# DESIGN EXAMPLES—SECTION 7

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## 7.0 CASE STUDY—GREENWOOD GULCH

Greenwood Gulch, a tributary of Little Dry Creek, flows in a northwesterly direction through Greenwood Village (Figures 1 and 2). The headwater area of Greenwood Gulch is dominated by high density office park developments, the central area by single family residential development and the lower area by a regional park, rural residential lots and a residential golf course development. The Highline Canal transverses the basin near the center of the watershed and intercepts the entire base flow of Greenwood Gulch. The watershed is virtually built-out with little potential for additional infill development.

**Table 1—Greenwood Gulch Hydrology**

| Condition | Flow at Holly Street |
|---|---|
| Base Flow | |
| winter | 2 cfs |
| summer | 5 cfs |
| 2-year Storm | 830 cfs |
| 10-year Storm | 1200 cfs |
| 50-year Storm | 1620 cfs |
| 100-year Storm | 1750 cfs |

The urbanization of the watershed has changed Greenwood Gulch from an intermittent stream to a perennial stream with an average wintertime base flow of approximately 2 cfs and an average summertime base flow of approximately 5 cfs. Stormwater flows have also increased substantially over predevelopment conditions. The new flow regime has caused significant erosion of the stream channel in the central parts of the watershed.

The increased erosion, in combination with some residential encroachment of the natural floodplain, threatened some private properties between Orchard Avenue and Holly Street (Photo 1). Informal attempts at erosion control by the property owners along Greenwood Gulch proved to be ineffective. The eroded materials tended to be deposited downstream in the vicinity of the Holly Street bridge. The aggradation of the channel and over bank areas at the Holly Street bridge reduced the flood conveyance capacity of the bridge and increased the flood risks for neighboring properties.

*Photo 1. Erosion of Residential Properties*

The new flow regime initially caused the growth of wetlands in the Greenwood Gulch floodplain between Holly Street and the Highline Canal. A new residential development in this area in the 1990s perceived the wetlands as a valuable asset, avoided encroachment in the floodplain, included wetland symbols in its logo and adopted “The Preserve” as its name. Homes were constructed and occupied alongside the riparian corridor of the 100-year floodplain beginning in the early 1990s. The Greenwood Gulch corridor also contained a heavily used regional trail connecting to the Highline Canal Trail and Greenwood Village’s Perry Preserve Regional Park.

The changing flow and channel erosion regimes, however, were dynamic and eventually the channel became incised in some places to a depth of approximately 10 feet (Photo 2). This further changed the hydrologic regime by lowering the water table in the floodplain, drying up the riparian wetlands and allowing for the encroachment of noxious weeds. The public voiced significant concern with the erosion damage to the trail and the loss of the wetland habitat.

*Photo 2. Loss of Wetland Habitat*

## 7.1 Design

The District, in cooperation with Greenwood Village, initially identified four options in 1996 for controlling erosion in the 1,400-foot reach of Greenwood Gulch from Orchard Avenue to approximately 700 feet upstream of the Holly Street bridge. The local community requested an expansion of the study to control erosion for the entire 2,100-foot reach between Orchard Avenue and Holly Street, restore the lost flood conveyance capacity of the Holly Street bridge, and control the ongoing erosion and loss of wetland habitat in the 2,900-foot reach between Holly Street and the Highline Canal.

Pre-design studies evaluated excavation of aggraded materials to restore the conveyance capacity of the Holly Street Bridge, relocation of the trail beneath the bridge alongside the improved stream channel, placement of six additional low-head drop structures in the floodplain downstream of the Holly Street bridge and placement of one moderate head drop structure (8 feet) in the channel immediately upstream of the Highline Canal. The low-head drop structures downstream of the Holly Street bridge would be designed to span the entire 100-year floodplain (60 to 100 feet wide) to eliminate channel erosion and spread the base flows to restore the wetland hydrology throughout the width of the floodplain. Hydraulic studies were also completed using HEC-RAS computer modeling methods to ensure that the flattened channel grades between drop structures would not increase flood elevations during the 100-year storm event.

The District, after consideration of all the alternatives, decided to participate in the costs for the final design, construction, and maintenance of the Greenwood Village proposal. The District retained the design team of Sellards and Grigg, Inc., Water & Waste Engineering, Inc., and Design Concepts, Inc. to prepare the final design and construction documents.

## 7.2 Criteria

The design followed the District criteria that were applicable to the aesthetic, recreation and wetland restoration goals of the community.

The final design for the reach between Orchard Avenue and the Holly Street bridge included one 4-foot large boulder drop structure immediately downstream of the Orchard Road bridge and six large boulder 1.5-foot drop structures (Photo 3 and Figures 3 and 4). The inclusion of these drop structures flattened the channel bottom slope to an average of 0.30%. The channel side slopes were regraded to slopes ranging from 2:1 to 3.7:1 and were protected with Type M riprap soil.

*Photo 3 Large Boulder Drop Structure*

The large boulders (5 to 6 feet diameter) presented the opportunity to minimize the depth of grout required to stabilize the boulders. This improved the design aesthetics without any apparent increase in the costs of construction. The locations and alignments for the drop structures were chosen carefully to encourage the formation of some sinuosity in the alignment of the channel. The placement of the boulders during construction was also carefully managed to bring a natural appearance to the construction. The side slopes were planted with a mixture of native grasses, shrubs and trees to control side slope erosion and riparian wildlife habitat (Figure 5).

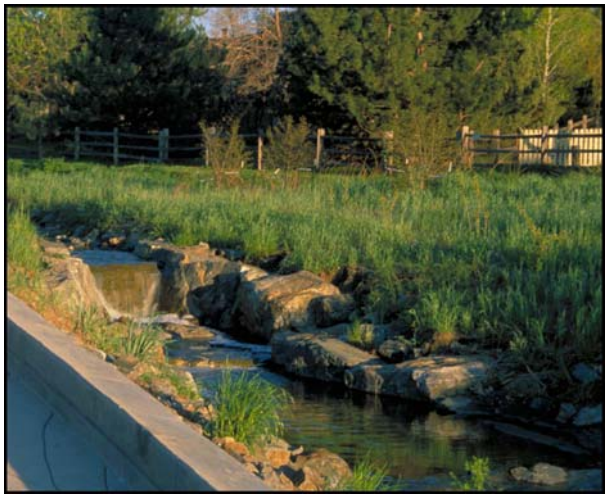

*Photo 4 Two-Tier Large Boulder Drop Structure*

*Photo 5 Holly Street Bridge and Riparian Trail*

One two-tier large boulder 4.0-foot drop structure was added upstream of the Holly Street bridge to lower the channel bottom to restore the conveyance capacity of the Holly Street bridge (Photo 4 and Figures 3 and 6).

