Title
Using vegetated strips to manage runoff from Zone 7 Water Agency access roads

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Abstract

The Zone 7 Water Agency uses concrete V-ditches to manage stormwater runoff from access roads near creeks. We attempted to find a way to manage runoff that would filter the stormwater and cost less than concrete V-ditches. Using Tassajara Creek in Dublin, California, as a case study, we designed a low-maintenance vegetated strip that would be capable of filtering pollutants from runoff, even while conveying the expected Q_{100} flow of 0.451 cfs. Our vegetated strip would cost \$5-\$10 per linear foot, compared to \$16 per linear foot for Tassajara Creek's V-ditches. Zone 7 could adopt this design without changing any of its guidelines for managing runoff from access roads. Because Zone 7 has more confidence in the performance of concrete channels during high flows, we recommend that Zone 7 implement our design on a trial basis and monitor its performance.

Introduction

Storm runoff is a major concern in urban areas. To control overland flow, cities have begun to use vegetated methods, such as vegetated filter strips, grassy swales, and extended detention basins (NCTCG, 2004: Parsons et al. 2004). Compared to conventional systems like concrete curbs, gutters, and channels, vegetated methods are relatively inexpensive, and when properly designed, they can effectively reduce peak runoff and flow velocity and remove sediment and urban non-point pollution (NCTCG, 2004: EPA, 1999). A well-designed vegetated channel should require little more maintenance than 1-3 checks per year for erosion and vegetation loss; regular mowing when the grass reaches a height of 6 inches; and the removal of debris after large storms (SQTF, 1993: 5-35; METRO 2002: 49).

The effectiveness of vegetated channels is affected by soil and geomorphologic conditions, vegetation, and hydraulic characteristics (Parsons et al., 2004; EPA, 1999). Vegetated channels can easily fail when they are improperly designed or installed. Vegetated channels are most effective on large, flat areas (Government of British Colombia, 2004). They are not effective when their longitudinal slope exceeds 2.5 percent (CASQA, 2003: 2). High volumes or velocities of water can erode the channel, and selecting suitable vegetation is essential to avoid channel erosion (EPA. 2004). If these needs are not met, maintenance needs, including irrigation, re-seeding, and periodic inspection, can become a serious burden (Government of British Columbia, 2004: NCTCG, 2004). These issues can lead hydraulic engineers to specify concrete channels even when vegetated methods may be suitable.

The Zone 7 Water Agency in Alameda County, California ("Zone 7"), currently uses small concrete channels to prevent water from running off of paved access roads into creeks (Zone 7, 2004). These channels, known as V-ditches, are a relatively minor expense in the context of a major flood control project, but they require a significant capital investment. At Tassajara Creek in Dublin, California, where the agency completed a creek restoration project in 1999, the county built 8,500 linear feet of V-ditches at a cost of $16 per linear foot, for a total of $136,000; at Arroyo Mocho and Arroyo Las Positas in Livermore, California, the agency built 6,160 linear feet of V-ditches at a cost of $12 per linear foot, for a total of $74,500 (Stuart Cook, Alameda County Surplus Property Authority, personal communication, 4/5/2004).

Zone 7's policy is that building ditches from concrete is the most effective way to accommodate 100-year storms and maintain the ditches' structural integrity during high flows (Jeff Tang, Zone 7 Water Agency, personal communication, 4/13/2004). However, there are disadvantages to using V-ditches. Because they only convey water into drop structures, which drain directly into the creek, they do not filter or detain runoff before it enters the channel. Also, the ditches can crack, requiring additional maintenance.

For this project, our goal was to find a more environmentally-friendly and cost-effective way to manage stormwater runoff from Zone 7's access roads. Using a section of Tassajara Creek in Dublin, California, as a case study, we assessed the concrete V-ditch currently used at the site, then designed a vegetated channel to replace it that could filter pollutants from runoff before discharging water into the creek. We attempted to create an inexpensive design that would require little maintenance, yet still provide enough capacity to handle a 100-year storm. In addition, we examined concrete and earthen V-ditches along Arroyo Las Positas for comparison with Tassajara Creek.

Methods

Field survey

On March 25, 2004, we surveyed a cross-section of the access road and V-ditch on the east side of Tassajara Creek between Central Parkway and Dublin Boulevard (Figure 1). Using a level and a measuring rod, we measured the elevations at seven stations on the access road and the V-ditch. As a benchmark, we used the bottom of a pylon in the middle of the access road, just south of Central Parkway (Figure 2); we gave this benchmark an arbitrary elevation of 100 feet. We photographed several sections of the access road and its V-ditch for illustrative purposes and to provide a record of their condition.

In addition, we visited another site that Zone 7 manages, the confluence of Arroyo Mocho and Arroyo Las Positas in Livermore, CA, on April 14, 2004. Two reaches of Arroyo Las Positas were restored at different times, one in the early 1990s and another in 2003 and 2004 (Stuart Cook, personal communication, 4/14/2004), and Zone 7 used different methods to manage runoff from access roads on each reach. We observed and photographed the different structures for conveying runoff.

