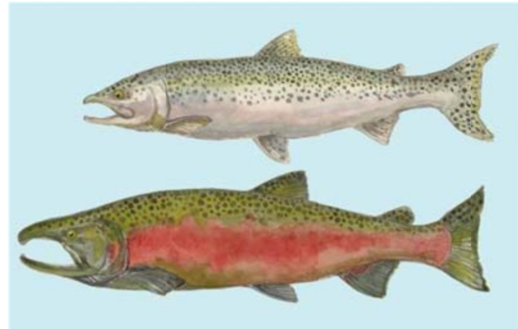
FISH HABITAT ENHANCEMENT FEASIBILITY STUDY

Draft Report • March 2011



DRY CREEK
WARM SPRINGS DAM
TO THE RUSSIAN RIVER
SONOMA COUNTY, CA

PREPARED FOR

SONOMA COUNTY WATER AGENCY
404 AVIATION BOULEVARD
SANTA ROSA, CA 95403

DRAFT

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MARCH 2011

EXECUTIVE SUMMARY

Introduction

The Dry Creek Fish Habitat Enhancement Feasibility Study is being conducted to facilitate fish habitat enhancement in Dry Creek, a major tributary to the Russian River in Sonoma County, California. Dry Creek is home to ESA-listed native fish, including Central California Coast (CCC) coho salmon (Onchorhynchus kisutch; endangered), steelhead trout (O. mykiss; threatened), and California Coastal (CC) Chinook salmon (O. tshawytscha; threatened). This effort will enhance channel and riparian conditions on lower Dry Creek to benefit juvenile life stages of ESA-listed coho salmon and steelhead trout, which will aid in their recovery within the region and satisfy requirements enumerated by the Final Biological Opinion for Water Supply, Flood Control and Channel Maintenance Activities for the Russian River Watershed (RRBO; NMFS 2008).

The feasibility study is being conducted in three phases including: (I) inventory and assessment of current conditions, (II) feasibility assessment of habitat enhancement approaches, and (III) conceptual design of habitat enhancement approaches deemed feasible. Current conditions were assessed based on a field inventory completed in summer 2009, detailed results of which can be found in the Current Conditions Inventory Report that concluded Phase I (Inter-Fluve 2010). Phase II, the focus of this report, is a feasibility study of habitat enhancement approaches over the entire 14 miles of Dry Creek flowing from Warm Springs Dam to its confluence with the Russian River. The feasibility study included the following primary components:

1. Field survey of Dry Creek to support development of a one-dimensional planning-level hydraulic model over the project reach.
2. Geotechnical subsurface exploration at select locations to inform the feasibility assessment.
3. Quantitative assessment of the hydraulic and geomorphic processes in Dry Creek.
4. Assessment of the feasibility of fish habitat enhancement based on geomorphic, hydraulic, engineering and construction considerations.

Hydrology & Geomorphology

Dry Creek's current hydrology results from regulation by Warm Springs Dam (WSD) and unregulated tributaries which enter Dry Creek below WSD. In general, regulation by WSD has reduced the magnitude of peak flows by several hundred percent while substantially elevating baseflow during the summer-fall period. Regional hydrology is dominated by winter rain events between November and March. Flood events still occur in the November to March timeframe, however the magnitude of such events are severely reduced compared to the unregulated period preceding dam construction.

The current geomorphology of lower Dry Creek is a result of the interaction of local geology, watershed characteristics, hydrology, and vegetative characteristics; the legacy of channel evolution and response to land management changes; and the ongoing influence of flow management. Lower Dry Creek is an incised, perennial, alluvial gravel bed stream that has responded to substantial human-induced hydrologic and geomorphic change over the past 150 years. Following base-level lowering, widespread systemic incision occurred which led to the development of an incised stream system flowing through a narrow active channel zone inset 10 – 30 feet below the adjacent agricultural valley floor.

The primary determinant of current geomorphic conditions is the influence of the dam, expressed through modified sediment supply, altered hydrology and the growth of riparian vegetation. Geomorphic function along Dry Creek varies according to the dominant processes at each location, and is determined by distance from WSD, location relative to unregulated tributaries downstream of WSD, and distance upstream of the Russian River. The unregulated tributaries moderate the influence of WSD on upstream sediment supply and flow regulation, while the backwater profile from the Russian River during floods directly affects the conditions in the downstream 3 miles of the study reach.

Hydraulic Modeling and Analyses

A planning-level one-dimensional hydraulic model was developed for the 13.9 mile study reach using bathymetric and topographic data collected during 2009 and 2010 field surveys, supplemented by LiDAR data. The model was calibrated to observed water surface elevations and surveyed high water marks. Model results were used to examine trends in sediment mobilization and effective discharge characteristics, and flood inundation patterns.

To evaluate general trends in the ability of Dry Creek to mobilize and convey sediment, channel competence-based calculations were completed. These calculations compared the shear stress needed to mobilize bed sediments with the shear stress exerted by flow in the channel at several discharge levels. The results suggest that surface substrate may be mobilized at all of the locations that were analyzed for the 2- and 10-year flood events, while moderately high flows occurring at a sub-annual frequency are able to mobilize surface sediments in select locations. The flow that is exceeded at least 20% of the time in winter months is able to transport the bed sediment load at many locations. These patterns are modified by the backwater profile created by the Russian River during large floods in the lower three miles of the study reach, which reduces the ability of Dry Creek to transport sediment in this stream segment.

Effective discharge, or the flow (or flow range) which transports the greatest cumulative volume of bed sediment of the long term, was estimated at several locations along the reach. The results reflect the influence of WSD and the unregulated tributaries below the dam on channel processes and are consistent with the results of the bed sediment mobility analysis. At select locations downstream of Pena Creek, the effective discharge is estimated to occur on a sub-annual basis. Between Pena Creek and WSD, the effective discharge is estimated in the range of a 2 – 3 year return interval flood event. The results of the effective discharge and sediment mobility calculations are consistent with field indications which suggest that Dry Creek has evolved to a condition which efficiently transports the bed sediment supplied to the reach despite the drastically reduced flood hydrology.

Fish Habitat Enhancement

The RRBO requires six miles of fish habitat enhancements to be implemented over the 13.9 study reach over three phases by 2020. Generally, Dry Creek currently lacks high quality main channel and off-channel habitats which are critical for juvenile coho and steelhead rearing. The proposed habitat enhancements aim to directly address these deficiencies. Specific criteria from the RRBO are summarized in the main section of the report. The methodology by which habitat benefits will measured is an important consideration in assessing the feasibility of meeting these criteria.

The primary types of habitat considered for enhancement include mainstem in-channel and off-channel habitats. Pool-riffle habitat is the primary desired in-channel habitat. As specified in the RRBO, optimal pool conditions for steelhead and coho rearing are 2 to 4 ft deep habitats with significant areas there water column velocities are less than 0.2 ft/s. Calculations were made to estimate the width of the channel needed to meet these criteria. A substantially wider channel than the current channel would be required to meet the criteria. The estimated required widths are wider than the existing channel corridor in many locations. As only a portion of the 13.9 miles of channel would be widened, this approach would create a multitude of hydraulic expansions and contractions, creating discontinuities in sediment transport and other processes. Furthermore, given current hydrology and vegetation patterns, it is estimated that a widened channel may ultimately evolve back towards a state similar to that currently observed in Dry Creek. These factors challenge the ability to meet the criteria listed above simply through pool-riffle enhancement, if the criteria are narrowly interpreted. Nevertheless, enhancements are feasible which will lead to improved fish rearing habitat conditions in the main channel. Strategic LWD placements can be used create fish cover and refugia from high velocities. Riffles can also be constructed to modify existing poorly-functioning pool habitats to reduce velocities. Riffle construction can be considered a tactical sediment augmentation approach to offset the reduced sediment supply due to regulation.

Off-channel habitat types appropriate for enhancement in Dry Creek include alcoves, backwater channels and side channels. Side channels, backwaters and alcoves are used heavily by juvenile salmonids when available to them. Due to the challenges in reaching optimal velocity criteria in the main channel, off-channel habitats provide notable opportunities for meeting depth, cover, complexity and velocity criteria. There are numerous locations where off-channel habitats may be considered to provide enhanced habitat. Feasibility considerations include potential for nuisance sedimentation, disconnection due to deposition of debris, or channel change stranding the habitat during summer baseflow. In pristine systems, individual off-channel habitats may be transient over the long term, or may be persistent through time. Often, in a healthy and unconstrained stream system, these habitats will be abandoned and recreated as an alluvial channel migrates across its floodplain, resulting in an approximately constant overall quantity of habitat over the long-term. Based on observations of persistent off-channel habitats in Dry Creek, general guidelines were developed to facilitate the longevity of these habitats if constructed for enhancement.

<u>Construction feasibility considerations</u>

The nature of land use and infrastructure along lower Dry Creek presents logistical challenges for the construction phase of the habitat enhancement effort. Existing transportation corridors consist of relatively narrow, winding two-lane roads and few heavy load capacity stream crossings, with substantial recreational and farm traffic. Furthermore, the narrow incised creek corridor and proximity to vineyard operations limit available access corridors and staging areas. Dust control is also a significant issue due to the sensitivity of vines growing in close proximity to the creek. Nevertheless, the logistical challenges can be planned for in developing detailed enhancement strategies.

