EXECUTIVE SUMMARY

PROJECT OVERVIEW

The Upper Willow Creek Watershed Flood Control and Stream Stability Study was conducted by Agro Engineering, Inc. for the Willow Creek Reclamation Committee (WCRC) in Creede, Colorado. Funding was provided by the Colorado Water Conservation Board (CWCB) and the Federal Emergency Management Agency's (FEMA's) Project Impact. Project review was provided by Montgomery Watson Harza Americas, Inc.

The primary purpose of the study was to analyze Upper Willow Creek for flood control and debris/sediment problems, and develop a plan to address these problems. The study reach was limited to the portion of Upper Willow Creek and its associated watershed above the masonry flume in downtown Creede. The goals of the study were to:

1) Quantify the risk of flood damage from Upper Willow Creek
2) Examine problems related to debris and sediment transport in Upper Willow Creek
3) Develop strategies to reduce the risk of property damage and destabilization of potential pollution sources during flood events and improve the aesthetic qualities, habitat conditions, and physical functioning of Upper Willow Creek

The Willow Creek watershed is located in the eastern San Juan Mountains in southwestern Colorado. Willow Creek enters the Rio Grande just below the City of Creede. The Willow Creek watershed extends to the Continental Divide with a high point of 13895 feet and drains to the Rio Grande just downstream of Creede. The watershed is characterized by steep slopes in its drop to Creede which is at an elevation of 8870 feet.

DATA ANALYSIS

Topography

For general watershed analysis, lower resolution, 40-foot topographic contours were developed for the Willow Creek watershed using Digital Elevation Models (DEMs) from the U.S. Geological Survey.

Higher resolution topography was developed in the channel floodplain area of Upper Willow for hydraulic modeling. To create topography in the wider floodplain areas, a grid of 661 survey points was measured using traditional surveying to establish elevation and a Global Positioning System unit to record horizontal position. Cross-sections were measured at regular representative and critical locations in the main channel using a survey tape to establish higher horizontal accuracy. A total of 55 cross-sections, with 1077 individual points, were measured in the field.

Aerial color photographs were taken of the floodplain area of Upper Willow Creek to facilitate the contouring of topographic features. Individual photos were geo-referenced and mosaiced using Geographic Information System (GIS) software. Two-foot topographic contours were drawn on the aerial photos using the survey points.

Floodplain Analysis

To establish hydrology for the current study, the Natural Resources Conservation Service and Colorado Water Conservation Board developed a set of discharge-frequency estimates using a regional watershed methodology. Seventeen watersheds of similar size and relatively close geographic proximity were studied, and a regression analysis of watershed variables was used to estimate discharge-frequency for Willow Creek. The discharge-frequency estimates were similar to earlier estimates by the Colorado Water Conservation Board, but were significantly smaller than estimates from the Army Corps. The discrepancy has arisen in the confidence placed in historic flood estimates.

The U.S. Army Corps of Engineers' (Army Corps) Hydraulic Engineering Center River Analysis System model (HEC-RAS) was used to model channel hydraulics. HEC-RAS is a one-dimensional, steady flow model that can model mixed flow regimes of sub-critical and super-critical flow as well as bridges, culverts, and weirs. A distance of 3087 feet on Willow Creek from the flume entrance to the confluence, 9629 feet on West Willow Creek, and 3153 on East Willow Creek were modeled in HEC-RAS using a total of 104 cross-sections.

HEC-RAS was used to determine water surface elevations, and these water surface elevations were mapped on the topography to delineate areas that are expected to be inundated by floods. The 100-year floodplain was mapped from the entrance to the flume to above the Commodore Mine in West Willow Creek and above North Creede on East Willow Creek. Floodplains for other flood return intervals were mapped at critical locations.