Estimating runoff and concrete channel capacity

To determine the amount of runoff that our vegetated channel would need to convey, we used the Rational method (Dunne and Leopold, 1978: 298-305, 370-372) to estimate the runoff from the access road in a 100-year storm. The Rational method, expressed in the following formula, is well-suited for small drainage areas such as an access road.

$Q = CIA$

Where Q = peak discharge (cfs) for a given rainfall intensity
C = cover factor (Rational coefficient) representing the surface's infiltration characteristics
I = rainfall intensity (in/hr) for a storm event
A = drainage area (ac)

We calculated the drainage area by measuring the width of the Tassajara Creek access road in feet, then multiplying the path's approximate width by 800 feet, the maximum length that Zone 7 allows between drop structures in V-ditches (Zone 7, 2004). We then converted this value to acres.

We obtained the mean annual precipitation from the National Oceanic and Atmospheric Administration's National Climactic Data Center (NCDC, 2004) (Appendix 1). Since no gauging station exists in Dublin, we used data from Livermore, CA. This station is within about 10 miles of Dublin, and it has been in operation since 1931, longer than other stations near Dublin. We obtained the site's elevation from a map of local watersheds; the elevation is approximately 350 feet throughout our study area (Sowers and Richard, 2003).

To calculate the flow velocity in the concrete V-ditch, we used the Manning equation:

$v = c(s^{0.5} R^{0.67})/n$

Where v = velocity (ft/s)
c = 1.49
s = energy slope = dh/dl
R = cross-sectional area/wetted perimeter
= hydraulic radius
n = coefficient of roughness

When we applied the Manning equation to estimate the V-ditch's capacity, we used two different values for the roughness coefficient, *n*, which cannot be measured directly but which significantly changes the equation's result. First, we used the value 0.013, a standard value for trowel-finished concrete surfaces (Chow, 1959: 111). We believe this *n* value reflects the design capacity of the V-ditch. We also applied the Chow method (Chow, 1959: 109), which accounts for various channel characteristics such as obstructions and vegetation, to estimate the value of *n* at 0.023. We believe this *n* value more accurately reflects the actual capacity of the V-ditch. Appendix 2 provides the information we used to derive this estimate.

Creating an alternative design

After estimating the amount of runoff and the capacity of the V-ditch, we designed a vegetated strip with a capacity that is suitable for the site. The channel would run parallel to the access road, much like the existing V-ditch. To calculate the strip's capacity, we needed to choose an appropriate Manning's *n* value for a vegetated channel. A number of experts recommend an *n* of 0.20 (Lichten, 1997: 55). However, a more recent publication by the California Stormwater Quality Association recommends an *n* of 0.25 (CASQA, 2003: 2). We chose to use this higher value, which might better reflect how the channel would perform if it contained debris or invasive vegetation.

Results

Tassajara Creek observations and calculations

Our field observations indicated that the access road along Tassajara Creek is approximately 12 feet wide, with a slight bank towards a concrete V-ditch that is approximately 3 feet wide (Figure 4). The surface of the V-ditch is fairly smooth. We noticed several places where the concrete had cracked and been patched, but it was not clear whether the cracks had developed during construction or whether Zone 7 had repaired them as a maintenance task. We also found unrepaired cracks in several parts of the ditch, although none of them appeared to pose an immediate threat to the ditch's structural integrity (Figure 5).

All of the drainage grates in the V-ditch were covered by debris, including leaves, silt, and bark chips from the adjacent landscaping strip. Blankets of leaves covered as much as half of each drainage grate (Figure 4). Also, at several locations along the access road, the V-ditch enters one or two pipes, each with a diameter of 0.5 ft, so that cars can drive from adjacent streets onto the access road. The entrance to each pipe was at least partially blocked by debris (Figure 5). We conducted our observations during the rainy season, so the deposits may have been recent. However, it was not possible to determine how long they had been there or whether they had impeded the flow of runoff during earlier storms.

When we used a Manning's *n* value of 0.013, the standard for concrete surfaces, we estimated the ditch's capacity to be 3.77 cubic feet per second (cfs). Appendix 4 shows the values we used to calculate this estimate. Assuming all other variables remain the same, but using the *n* value 0.023, which accounts for the obstructions we observed in the ditch, we estimated a capacity of 2.13 cfs. However, the Manning equation does not account for factors such as clogged drainage pipes; the obstructions we observed in the ditch would reduce its capacity by an unknown amount.

To estimate runoff from the access road, we determined that the average annual rainfall at the Livermore, CA rain gauge between 1931 and 2003 was 14.73 inches (NCDC, 2004). We used a nomograph from Dunne and Leopold (1978: 303) to estimate that the runoff's time of concentration is 10 minutes. Based on this time of concentration and average annual rainfall, we used precipitation depth-duration-frequency data from Rantz (1971: 2) to estimate the Q_{100} rainfall intensity at 2.28 in/hr. Given that the road is about 12 feet wide, and the maximum distance allowed between drop structures is 800 ft, the maximum drainage area feeding into a section of the V-ditch is 9600 ft^2 (0.220 ac). We used a cover factor of 0.9, the highest recommended value for paved surfaces (Ferguson and Debo, 1990); 0.8 might have been a more appropriate value, given the access road's flat slope, but we wanted to ensure that our estimate was conservative. Based on all of these values, the Rational estimate of the Q_{100} flow from the access road is 0.451 cfs.