The typical in-water work period for the region is June 15 to October 15 in order to minimize impacts on migrating adult salmonids and to concentrate ground disturbing activity during the dry season. In order to satisfactorily construct the enhancements and prevent excessive turbidity to the active flowing stream, it may be necessary to divert the stream around and/or dewater active work zones. Pumped diversion systems provide the benefits of moving the water out of the creek corridor, and maximize the available work space in the corridor, which will facilitate efficient and competent completion of the work, including concurrent completion of work at multiple sites within a reach. However, the high daily expense of a pumped diversion system will need to be weighed against the potential limitations of less expensive approaches as each project nears implementation.

Feasibility of habitat enhancement by primary creek segment

Channel processes and dynamics vary along the length of Dry Creek, which suggest tailoring the enhancement approach in each segment to match the prevailing fluvial processes at each location. In general, the approaches may fall in a range defined by strongly process-reliant at one end, and direct habitat construction at the other end. Accordingly, Lower Dry Creek has been split into three segments based on dominant physical processes and other shared characteristics: 1) upstream of Pena Creek (RM 11 to 13.7), 2) Pena Creek to the grade control sills (RM 3 to 11), and 3) from the grade control sills to the Russian River confluence (RM 0 to 3). Generally, enhancement projects will be identified to include a series of main channel and off-channel enhancements which link together.

- Upstream of Pena Creek, construction of late-successional habitat was assessed to be feasible with low risk of the constructed habitat being compromised due to nuisance sediment deposition or other factors. Conversely, relying on channel processes to create the habitat was deemed to have low feasibility due to the lack of sediment supply and highly regulated hydrology. Generally, enhancement through direct habitat construction can be considered as having low risk of failure in this segment relative to other segments.

- The middle segment stretching from RM 3 - 11 has greater sediment supply than the upstream reach due to the unregulated tributaries which enter Dry Creek below WSD. This increases the risk for nuisance sedimentation impacts to potential directly-constructed off-channel habitat. This risk can be mitigated through appropriate site selection and other considerations discussed in this report. In this segment, off-channel enhancements may shift in character due to channel processes, again dependent on the characteristics of each site. Conversely, several large off-channel opportunities may lend themselves to a more dynamic, process-focused approach, or combined approach. In summary, the preferred enhancement approach to each site is more variable in this segment than the other two segments, and careful consideration of the attributes of each proposed location will determine the corresponding advisable enhancement strategy.

- In the downstream segment (RM 0-3), there is high risk that a direct habitat construction approach would be compromised by sedimentation due to the backwater influence of the Russian River. Conversely, enhancement that relies on a modified process-driven approach likely provides the best option in this segment. Based on observations of existing intact rearing habitats, it is possible that fluvial processes may be sufficiently intact to create target habitats over time provided the stage is set for habitat development to occur.

Conclusions related to the feasibility of fish habitat enhancement in Dry Creek

The following are the primary conclusions resulting from the study:

- It is feasible to enhance fish habitat in Dry Creek to benefit juvenile life stages of coho salmon and steelhead trout.
- The ability of fish habitat enhancement efforts to meet the targets spelled out in the RRBO will be influenced by the scoring methods developed to evaluate project success.
- Both instream and off-channel habitat enhancement can be considered.
- Off-channel habitats are likely best able to meet specific juvenile habitat preference criteria contained in the RRBO.
- Instream habitats can be improved, but are unlikely to meet habitat preference criteria contained in the RRBO if the criteria are narrowly interpreted.
- Because the dominant physical processes vary over the length of lower Dry Creek, the viable approaches to enhance fish habitat will also vary at each location. These approaches can be generally grouped as described above, and also in greater detail in Section 5 of the report.
- Numerous fish habitat enhancement opportunities were identified. On the basis of adjacent stream length, these off-channel and mainstem opportunities are distributed over 1.6, 2.1, and 5 miles above Pena Creek, below the grade control sills, and middle channel segments, respectively. It should be noted that the length of enhancement that can be credited based on the identified opportunities will depend on the habitat benefit scoring methodology.

Next Steps

Following the conclusion of the feasibility study phase, concept designs will be developed for enhancement opportunities identified to be feasible in this report. Concept design development will be completed during the summer 2011. In development of concept designs, project enhancement reaches will be identified which will be comprised of multiple feature sites (i.e. backwater channel, alcove, main channel pool enhancement, riffle construction). Following the development of concept designs, the enhancement reaches will be ranked based on their habitat potential and geomorphic risk and characterized in terms of their costs, and other considerations which may impede or facilitate implementation.

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We would like to acknowledge the following groups for their respective contributions to this study:

Sonoma County Water Agency Staff
Dry Creek Property Owners
Dry Creek Advisory Group Members
National Marine Fisheries Service Staff
California Department of Fish and Game Staff
U.S. Army Corps of Engineers Staff

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1 INTRODUCTION

Dry Creek, a major tributary to the Russian River, flows 32 miles from its source at Snow Mountain near Hopland, CA to its mouth near Healdsburg in Sonoma County, California (Figure 1). Warm Springs Dam (WSD) at river mile (RM) 13.9 divides the rugged terrain and steeper channel of the upper watershed from the relatively flat agricultural valley and lower gradient channel that is present below the dam. Since 1984, WSD is operated by the Army Corps of Engineers to control floods, and by the Sonoma County Water Agency (Water Agency) to supply potable water to 600,000 consumers in Sonoma and northern Marin Counties. The dam is one of multiple facilities that comprise the Russian River Water Supply and Flood Control Project (RRWSFC).

Dry Creek is home to ESA-listed native fish, including Central California Coast (CCC) coho salmon (Onchorhynchus kisutch; endangered) and steelhead trout (O. mykiss; threatened), and California Coastal (CC) Chinook salmon (O. tshawytscha; threatened). The National Marine Fisheries Service (NMFS) has determined that the operation of WSD could threaten the survival of coho salmon and steelhead trout in Dry Creek, and/or adversely affect their critical habitats. In 2008 NMFS issued the Biological Opinion for Water Supply, Flood Control and Channel Maintenance Activities for the Russian River Watershed (RRBO; NMFS 2008), which requires improvements to existing fish habitat in Dry Creek. In particular, key requirements focus on rearing and refugia habitat for these coho and steelhead.

Dry Creek is seen as a significant opportunity for recovery of coho and steelhead in the region due to the relative abundance of cool water in the late summer months which is atypical of streams in the region. Late summer rearing conditions are considered a critical bottleneck for species recovery. Habitat enhancement goals for Dry Creek are discussed later in this document and detailed more specifically in the RRBO (NMFS 2008).

The RRBO lays out a timeline for the habitat work, which will ultimately result in six miles of habitat enhancement in Dry Creek by 2020. This feasibility study explores options for habitat enhancement to meet the goals of the RRBO.

2 SCOPE OF WORK

The feasibility study is being conducted in three phases. Phase 1 included inventory and assessment of current conditions along Dry Creek between Warm Springs Dam and the confluence with the Russian River (hereafter referred to as 'lower Dry Creek'). Completed between the summer of 2009 and the spring of 2010, the final version of the Dry Creek Current Conditions Report was issued in December 2010. Conducted between the summer of 2010 to the winter of 2011, Phase 2 has included detailed feasibility assessment of habitat enhancement approaches, and is the subject of this draft report. Phase 3 will include conceptual design of habitat enhancement approaches deemed feasible, and will be completed in summer 2011.

The present document reports the results of the feasibility assessment. The effort included the following primary tasks:

1. Field survey of Dry Creek to support development of a one-dimensional hydraulic model.
2. Geotechnical subsurface exploration at select locations to inform the feasibility assessment.
3. Quantitative assessment of the hydraulic and geomorphic processes in Dry Creek.
4. Assessment of the feasibility of fish habitat enhancement based on geomorphic, hydraulic, engineering and construction perspectives.

The following sections report the results of the feasibility assessment.