During large floods in Willow Creek, the flow at many, particularly upstream, locations will be high velocity "supercritical" flow. Supercritical flow is highly erosive, and large floods could potentially erode and damage channel banks, levees, and hydraulic structures, especially if debris blockage occurs. Without any debris blockage or structural failures, 100-yr flood levels can generally be contained by the Willow Creek channel or push up levees. However, flooding and overbank flows will occur at all culverts and pipes in the study reach as well as the weir upstream of the mining museum. Locations of potential flooding are discussed in the following paragraphs.

Overtopping of Weir Above Mining Museum Area

The earthen and wood weir upstream of the mining museum area will be overtopped starting at the 25-year flood return interval. Flood flows will enter the depression west of the main channel and flow downstream into the parking area east of the mining museum. Floods larger than the 100-year flood will flood the mining museum and fire department tunnels. However, these flows should re-enter Willow Creek and be contained by the levees of the masonry flume. Failure of the deteriorated earthen dam and weir upon overtopping and failure of the earthen push-up levees below the weir is probable and could cause increased flooding at lesser flood return intervals.

Windy Gulch Culvert

Windy Gulch forms a sub-watershed within the Willow Creek watershed, and the normally dry channel enters Willow Creek through a culvert just above the levees of the masonry flume. Unfortunately, hydrology of the sub-watershed is somewhat uncertain. However, even with uncertain hydrology, it is clear that the culvert is undersized to pass high flood flows. The

roadway will be overtopped during flood events initiating at the 10-year level. A portion of the overtopping flow will flow down the road and potentially cause flooding in downtown Creede.

Entrance to Army Corps Flume
The Army Corps constructed large levees to guide flood flows into the masonry flume. Flooding and overbank flows caused by Willow Creek should re-enter the forebay upstream of the levees, be contained by the levees, and enter the masonry flume. However, flooding originating from Windy Gulch may circumvent the levees and flow towards downtown Creede. In addition to the Windy Gulch problem, a small modification to upper end of the approach levees is needed to ensure a three-foot freeboard in the levees. This amount of freeboard is often required by the Army Corps in order to recognize that downstream structures are not located in the floodplain.

North Creede Culvert
The hydraulic analysis indicated that the culvert in North Creede will be overtopped in nearly all flood events. Personal accounts of flooding indicate that floods typically erode the roadway near the culvert. A large flood will probably damage surrounding structures.

West Willow Creek Culvert
The Bachelor Loop road crosses a culvert just upstream of the concrete bridge below the Commodore Mine. Hydraulic analyses show that the culvert will cause overtopping of the roadway parking area during the 100-year flood, although plugging of the culvert by debris will probably cause flooding during a smaller flood. The overbank flooding may cause localized damage to the road, but should reenter the channel downstream of the culvert.

Commodore Mine
A flume and metal pipe carry West Willow Creek over and through the large Commodore mine tailings pile. Hydraulic analysis indicated that the Commodore pipe system cannot pass high flood flows. The 10-year event will cause flooding of the depressed area at the pipe entrance. A 25-year flood will overtop the tailings pile, causing a high velocity flow down the very steep face of the pile. This event could potentially erode tons of mine tailings and mine debris into Willow Creek. Fine tailing sediments would probably be carried by the flood into the Rio Grande.

Amethyst Mine Culvert
The hydraulic analysis showed that the 100-year flood should cause overtopping of the culvert. However, debris will probably plug the "grizzly" grating in front of the culvert at a much smaller flow and cause damage to the entrance to the Amethyst Mine and surrounding tailings areas.

Watershed Conditions
The physical characteristics of the Willow Creek watershed were quantified in GIS using the DEMs and vegetative studies from the U.S. Forest Service. Maps representing the slope, primary cover type, percent forest, and percent of barren land were produced.

Specific sediment sources in the Willow Creek watershed that may be contributing sediments to the Willow Creek channel were identified using aerial photography and delineated in GIS. Mapped sediment sources included areas of mine tailings, mine related disturbance, mobile talus/scree, and roadways.