Arroyo Las Positas observations

At the newly modified reach of Arroyo Las Positas, the access road is approximately 12 feet wide, and its concrete V-ditch is approximately 2 feet wide. We did not observe any cracks or other damage to the V-ditch. During construction of the project, workers had covered a hill adjacent to the ditch with straw to prevent erosion; some of this straw had fallen or been washed into the ditch (Figure 6).

The reach that Zone 7 modified in the early 1990s uses an earthen V-ditch, lined with gravel, to convey runoff from the unpaved access road. This V-ditch did not appear to have any vegetation or other material that would hold its banks in place. In many places, the ditch appears to have collapsed, becoming a slight depression in the ground rather than a distinct channel. Figure 6 shows an example of the earthen V-ditch's appearance.

Vegetated strip design

As an alternative to the V-ditch, our proposed design for the vegetated strip is a shallow earthen trench, 5 feet wide and 0.5 feet deep, with a flat bottom. The strip has shallow sides so that the side slopes have a 3:1 horizontal:vertical grade, the maximum recommended value. The strip's slope is roughly 1 percent. The strip is designed primarily to convey water and filter pollutants from it, not to infiltrate it into the ground. A gravel underdrain, 2 feet wide and 0.5 feet deep, with a 3 inch PVC perforated drainage pipe ensures that water does not pool and create a breeding ground for mosquitoes or undermine the adjacent access road. Drop structures carry water from the strip into the creek. Figure 8 illustrates the design for the vegetated strip.

With a Manning's *n* value of 0.25, we estimate that the strip can convey 0.541 cfs, less than the capacity of the concrete V-ditch but large enough to handle the estimated Q_{100} of 0.451 cfs. Even at this level, the flow's velocity should be only 0.309 ft/s, ensuring that the vegetation can still filter pollutants from the water (Lichten, 1997: 48). Appendix 5 compares several characteristics of our proposal with the existing concrete V-ditch.

We recommend planting the strip with California brome (*Bromus carinatus*), a native perennial grass that is adapted to California's Mediterranean climate and thus requires no irrigation during the summer (Lichten, 1997: 84). The grass' root system should minimize erosion in the strip, reducing the need for maintenance.

This design complies with all of Zone 7's guidelines for controlling runoff from surface roads (see Appendix 6 for the guidelines). Zone 7 already permits the construction of earthen V-ditches, and the proposed design meets the minimum depth requirement of six inches and exceeds the minimum width requirement of two feet (Zone 7, 2004). However, as mentioned earlier, the agency's position is that concrete V-ditches are less likely than earthen ditches to fail or require large amounts of maintenance, especially during or after a Q_{100} storm (Jeff Tang, Zone 7 Water Agency, personal communication, 4/13/2004).

Cost estimates for this type of vegetated channel range from $4.50 to $15 per linear foot; higher estimates reflect the inclusion of features such as check dams, which were not necessary in our design (FHWA; ACCWP). According to estimates obtained by the Alameda County

Surplus Property Authority, the construction cost of our design would be approximately $5 per linear foot, meaning that it would have cost $42,500 to implement our design at Tassajara Creek—$93,500 less than the cost of building concrete V-ditches (Stuart Cook, Alameda County Surplus Property Authority, personal communication, 5/3/2004). The cost could be lower if the strip and the access road were built in conjunction with one another. If the design actually cost $10 per linear foot to build, which we consider to be an overly conservative estimate, it would have cost $85,000 to implement at Tassajara Creek—$51,000 less than the cost of the V-ditches.

Discussion

Our observations and calculations indicate that Zone 7 could build vegetated strips instead of concrete V-ditches in the future. Our proposed design for a vegetated strip offers a variety of benefits. First, because of their higher roughness coefficient, vegetated strips slow runoff velocity and attenuate peak runoff rates during a storm. Also, although the strips do not drastically alter the total volume of runoff reaching the creek, some water could evaporate from the strips and be taken up by the vegetation (METRO, 2002: 48; Dunne and Leopold, 1978: 88, 127).

There is considerable evidence that vegetated strips can also improve water quality. By passing runoff through vegetation or soil, they slow runoff and allow sediments to come out of suspension, including oils and grease, nutrients, metals, and bacteria (METRO, 2002: 48). With a concrete channel, these pollutants drain straight into the creek.

Another important benefit of vegetated strips is their potential cost savings to Zone 7. The literature and the cost estimates we obtained suggest that it would cost less to build our vegetated strip than a concrete V-ditch—$2-$7 less per linear foot than the V-ditch at Arroyo Las Positas, and $6-$11 less than the wider V-ditch at Tassajara Creek.

