A Restoration and Monitoring Plan for *Puccinellia howellii*, Whiskeytown National Recreation Area, California

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Introduction

This report presents concepts and plans for restoring salt springs habitat that supports the only known occurrence of the endemic grass species *Puccinellia howellii*. Over the past several decades a number of alterations to site landforms, ground and surface water flow patterns, water chemistry, and water table depth relationships have occurred, reducing the available habitat for *P. howellii* by more than 50%. We outline approaches to restore these areas to their historic, pre-disturbance condition.

Puccinellia howellii was first described by Davis (1990) and its distribution at the three springs identified by Martz and Villa (1990). Previous analyses of this species and the site have been conducted by Fulgham et al. (1997) and Levine et al. (2002) who studied the autecology and habitats occupied by *P. howellii* and other species on site. Baca (1995) analyzed approaches for reducing competing species. California Department of Transportation has analyzed spring flows and the effects of highway road-cut blasting on flows (Casey 1993). Our previous report summarizes current knowledge of this taxon and impacts to the site (Cooper and Wolf 2005). Site geology and likely ground water flow paths of were reviewed by Culhane and Martin (2007).

This information is used as the basis for a restoration plan and we outline steps necessary to reestablish the natural landforms and hydrologic, geochemical and edaphic processes required to support *P. howellii*. In support of this project, two Technical Assistance Requests were fulfilled by the NPS's Water Resources Division (WRD). A site visit by WRD staff was conducted in March 2007, when strategies to improve the habitat were discussed among the authors of this report, park staff, and interagency partners.

In this report we: 1) summarize the degree and extent to which *P. howellii* habitat has been impacted; 2) provide guidelines on how the habitat could be restored; and, 3) suggest a strategy for post restoration monitoring. Implementation of the restoration will be conducted with NPS partners, which include the California Department of Transportation (Caltrans), California Department of Fish and Game, and the U.S. Fish and Wildlife Service (USFWS).

Site Description and History

The entire known population of *Puccinellia howellii* (Howell's alkali grass) occurs on a 1-acre salt spring complex in the foothills of the Klamath Mountains, in Whiskeytown National Recreation Area, California. This species has one of the most limited ranges of any plant species known in the U.S. California State Highway 299 West runs across the uppermost portion of the salt spring and causes several direct and indirect impacts to the site. These include: burial of a portion of the site under road fill, diversion of saltwater flow by a large berm, discharge of freshwater runoff from culverts and the road fill prism onto the site, and sediment discharge onto the site from fill material. The primary indirect impact of the roadway is vehicle and foot traffic from visitors stopping at a large pullout along the road.

In 1993, a realignment of Highway 299 buried 1,200 ft^2 of *Puccinellia howellii* habitat, and Caltrans attempted to mitigate this loss by restoring an area in Spring 2 that was thought to be historic habitat. The mitigation area had been buried under road fill and mine spoil early in the 20^{th} century. Spoil material was excavated from Spring 2 during the restoration, and *Puccinellia* plants were transplanted to the mitigation site from the area to be buried by the highway realignment. Along with the mitigation efforts, a broader study of the entire site including water chemistry, soil, and vegetation analyses, greenhouse experiments, and establishment of monitoring plots to track vegetation changes was conducted (Fulgham et al. 1997).

Initially the transplanted *Puccinellia howellii* survived. However, *Distichlis spicata*, a native salt grass that grew on-site prior to the mitigation, grew over the transplanted area and most *Puccinellia* plants died. This prompted an investigation into the use of burning, clipping, and herbicide application treatments to control what was seen as a *Distichlis* invasion into *Puccinellia* habitat. While herbicide did kill *Distichlis*, it also killed *Puccinellia*, and the burning and clipping treatments tended to favor *Distichlis* (Bacca 1995). These treatments were ineffective at excluding *Distichlis* and maintaining *Puccinellia* cover. Most likely this occurred because the mitigation area was not suitable habitat for *Puccinellia*, but is appropriate for *Distichlis*.

Our research over the past 4 years has not only determined the habitat requirements for *Puccinellia howellii*, but also clarified all site impacts. This report provides specific future restoration guidance to ameliorate these impacts and restore species habitat and populations.

Habitat of *Puccinellia howellii*

The initial study of the habitat affinities of *Puccinellia howellii* (Fulgham et al. 1997) and a more recent study (Cooper and Wolf 2005) both concluded that *Puccinellia* and *Distichlis* occupy distinct sites with different environmental characteristics. Fulgham et al. found that only 4.9% of vegetation plots supported both *Puccinellia* and *Distichlis* at >5% cover. By this same criterion, only 2.2% of our 2005 vegetation plots had both *Puccinellia* and *Distichlis*. Through ordination analysis of the vegetation and environmental parameters, Fulgham et al. (1997) found that *Puccinellia* was associated with sites that have high winter salinity, low Mg, and were commonly inundated. Sites with *Distichlis* were typified by high Mg, low winter salinity, high P and N, and were rarely inundated. Our 2005 vegetation analysis also identified different habitats for *Puccinellia* and *Distichlis*. The primary distinction was the tendency of *Distichlis* to occupy lower salinity sites, with a secondary inclination towards sites with deeper water tables and higher pH values (Figure 1). Both reports also found that *Triglochin maritima,* another native halophyte, shares a nearly identical habitat with *Puccinellia* and they commonly co-occur. *Puccinellia* is most abundant in habitats with high summer water tables, prefers the most acid (low pH) sites, and occupies the middle ground of the winter salinity (EC) gradient. Winter salinity is key because that is the rainy season, and the time when freshwater can most influence sites. Our ordination is presented in Figure 1.

Analysis of the environmental data and *Puccinellia howellii* cover in a spatially explicit form reveals many patterns that are critical to understanding the variability of the site and the impacts that have occurred. Ninety-three ground water monitoring wells installed on site served as the center of the vegetation plots and as the collection points for water level, water chemistry, and soil data. In addition, sediment deposition was monitored at over 200 points across the study area. All data points were topographically surveyed with a total station and placed in a GIS to explore spatial patterns in the data.