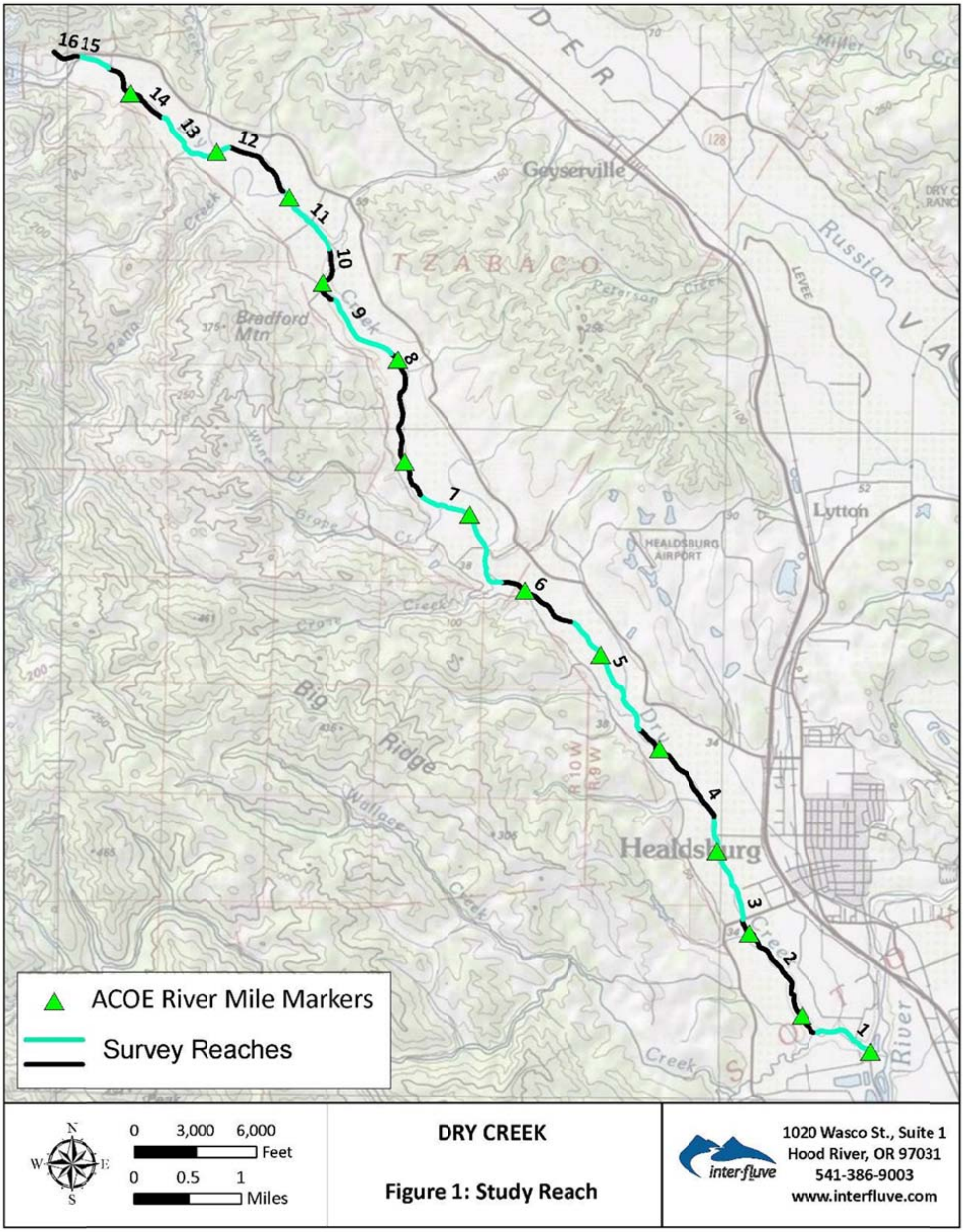


Figure 1: Map of Lower Dry Creek between Warm Springs Dam and the Russian River.

3 DRY CREEK HABITAT ENHANCEMENT GOALS AND OBJECTIVES

The following section describes the goals and objectives for the Dry Creek Habitat Enhancement Project.

PROJECT GOALS AND OBJECTIVES

3.1 PROJECT GOAL

In the broadest sense, the goal of the Dry Creek Habitat Enhancement Project is to:

- Enhance channel and riparian conditions on lower Dry Creek to benefit juvenile life stages of ESA-listed coho salmon and steelhead trout, which will aid in their recovery within the region.

3.2 ATTENDANT OBJECTIVES

Attendant to the project goal, the following are the primary objectives for the Dry Creek Habitat Enhancement Project:

- Enhance summer rearing habitat for coho salmon and steelhead to 'near-ideal' conditions,
- Enhance summer rearing habitat for steelhead to 'near-ideal' conditions,
- Create refugia from winter high-flow releases for both coho salmon and steelhead,
- Enhance habitat, and to the extent feasible, minimize impacts on private property and infrastructure.
- Enhance habitat without adversely affecting Chinook salmon.

Figure 2. Warm Springs Dam.

4 DRY CREEK CURRENT CONDITIONS

The current hydrologic, geomorphic and fish habitat conditions of Dry Creek were assessed through existing information and field inventory in Phase 1 of the study. The assessment results are summarized here and are presented in greater detail in the Current Conditions Inventory Report (CCIR: Inter-Fluve 2010), with individual reach summaries included in Appendix A to this report. Sections 4.1 to 4.3 below provide a brief overview of selected sections of the CCIR. In addition, Sections 0 to 4.5.4 provide additional quantitative analyses which support the conclusions drawn in the CCIR, and provide required information for the feasibility assessment.

4.1 WATERSHED CONTEXT

The Dry Creek watershed is located in the interior coast range of northern Sonoma and southern Mendocino counties, approximately 30 miles from the Pacific Ocean and 60 miles north of San Francisco Bay. Dry Creek is a 32 mile long fourth-order tributary that drains 217 square miles of rugged terrain in the southwestern portion of the Russian River Basin in a generally northwest to southeast direction. Dry Creek historically ranked first for sediment contribution and second for runoff out of all the Russian River tributaries (Army Corps of Engineers 1984).

WSD is located on Dry Creek at river mile 13.9, at the confluence of Dry and Warm Springs Creeks, and is considered the upstream extent of lower Dry Creek. The 130 square mile watershed located above the dam is characterized by steep, mountainous terrain with basin slopes ranging from 30% to 80% and channel gradient ranging from 8 to 200 feet per mile (0.2 to 3.8%; Army Corps of Engineers 1987a). Downstream of the dam, lower Dry Creek is a gravel bed river that flows through a low gradient agricultural valley 0.5 to 1 mile wide with approximate average gradient of 0.2%. Principal tributaries entering Dry Creek below WSD include Pena Creek (drainage area 22.3 sq. mi.) and Mill Creek (drainage area 22 sq. mi.). Agricultural production in the lower Dry Creek valley was based on orchard fruit through the 1970s. Grapes are the primary agricultural crop today.

The Dry Creek watershed lies within a region of Mediterranean climate, characterized by warm, dry summers and cool, wet winters. In the pre-dam era (before 1984), Dry Creek could be characterized as having a seasonal flow regime maintaining higher flow through the winter and spring and typically very low flow in the summer and early fall. Flow rates under natural conditions increased three orders of magnitude during the winter. After operation of the dam commenced in 1984, the flow regime changed to a perennial stream with much less variation in flow rates between summer and winter. Summers have consistent base flow while winter peak flows are reduced relative to natural flow conditions.

The geology of the Dry Creek drainage is characterized by a structurally controlled valley that generally lies on the boundary between sedimentary units of the Great Valley Complex (Healdsburg terrane) to the east and various fault bounded lenses of the Coast Range ophiolite and metamorphic rock units of the Franciscan Complex to the west (Blake, Graymer, and Stamski, 2002). The contact between the sedimentary rock of the Great Valley Complex and the volcanic and intrusive rocks of the Coast Range ophiolite is obscured beneath Quaternary alluvium of the lower Dry Creek floodplain (Inter-Fluve 2010). The youngest sediments found within the valley are stream channel and floodplain deposits associated with Dry Creek and include up to three terrace deposits, the oldest of which appears to be approximately 1,000 years old (Harvey and Schumm, 1985). Harvey and Schumm (1985) note that outcrops of bedrock are almost entirely found where the present channel of Dry Creek is located near the western flank of the valley. The only exception to this occurs near Warm Springs Dam, where Dry Creek abuts the northeastern flank of the valley along exposed outcrops of Great Valley Complex sandstones.

Stereo-paired aerial photographs of the northern portion of lower Dry Creek, from river reach 7 to reach 16, and surrounding areas, were analyzed for the presence of prominent topographic lineaments and geologic structural trends that might adversely impact possible habitat enhancement improvements. Stereoscopic analysis of the aerial photos and digital imagery suggests that one or more reaches of Dry Creek may be structurally controlled along traces of the Healdsburg fault or other lineaments that we infer may be associated with the fault. Across the site, several sections of lower Dry Creek exhibit unusually low sinuosity for a stream in a dominantly alluvial drainage. These low sinuosity reaches are either coincident with and/or parallel to mapped strands of the Healdsburg fault (Figure 3). In particular, portions of reaches 10 through 12 are located on or along the projected trace of a mapped fault strand. Along the southwestern margin of the drainage, low sinuosity portions of reaches 3-5, 8-9, and 13-15 are all generally aligned along a linear trend that parallels mapped strands of the Healdsburg fault.