The risk that these sources may contribute sediments to Willow Creek varies based on many variables including vegetative cover, slope, the degree of disturbance, and the distance to the Willow Creek channel. In the GIS, these watershed characteristics were combined spatially using a mathematical manipulation to create a map indicating the potential for areas to contribute sediments to the Willow Creek stream system. Sediment sources that may be critical to protect are indicated on the map.

Sediment Transport and Debris

The channel bed in the majority of the study reach is "armored". This armoring will tend to resist hydraulic stresses under typical flow conditions, but will be broken down and transported as "bedload" during high flood flows. In a steep mountain stream such as Willow Creek, bedload transport (rather than suspended sediment transport) is the channel-defining process.

Shear stress data from the HEC-RAS model and approximate field data of sediment size were used to calculate a potential bedload transport rate by sediment size fraction for every cross-section in the HEC-RAS model for the various flood flow levels. Potential bedload rates are very high in Willow Creek and East Willow Creek and rather extreme in the steepening section of West Willow Creek to the Commodore Mine.

The bedload transport rate in tons per hour was converted to a total weight or volume of sediment transported during a flood event using very approximate assumptions about the duration of flood events. Willow Creek has the potential to produce enormous volumes of bedload during high flow events. Man has probably increased sedimentation rates in the area, and this bedload potential must be considered to protect hydraulic structures as well as control channel stability and flooding.

Many areas of the Willow Creek channel were noted to have significant amounts of timber debris. This timber debris will be easily mobilized during small flood events and could easily plug culverts or other structures. Several locations where timber debris has collected were noted in the text. Much of this debris could be removed from the channel relatively easily. The area below the Commodore Mine has an enormous amount of deteriorating mine cribbings and other timber debris. Timber removal in this area could be more difficult, but could be a very important measure to lower the risk of flood damage.

ALTERNATE MITIGATION STRATEGIES

Mitigation strategies were developed to address problems that were identified. Preliminary designs and approximate cost estimates were developed for a number of projects. The following figure shows the location of potential projects. These projects are discussed briefly in the following paragraphs.