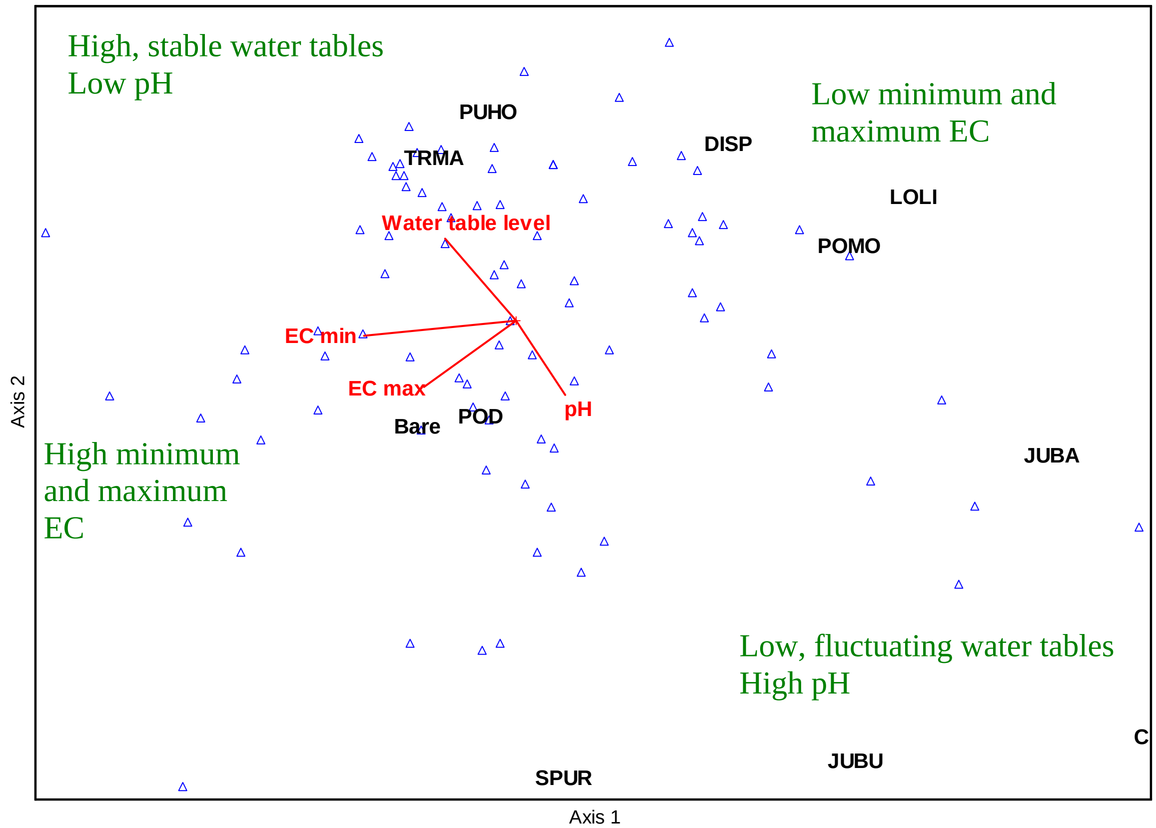


Figure 1. Direct gradient analysis showing the distribution of plots (blue triangles) and species centroids in relation to significant gradients in environmental parameters (radiating red lines). The environmental parameters increase in value along the red lines in the direction of their label, and decrease in the opposite direction. PUHO = *Puccinellia howellii*, TRMA = *Triglochin maritima*, DISP = *Distichlis spicata*, Bare = bare ground, POD = Plaque of Death, LOLI = *Lolium multiflorum*, POMO = *Polypogon monspeliensis*, JUBA = *Juncus balticus*, SPUR = *Spergularia marina*, JUBU = *Juncus bufonis*, C = *Cirsium vulgare*. EC = electrical conductivity (Cooper and Wolf 2005).

Across the site most holes bored for well installation had less than 30 cm of sediment overlying bedrock. However, on the east side of Spring 2, in part of the mitigation area used by Bacca (1995), sediment thickness exceeded 150 cm. Two other plots also had very thick sediment, one at the base of the large berm above Spring 1, and the other in the alluvial fan deposited by water flowing through a culvert under the highway. At 20 out of 28 study plots with more than 33 cm of sediment, *Puccinellia* cover was less than 7% (Figure 2). The mitigation area is also a zone of high sediment flux, with ~0.5 g/day deposited per 100 cm^2 during the winter months (Figure 3). The northeastern section of Spring 1, down slope from a large roadway berm, and the slope below bare ground that may have been a construction staging area at Spring 3 also receive large amounts of sediment.

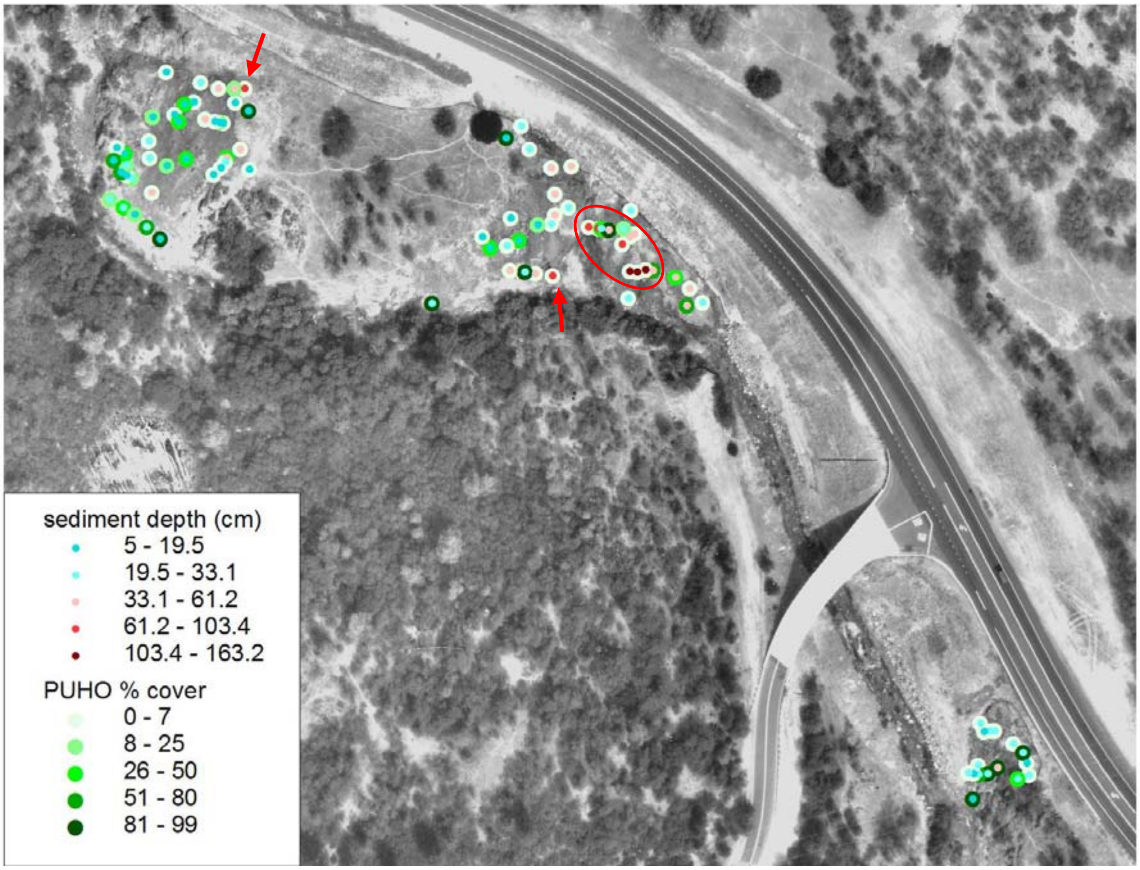


Figure 2. Aerial photograph of the spring complex with study plots shown as dots. The three clusters of study plots are from upper left to lower right, springs 1, 2, and 3. Larger dots in shades of green show percent cover of *Puccinellia howellii* at each plot. Smaller dots show the sediment thickness in each study plot. The red circle highlights the area of deep sediment on the east side of Spring 2. The red arrows show two other locations of deep sediment, below the berm at Spring 1 on left, in the alluvial fan in Spring 2 at center.

Two distinct water sources, groundwater fed springs, and precipitation-fed flow paths supply water to the site, each with different chemical content. Groundwater emerges from numerous spring discharge points and perennially irrigates the gravel slopes of the natural spring complex. Groundwater has a flow path with long residence time within the bedrock aquifer during which it becomes highly reduced geochemically, leading to the formation of hydrogen sulfide, and accumulates sufficient salts to raise the pH to >9. Water with very high pH and low redox potentials (Eh) discharges from many springs in the study area. After water discharges to the soil surface the hydrogen sulfide oxidizes to form sulfuric acid and the Eh rises while the pH drops from >9 to <6. *Puccinellia* does not grow at the spring discharge points, but thrives in down gradient sites perennially irrigated by springs (Figure 4). The presence of spring discharge points and water sheet flowing over and through fractured and decomposed bedrock is critical habitat for the establishment and persistence of *Puccinellia* individuals. At the spring 2 mitigation site used by Caltrans, it appears that one or more springs is buried under >150 cm of sediment, because water with pH >8 discharges upward through the holes we augered for ground water monitoring well installation. Thus, the fill confines the springs and allows its discharging water to flow upward more than a meter through fill.