Zone 7's concerns about the maintenance of earthen vegetated strips are understandable, especially considering the degraded state of the unvegetated earthen ditch at Arroyo Las Positas. However, our observations indicate that concrete V-ditches have their own maintenance needs as well; at Tassajara Creek, we saw several cracks that had been repaired in the past and others that would require repairs in the future. Also, the most serious maintenance issue appeared to be debris such as mulch and dead leaves that clogged pipes and drainage grates. Regardless of the material used to build the V-ditch, someone must remove this debris often enough that it does not impede runoff during a storm.

The predicted velocity of water in the vegetated strip during a Q_{100} storm, 0.309 ft/s, is not high enough to cause a vegetated earthen channel to become unstable (Lichten, 1997: 61-64), and a healthy vegetation root system would minimize erosion. If they are properly designed and appropriate vegetation is selected, vegetated strips should require relatively little maintenance. Although Portland, Oregon's METRO (2002: 49) recommends periodic irrigation to keep vegetation alive in extreme drought, we believe this would not be necessary here, since California brome is a native species of grass that is adapted to the local climate (Lichten, 1997: 84).

The vegetated strip we propose is several feet wider than some of Zone 7's existing V-ditches. Zone 7 could account for this added width when it designs future projects, but if an existing V-ditch needed to be replaced, it could be somewhat difficult to replace it with a vegetated strip. At Tassajara Creek, it would be relatively easy to take the additional right-of-way from the access road or the landscaping strip, although Zone 7's current guidelines for road width would prohibit the former (Zone 7, 2004). At Arroyo Las Positas, however, because the V-ditch is narrower, set below the road, and adjacent to the property line, it could be slightly more difficult to replace the ditch with a vegetated strip.

Conclusions

We have demonstrated that the Zone 7 Water Agency could use vegetated strips to convey runoff from access roads without incurring excessive maintenance needs or foregoing the ability to handle Q_{100} flows. In addition, Zone 7 could use the vegetated method without revising its current guidelines for the construction of V-ditches. The agency should consider using vegetated strips in the future instead of concrete V-ditches. If Zone 7 is not confident that earthen strips will maintain their integrity over time, it could construct vegetated strips for a single flood control project and monitor their performance. Zone 7 could also build test strips in a controlled environment and evaluate their condition after conveying different flows.

Regardless of whether Zone 7 ever uses vegetated strips to control runoff, we recommend that it take additional steps to prevent debris from accumulating in V-ditches; no structure will convey runoff efficiently if it is so clogged with debris that water cannot move through it. In particular, Zone 7 should not allow mulch or similar materials to be used where storms will wash them into a V-ditch. On landscaping strips like the one we observed at Tassajara Creek, it would be more appropriate to use a vegetative ground cover, which would create less debris and perhaps offer more protection against soil erosion. These policies should reduce the maintenance requirements for V-ditches and allow them to convey water more efficiently.

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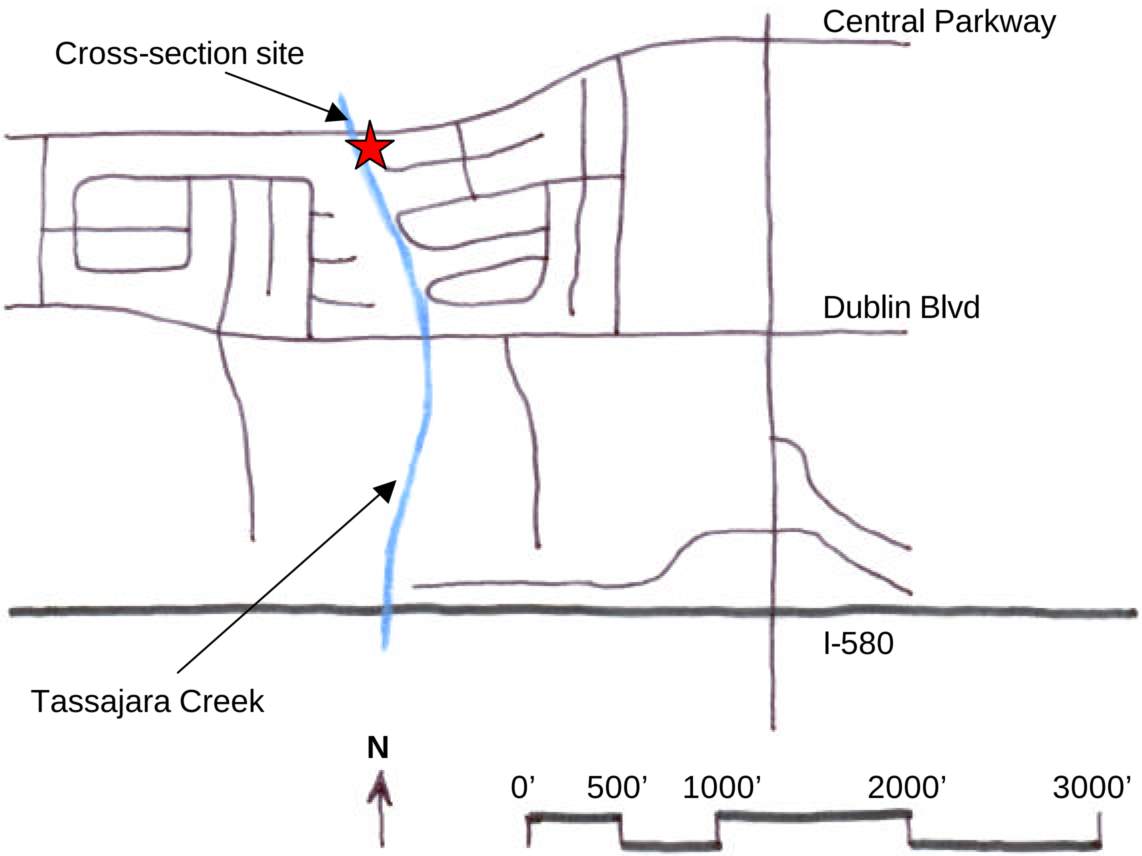
Figures