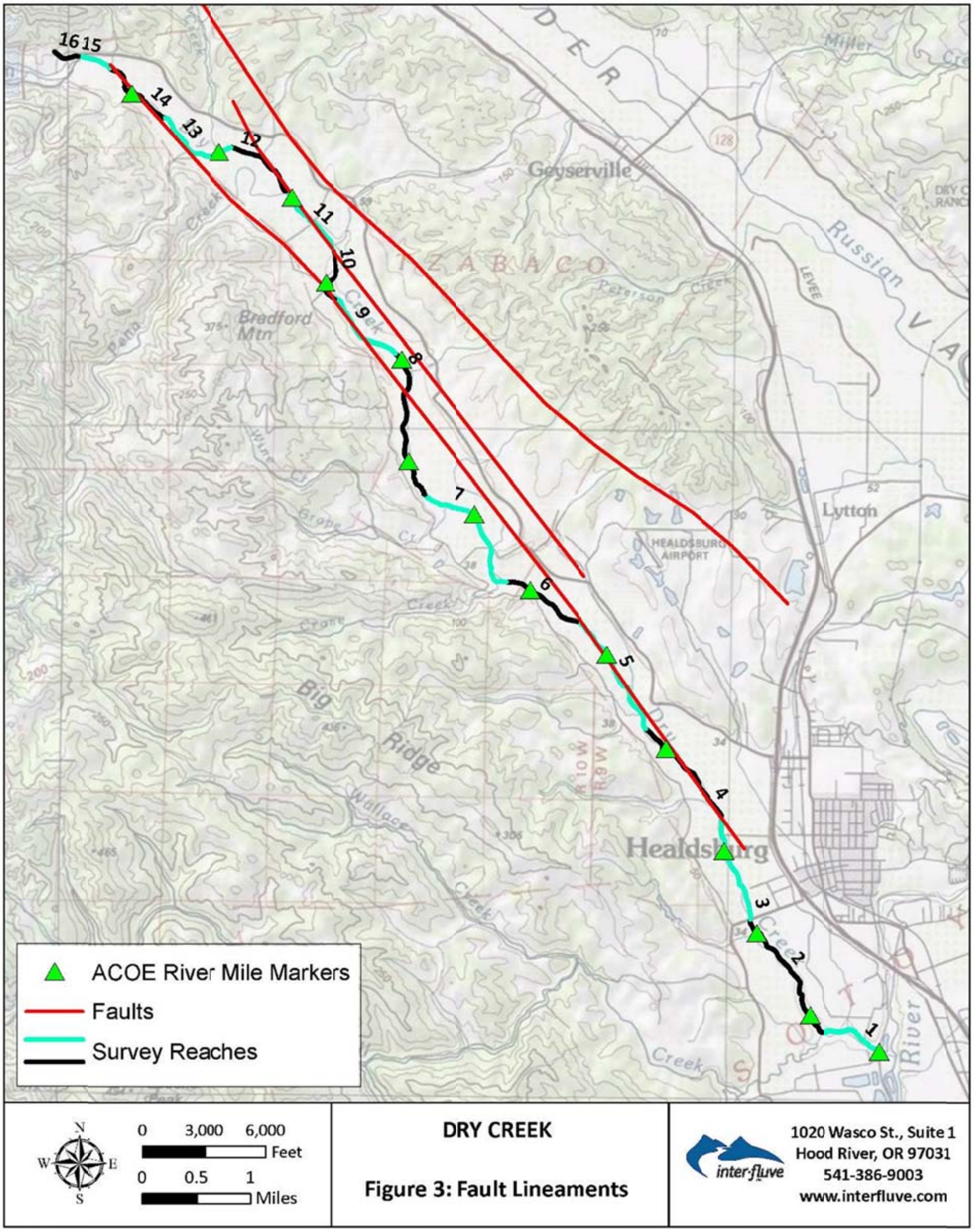


Figure 3: Fault lineaments in the Dry Creek valley.

4.2 DRY CREEK WATERSHED MANAGEMENT

The present condition of lower Dry Creek expresses the legacy of management in the basin, beginning with the settlement of the valley in the 1850s. Between 1850 and 1870, approximately 40% percent of the forested watershed area was cleared and converted to grazing land. This land use change had the effect of modifying runoff characteristics and sediment production, which led to an initial period of aggradation and subsequent degradation of lower Dry Creek between 1850 and 1900 (Army Corps of Engineers 1987a). At the time of European settlement, lower Dry Creek regularly spilled over its banks onto the historic floodplain, which is the area utilized for agricultural production today. In conjunction with conversion of the former floodplain for agricultural production in the lower reaches of Dry Creek, additional clearing, drainage and manipulation of tributary streams occurred.

Gravel mining began in the Russian River near Healdsburg around 1900, continued in various locations within the mainstem until the late 1960s, and then shifted to the Russian River terraces downstream of Healdsburg. Gravel mining also occurred along lower Dry Creek from the 1950s to the 1970s near the Mill Street Bridge (approximately 2 miles upstream of the mouth). The Potter Valley project was constructed in the early 1900s, which supplemented flows in the Russian River with water from the Eel River in northern California. In conjunction with the construction of the Healdsburg (1952) and Coyote (1959) Dams on the Russian River, gravel mining and other activities resulted in a significant lowering of the base level for Dry Creek. Base level lowering at the mouth of Dry Creek led to channel incision which propagated up the main channel of Dry Creek, which in turn propagated up the tributaries (Army Corps of Engineers 1987a). In response to the channel incision, significant numbers of bed and bank stabilization measures were installed by landowners and public entities along Dry Creek and its tributaries. This included installation of three grade control structures between river miles 3 and 4 by the Army Corps of Engineers in the early 1980s (Harvey and Schumm 1985). Historic evolution of Dry Creek is discussed further in subsequent sections in this document.

First investigated in the early 1940s, construction of Warm Springs Dam on Dry Creek at river mile 13.9 was authorized under the Flood Control Act of 1962 to provide flood control, water storage and recreation. The construction phase of the project commenced in 1967, with construction of the dam itself commencing in 1970. The dam embankment and outlet works were completed in 1982, and achieved full pool in 1983. WSD is a 319 -ft tall, 3000-ft long earthen dam with a storage capacity at gross pool of 381,000 acre-feet. This equates to approximately 230% of the mean annual runoff of Dry Creek over the period 1916-1980 (Army Corps of Engineers 1984). Construction of the dam stopped the supply of bed material from the upper watershed and dam operation reduces the magnitude of all floods with at least a 2-year return interval by more than 70% (Simons and Li 1980). Although peak flows are reduced, base flows have increased to provide continuous flow throughout the year along this traditionally seasonal stream (Army Corps of Engineers 1987a).

4.3 LOWER DRY CREEK REACH DELINEATION

The length of Dry Creek that is the focus of this study extends from WSD to the confluence of Dry Creek with the Russian River, a total stream length of approximately 13.9 miles (referred to as lower Dry Creek). Lower Dry Creek was delineated into reaches using existing data to facilitate organization of study field efforts and analyses (Inter-Fluve 2010). The delineated reaches are reported in
Table 1 and are shown on Figure 1. A total of 16 reaches were delineated, ranging in length from 1340 ft to 7700 ft and averaging 4580 ft.

Table 1: Reach delineation results for lower Dry Creek. DS = downstream; US = upstream; RM = river mile.

Reach	DS end (RM)	DS end (landmark)	US end (RM)	US end (landmark)	Length (ft)
1	0.0	Dry Creek Mouth	0.7	Mill Creek confluence	3550
2	0.7	Mill Creek confluence	2.0	Westside Road	7000
3	2.0	Westside Road	3.0	Fault lineament; 1150' DS of Sill 1	5450
4	3.0	Fault lineament; 1150' DS of Sill 1	4.1	1600' US of Sill 3, at US end of check dam impoundment	5880
5	4.1	1600' US of Sill 3, at US end of check dam impoundment	5.4	Fault lineament, 150' DS of Kelley Creek	6640
6	5.4	Fault lineament, 150' DS of Kelley Creek	6.2	Bedrock outcrop, 475' DS of Crane Creek	4150
7	6.2	Bedrock outcrop, 475' DS of Crane Creek	7.5	Bedrock outcrop, 950' US of Grape Creek	6940
8	7.5	Bedrock outcrop, 950' US of Grape Creek	9.0	Change in relative confinement	7700
9	9.0	Change in relative confinement	9.8	Change in relative confinement, and fault lineament	4220
10	9.8	Change in relative confinement, and fault lineament	10.3	Unnamed Tributary	3040
11	10.3	Unnamed Tributary	11.0	Pena Creek confluence	3755
12	11.0	Pena Creek confluence	11.7	Gradient shift, 700' DS of Dutcher Creek	3700
13	11.7	Gradient shift, 700' DS of Dutcher Creek	12.6	Steep riffle	4345
14	12.6	Steep riffle	13.3	Schoolhouse Creek confluence	3930
15	13.3	Schoolhouse Creek confluence	13.7	Bord Bridge	1680
16	13.7	Bord Bridge	13.9	Dam Outlet	1340

4.4 HYDROLOGY

Streamflow delivered to Lower Dry Creek is generated by a 217 mi^2 watershed. This area includes a 130 mi^2 area from which streamflows are regulated by WSD and an 87 mi^2 unregulated watershed downstream of the dam. The unregulated watershed downstream of WSD consists of tributary watersheds and areas draining directly to Dry Creek. Unregulated streamflows in the region are largely dominated by winter rain events between November and March. As described in greater detail in the CCIR (Inter-Fluve 2010) and summarized below, the hydrologic regime of lower Dry Creek has been substantially affected by operation of Warm Springs Dam.

4.4.1 Streamflow Regulation by Warm Springs Dam

The effect of streamflow regulation by WSD is discussed in detail in the CCIR (Inter-Fluve 2010). In general, regulation by WSD reduces the magnitudes of peak flows by several hundred percent (Table 2) while substantially elevating baseflows during the summer-fall low flow period (Figure 4).

Table 2: Summary of peak flow reduction by WSD. Source: Water Control Manual, Army Corps of Engineers 1984.