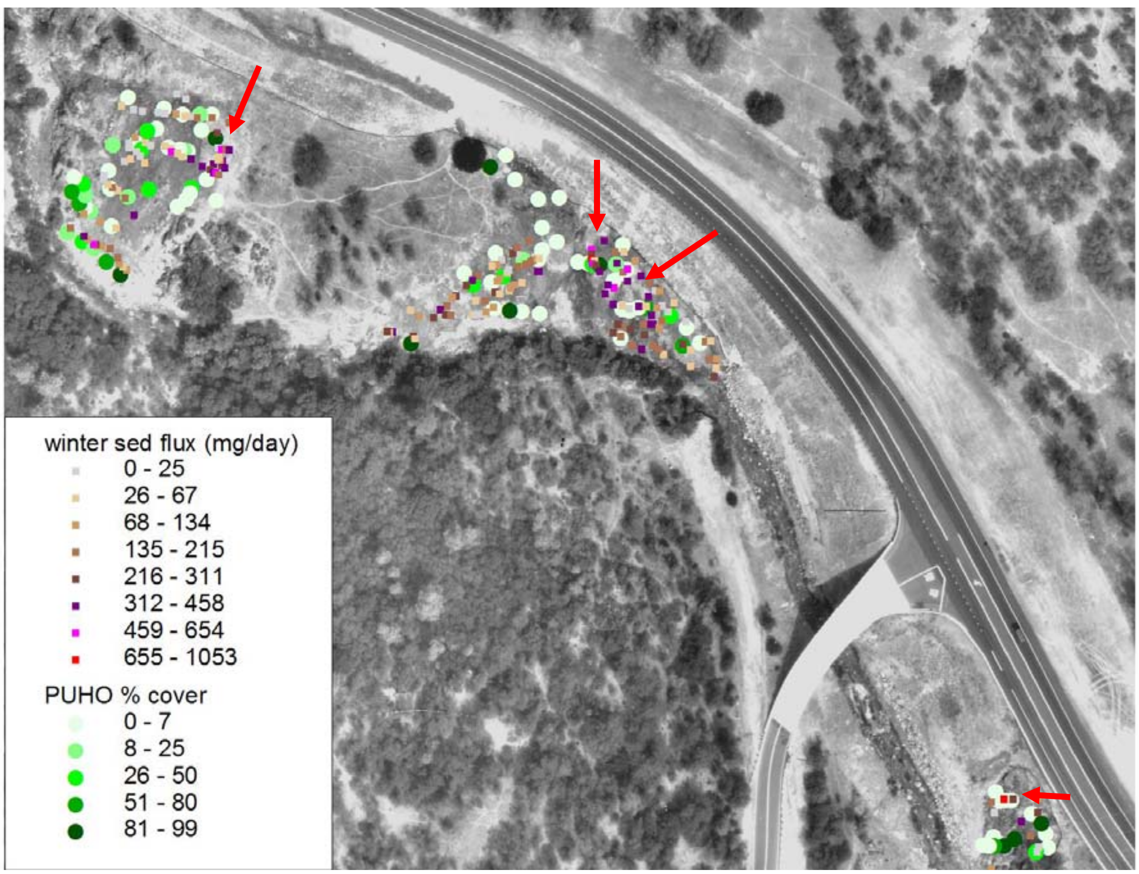


Figure 3. The study area with *Puccinellia* cover and sediment flux data. The red arrows highlight the areas of greatest sediment deposition during the winter months.

Rainwater, by contrast, falls directly onto the site or flows to it from the highway or through culverts, has a very short flow path with little residence time in aquifers, and is slightly acidic with low solute concentrations. We term this input "freshwater". There are three primary delivery locations for freshwater onto the site: 1) runoff from the highway runs down the *Juncus balticus* fan and into spring 2; 2) a culvert under the highway discharges surface flow onto a large vegetated alluvial fan in spring two that extends to Willow Creek; and, 3) two drainage pipes discharge runoff from the roadway and road fill prism onto Spring 3 (Figure 5). Additionally, the berm and road fill prisms that border the northern edges of all springs are large unconsolidated gravel and rock landforms that may store and discharge rainwater onto the site as non-point sources, which can be identified where iron staining occurs, particularly at spring 2 but also at spring 3. Areas irrigated by surface water flow have near neutral pH (see Figure 4), have low salinity during the winter rainy season (the *Puccinellia* growing season), and do not support *Puccinellia*.

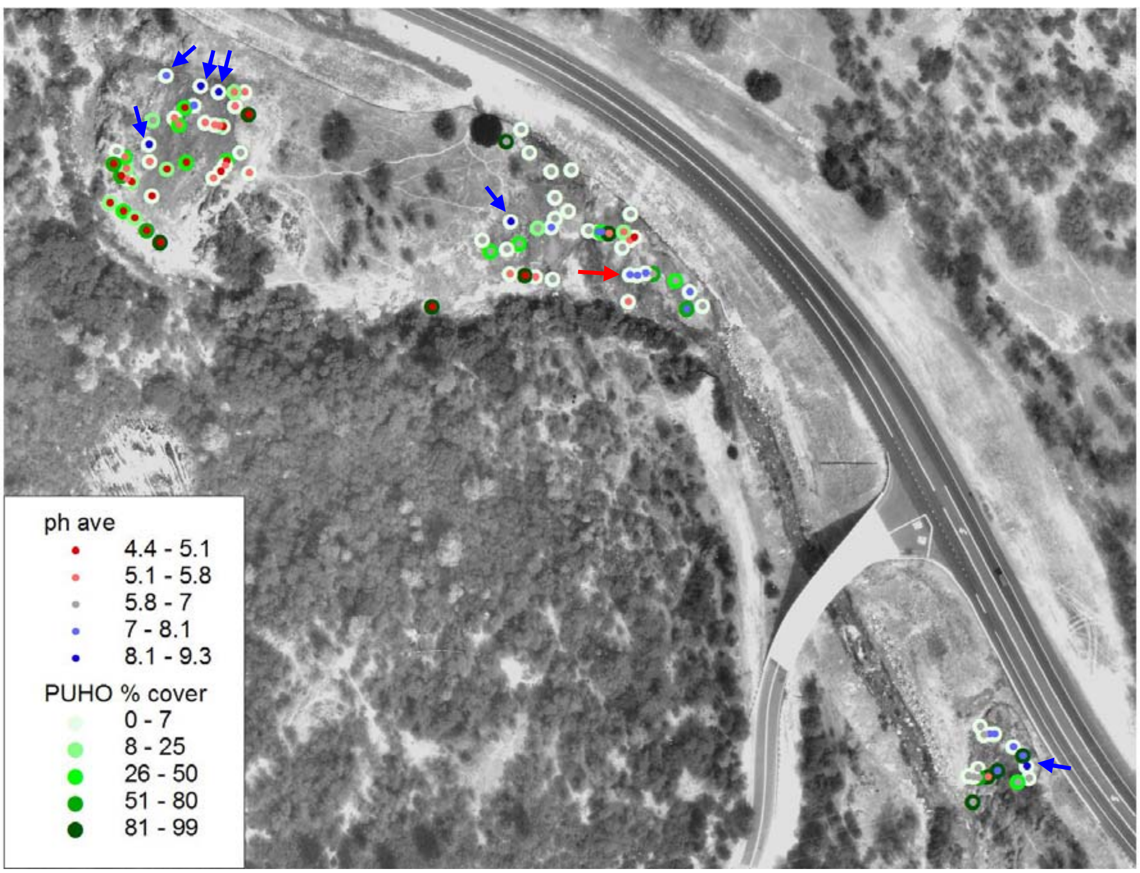


Figure 4. Cover of *Puccinellia* and the average pH at the study plots. The blue arrows indicate spring discharge locations where very basic water emerges from the ground. The red arrow indicates the springs that are buried under >150 cm of sediment.

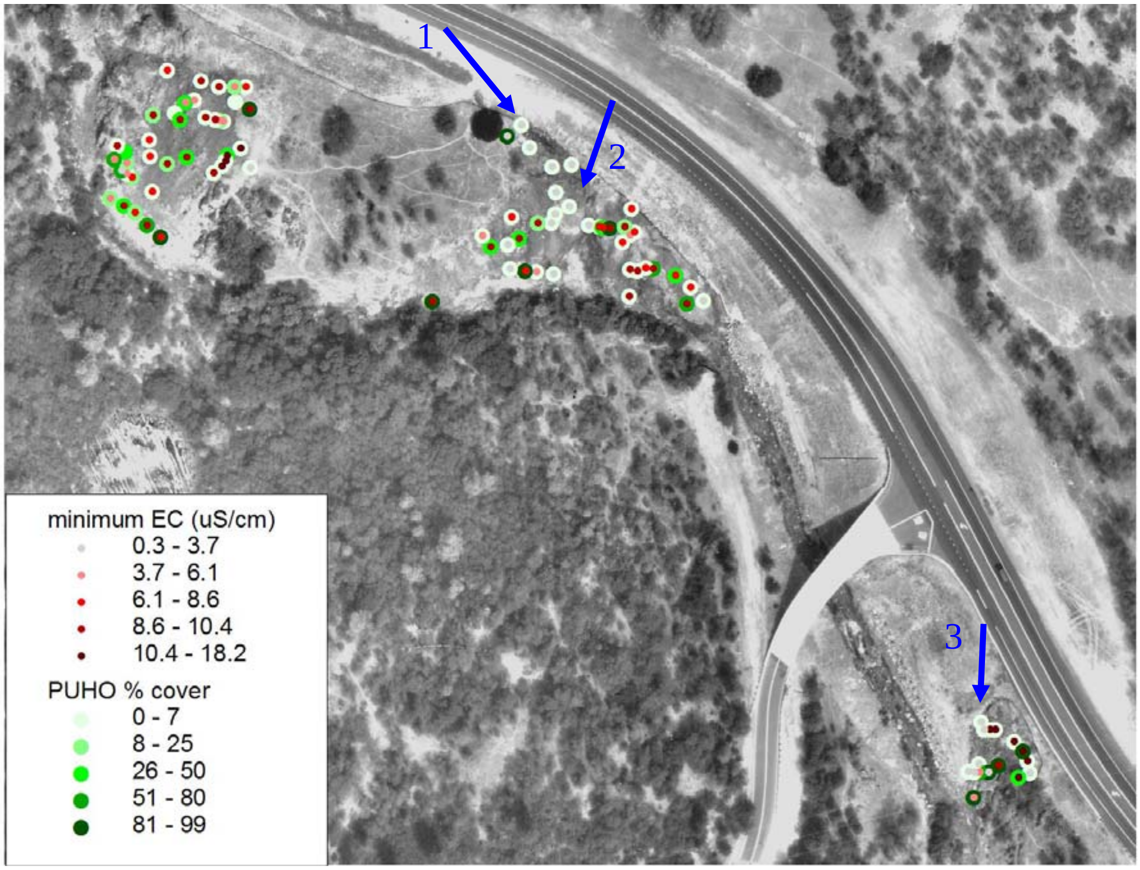


Figure 5. The spring complex with cover of *Puccinellia* shown with the minimum (winter low) salinity, measured as electrical conductivity (EC in uS/cm). The blue arrows highlight the three major sources of fresh water pollution and associated on site low salinity sites where *Puccinellia* does not occur.