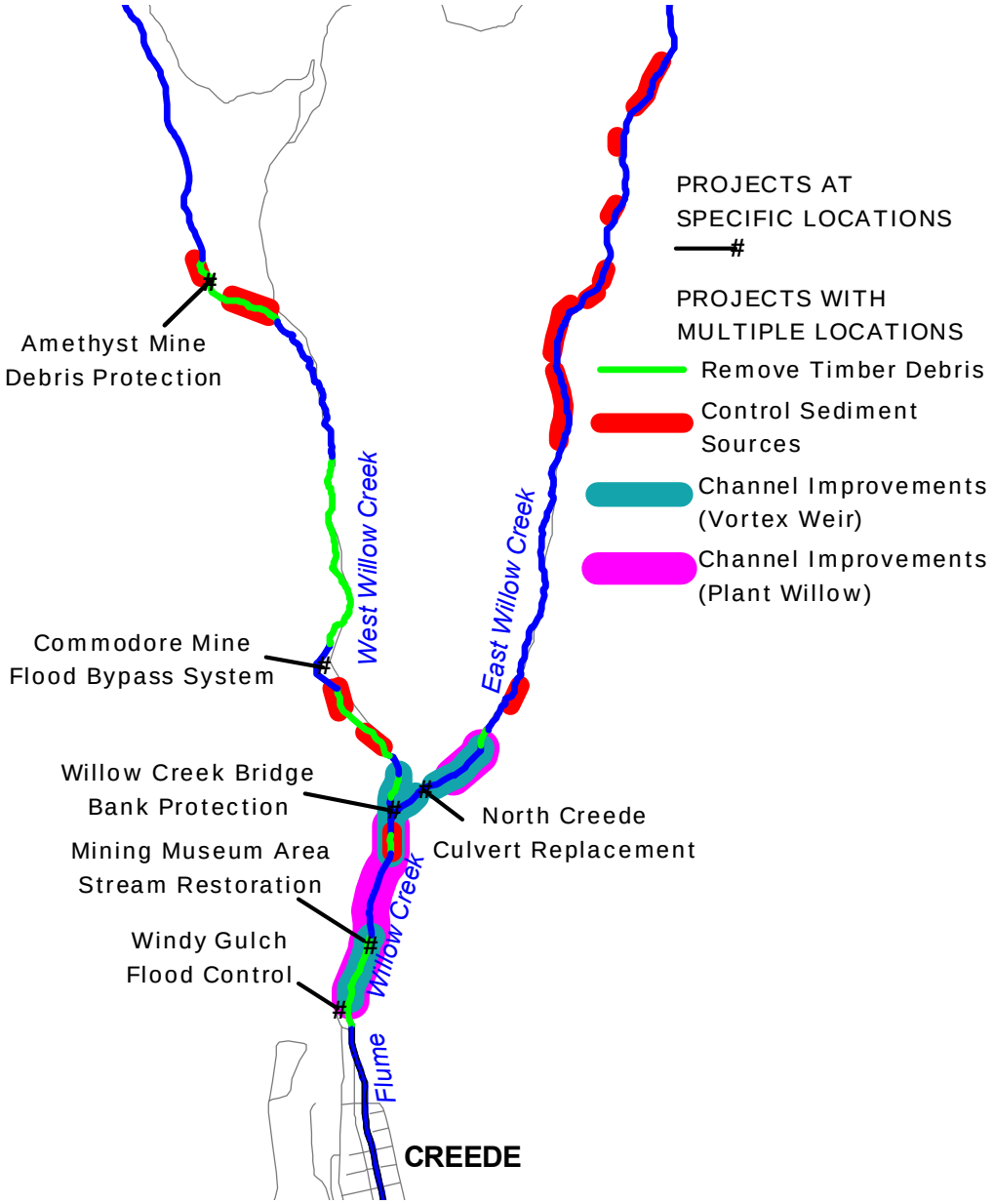

Figure ES.1. Locations of Potential Mitigation Projects

Projects at Specific Locations

Windy Gulch Culvert

The hydrology of Windy Gulch is somewhat uncertain. However, using the best current hydrologic estimate, a 12-foot wide by 12-foot high culvert would be required to pass a 100-year flood. This size is not feasible given the culvert location. Therefore, an overflow system was proposed to safely pass water that overflows the culvert over the roadway to Willow Creek.

The roadway could be raised 2 foot on both sides of a concrete overflow pan. The steeper slopes and dip will create an awkward road design, but vehicles should still be able to maneuver satisfactorily over the area. The current culvert could be replaced with a 6-foot wide by 2-foot high box culvert to pass small floods without blocking the Bachelor Loop Road and access to upstream locations except during exceptionally high floods.

Topographic re-design of the area would also allow for a short raising and continuation of the Army Corps levees for the flume entrance. This will allow the freeboard of the 100-year flood in Willow Creek to be raised from less than 3 foot at the tip of the levees to above 3 foot at all locations within the flume forebay. Therefore, the project should protect downtown Creede from upstream flooding by Windy Gulch at the 100-year level and should also help meet the Army Corps 100-year flood 3-foot freeboard requirements in Willow Creek. The project should cost roughly $60,000.

Mining Museum Area Restoration

A comprehensive project to restore the stream reach above the entrance to the masonry flume in the wider floodplain area near the mining museum was proposed to address multiple problems and opportunities. A project was envisioned to control flooding of the mining museum area and fire department tunnels and lower the transport of sediments into the masonry flume. The control of downstream sedimentation could be very important to the success of the "sinuous" stream channel restoration that is being considered below the flume downstream of Creede. The project could also enhance the visual, aesthetic, stream habitat, and recreational values of the area. A restoration design was proposed that was intended to be a first step to a final restoration design of the reach.