Figure 1: Tassajara Creek study area



Source: CSAA, 2002.

Figure 2: Benchmark site, Tassajara Creek, 3/25/2004

Benchmark site

Figure 4: Cross-section of Tassajara Creek access road at Central Parkway, 3/25/2004

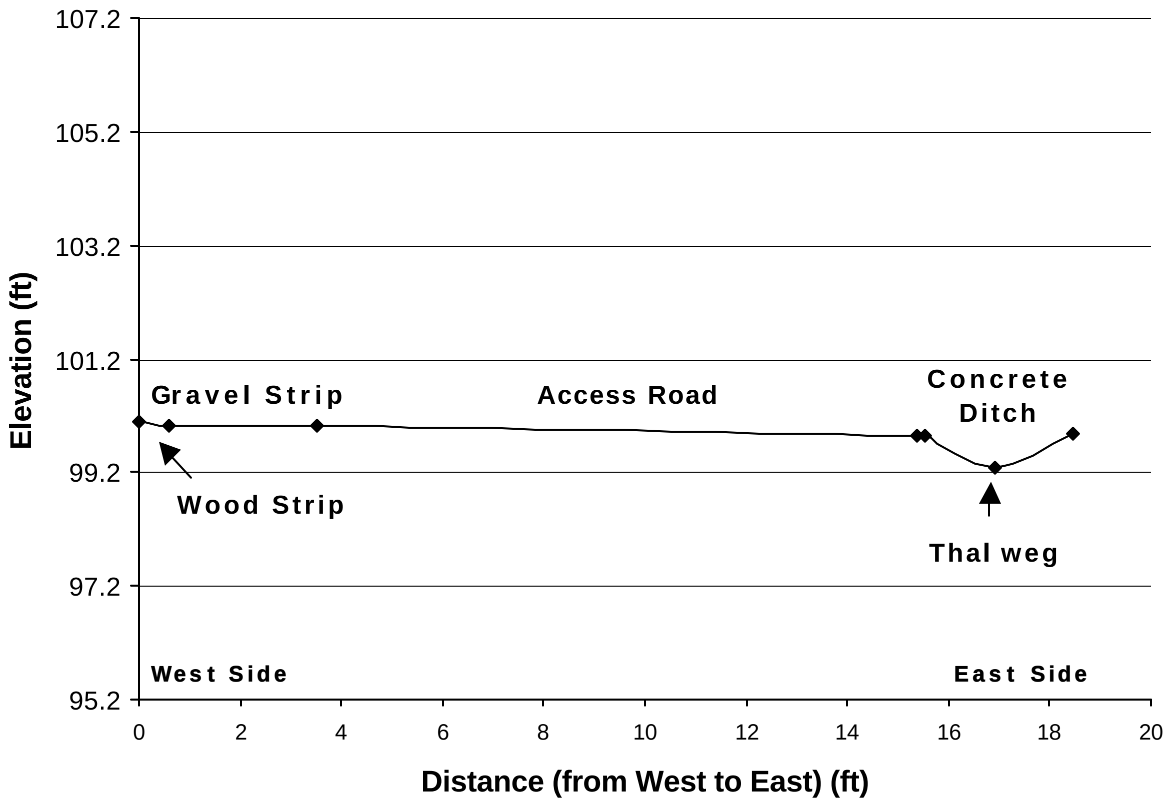


Figure 3: Cracks in V-ditch at Tassajara Creek, 3/25/2004

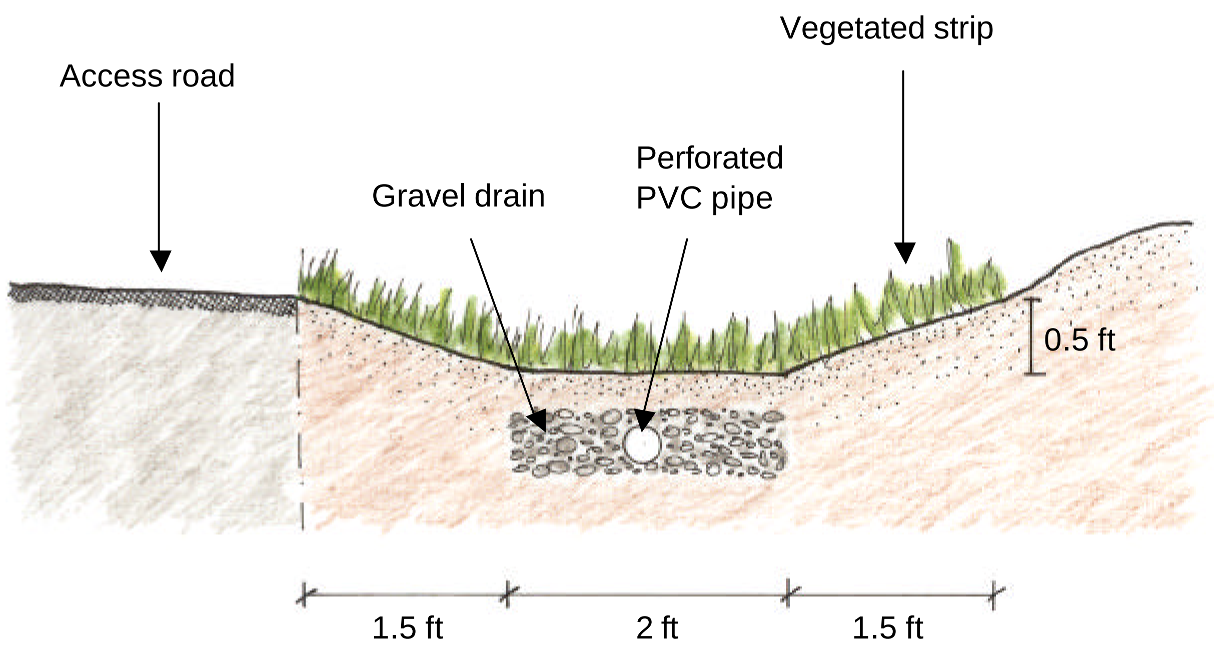
Figure 4: Debris clogging a drainage grate at Tassajara Creek, 3/25/2004

Figure 5: Pipes filled with debris at Tassajara Creek, 3/25/2004

Figure 6: V-ditch partially covered with straw at Arroyo Las Positas, 4/14/2004

Figure 7: Earthen V-ditch at Arroyo Las Positas, looking downstream, 4/14/2004

Figure 8: Vegetated strip design



Appendices

Appendix 1: Annual inches of precipitation in Livermore, CA

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1931	3.45	1.67	0.57	0.36	0.93	0.11	0.00	0.00	0.00	0.27	1.89	5.63	14.88
1932	1.29	3.15	0.19	0.41	0.37	0.00	0.00	0.00	0.00	0.00	0.51	2.03	7.95
1933	4.51	0.44	2.09	0.13	0.70	0.03	0.00	0.00	0.01	0.75	0.00	3.69	12.35