Summary of Impacts

Potential negative impacts to *Puccinellia howellii* are those that shift the habitat out of the narrow range of suitable salinity, pH, water table depth, and sediment thickness and influx. Excessive fresh water and sediment discharge onto the site, due mainly to highway related structures, are a primary threat to the maintenance of viable habitat (Figure 6). Fresh water is a pollutant in this salt spring complex and has had dramatic effects on limiting the distribution of *Puccinellia*. Currently, a primary impact is the discharge of fresh water onto Spring 2 from the berm diversion and the under-highway culvert, and the pipes at Spring 3 that drain road fill. The fresh water dilutes salts and acidity and shifts the habitat suitability away from *Puccinellia* and towards *Distichlis, Juncus balticus* and annual glycophytes. The next largest impact is the presence of large amounts of fill dirt on or adjacent to the springs, covering suitable habitat and burying seedlings as they emerge in the rainy season. Four areas receive significant sediment input from human-made features: 1) the east side of Spring 2, where the mitigation was attempted, has deep sediment and high sediment accumulation rates, 2) the east side of Spring 1 below the fill berm where high sediment input occurs, 3) the alluvial fans associated with the water diverted by the berm and the highway culvert both deposit large amounts of sediment on and around Spring 2; and, 4) at Spring 3 below a central bare area that may be fill or some other construction disturbance, large amounts of sediment are transported by rain events.

Between spring 1 and the highway the road cut and large berm between diverts approximately 0.9 gal/min of groundwater discharge from Spring 1 and down to the *Juncus balticus* alluvial fan at Spring 2. A small patch of *Puccinellia* at the top of this fan is supported by this water, and a sizable roadside population of *Puccinellia* has become established in the pullout above the berm. In the absence of the berm, this flow would drain south into Spring 1.

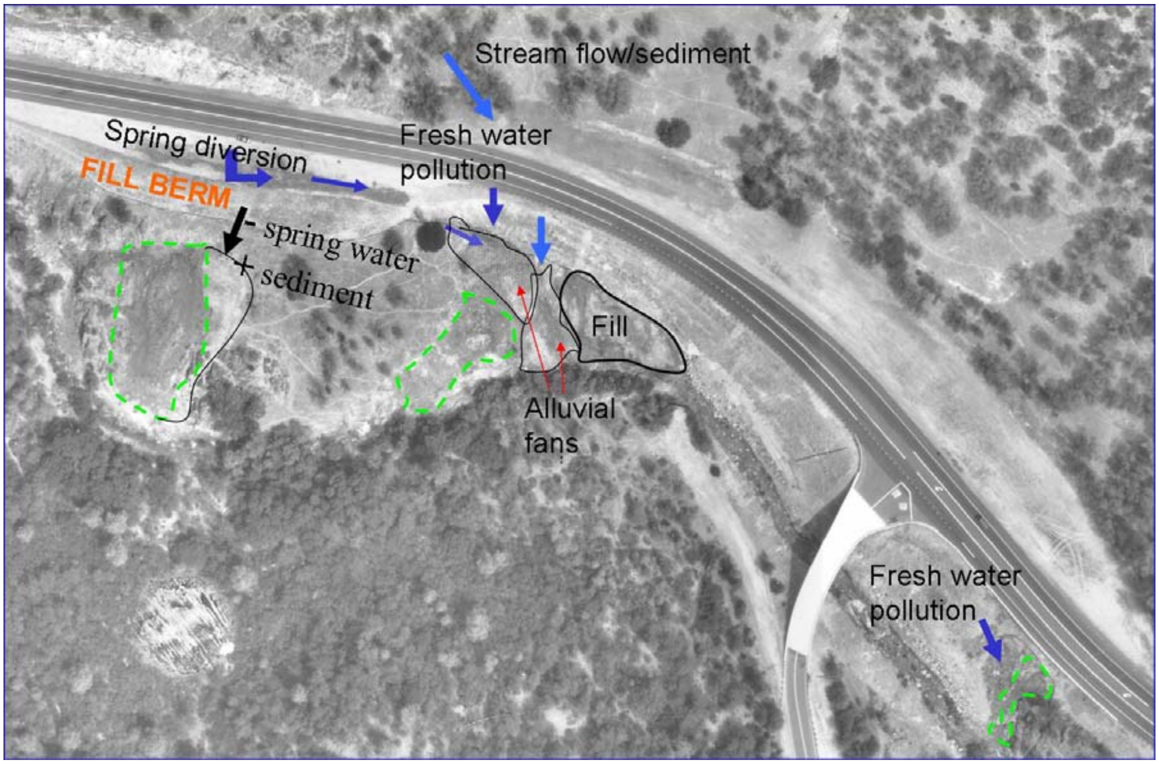


Figure 6. The spring complex showing a summary of impacts that occur. The green dashed lines show the approximate extent of primary *Puccinellia* growth.

Proposed Restoration Projects

<u>Fresh water Pollution Abatement</u>

Fresh water is a pollutant in this salt spring complex and has had dramatic effects on limiting the distribution of *Puccinellia*. To address this issue three separate projects are suggested, one for spring 3 and two for spring 2. The discharge of drainage from road fill directly onto Spring 3 is the easiest impact to address. Fresh water drains onto the site through two 8-inch black plastic pipes (Figure 7). The pipe lengths should be increased so that water discharges directly into Willow Creek. New ground water monitoring wells and vegetation plots should be added to monitor the effects of the proposed restoration activities (removing fresh water from spring 3 on water chemistry, ground water levels and vegetation). It likely won't be necessary to plant *Puccinellia*, but it might be necessary to remove *Distichlis* patches using hand shovels to expose bare soil for *Puccinellia* to establish.

Figure 7. One of two 8-inch plastic culverts that discharge fresh water from the road fill onto Spring 3. The grass in the foreground is *Distichlis spicata*.

Figure 8. Looking east from the highway into Spring 2. The *Juncus balticus* (dark colored plant) fan and fresh water area is bounded by the red line.

Figure 9. Looking north toward the highway in Spring 2. The alluvial fan and fresh water plume formed by the culvert stream is bounded by the red line.

At spring 2, two large projects are proposed. First, surface water runoff from the highway must be rerouted. Presently rainwater flows from the highway into the northwestern corner of spring 2, creating and supporting a large freshwater marsh dominated by *Juncus balticus* (Figure 8). This water must be captured at the highway and diverted into the culvert located beneath the highway. This could be done by installing a perforated pipe near the junction of the highway and the *Juncus* stand to capture flow into this area. This pipe would then feed the stream that discharges from the culvert.

The second project is the redesign of the channel that formed by stream discharge from the culvert located beneath the highway. This stream has deposited a large mineral sediment alluvial fan, which is irrigated with fresh water (Figure 9). The sediment must be removed and a stable channel constructed to guide culvert water to Willow Creek. This project should be designed by Caltrans with assistance from NPS WRD staff. Although the fresh water in this channel is from a natural drainage system above the highway, it also receives augmented flow and sediment loads from dirt roads and the highway. In conjunction with the removal of the alluvial fan, a plan to prevent further sedimentation must be developed and implemented. One possible solution is to construct a settling pond upstream of the highway which would be dredged periodically to remove accumulated sediment. Another solution may be to extend the culvert through Spring 2 to Willow Creek.