	Downstream of Pena Creek	Yoakim Bridge (USGS No. 1465200)
Flow Event	Post-Dam Peak Flow (cfs)	Pre-Dam Peak Flow (cfs)
2-year	-	23000
5-year	-	25000
10-year	6700	30000
25-year	-	35000
50-year	9600	38000
100-year	11000	40000
200-year	-	45000
500-year	14000	48000

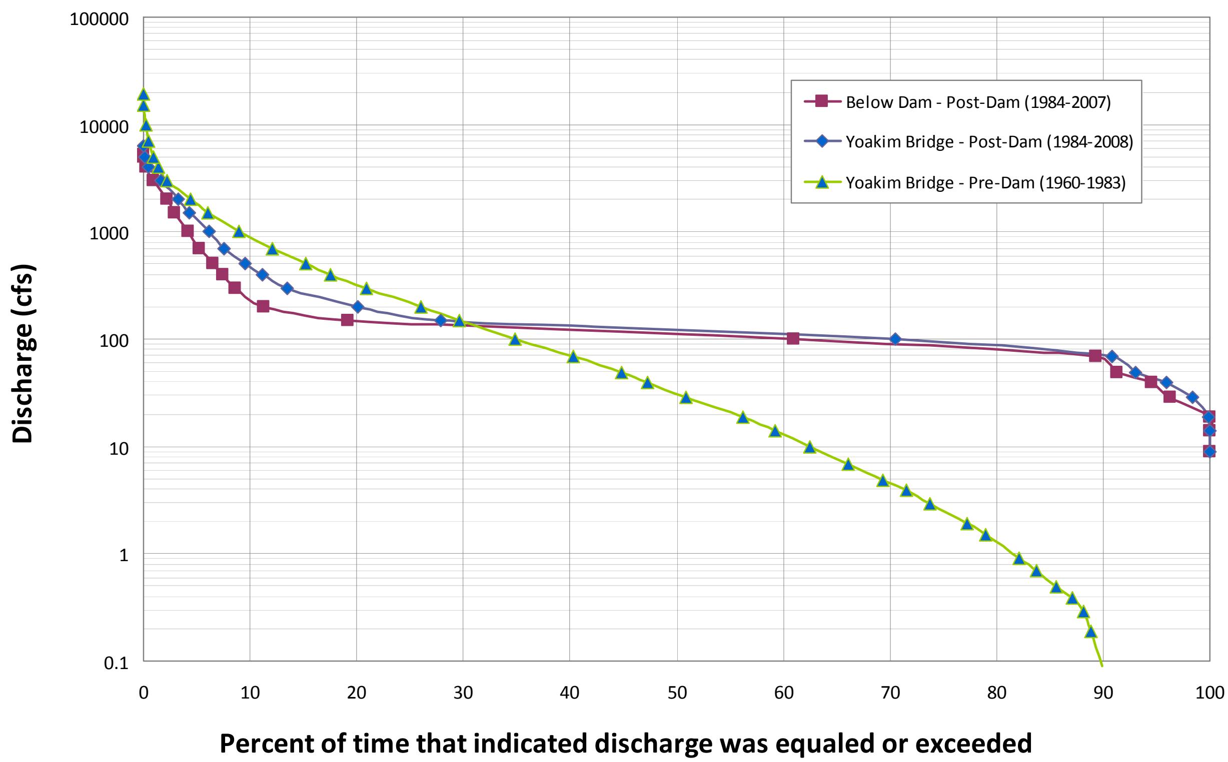


Figure 4: Flow duration curves for Dry Creek at the USGS gage station below the dam (post-dam) and at Yoakim Bridge (pre- and post-dam).

4.4.2 Flood Frequency Estimates

To support the hydraulic modeling and feasibility analyses, flood frequency estimates were developed for Dry Creek at the outlet of the dam and at several tributary confluences in the 13.9 mile study reach. The analysis considered the outflow of WSD, the contribution of unregulated tributary streams which enter Dry Creek below the dam and areas directly tributary to the stream (see Figure 5). The available data and calculations used to derive flood frequency estimates are described in more detail below.

The following sources of data were available for use in the analysis:

- WSD Water Control Manual (U.S. Army Corps of Engineers 1984) – regulated peak flow estimates for 10-year, 50-year, 100-year and 500-year return period floods over 7 sub-reaches.

- USGS gage data:
  a. USGS Gage 11465000 Dry Creek below WSD near Geyserville (drainage area = 130 mi^2) – available flow record includes 1981 to present.
  b. USGS Gage 11465200 Dry Creek near Geyserville (Yoakim Bridge; drainage area = 162 mi^2) – available flow record includes 1959 to present
  c. USGS gage 11465150 Pena Creek near Geyserville (drainage area = 22 mi^2) - available flow record includes 1979 to 1990.

d. Incremental watershed area between WSD and Yoakim Bridge (drainage area = 32 mi^2) - 29-year record (1981-present) of the peak flows generated by the unregulated tributaries (Schoolhouse, Dutcher, Fall and Pena) and other areas draining directly to Dry Creek between WSD and Yoakim Bridge. This flow series was calculated based on the annual peak flows at the Yoakim Bridge gage and the corresponding instantaneous peak discharge at the WSD gage (adjusted by one hour for the travel time of water). This incremental area is hereafter referred to as the 'Incremental Watershed'.

- Peak flow estimates for Mill Creek based on the Modified Rational Method – Peak flow estimates prepared by the Soil Conservation Service (SCS) in 1968 for Mill Creek (drainage area 22 mi^2). These estimates were summarized by Prunuske Chatham Incorporated (2010).

Based on the available data, two independent methods were used to calculate flood flow estimates, described below. The peak flow estimates were for Mill Creek developed by the SCS were compared to the estimates based on the other sources of data.

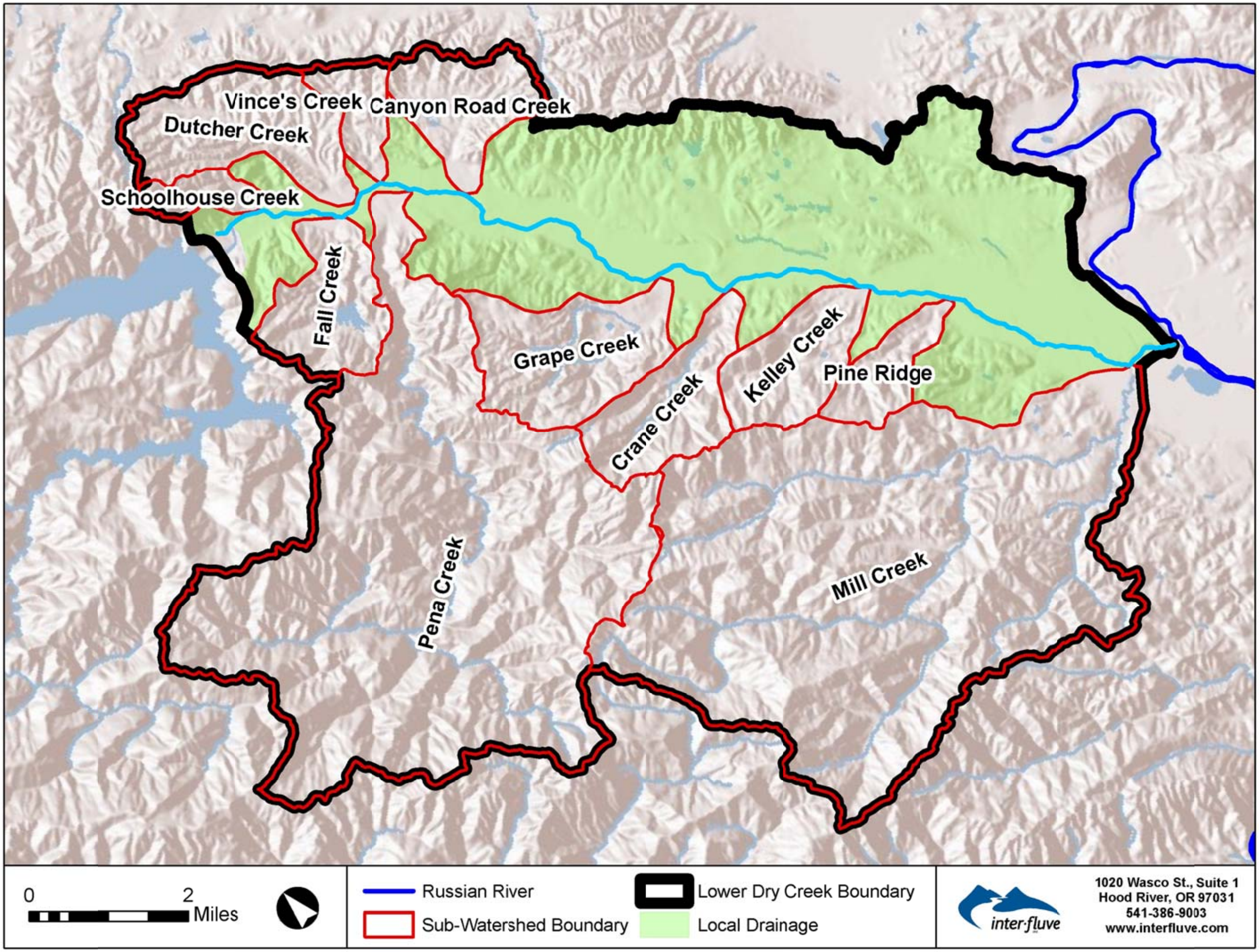


Figure 5. Sub-watershed boundaries in lower Dry Creek used in the flood frequency estimates described in Section 4.4.2. Named tributaries outlined in red, while other areas directly tributary to Dry Creek are outlined in green.