The bridge abutments and an 18-inch gas main crossing the stream channel complicated the relocation of the trail below the Holly Street bridge (Figure 6). The bridge abutments required structural shoring with a 12-inch-thick by 5.2-foot-high concrete wall. The trail was separated from the stream channel by means of a 6-

foot-high curved wall (Photo 5). In one location, the top of the trail was approximately 2 feet below the channel bottom. A sump pump dewaters the foundation for the trail. The trail is protected with a Type H riprap slope against the trail wall with the opposite protected by Type M riprap soil.

The design for the restoration of the wetland habitat downstream of Holly Street was based on analyses of 1948 to 1995 aerial photographs to document the changing wetland habitat, soil borings, four groundwater monitoring wells, and detailed vegetation surveys. The goal of the design was the restoration and maintenance of approximately 8 acres of wetland habitat between Holly Street and the Highline Canal.

The construction included the excavation of approximately 9,000 cubic yards of sediment deposits (Photo 6). The floodplain was then graded to maintain a "channel" slope of 0.38% to 0.40% between three drop structures constructed with 36-inch minimum dimension boulders (Figure 7). The boulders were carefully placed with strict tolerances (+/-2 inches) for top edge elevations to create a wide (80 to 170 feet) flat-bottomed channel (Figure 8). The drop structures were installed in a curvilinear configuration to minimize their potential visual impact.

*Photo 6 Excavation of Accumulated Sediment*

This wide and level configuration for the drop structures encouraged surface flows to spread throughout most of the width of the floodplain shortly following construction (Photos 7 and 8). The flat channel slopes control channel erosion and the wide flow path encourages infiltration of base flows and stormwater. In addition, the cutoff walls at each drop structure impede the longitudinal flow of groundwater, causing it to rise closer to the surface. These higher groundwater elevations, combined with the shallow surface

*Photo 7 Upstream View toward Holly Street with Lower Drop No.1 in Foreground*

*Photo 8 Downstream View from Holly Street toward Lower Drops No. 2 and No. 3*

flows, combine to create wetland conditions throughout much of the floodplain. The trail was moved to the edge of the floodplain into an upland area (above the 10-year flood elevation wherever possible). This made the trail more usable and reduced the risk of further erosion damage.

Transplanted root pads (minimum 6 square feet by 6 inches deep) were placed in the channel bottom to encourage rapid restoration of the wetland areas. Upland shrubs and trees were planted along the edge of the channel bottom to provide shading and a variety of wildlife habitat (Figure 9). The wetland vegetation spread very quickly, and within the first growing season, a healthy community of wetland plants was established in the designated areas (Photos 9 and 10).

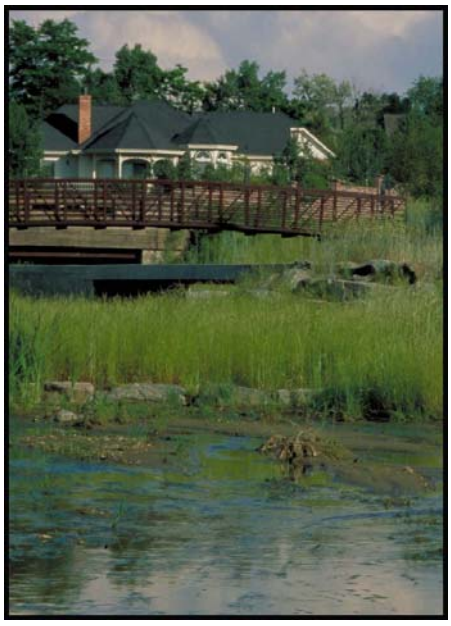

*Photo 9 View toward Holly Street and Wetland Area and Lower Drop No. 2*

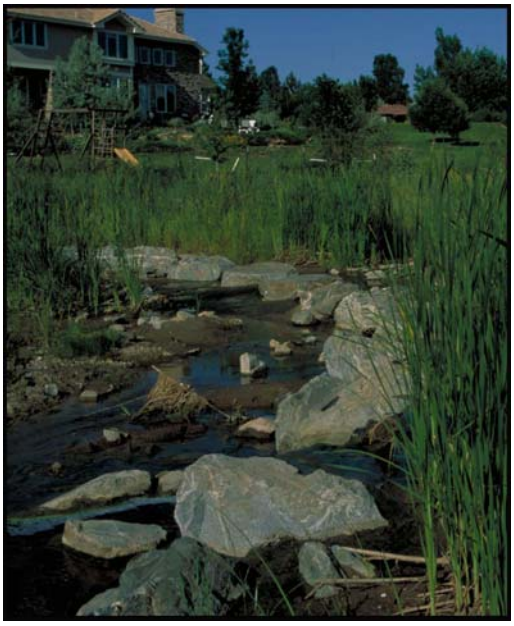

*Photo 10 Base Flow over Lower Drop*

The design of the lowermost drop structures, immediately upstream of the Highline Canal, presented different challenges. Greenwood Gulch had split into two distinct flow channels. The slopes of the channels were less than 0.5% and a healthy wetland habitat dominated the last 1,100 feet of the Greenwood Gulch floodplain before it discharged into the Highline Canal. Two 8-foot-deep erosion channels, however, had worked their way about 150 feet back from the Highline Canal. If left alone, these erosion channels would likely continue to work their way back upstream and ultimately threaten the nearby wetland areas.

Two large boulder drop structures were constructed approximately 150 feet upstream of the Highline Canal on the two channels (Figure 10 and Photo 11). The same large boulder design concepts used upstream of Holly Street were applied to these lowermost 4-foot-high two-tiered drop structures. Both

included bridges for pedestrian trail crossings over the split Greenwood Gulch channels.

## 7.3 Construction

The District awarded the construction contract to Randall & Blake, Inc. in the spring of 1998. The District administered the contract via an intergovernmental agreement with Greenwood Village. The contract was awarded in two phases to accommodate right of way negotiations with homeowners adjacent to the upstream portion of the project. Some delays were encountered during construction due to thunderstorm activity and unforeseen conditions at the Holly Street bridge. The construction sequence was adjusted in the fall of 1998 to accommodate the critical fall planting of vegetation.