1934	1.29	2.86	0.00	0.13	0.60	0.53	0.00	0.00	0.27	0.62	2.71	2.32	11.33
1935	3.53	0.52	3.16	3.28	0.00	0.00	0.00	0.04	0.00	0.79	0.21	1.53	13.06
1936	3.28	6.76	0.71	0.63	0.46	0.10	0.00	0.00	0.00	0.40	0.02	3.26	15.62
1937	3.38	4.13	5.07	0.68	0.17	0.20	0.00	0.00	0.00	0.55	2.46	4.57	21.21
1938	2.40	6.14	4.09	0.90	0.02	0.00	0.00	0.00	0.00	1.00	1.08	0.52	16.15
1939	2.40	1.57	2.18	0.53	0.18	0.00	0.00	0.00	0.16	1.23	0.15	0.78	9.18
1940	8.13	5.14	2.60	0.35	0.14	0.00	0.00	0.00	0.25	0.50	0.43	4.63	22.17
1941	3.24	4.19	2.07	2.76	0.23	0.00	0.00	0.03	0.00	0.72	0.89	5.34	19.47
1942	3.89	1.68	1.42	3.10	1.00	0.00	0.00	0.00	0.09	1.08	3.05	1.73	17.04
1943	4.48	1.68	2.39	1.14	0.00	0.06	0.00	0.00	0.00	0.30	0.53	1.23	11.81
1944	2.36	4.89	1.01	0.94	0.73	0.00	0.00	0.00	0.00	0.77	3.41	2.03	16.14
1945	0.87	3.68	3.19	0.20	0.17	0.00	0.00	0.02	0.00	1.07	2.07	2.98	14.25
1946	0.76	1.23	1.69	0.02	0.61	0.00	0.24	0.00	0.02	0.02	2.93	2.07	9.59
1947	0.69	1.45	2.34	0.53	0.17	0.36	0.00	0.00	0.00	1.84	0.85	0.51	8.74