4.4.2.1 Peak flow series based on water control manual estimates

The peak flow estimates from the Water Control Manual were supplemented with additional locations along Dry Creek (see Table 3), and with estimates for the 1-, 2-, 5- and 25-year return period peak flows (Q1, Q2, Q5 and Q25, respectively). At the locations where the Q10, Q50, Q100 and Q500 were already available, these data were plotted in semi-log space. Based on least-squares regression of these values, peak flow estimates were then extrapolated for the Q1, Q2, Q5 and Q25 events. Finally, the peak flow estimates were distributed to the additional locations based on the ratios of the relative drainage areas between the locations where flow estimates were available and the locations where flow estimates were desired. The resulting estimated peak flows are summarized in Table 3 and are shown in Figure 7.

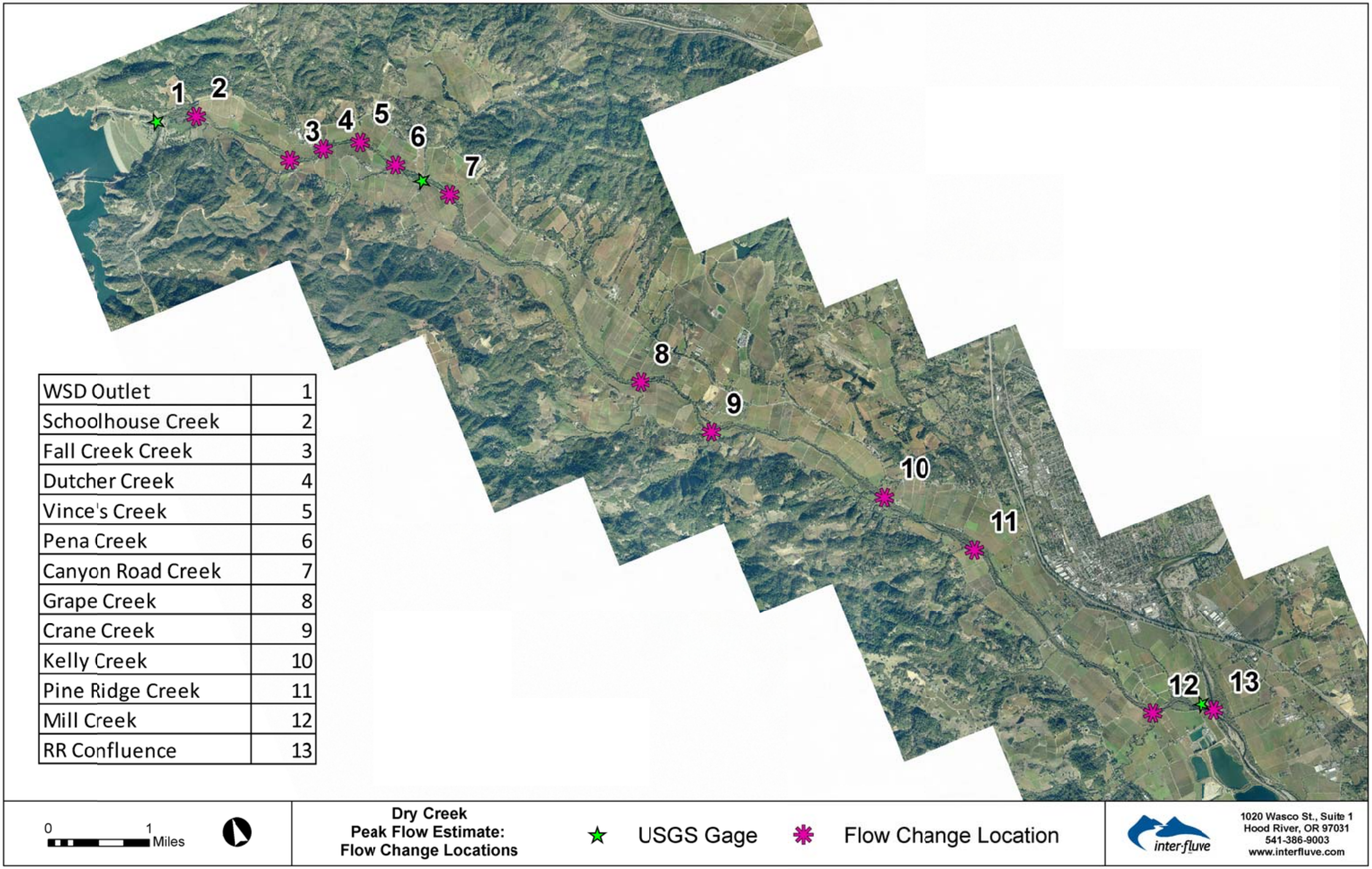


Figure 6. Peak flow estimate flow change locations and landmarks along lower Dry Creek.

4.4.2.2 Peak flow series based on available USGS gage data

The basic approach to developing the peak flow series based on the available gage data was to first estimate peak flow magnitudes for the tributary and local drainage areas - which are not regulated by dams or other infrastructure - that have corresponding peak flow data, and then to extrapolate the peak flow estimates to the other watershed areas between WSD and the Russian River for which peak flow data do not exist. Peak flow estimates for unregulated areas below WSD (Pena Creek and the Incremental Watershed) were developed using the standard Log Pearson Type III Method.

The peak flow estimates for Pena Creek and the Incremental Watershed were then extrapolated to the other sub-watersheds between Yoakim Bridge and the Russian River. The Incremental Watershed between WSD and Yoakim Bridge contains Pena Creek, Schoolhouse Creek, Dutcher Creek, Fall Creek, Vince's Creek, and areas directly tributary to the creek. Of these tributaries, Pena Creek is much larger with greater relief, and its headwaters extend westward into the interior Coast Range. The smaller tributaries have watersheds that are local to the lower Dry Creek valley, with less relief. Because of these differences, the runoff characteristics between these watersheds vary.

Downstream of Yoakim Bridge, the Mill Creek watershed is similar in size and characteristics to Pena Creek. Thus, Pena Creek peak flow estimates were used to extrapolate peak flow estimates for Mill Creek. The other sub-watersheds between Yoakim Bridge and the Russian River are most similar to Schoolhouse, Fall, Vince's and Dutcher Creeks in size and relief. In order to extrapolate peak flow estimates for these watersheds, a third set of unregulated peak flow estimates was calculated by subtracting the peak flow estimates for Pena Creek from the peak flow estimates for the Incremental Watershed. The resulting values reflect the characteristics of the combined Schoolhouse, Vince's, Fall and Dutcher Creek watersheds. The peak flow estimates over this combined area were then used to extrapolate peak flow values for all watershed areas between Yoakim Bridge and the Russian River confluence, with the exception of Mill Creek (see above).

Peak flow discharge tends not to be linearly correlated with watershed area in many regional regression studies. Instead, peak flow estimates based on regional regression often take the form:

$$Q = C \times DA^y,$$

where Q is discharge (cfs), DA is drainage area (square miles), C is a combined factor which may contain constants and other variables such as precipitation, and y is a coefficient determined empirically through regression of many sets of peak flow data across a region (e.g. Waananen and Crippen 1977). Both C and y may vary with the return period of interest. To extrapolate peak flow estimates from one watershed to another watershed, the equation shown above can be combined and simplified for the two watersheds as follows:

$$Q_i/Q_j = DA_i^y / DA_j^y,$$

where the subscript i denotes the watershed for which a peak flow estimate is known, and subscript j refers to the watershed for which the extrapolated peak flow estimate is desired. For this study, the values for the exponent y were adopted from the applicable USGS regional regression equations for the North Coast region (Waananen and Crippen 1977).

After peak flow estimates were extrapolated to the sub-watersheds downstream of Yoakim Bridge, they were combined into a cumulative peak flow series, with flow changes located at each tributary confluence with Dry Creek. It should be noted that the original high flow release schedule included in the 1984 Water Control Manual for WSD (USACE 1984) was revised during recent ESA consultation between USACE, NMFS, and the Water Agency (Entrix, Inc. 2004). One of the revisions to the original high flow release schedule is that during peak flow periods, flows are now monitored both at the Russian River near Guerneville and the Dry Creek at Yoakim Bridge streamgages. Dam releases are controlled to attempt to keep flow magnitude below 7000 cfs at the Yoakim Bridge gage if practicable. The effect of this change is incorporated in the cumulative peak flow series. The cumulative peak flow series that was estimated using the available gage data and extrapolation of peak flow estimates to ungaged sub-watersheds is summarized in Table 3 and shown in Figure 7.

Table 3: Peak flow estimates at locations downstream of Warm Springs Dam. Estimates in columns labeled WCM derived from values included in 1984 Water Control Manual. Estimates in columns labeled Gage Data based on flood frequency analysis of available gage data, and extrapolation to ungaged watersheds. Q1, Q2, Q5, Q10, Q25, Q50 and Q100 refer to peak flood discharges with return intervals of 1, 2, 5, 10, 25, 50, 100 years, respectively.