Dewatering of Spring 1

A recent highway realignment project cut into bedrock north of spring 1 to widen the road. A berm was constructed to prevent vehicles and their contents from inadvertently entering spring 1. However, this berm captures ground water discharging from the bedrock aquifer that should flow into spring 1, and channels it into spring 2 through the *Juncus balticus* alluvial fan. Removal of the berm (3,800 m^3, or 4,965 yd^3) will eliminate the dewatering of spring 1 and reduce inputs of mineral sediment from erosion of the berm to the northeast side of Spring 1. Existing and additional data points should be monitored before and after the removal or modification of the berm to determine if water chemistry, water level, sediment flux, or vegetation change as result of the project.   Existing contours, showing the berm, as well as proposed contours and thickness of fill to be removed, are shown in Figures 10 and 11 a, b, c. A channel likely is not necessary to effect this flow change.

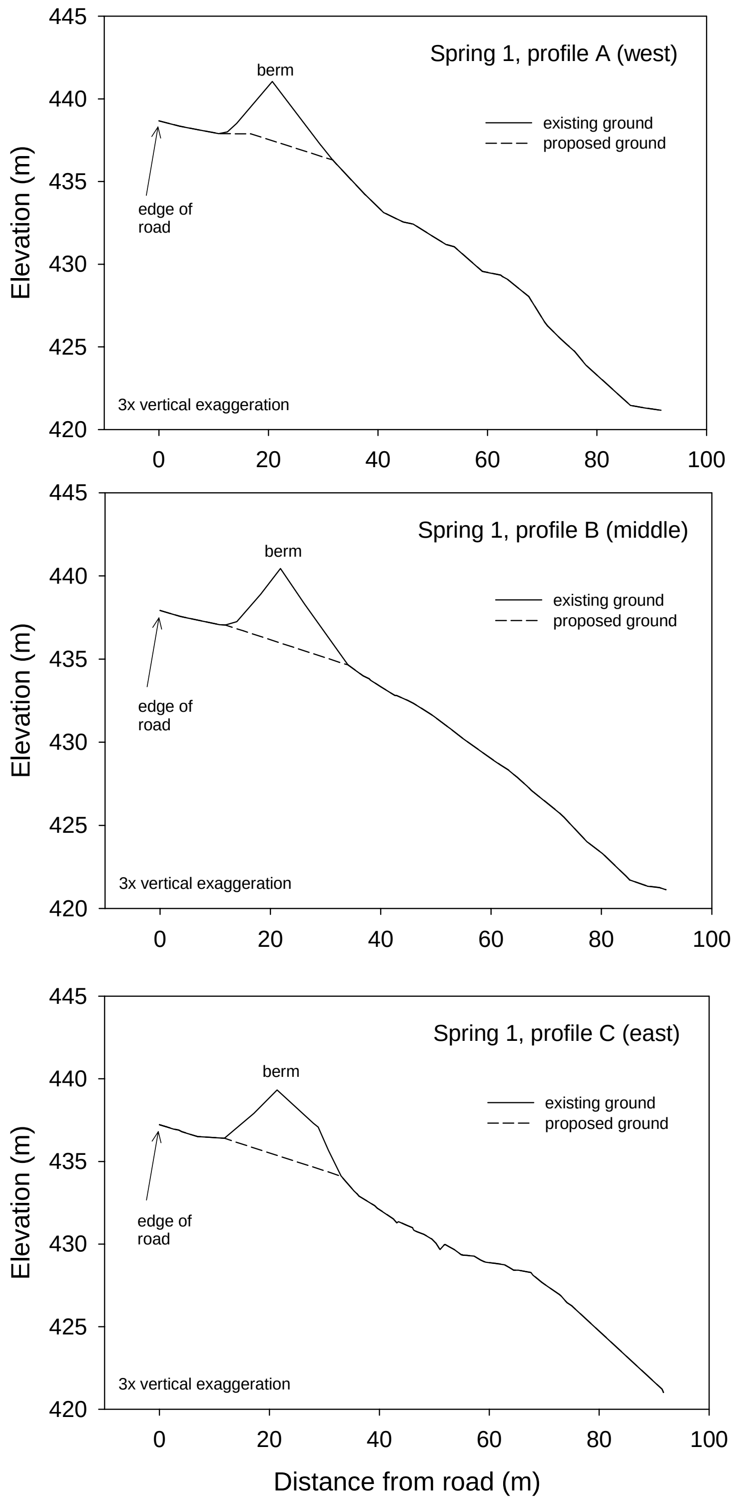
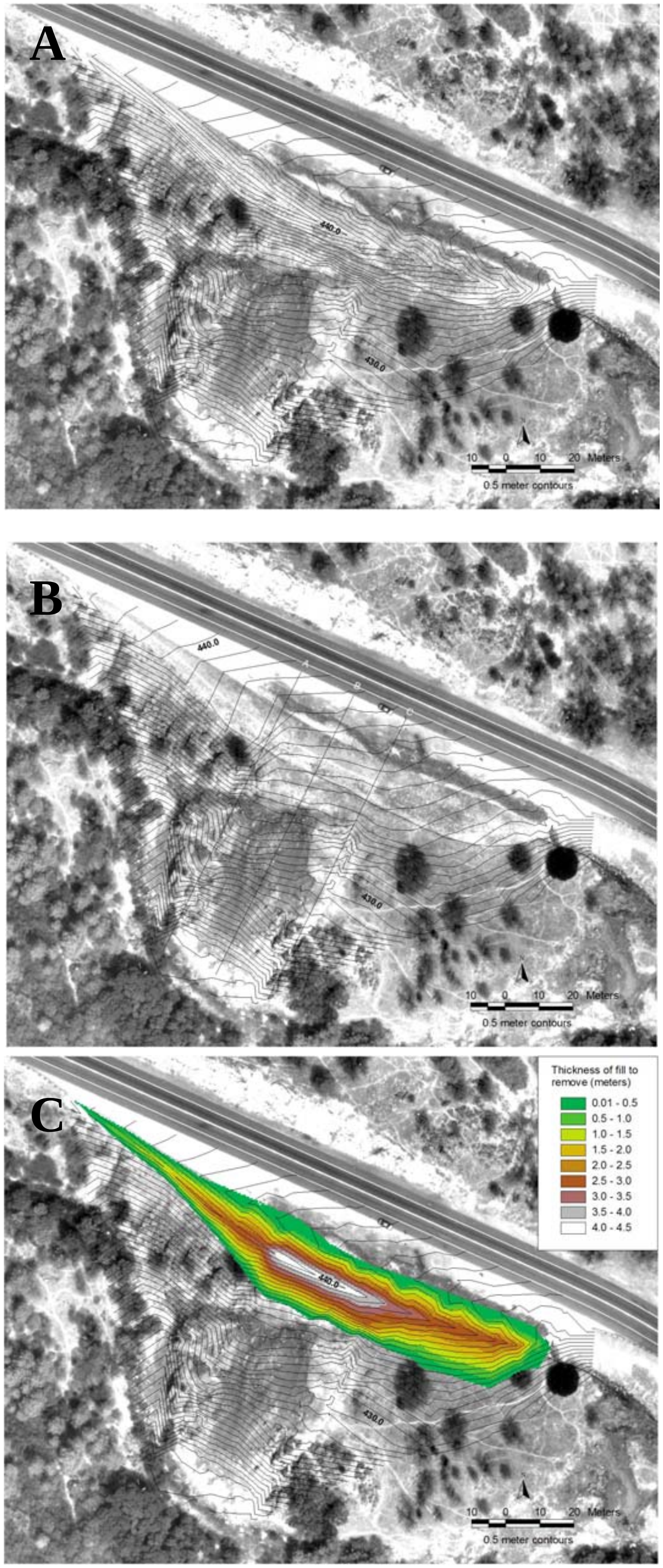


Figure 10. Profiles A, B, C of proposed fill removal. For profile locations see Fig. 11b.



Figures 11a, b, c. Existing topography (A) and proposed topography (B) for fill removal in spring 1, and thickness of fill to be removed (C).