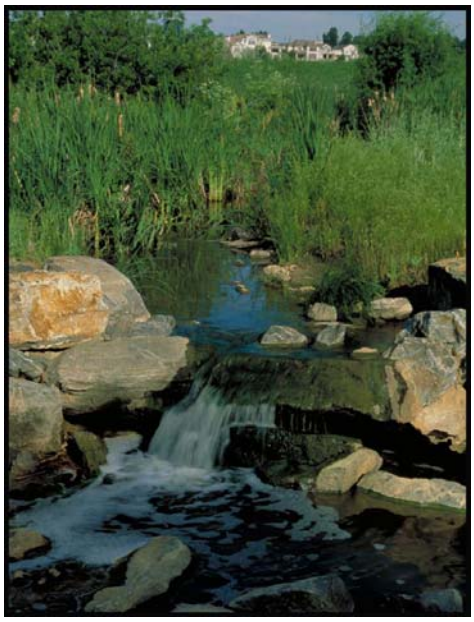

*Photo 11 Upstream View of Drop Structure No. 2 from Pedestrian Crossing*

## 7.4 Success

The Greenwood Gulch Channel Improvement Project is a success. The revegetation has been successful and the erosion has been controlled. The damage to private properties from Orchard Road to Holly Street has been stopped and approximately 8 acres of wetland habitat have been restored from Holly Street to the Highline Canal. The trail from Orchard Road to the Highline Canal is one of the most heavily used trails in the Greenwood Village trail system. The large boulder drop structures are visual amenities and the riffle/pool flow patterns in the narrow channel upstream of Holly have improved the wildlife habitat of the riparian corridor. The wetlands below Holly Street also improve the urban wildlife habitat and are an amenity for enjoyment by the users of the trail. The entire project has enhanced the property values for the area and has received ongoing support from the local community.