Location / Tributary Confluence	Cum. Drainage Area (sq. mi.)	River Mile	Dist. Upstream from Russian River Conf. (ft)	Q1		Q2		Q5		Q10		Q25		Q50		Q100	
				WCM[1] (cfs)	Gage Data (cfs)	WCM[1] (cfs)	Gage Data (cfs)	WCM[1] (cfs)	Gage Data (cfs)	WCM[1] (cfs)	Gage Data (cfs)	WCM[1] (cfs)	Gage Data (cfs)	WCM[1] (cfs)	Gage Data (cfs)	WCM[1] (cfs)	Gage Data (cfs)
Outlet of Warm Springs Dam	130	13.8	72829	1500	400	2500	2450	4000	4300	**6000**	5500	6000	6000	**6000**	6000	**6000**	6000
Schoolhouse Creek	130.8	13.2	69781	1511	431	2522	2500	4033	4436	6022	5668	6039	6270	6056	6297	6100	6300
Fall Creek	133.7	12.1	64002	1551	529	2603	2550	4154	4867	6103	6192	6180	6500	6257	6500	6463	7000
Dutcher Creek	137.2	11.7	61861	1600	644	2700	2600	4300	5366	**6200**	6797	6350	6800	**6500**	7000	**6900**	7500
Vince's Creek	138.1	11.3	59863	1629	676	2737	2650	4341	5508	6219	6971	6428	7000	6619	7500	7058	8000
Pena Creek	160.6	10.9	57573	2358	1059	3655	2790	5369	7000	**6700**	7000	8380	7400	**9600**	8100	**11000**	8600
Canyon Road Creek	162.9	10.3	54265	2434	1137	3758	3025	5507	7339	6846	7412	8580	8056	9833	8821	11291	9223
Grape Creek	171.2	7.2	38042	2707	1392	4127	3795	6004	8444	7371	8743	9302	10152	10673	11127	12342	11214
Crane Creek	176.4	6.2	32840	2878	1559	4359	4301	6316	9174	**7700**	9626	9754	11550	**11200**	12500	**13000**	12700
Kelly Creek	181.2	4.3	22462	3107	1715	4697	4770	6799	9850	**8200**	10445	10490	12846	**12100**	13700	**14100**	14100
Pine Ridge Canyon	183.1	3.2	16717	3485	1782	5144	4974	7336	10147	**8700**	10808	11187	13426	**13000**	14300	**15000**	14700
Mill Creek	209.2	0.7	3480	5371	2222	7610	7092	10569	13682	**12500**	15374	15767	18948	**18000**	20500	**21000**	21103
RR Confluence	217	13.8	72829		2442		7757		14631		16510		20726		22000		22792

[1] **Bold italicized** values represent values as appear in the WCM. All other values in column labeled WCM have been extrapolated or interpolated.

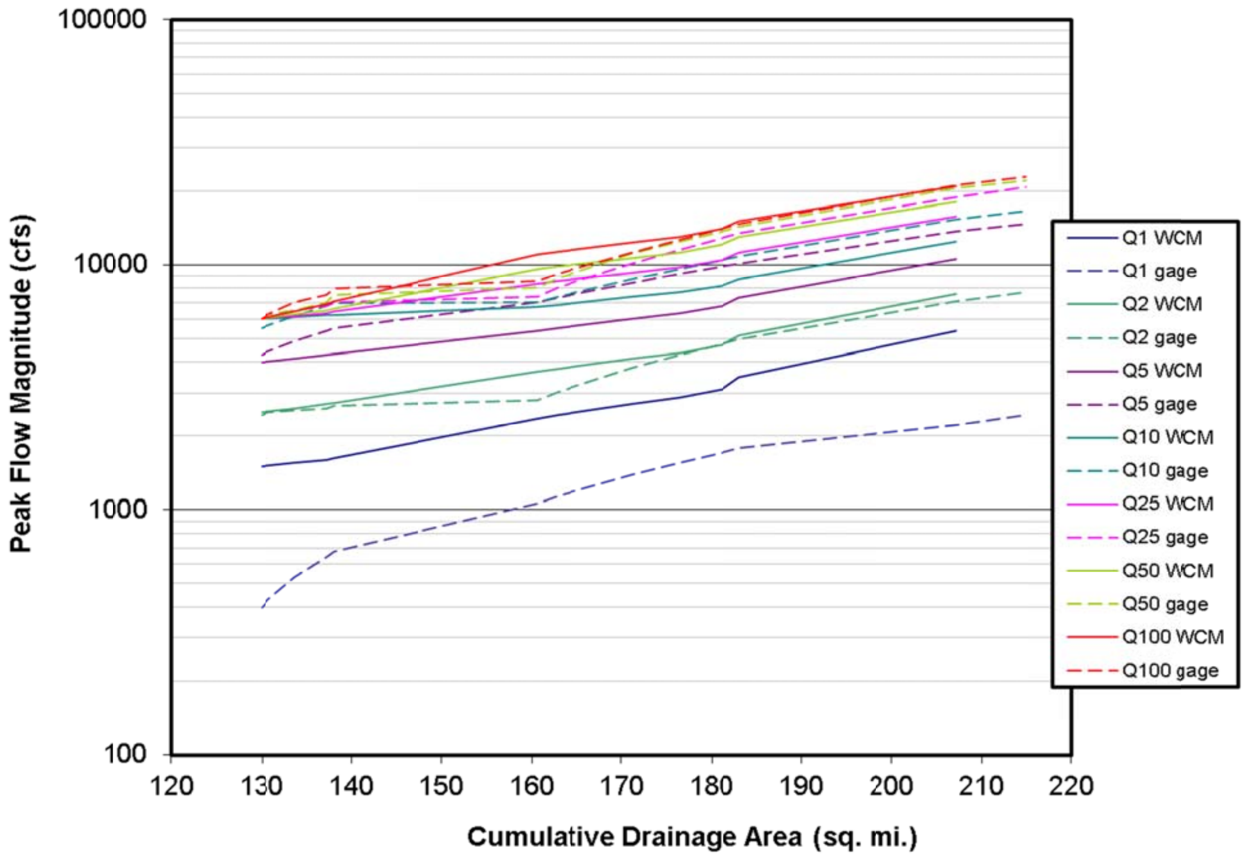


Figure 7. Peak flow estimates at locations downstream of Warm Springs Dam. Estimates labeled WCM derived from values included in 1984 Water Control Manual. Estimates labeled Gage Data based on flood frequency analysis of available USGS gage data, and extrapolation to ungaged watersheds.

4.4.2.3 Comparison of peak flow estimates

In general, the peak flow series estimates generated by the two methods compare reasonably well. The values based on the gage data tend to be relatively lower for Q1 and selected reaches for the Q2, Q25, Q50 and Q100 peak flow events. Conversely, the values based on the WCM tend to be lower for the Q5 and Q10 peak flow events. While there is some variability between the results of peak flow estimation methods, the range in the estimates likely bracket the true values. For reference, Figure 8 summarizes the annual peak flow events that have been recorded at the gages below WSD and at Yoakim Bridge gages in the post-dam period. The peak flow estimates based on the available gage data for the unregulated areas of the watershed downstream of WSD were adopted for use in this study rather than the WCM estimates.

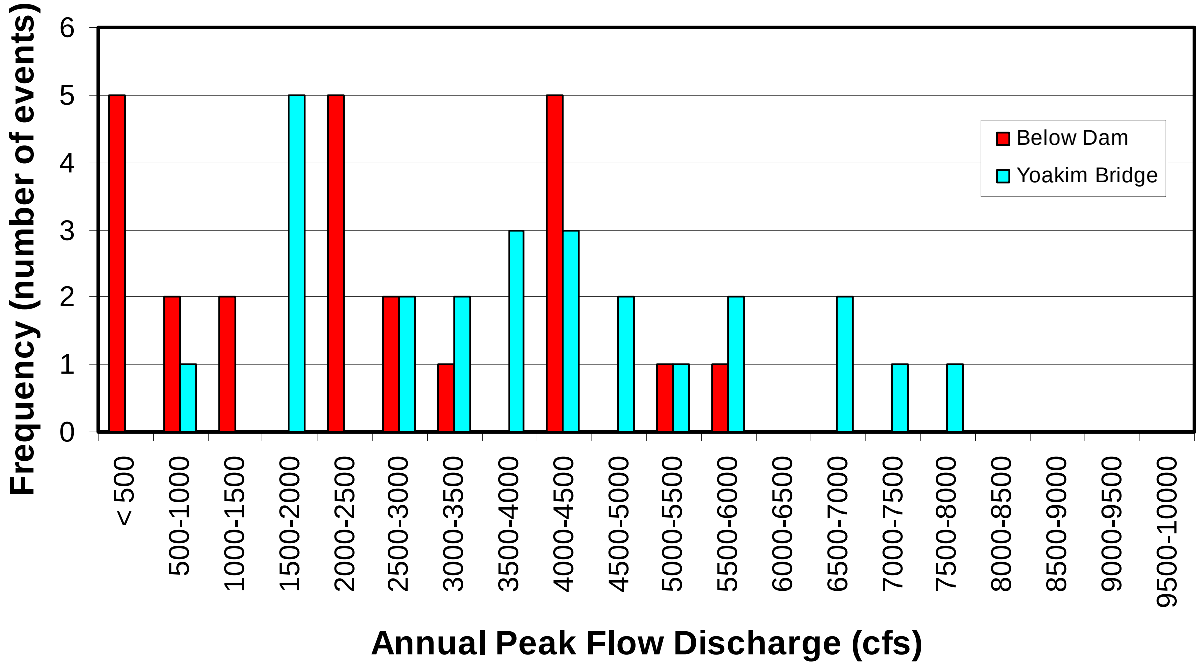


Figure 8: Histogram showing relative frequency of annual peak flows of varying discharge for the post-dam period.