The design would remove the angled earthen weir and replace it with a shorter, more perpendicular weir that would maintain flow depth at low flows while safely passing flood flows. Permanent water level sedimentation basins would be excavated upstream of the weir, and upstream of flume into a current drainage pond. Two large boulder drops were envisioned to create waterfalls into both of the sedimentation basins.

The main channel would be reshaped to create a more natural flow line and meander for the stream. The current large depression to the east of the roadway would be filled to create channel contouring and remove the reliance on push up levees. The stream reach was designed to have a 2% channel slope. This is within the slope range for a Rosgen B3 type channel that is probably most appropriate in this location. A relatively narrow main channel was designed to maintain depth at low flows, but a wider floodplain area was designed within the channel area that would safely accept flood flows and lower shear stresses at high flows.

A bike trail / walking path was envisioned that would pass along the stream reach. The trail could eventually be continued upstream. In addition, small areas of willow could be planted at several points along the channel edge. A stream restoration of this type would probably cost at least $350,000.

North Creede Culvert

For the culvert at North Creede, designs and approximate cost estimates for a range of culvert types and flood return intervals were developed. Corrugated metal pipe, corrugated metal pipe arch, corrugated metal and concrete open bottom arches, and concrete box culverts were considered. The culvert type that appeared most cost effective for each flood return interval was suggested. Removal of the culvert and placement of long retaining walls and a timber footbridge was also considered, as well as complete removal of the cabin and restoration of the stream.

Approximate costs for culvert projects ranged from $45,000 at the 5-year level to $100,000 at the 100-year level. 100-year protection with a footbridge may cost about $70,000, while removal of the cabin with compensation to the owner would probably cost several hundred thousand dollars. Flood protection at the 100-year level may not be necessary at the site. The city council and mayor, property owners in North Creede, interested citizens, and possible funding agencies will need to weigh project cost versus risk of damage and the desired level of flood protection.

Commodore Flood Bypass System

Potential flooding over the Commodore Mine tailings piles could potentially cause catastrophic damage to Willow Creek, downtown Creede, and the Rio Grande. However, the construction of a flood bypass over the commodore tailings pile will be a difficult challenge given the steep and unstable slopes and the need for historic preservation at the site.

Two options were considered to address the Commodore pipe problems. The first option was to remove the wooden flume and extend a more adequate pipe from the stream through the upper tailings pile to the entrance of the existing concrete pipe. This option would use the existing pipe system to convey large floods and would cost approximately $400,000. However, conveyance of a large flood through the existing steel pipe sections could potentially cause pipe failure, severe damage, and end up causing flood waters to overtop the tailings piles. Therefore, this option was not considered favorable.

The second option considered was to install a complete system to convey large flood flows over the tailings pile. In this case, a conveyance system would have to be installed down the tall and very steep slopes of the lower Commodore tailings piles. Heavy equipment operation on these slopes may be extremely difficult. The installation would also be visible from the bachelor loop road and may alter the historic character of the area. However, this option may be required to fully ensure flood protection for the tailings piles.

A very preliminary system was proposed to convey floods over the tailings pile. A 12-foot wide by 5-foot tall concrete box culvert was designed to pass water from West Willow Creek over the flat portion of the upper tailings pile before entering an 8-foot diameter pipe to drop to the top of the lower tailings pile. A 6-foot diameter pipe would convey water down the steep slope of the

lower tailings pile to the stream below. Numerous large thrust blocks, support blocks, and a concrete stilling basin would be required. It was considered important to continue to pass low flows into the current steel pipe and pipe "waterfall" for aesthetic reasons. Two scenarios were envisioned to accomplish this. Low flows could still be passed through the current flume and pipe systems while only flood flows could be directed to the bypass system. Alternatively, all flow could be directed into the new system which could pass low flows to the steel pipe at the location where the new system would intersect the old system. This would be slightly more expensive, but would allow for removal of the deteriorated wooden flume and drop that may soon cause a failure. It was estimated that the project would cost at least $900,000. However, extensive design will still be required to determine the most appropriate system, materials, and construction methods given the difficult conditions.