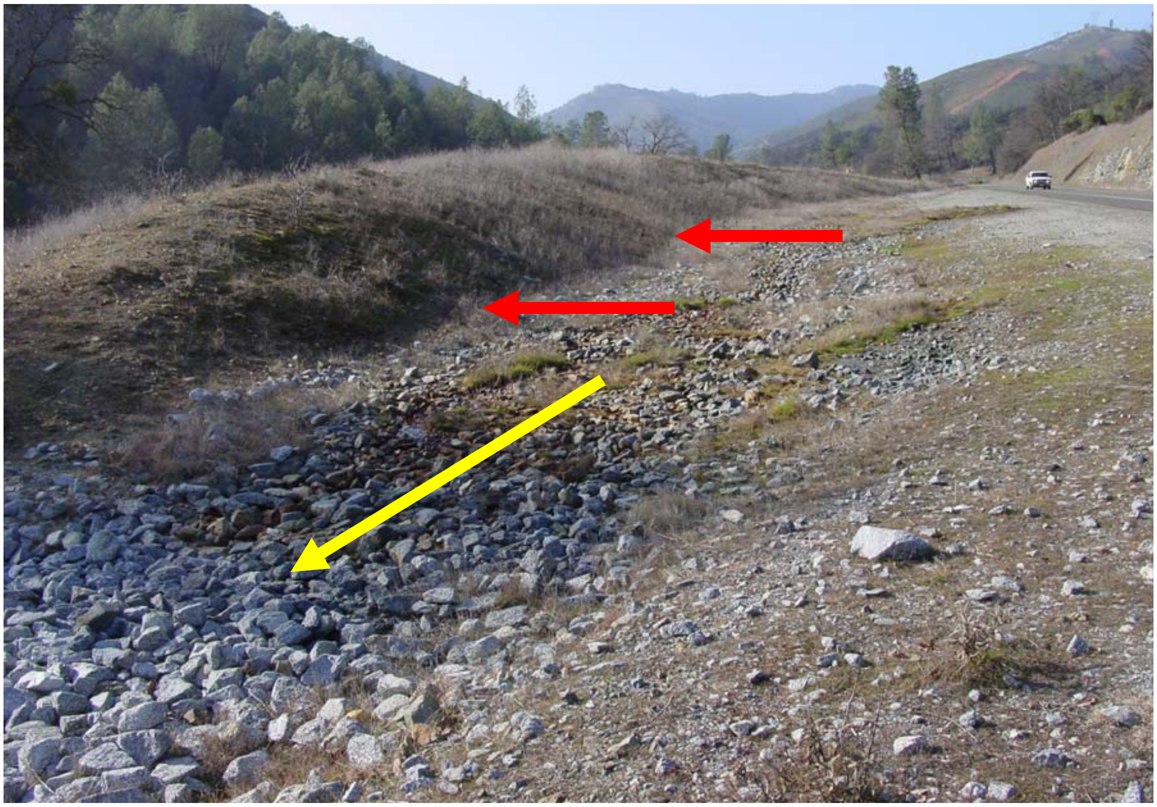


Figure 12. View looking west along the highway to the pull-off. Once the berm is removed, the area should be graded so that water that now flows east in the direction of the yellow arrow, instead will flow south in the direction of the red arrows.

Removal of Fill Material from Springs 2 and 3

Areas in spring 2 and possibly spring 3 have significant mineral sediment deposits that should be removed to expose the natural mineral springs/bedrock surface. The largest area of fill is in Spring 2 (Figure 13). A portion of this fill was removed years ago during a CalTrans mitigation project (Bacca 1990). However, insufficient sediment was removed to create the appropriate irrigated gravel environment that is suitable habitat for *Puccinellia*. Additional sediment should be removed (471 m^3, or 616 yd^3) so that a maximum 20 cm of decomposed bedrock exists above the consolidated bedrock, which would closely match baseline conditions in the best remaining habitats in springs 1 and 2. Existing topographic contours for spring 2 are shown in Figure 15a, and our proposed ground surface is shown in Figure 15b. Figures 15c and the profiles in Figures 16 a-g, show the thickness of fill that should be removed. The fill removal should be done with small excavators or backhoe, and sediment transported off site in small trucks, likely using the *Juncus balticus* fan to access the site.

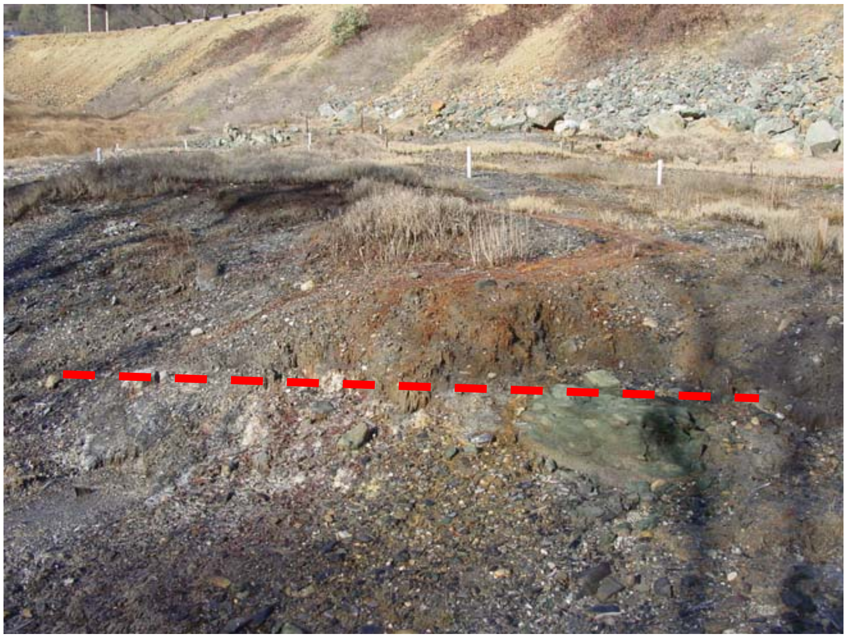
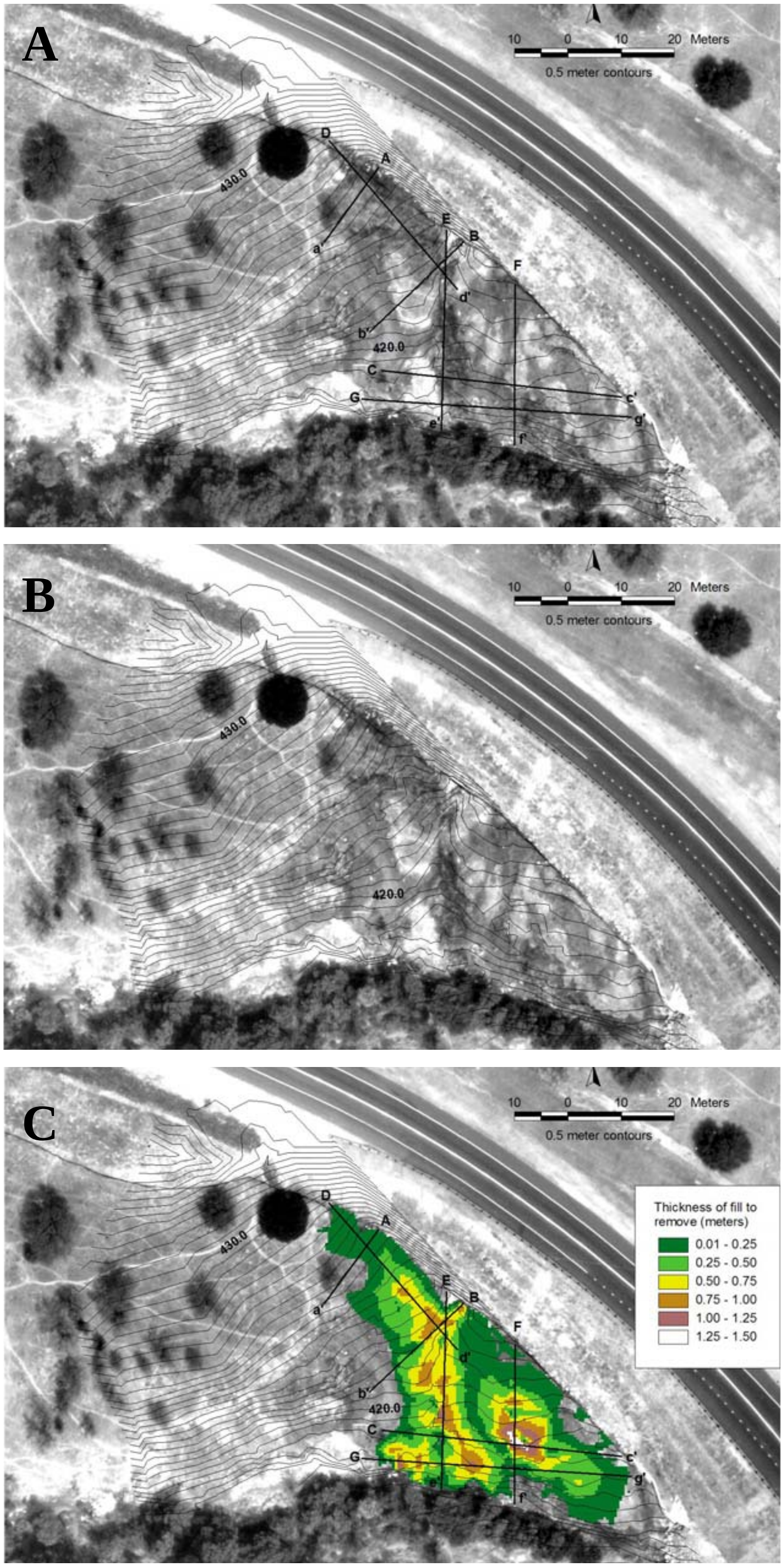