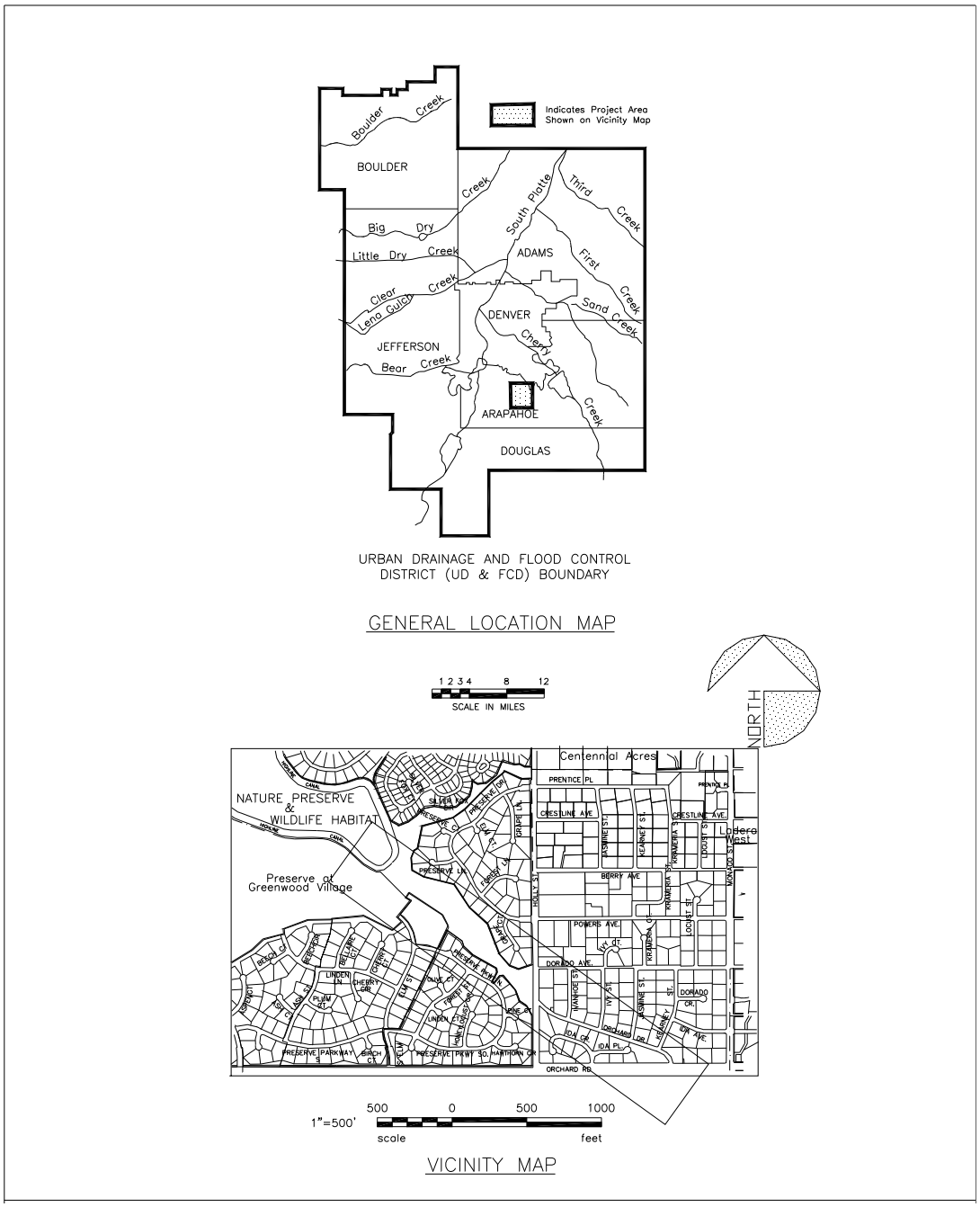


**Figure 1—Location and Vicinity Maps**


**Figure 2—Urbanization of Greenwood Gulch**

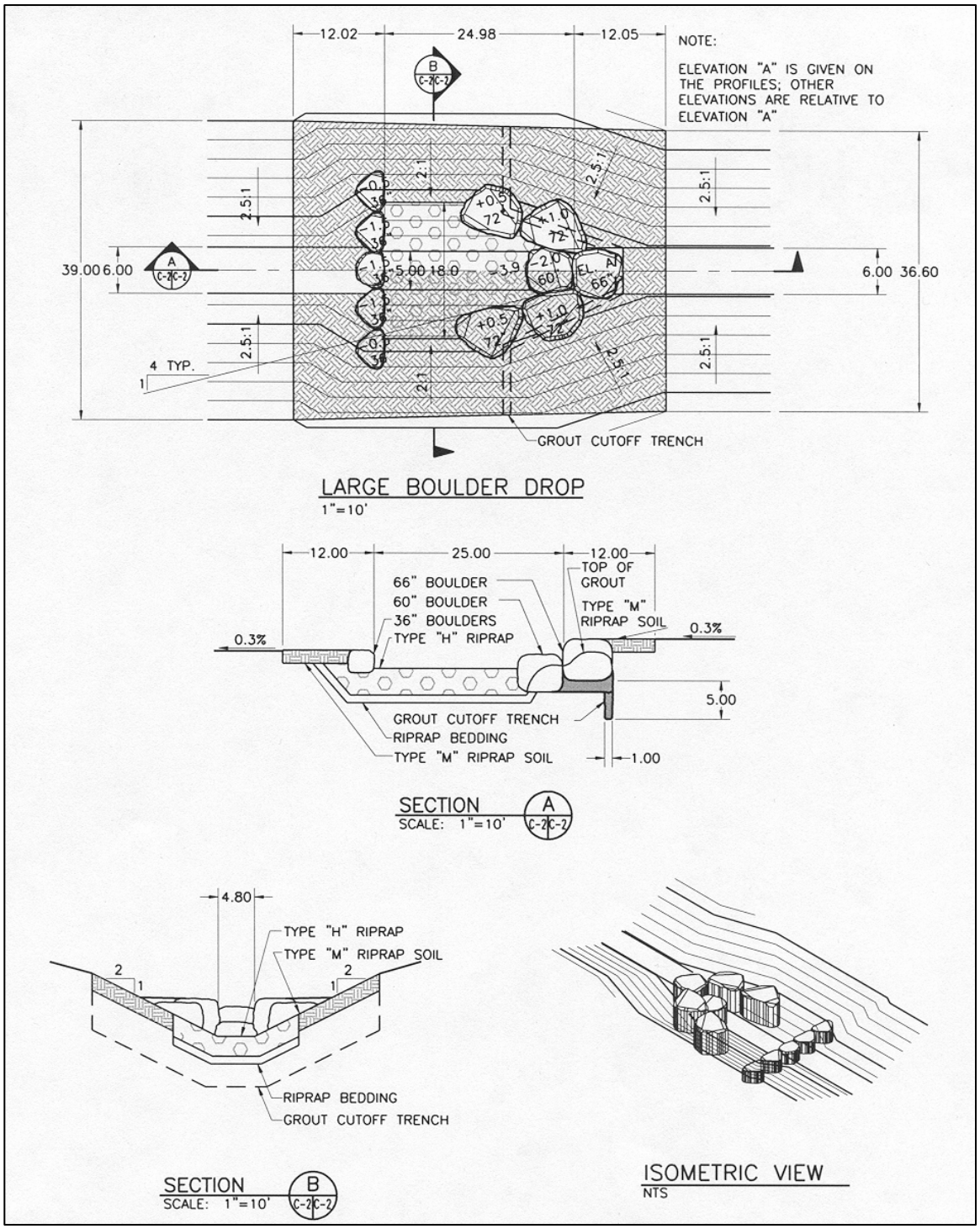