Micro-hydro power generation was also briefly considered for the flood bypass system. Power generation could potentially help offset construction costs or costs for potential treatment of water from the Nelson Tunnel. However, due to the small flow in West Willow Creek during winter months, it appeared that a micro-hydro power project would not be cost effective.

It will be very important to ensure that large sediments and debris will not enter a closed flood bypass system. A design for three "grizzly" gratings was proposed to protect the flood bypass system. This project should be considered as part of any flood bypass project, and would raise the cost of the project by about $30,000.

Amethyst Mine Debris Protection

A new "grizzly" grating was also proposed for the area upstream of the culvert at the Amethyst Mine to protect the current grating on the culvert from being plugged by timber debris. The grizzly would span about 50 feet and contain sediment and debris in an area between large rock walls. The project would cost approximately $15,000. Removal of timber debris upstream of the area could help this problem in the short term.

Bank Protection below West Willow Bridge

A small project was proposed to protect the bank that is being eroded below the concrete bridge on West Willow Creek. The bank could be pulled back to a 2:1 horizontal to vertical slope or gentler, and heavy rock placed to protect the bank. The project should cost approximately $8000. A timber retaining wall could also be considered.

Projects with Multiple Locations

Timber Debris Removal

Locations of accumulated timber debris were noted in the study. It was proposed that the Willow Creek Reclamation Committee could organize a community effort to remove timber debris throughout Upper Willow Creek. Cleanup of areas other than below the Commodore Mine wouldn't require much funding, but collaboration of Mineral County or other agencies with a dump truck, backhoe, and/or winch would be useful.

Removal of timber debris below the Commodore Mine will be more difficult. However, the access road into the area could be restored so that heavy equipment could enter the area. Several

slide areas of the road would have to be repaired, and a temporary bridge may be required across West Willow Creek. In addition to a dozer to restore the road, a dump truck, backhoe, excavation, or heavy winch equipment may be required. Several timber cribbings could possibly be restored. Approximately $25,000 may be needed to complete the project.

Channel Improvements

During flood events, Willow Creek will be highly erosive. In addition, many stream areas have been disturbed by mining or road building activities. Therefore, general channel improvements were recommended for Upper Willow Creek. In other mountain streams similar to Upper Willow Creek, the installation of vortex weirs, and the planting of willows to stabilize banks have proven to be the most successful measures to stabilize banks and decrease high sediment transport and erosion rates. The vortex weirs would be constructed of large boulders with adequate foundations placed on spacings of about 3.5 to 4 times the bankfull width. Both measures would also improve aesthetics and potential fish habitat in the stream.

Further evaluation is needed to determine the most beneficial locations to improve stream conditions with willow planting and vortex weirs. Willow re-vegetation would be beneficial throughout the area. Upper Willow Creek between the flume and the confluence have many potential locations, and current fish populations could benefit from re-vegetation of smaller disturbed areas in East Willow Creek. High velocities and bank erosion could be reduced between cross-section 20 (below the confluence) and cross-section 25 on West Willow Creek using vortex weirs, as well as in the area of the mining museum restoration (described earlier). East Willow Creek from the confluence through North Creede could also be improved with vortex weirs, although channel reshaping may also be beneficial between cross-sections 12 and 14. Upstream sediment sources could also be protected with willow and vortex weirs.

Sediment Source Controls

Locations of potential sediment sources were mapped, and many of these sources in the Willow Creek watershed should eventually be addressed. However, the most critical sources are probably those of mine tailings or fine sediment sources that are in direct contact with the creek. Locations of critical sediment sources that may be directly available for erosion and transport by Willow Creek were mapped. Further investigation is needed to prioritize these sources and design site-specific control measures.

PROJECT PRIORITIZATION AND IMPLEMENTATION

A wide variety of possible projects were identified to mitigate problems in Willow Creek. These projects vary in the degree to which they meet project goals and feasibility for funding and construction.