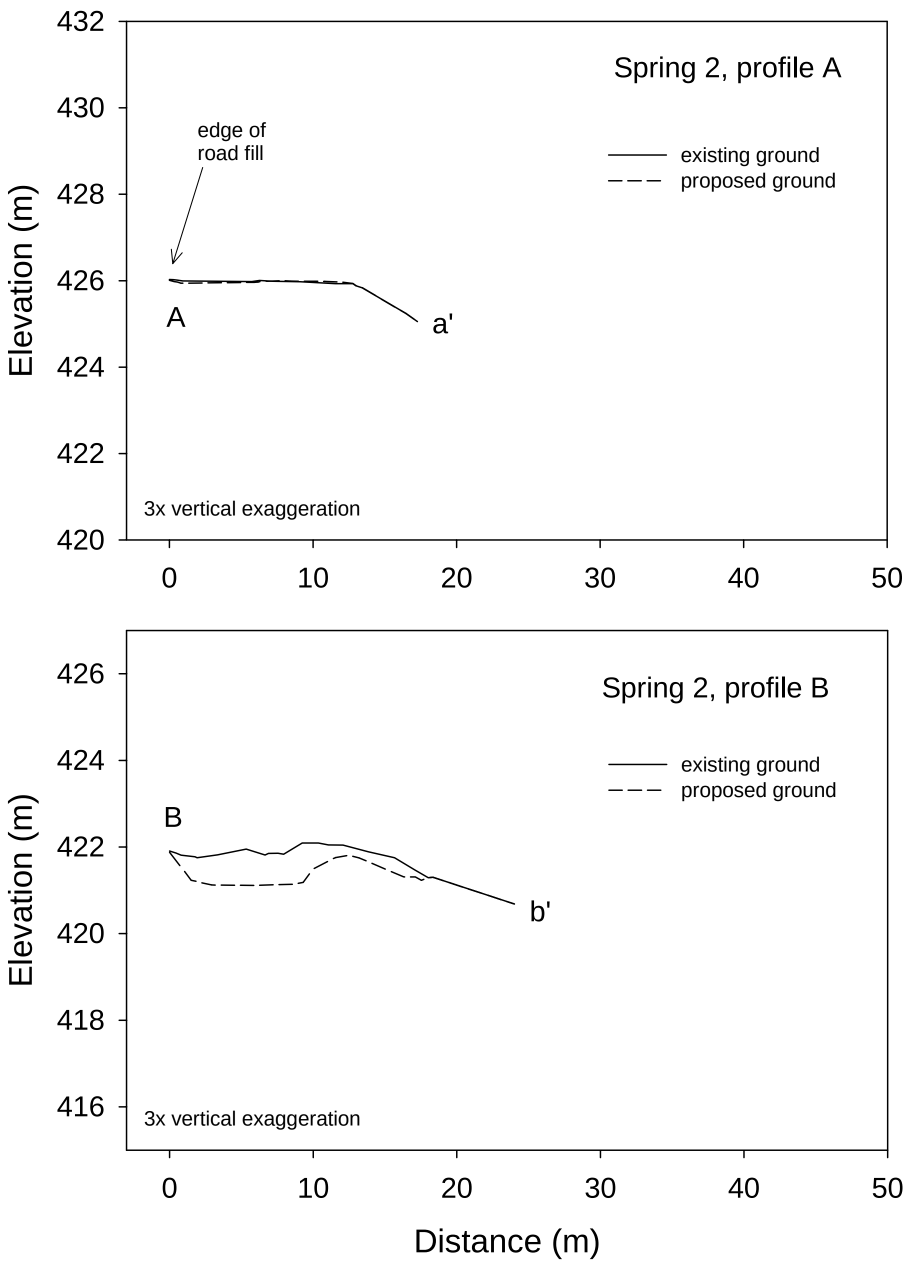
Figure 13 Fill thickness in Spring 2. Sediment above the dotted red line is fill.

Figure 14 Potential fill removal area in Spring 3.

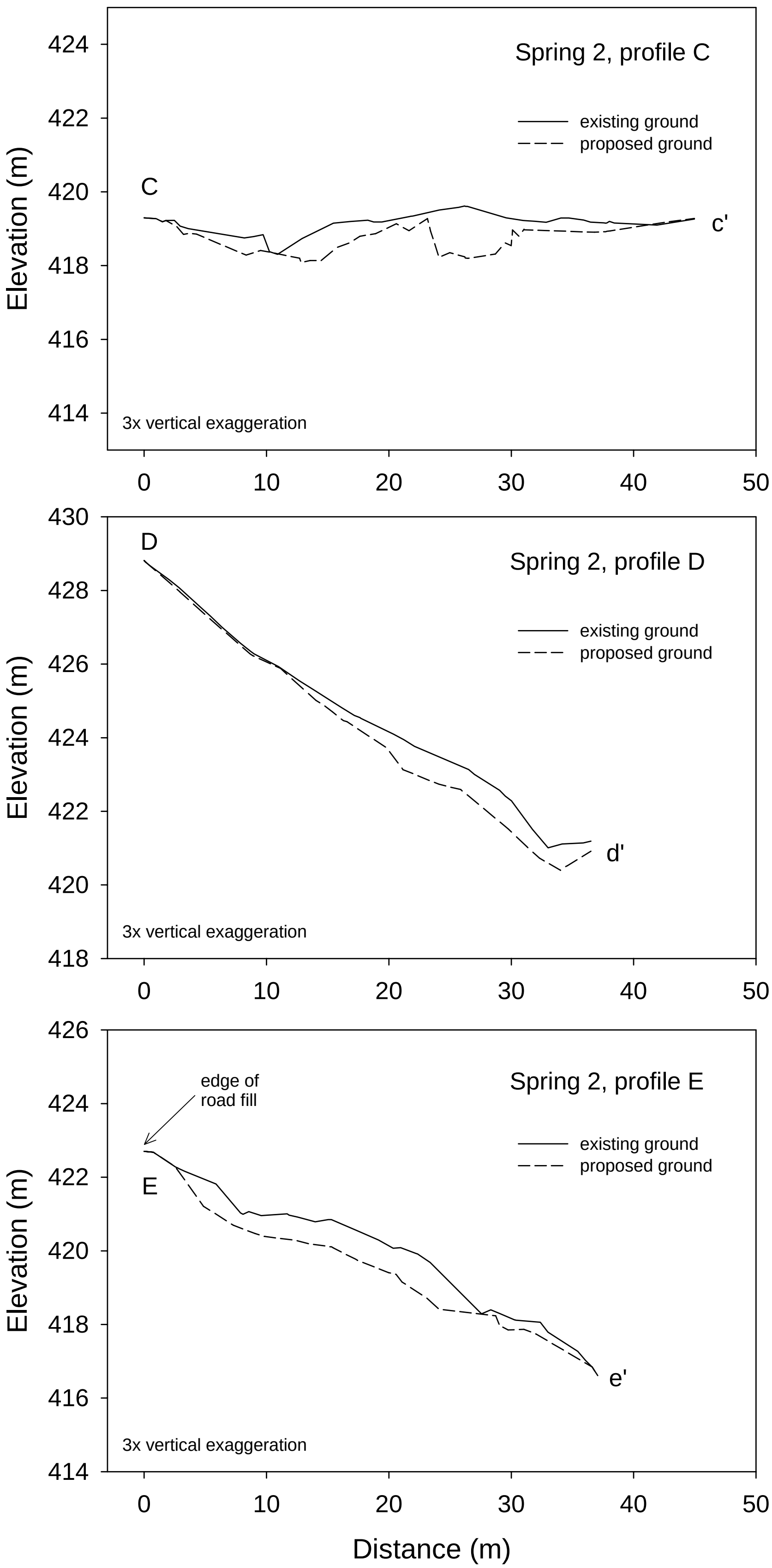


Figures 15. Plan views showing existing (a) and proposed (b) contours, and thickness of fill to be removed (c). Location of profiles (Figure 16) are on 15c.