**Figure 3—Large Boulder Drop Structure**

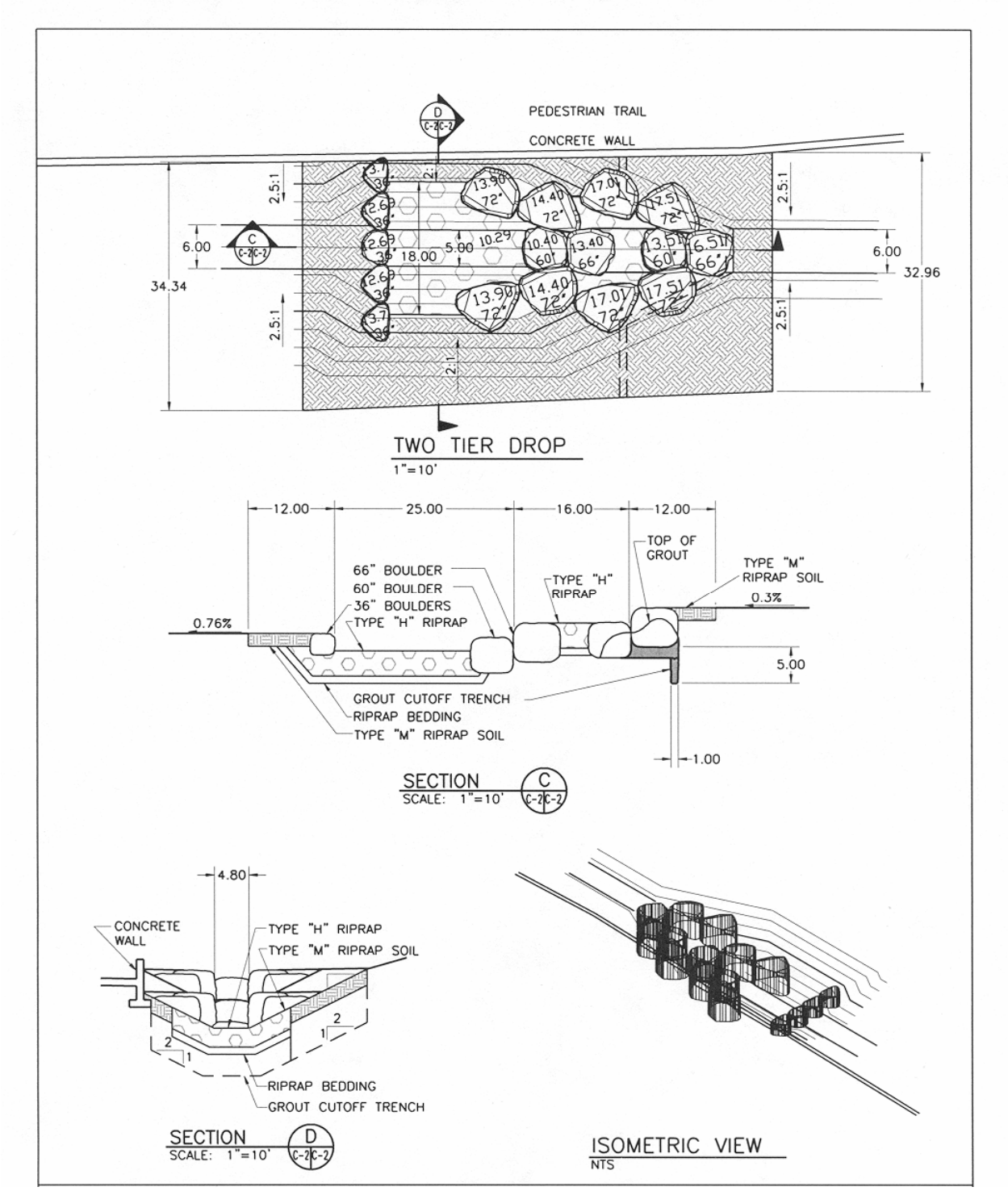


**Figure 4—Large Boulder Drop Structure**

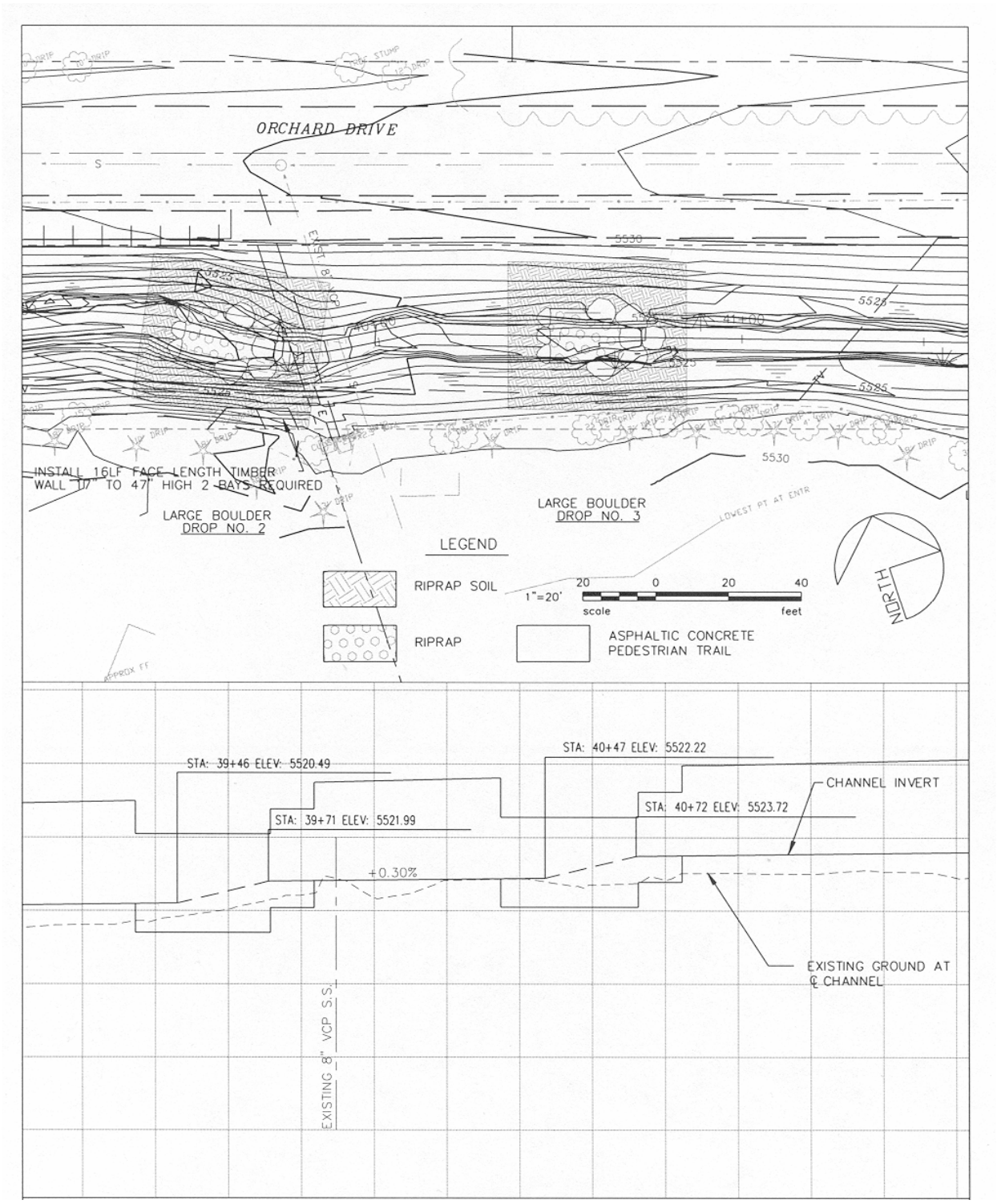


**Figure 5—Plan and Profile Upstream of Holly