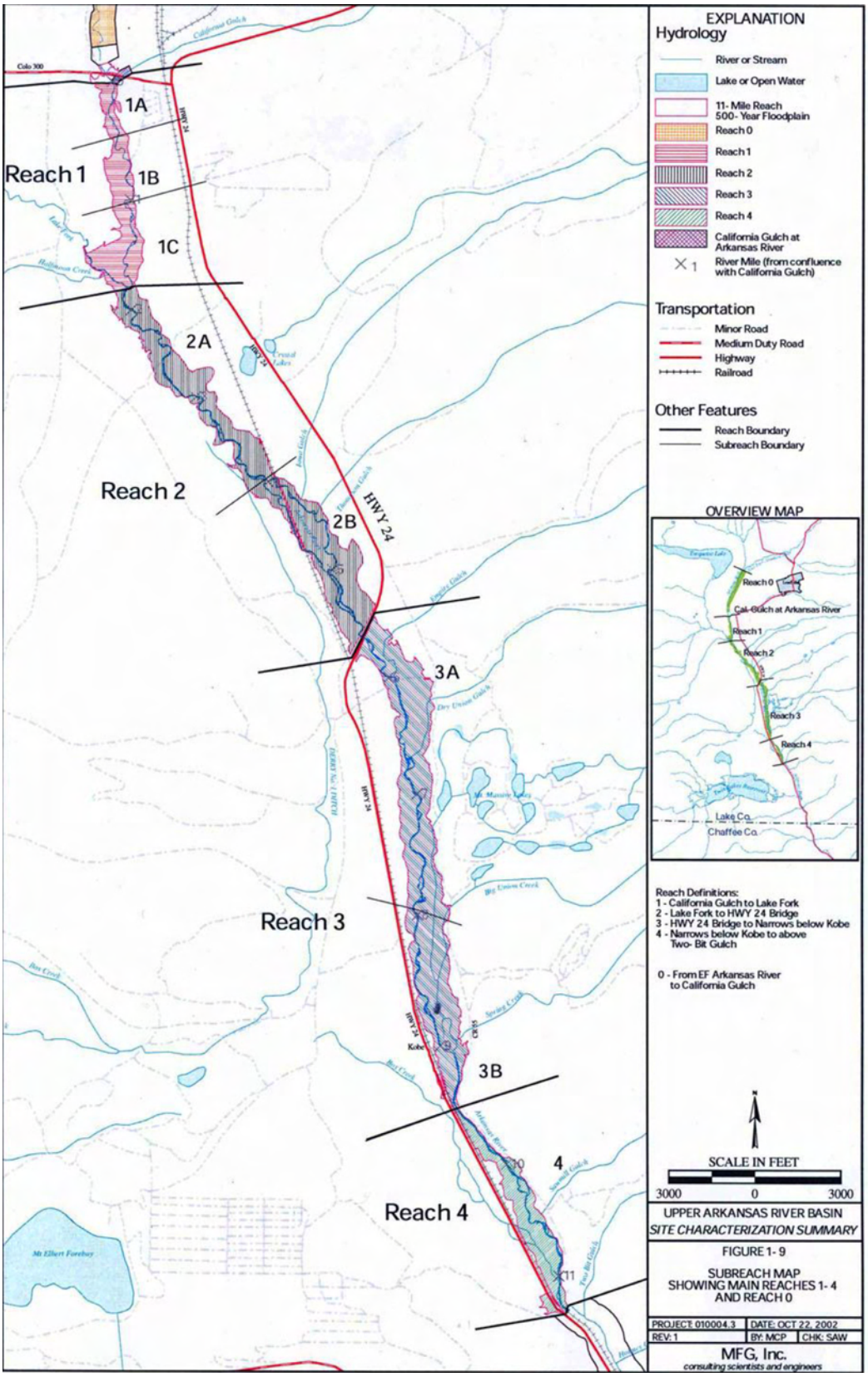

Figure A.1. Reaches 1–4 in the 11-mile reach of the Arkansas River below the confluence with California Gulch.

A.3 In-Stream Restoration Activities

Figures A.2–A.9 provide examples of the types of in-stream restoration activities that may be employed.

Figure A.2. Elevating riffle substrate.

Figure A.3. Reducing channel width by adding fill.

Figure A.4. Creating a point bar.

Figure A.5. Add riparian vegetation.

Figure A.6. Excavate a pool.

Figure A.7. Add overhead trout cover.

Figure A.8. Add a riparian bench with a cobble toe.

Figure A.9. Add a riparian bench with a stone/boulder toe.

A.4 Bank Erosion Treatments

Figures A.10–A.18 provide examples of the types of bank erosion treatments that may be employed.

Figure A.10. Log spur.

Figure A.11. Log vane.

Figure A.12. River bank root wad.

Figure A.13. Horizontal parallel log.

Figure A.14. Cross vane.

Figure A.15. Half cross (boulder) vane.

Figure A.16. Boulder J hook.

Figure A.17. Hard point.

Figure A.18. Single boulder deflector.

A.5 Aquatic Habitat Treatments

Figures A.19–A.23 provide examples of the types aquatic habitat treatments that may be employed.

Figure A.19. Rock garden.

Figure A.20. Boulder cluster.

Figure A.21. Stump.

Figure A.22. Random boulders.

Figure A.23. Mid-channel root wad/log.