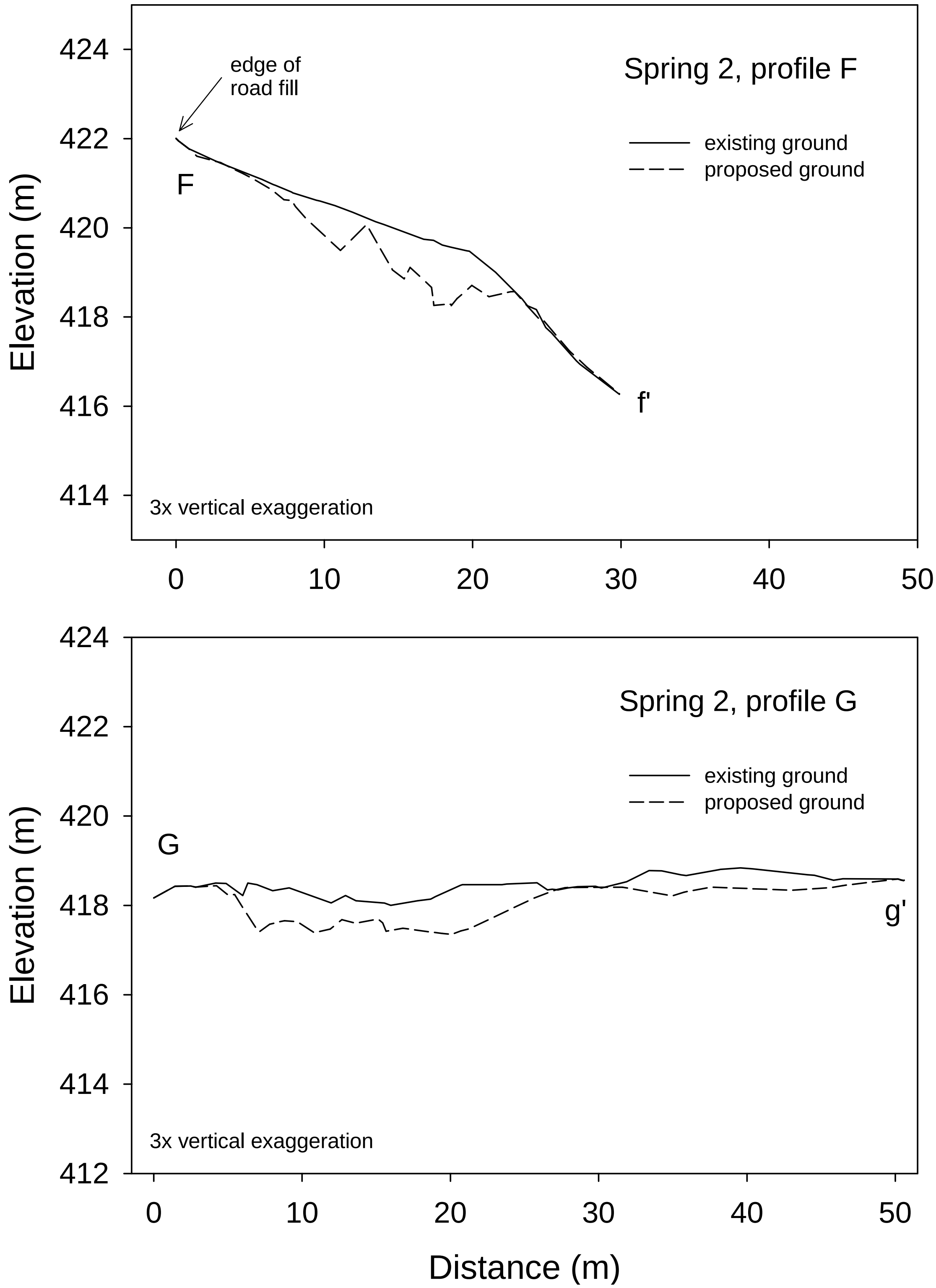
A small area of potential fill exists just beneath the wall at spring 3 (Figure 14). This area is unvegetated, and we are uncertain of the thickness of fill that exists and should be removed. We will do additional borings during the winter of 2007-2008 in this area, but it may be necessary to bring a small excavator into the site to accurately determine the volume of fill in place. Once fill is removed, these areas should have *Puccinellia* seed broadcast. If sufficient fine-textured sediment exists in the gravel matrix, a high pressure hose may be needed to flush the gravel free of fines.



Figures 16a-c. Profiles of existing and proposed ground for spring 2. Profile locations are shown in Figure 15c.


Spring 2, profile C
existing ground
proposed ground
C
c'
3x vertical exaggeration
Elevation (m)
424
422
420
418
416
414
0
10
20
30
40
50
Spring 2, profile D
existing ground
proposed ground
D
d'
3x vertical exaggeration
Elevation (m)
430
428
426
424
422
420
418
Spring 2, profile E
edge of
road fill
existing ground
proposed ground
E
e'
3x vertical exaggeration
Elevation (m)
426
424
422
420
418
416
414
Distance (m)

Figs. 16 c-e.



Figures 16 f and g.

Prioritization for Restoration Projects

We suggest that restoration projects be done in the following order:

1. Elongate fresh water discharge pipe so water enters Willow Creek at Spring 3.
2. Remove berm along highway pull-off north at Spring 1. The entire berm should be removed to allow ground water discharging into the pull-off to flow south into the eastern side of spring 1.
3. Remove fresh water input to spring 2, and remove sediment associated with the *Juncus* marsh.
4. Remove fill in the eastern side of spring 2.
5. Determine the nature and extent of fill at the northern side of spring 3, and possibly remove it.
6. Remove alluvial fan formed by the stream that flows through the culvert and create a new and stable stream channel from the culvert to Willow Creek.

Post-restoration Monitoring

A post-restoration monitoring program should be implemented for each project to determine whether the restoration has been successful. Specific goals for each project on water table depth, water chemistry, and *Puccinellia* establishment should be developed and provided in the restoration design package. A suite of existing monitoring wells should be identified that provide the desirable baseline for each project as well. Monitoring wells should be installed in the restoration area if they do not currently exist or would be impacted by restoration activities. Data on water table depth, water chemistry, and establishment and survival of *Puccinellia* and other taxa should be collected for a minimum of 3 years.

For each restoration project a minimum of 10 monitoring wells should be regularly measured to determine the depth to water table. On each visit the EC and pH of water in the well should be measured. At each monitoring well three 0.25 m^2 vegetation plots should be analyzed in June of each year. The plots should be permanently marked and located on the north, southeast, and southwestern side of the well 1 m from the well casing. Within each plot the number of *Puccinellia* plants should be counted. Plants should be put into size categories, of seedlings of the year, small tufts which are at least in their second year of life and larger tufts which are much older. In addition, the percent cover by plant species, as well as bare sediment should be recorded each year.

For sites where mineral sediment inputs are an issue, we suggest placing Astroturf squares, each 20x20 cm in size onto the ground, adhered with a 16 penny nail. The squares should be collected each summer, and the sediment removed by shaking into a zip lock bag after completely air drying. This sediment should be weighted, and converted to g/m^2.

The monitoring goals are to determine whether restoration sites attain hydrologic regimes, EC and pH, sediment flux and plant density similar to selected reference sites. A key element is determining which variables to measure for each site. We suggest that restoration projects be done in the following order:

1. Elongate fresh water discharge pipe so water enters Willow Creek at Spring 3. For this project we suggest measuring water tables, water chemistry, and plant density.
2. Remove berm along highway pull-off north at Spring 1. The entire berm should be removed to allow ground water discharging into the pull-off to flow south into the eastern side of spring 1. For this project water table, water chemistry, sediment flux and vegetation should be monitored.
3. Remove fresh water input to spring 2, and remove sediment associated with the *Juncus* marsh. For this project water table, water chemistry, and vegetation should be monitored.
4. Remove fill in the eastern side of spring 2. For this project water table, water chemistry, sediment flux and vegetation should be monitored.
5. Determine the nature and extent of fill at the northern side of spring 3, and possibly remove it. For this project water table, water chemistry, sediment flux and vegetation should be monitored.
6. Remove alluvial fan formed by the stream that flows through the culvert and create a new and stable stream channel from the culvert to Willow Creek. For this project water table, water chemistry, sediment flux and vegetation should be monitored.

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