Street**

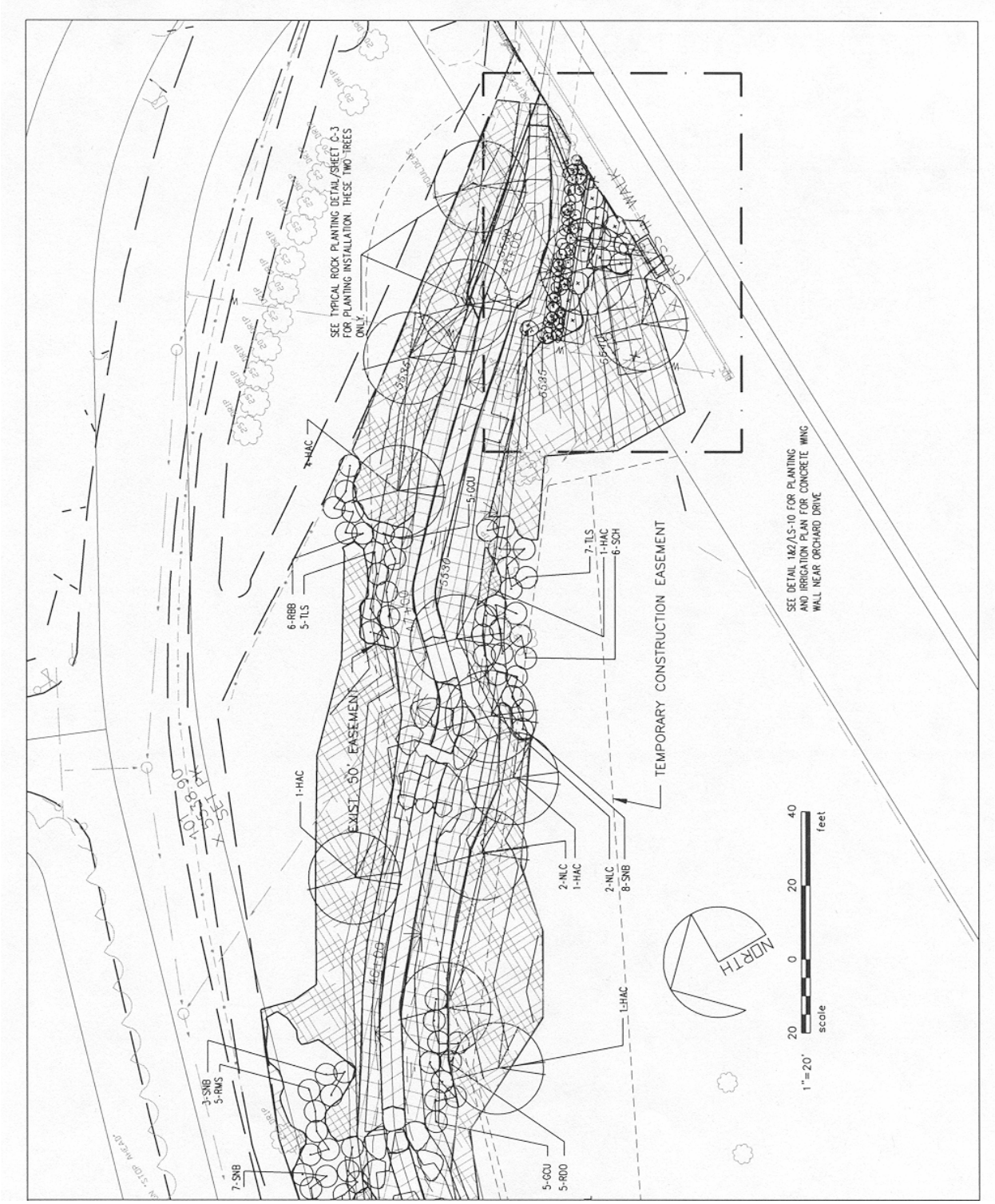


**Figure 6—Landscape Plan Upstream of Holly Street**

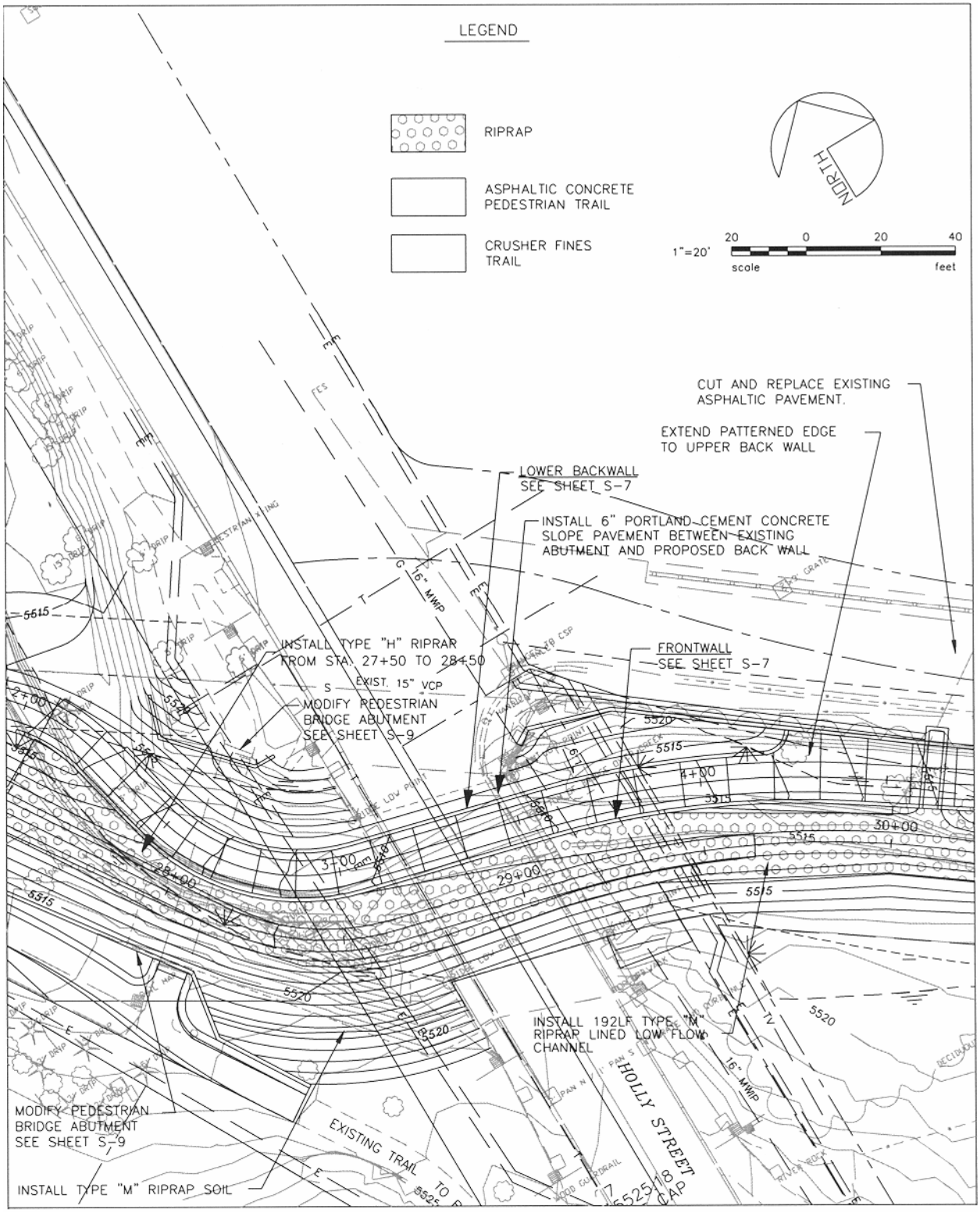


**Figure 7—Holly Street Bridge**

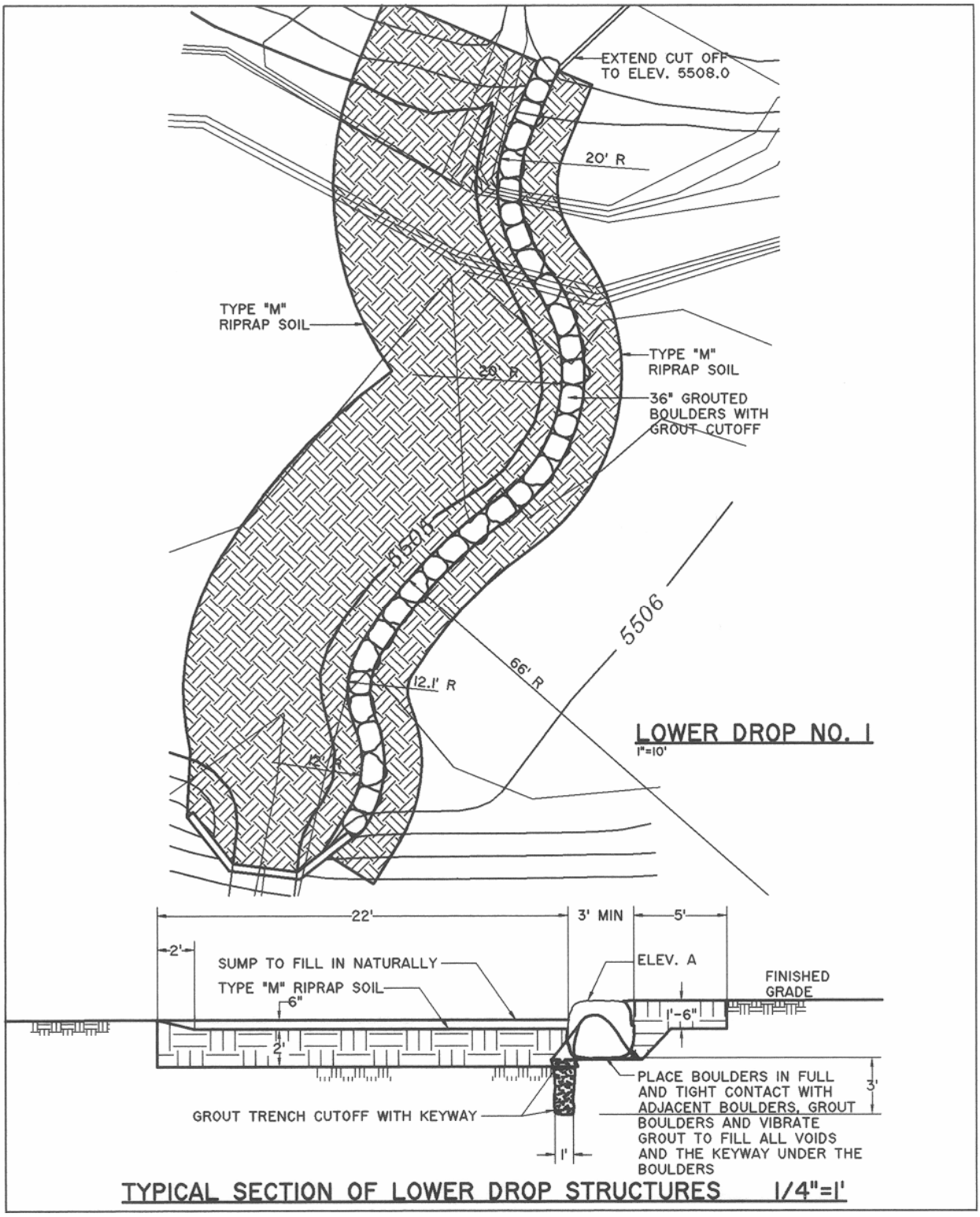