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1948	0.20	1.11	2.79	2.50	1.03	0.16	0.03	0.00	0.00	0.46	0.34	2.71	11.33
1949	1.39	2.47	3.38	0.02	0.34	0.00	0.03	0.16	0.05	0.08	1.20	1.21	10.33
1950	4.65	1.54	1.44	0.85	0.59	0.01	0.00	0.00	0.08	1.84	5.95	4.95	21.90
1951	2.23	1.87	1.82	0.55	0.35	0.06	0.00	0.00	0.00	1.04	3.15	6.07	17.14
1952	7.60	1.40	2.53	2.20	0.16	0.04	0.00	0.00	0.10	0.01	2.11	6.33	22.48
1953	2.07	0.05	1.12	1.92	0.61	0.59	0.00	0.15	0.00	0.21	1.38	0.64	8.74
1954	2.19	2.27	3.30	0.73	0.16	0.30	0.00	0.00	0.04	0.00	1.68	3.33	14.00
1955	3.28	1.69	0.40	1.37	0.65	0.00	0.00	0.01	0.01	0.01	1.31	10.15	18.88
1956	5.49	1.15	0.14	1.92	0.63	0.00	0.00	0.00	0.63	0.79	0.03	0.48	11.26
1957	2.65	2.23	1.30	1.14	2.74	0.04	0.00	0.00	0.05	1.06	0.37	2.26	13.84
1958	3.16	5.37	4.44	3.74	0.66	0.41	0.00	0.00	0.02	0.09	0.14	0.86	18.89
1959	2.45	3.59	0.29	0.35	0.00	0.00	0.00	0.07	1.89	0.00	0.00	0.75	9.39
1960	2.98	4.12	0.60	0.48	0.42	0.00	0.02	0.00	0.01	0.05	2.92	1.25	12.85
1961	2.08	1.04	1.92	1.03	0.69	0.19	0.00	0.13	0.16	0.15	2.24	0.82	10.45
1962	0.73	5.61	1.82	0.22	0.00	0.00	0.00	0.00	0.00	3.64	0.28	1.55	13.85
1963	1.40	4.50	2.60	3.47	0.70	0.00	0.00	0.00	0.33	0.93	3.18	0.19	17.30
1964	2.37	0.08	1.57	0.21	0.48	0.32	0.00	0.12	0.04	0.85	2.44	4.91	13.39
1965	2.11	0.59	1.73	1.53	0.00	0.00	0.00	0.21	0.00	0.03	4.22	3.23	13.65
1966	1.05	1.17	0.17	0.33	0.10	0.12	0.17	0.00	0.11	0.00	3.43	2.35	9.00
1967	6.14	0.29	4.15	4.65	0.19	0.48	0.00	0.00	0.02	0.24	0.88	1.62	18.66
1968	3.93	0.90	2.40	0.43	0.15	0.00	0.00	0.00	0.00	0.43	2.48	3.04	13.76
1969	6.28	4.76	0.55	1.24	0.08	0.00	0.00	0.00	0.00	1.10	0.49	2.34	16.84
1970	5.38	1.18	1.42	0.40	0.07	0.32	0.00	0.00	0.00	0.41	5.24	5.27	19.69
1971	1.19	0.33	1.75	1.37	0.54	0.00	0.00	0.00	0.13	0.04	0.46	3.27	9.08
1972	0.90	0.79	0.14	0.64	0.00	0.04	0.00	0.00	0.58	2.98	4.91	2.22	13.20
1973	5.50	3.83	2.63	0.29	0.03	0.00	0.00	0.00	0.08	2.08	3.71	3.80	21.95
1974	1.50	0.71	2.69	1.62	0.00	0.00	0.00	0.00	0.00	0.50	0.66	1.98	9.66
1975	0.84	3.65	5.24	1.42	0.00	0.06	0.10	0.35	0.00	1.27	0.08	0.21	13.22
1976	0.30	1.46	0.48	0.39	0.00	0.18	0.00	0.91	0.95	0.50	0.50	0.73	6.40
1977	1.15	0.83	0.82	0.16	1.01	0.00	0.10	0.00	0.22	0.13	1.34	3.07	8.83
1978	5.44	2.95	3.07	2.49	0.01	0.00	0.00	0.00	0.04	0.00	2.16	0.58	16.74
1979	4.52	3.19	1.86	0.88	0.34	0.00	0.06	0.00	0.00	1.51	1.13	2.66	16.15
1980	4.16	4.24	1.36	1.32	0.48	0.00	0.70	0.00	0.00	0.04	0.28	1.18	13.76
1981	3.97	1.11	2.94	0.61	0.11	0.00	0.00	0.00	0.06	2.07	3.44	2.57	16.88
1982	5.29	2.16	5.58	1.50	0.00	0.28	0.00	0.01	1.48	2.24	3.72	2.80	25.06
1983	6.28	5.56	6.14	3.51	0.21	0.00	0.00	0.50	1.02	0.27	5.44	3.44	32.37
1984	0.33	1.87	1.00	0.53	0.01	0.03	0.00	0.00	0.04	1.25	4.71	1.51	11.28
1985	0.48	1.25	2.62	0.32	0.07	0.22	0.00	0.03	0.13	0.89	2.69	1.97	10.67
1986	2.04	7.11	4.09	0.40	0.14	0.00	0.01	0.00	0.45	0.04	0.08	0.92	15.28
1987	1.83	3.47	2.30	0.16	0.09	unk	0.00	0.00	0.00	0.87	1.40	2.30	12.42 *
1988	1.78	0.38	0.26	1.15	0.45	0.10	0.00	0.00	0.00	0.11	1.92	2.03	8.18
1989	0.81	0.95	2.94	0.88	0.08	0.10	0.00	0.00	1.33	1.13	1.02	0.10	9.34
1990	1.54	2.46	0.87	0.37	1.78	0.00	0.02	0.00	0.06	0.08	0.39	1.45	9.02
1991	0.31	2.20	5.87	0.34	0.35	0.08	0.00	0.21	0.04	1.65	0.31	1.19	12.55
1992	1.39	4.61	1.97	0.43	0.00	0.09	0.00	0.00	0.00	0.90	0.15	4.79	14.33
1993	6.41	4.53	2.91	0.63	0.51	0.30	0.00	0.00	0.00	0.57	2.00	1.81	19.67
1994	0.94	3.33	0.15	1.20	1.78	0.04	0.00	0.00	0.00	0.58	unk	1.36	9.38 *
1995	6.64	0.33	6.66	1.02	0.92	0.70	0.00	0.00	0.00	0.00	0.01	5.37	21.65