A score was given to each project that indicates the degree to which the proposed project benefits the adopted goals of the WCRC. For each of the 6 WCRC goals, a score of 1.0 was given if the project would be "beneficial" to the goal, and a 0.5 was given if the project would be "somewhat beneficial". The sum of these scores for each project indicates the number of different types of benefits the project may have in conformance with WCRC goals, but does not give an absolute ranking of the effectiveness or priority of the project. Of the proposed projects, the planting of willow to stabilize banks benefited the most WCRC goals, while the Commodore Mine flood bypass system, the mining museum area steam restoration, installation of vortex weirs, and sediment source control projects ranked the next highest.

The WCRC discussed projects alternatives in depth, and ranked the priority of each general project location based primarily on the perceived risk or urgency of each problem. Project locations were ranked as 1) Commodore Mine, 2) North Creede, 3) Windy Gulch, 4) Amethyst Mine, 5) Mining Museum area, 6) general Upper Willow Creek watershed, and 7) bank below West Willow bridge. The general location noted as the Upper Willow Creek watershed includes the timber debris, vortex weir, willow planting, and sediment source control projects together. It was noted that timber debris may pose a higher risk and have a greater urgency than the other general watershed projects.

In considering project priorities, the Willow Creek Reclamation Committee has felt that all of these projects are important. It may be that, in general, what can be done first should be done first. Cost, potential funding partners, and many other factors may affect the order in which projects are pursued.

The next task for implementation of potential projects may be for the Willow Creek Reclamation Committee to further investigate potential partnerships and funding opportunities. A number of potential implementation partners or funding sources were identified, and a table was presented that matched potential partners to each potential project. The following paragraphs briefly list implementation steps suggested for each project.

Commodore Mine Flood Bypass System

- Convey high risk and priority of project to representatives of E.P.A. involved with WCRC
- Investigate funding opportunities such as E.P.A.'s Regional Geographic Initiative Program or Watershed Initiative program
- Project could be considered jointly with plan to treat water from Nelson Tunnel
- Work with community to develop acceptable plan considering visual and historic impacts
- Secure funding for both project design and construction

North Creede Culvert Replacement

- Support efforts of City of Creede and property owner to design and install new culvert
- Support possible needs to locate additional funding source for culvert installation

Windy Gulch Flood Control

- Approach CWCB, NRCS, or Army Corps to help refine hydrologic estimates
- Investigate possible funding sources including CWCB and Army Corps
- Project could possibly be combined with Mining Museum Area Restoration

Amethyst Mine Debris Protection

- Remove upstream timber debris to help problem in short term
- Investigate possible funding source for installation of "grizzly" grating

Restoration of Mining Museum Area Reach

- Evaluate Great Outdoor Colorado and EPA's Watershed Initiative Programs for funding
- Consider combining with other project elements depending on funding source (upstream willow / vortex weir drops, Windy Gulch, downstream "sinuous" channel)
- Include funding for final design in grant application

Willow Creek Bridge Bank Protection

- Approach Mineral County to complete this small project

Removal of Timber Debris

- Organize a community volunteer effort to remove timber debris from channel
- Ask Mineral County to lend a dump truck or other heavy equipment
- Initial effort could concentrate on identified areas except below Commodore mine
- More intensive effort could be organized to restore access road and remove timber debris below Commodore Mine.

Channel Improvements - Willow / Vortex Weir Drops

- Evaluate possible project locations
- Investigate funding sources including NRCS Wildlife Habitat Incentives Program, U.S. Fish and Wildlife Partners for Fish and Wildlife, Trout Unlimited, or other environmental or habitat related organizations
- Evaluate possibilities to use projects as demonstration projects and educational tools.
- Some locations could be combined with the mining museum area restoration plan.

Sediment Source Controls

- Prioritize sediment source control locations
- Investigate funding from U.S. Forest Service, NRCS Small Watersheds Program, or Colorado Department of Health