**Figure 8—Lower Drop Structure Downstream of Holly Street**

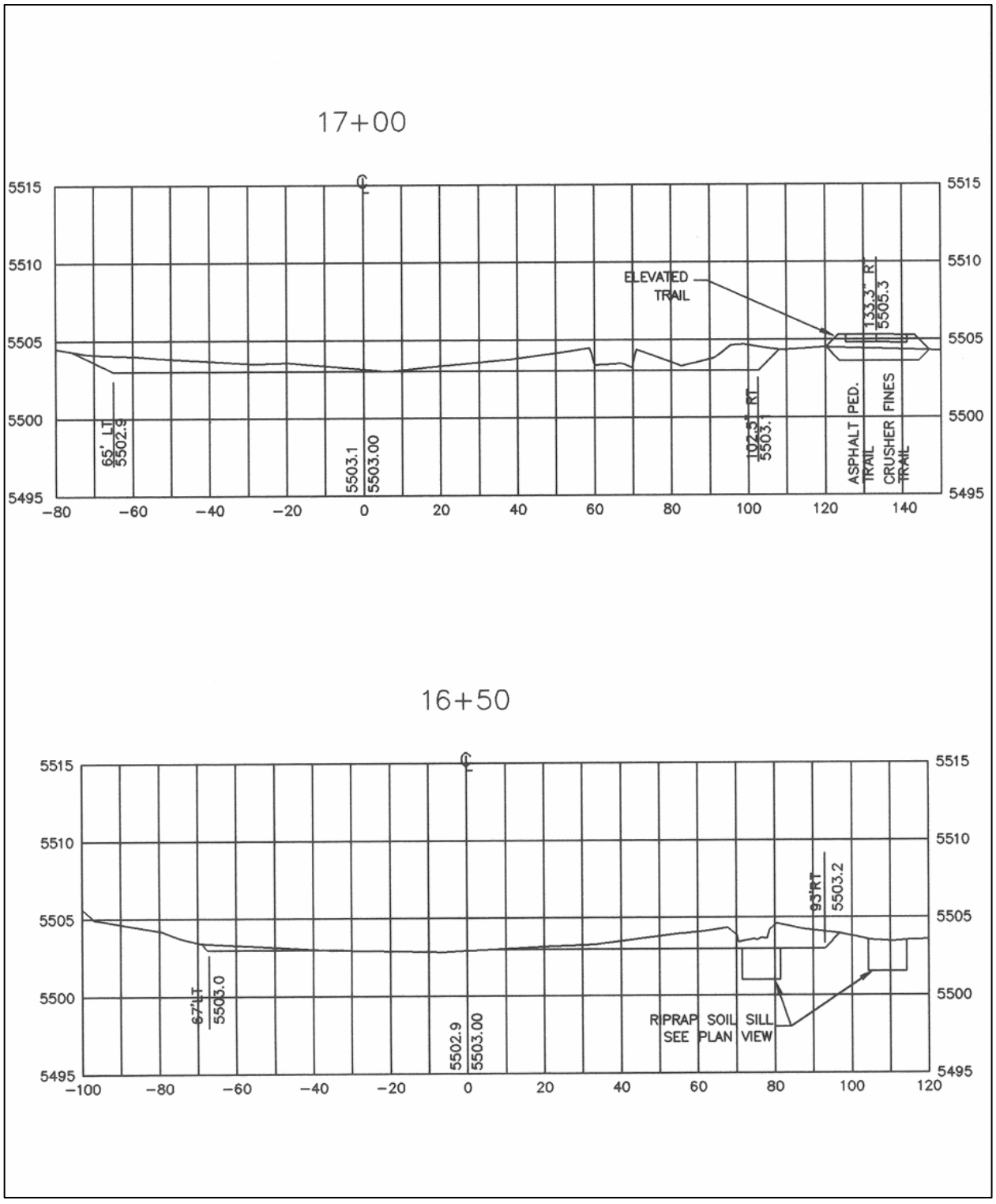


**Figure 9—Downstream of Holly Street Channel Cross Sections**