Year	Jan	Feb	Mar	Apr	May	Jun	Jul	Aug	Sep	Oct	Nov	Dec	Total
1996	5.17	4.10	2.34	1.91	1.05	0.00	0.00	0.00	0.00	1.08	2.55	4.43	22.63
1997	5.81	0.15	0.06	0.15	0.29	0.17	0.00	0.42	0.00	0.28	4.23	1.95	13.51
1998	5.47	7.30	2.37	1.37	2.00	0.13	0.00	0.00	0.18	0.54	2.48	0.73	22.57
1999	3.23	3.33	1.67	0.99	0.08	0.01	0.00	0.03	0.04	0.15	1.26	0.25	11.04
2000	4.61	4.87	1.25	0.59	0.69	0.18	0.00	0.01	0.24	unk	0.49	0.45	13.38 *
2001	1.92	2.89	1.22	1.80	0.00	0.12	0.00	0.00	0.09	0.37	1.92	5.09	15.42
2002	0.72	0.62	1.65	0.16	0.68	0.00	0.00	0.00	0.00	0.00	2.65	7.01	13.49
2003	0.66	1.31	1.07	3.09	0.95	0.00	0.00	0.29	0.00	0.02	2.02	3.57	12.98
											1931-2003 average		**14.73**

Source: NCDC, 2004. "Unk" indicates unknown precipitation. Asterisks (*) indicate that a month of precipitation data was missing and is therefore not included in the yearly total.

Appendix 2: Input used with Chow method to estimate Manning's *n*

$n = (n_0 + n_1 + n_2 + n_3 + n_4)\ m_5$

- Material involved (n_0): Trowel-finished concrete (0.013)
- Degree of irregularity (n_1): Smooth (0.000)
- Variations of channel cross section (n_2): Gradual (0.000)
- Relative effect of obstructions (n_3): Minor (0.010)
- Vegetation (n_4): None (0.000)
- Degree of meandering (m_5): Minor (1.000)

Appendix 3: Field measurements of access road and V-ditch at Tassajara Creek, 3/25/2004

STA	FS	BS	HT	EL	DIST	NOTES
BM1		4.29		100		Arbitrary elevation
			104.29			
ST1		4.19		100.1	0	Top of wood strip on west side of path. Wood strip is 1.3" wide.
ST2		4.27		100.02	0.6	On gravel strip
ST3		4.28		100.01	3.5	Far east side of gravel strip
ST4		4.43		99.86	15.38	Far east side of path. Wood strip between path and ditch is between 15.39 and 15.51.
ST5		4.44		99.85	15.54	Far west side of ditch, at top
ST6		5		99.29	16.9	Thalweg of ditch

ST7	4.4	99.89	18.45	Far east side of ditch, at top

Appendix 4: Values used to estimate existing capacity of Tassajara Creek V-ditch

- Cross-sectional area: 0.81 ft^2
- Wetted perimeter: 3.12 ft
- Slope: 1% (0.01)

Appendix 5: Comparison of existing V-ditch and proposed vegetated strip

Characteristic	V-ditch	Vegetated strip
Manning's *n* (roughness coefficient)	0.013-0.023	0.25
Width	3 ft	5 ft
Depth	0.5 ft	0.5 ft
Maximum capacity	2.13-3.77 cfs	0.541 cfs
Maximum velocity	2.63-4.65 ft/s	0.309 ft/s

Appendix 6: Zone 7 Water Agency guidelines for managing runoff from access roads

1. Surface runoff from access roads shall not be allowed to flow directly over the banks into the channel. Top of bank runoff shall be collected in a separate V-ditch or curb-gutter which leads to a drainage inlet and discharges into the creek, channel or arroyo through Alameda County Flood Control & Water Conservation District (ACFC&WCD) Standard Drawing SF-605 outfall structures. Spacing of drainage inlets/outfall structures shall be such that the length of ditches draining into them from either side shall not exceed eight hundred (800) feet.
2. V-ditches shall be adequately sized to take the surface drainage within the right-of-way and shall be a minimum of six (6) inches deep and two (2) feet wide. V-ditches shall be earthen, asphalt concrete, or concrete lined to Zone 7 standards…

Source: Zone 7, 2004.