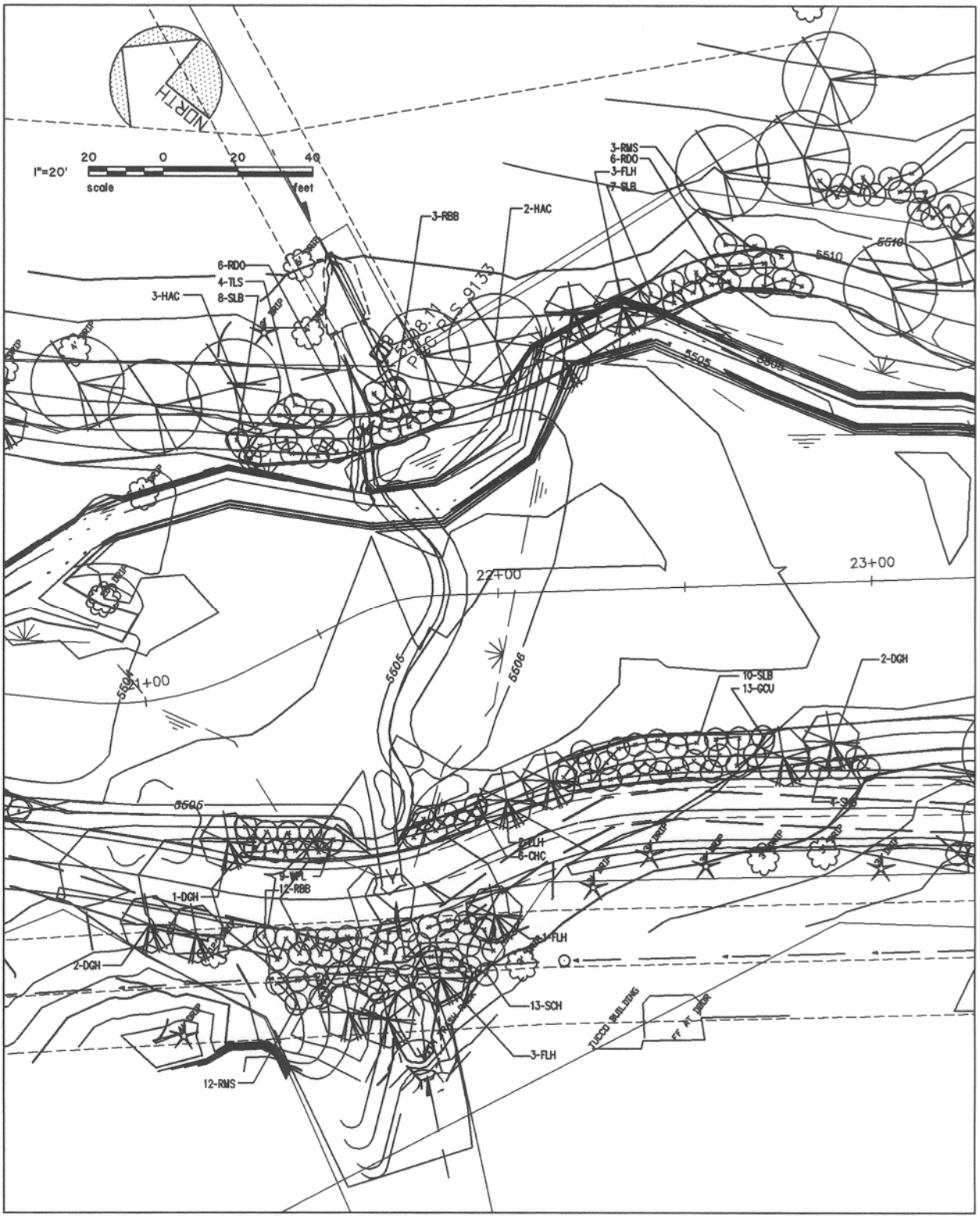


**Figure 10—Landscape Plan Downstream of Holly Street**

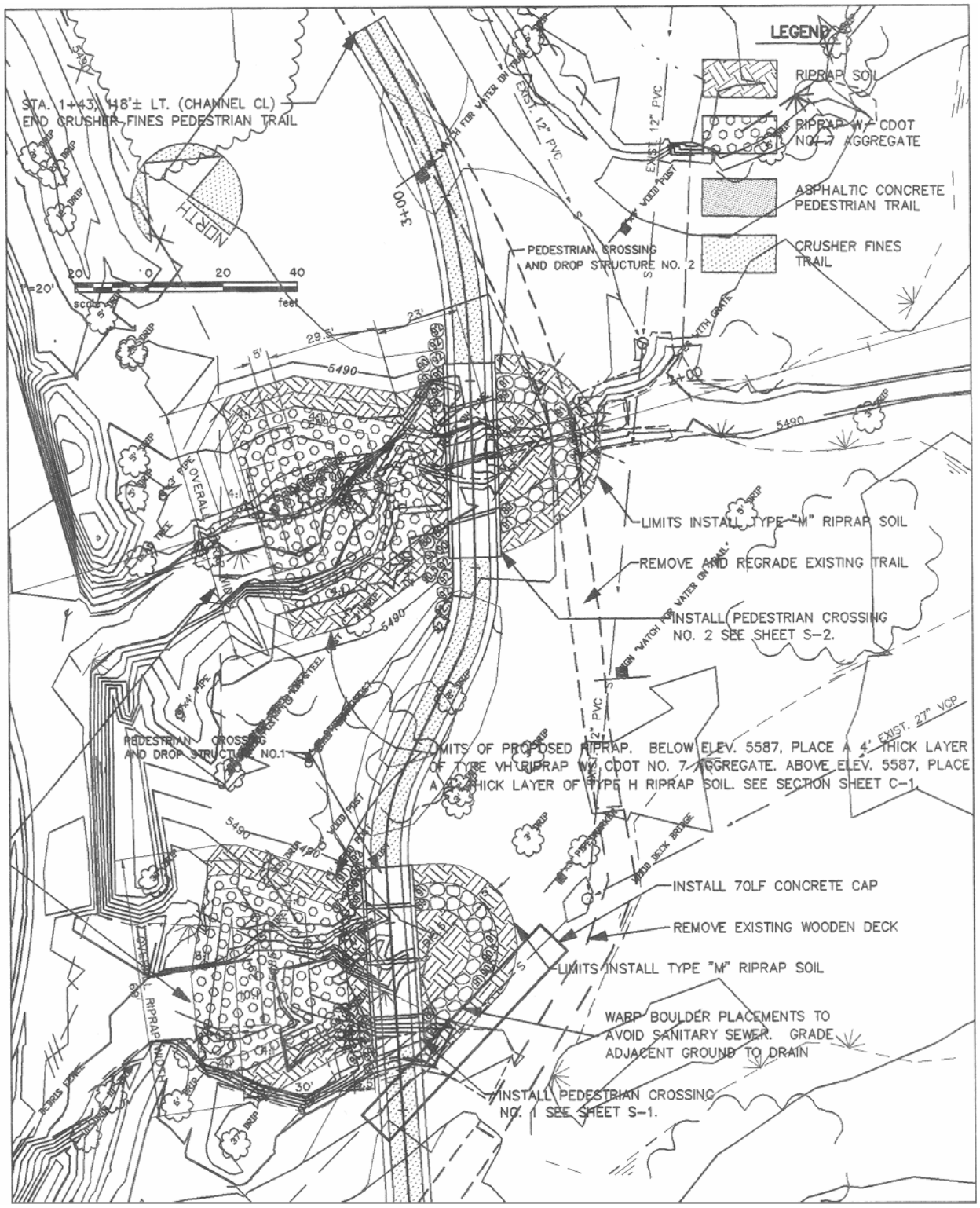


**Figure 11—Large Boulder Drop Above Highline Canal**