The peak flow estimates developed by the SCS (PCI 2010) for Mill Creek were compared to the peak flow estimates developed for Mill Creek by the above methods (Table 4). The SCS estimates were relatively similar to the other estimates for the Q2 event, but were substantially greater (30% to 40%) for the Q10, Q25 and Q100 events. The peak flow estimates based on the available gage data were used in subsequent analyses in this study.

Table 4. Comparison of peak flow estimates for Mill Creek based on three data sources.

Return Period (yrs)	Estimate based on WCM (cfs)	Estimate based on Gage Data (cfs)	Estimate based on SCS analysis (cfs)
2	2754	2118	2711
10	3800	4566	6015
25	4580	5522	7038
100	6000	6403	8922

4.4.3 Flow Duration

Flow duration curves were previously developed and detailed in the CCIR (Inter-Fluve 2010) using daily flow records from the USGS gaging stations below the dam and at Yoakim Bridge for the following scenarios: (1) post-dam, below the dam (1984-2007), (2) post-dam, at Yoakim Bridge (1984-2008), and (3) pre-dam, at Yoakim Bridge (1960-1983). Figure 4 presents flow-duration curves based on this analysis.

To support the feasibility analysis, additional flow duration curves were developed for the winter period only. The resulting flow duration curves for the Yoakim Bridge gage are shown in Figure 9. Similar trends are seen in the flow duration results for the gage below Warm Springs Dam.

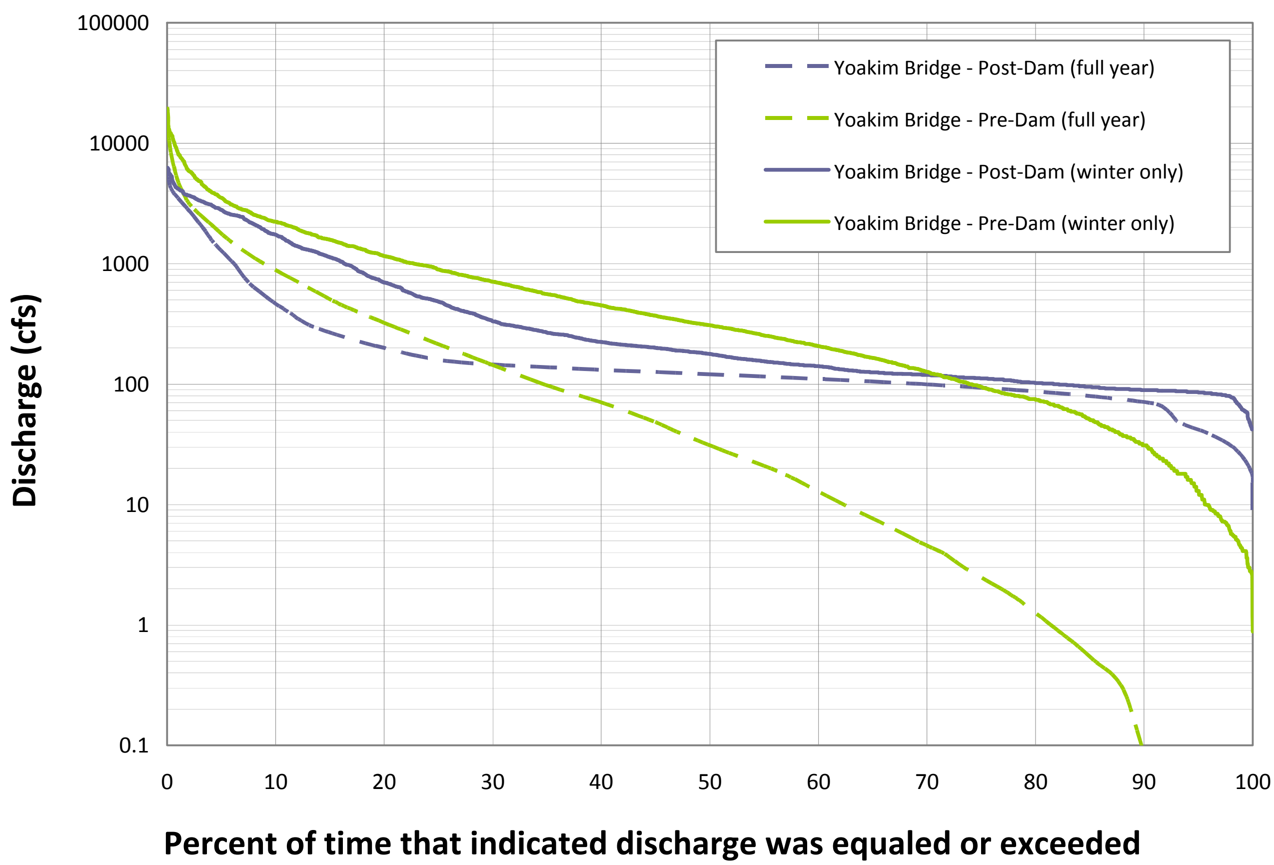


Figure 9. Flow duration curves for Dry Creek at the USGS gage station at Yoakim Bridge (pre- and post-dam) over annual and winter-only timeframes.

4.5 Stream Processes

4.5.1 Geomorphology

The CCIR discussed the geomorphic evolution of Dry Creek based on existing information and reports, and field observations. The following paragraphs summarize the primarily qualitative synthesis of the lines of evidence that were available during preparation of the CCIR. Subsequent to completion of the CCIR, additional data have been collected which provide a quantitative contribution to the discussion of Dry Creek's evolution, and are summarized in Section 4.5.1.1. Subsequent sections then provide a quantitative representation of contemporary river processes in Dry Creek.

The current geomorphology of lower Dry Creek is a result of the interaction between watershed characteristics, including local geology, hydrology, and vegetation; the legacy of channel evolution and response to land management changes; and the ongoing influence of flow management. Lower Dry Creek is an incised, perennial, alluvial gravel bed stream that has responded to significant human induced hydrologic and geomorphic change over the past 150 years. At the time of this report, the study reach is primarily composed of pool-riffle and plane-bed morphology (Montgomery and Buffington 1997) with an average channel gradient of 0.18%. The channel corridor is generally narrow relative to the active channel width, and relatively uniform in width over most of the study reach, with periodic wider reaches.

Widespread, systemic incision occurred historically in response to base-level lowering and other factors. Assessments completed in close proximity to the time of dam closure concluded that systemic degradation of lower Dry Creek had generally ceased by the time the dam came online (Harvey and Schumm 1985). The primary determinant of current geomorphic conditions is the influence of the dam, expressed through modified sediment supply, altered hydrology and the growth of riparian vegetation. Dam construction ceased delivery of bed material from the upper 60% of the watershed. The hydrologic regime has been converted from a seasonal runoff-based regime to a regime that combines moderate winter floods, year-round flows, and sustained, relatively high baseflow conditions. This shift substantially influences the mobility of the alluvial materials present in the creek, (discussed in greater detail in Sections 4.5.3 and 4.5.4). The regulated hydrology has also resulted in increased growth of riparian trees that influence bank erosion rates and sediment dynamics (see Section 4.5.1.2).

Based on field observations, the reduction in bedload supply is most noticeable in the reach between the dam and the confluence of Dutcher (RM 11.8) and Pena (RM 11) Creeks. The reduction in bed material supply is moderated by successive tributaries entering lower Dry Creek. The most significant of these in terms of bed material supply include Dutcher Creek (RM 11.8), Pena Creek (RM 11), Crane Creek (RM 6.3) and Mill Creek (RM 0.6). The reach between Pena Creek and Westside Bridge (RM 11 to RM 2) did not appear to be actively incising or aggrading, though there are selected areas of active channel adjustment. The reach between Westside Bridge and confluence with the Russian River appeared to be the most alluvial reach, in which the channel position and shape are most readily shaped by contemporary fluvial forces.

4.5.1.1 Evolution following dam closure

To supplement the field observations synthesized in the CCIR, additional data was collected during the feasibility study field investigation to provide a quantitative perspective to the evolution of Dry Creek since closure of WSD, primarily with respect to channel degradation. Discussed below, these data include repeat stream cross sections, longitudinal stream profiles, and USGS gaging station rating curves.

4.5.1.1.1 Repeat Degradation Range Surveys

A series of 24 stream cross sections were established in the Dry Creek study reach (Figure 10) during the planning of Warm Springs Dam and have been resurveyed several times. Referred to as 'degradation ranges', the earliest known survey of these cross sections was completed in 1940 (Harvey 1987). Subsequent resurveys of the cross sections were completed in 1964, 1974, 1976, 1980, 1981, and 1984 (Harvey and Schumm 1985). It is not known whether additional resurveys were completed following dam closure. Multiple inquiries to the Army Corps of Engineers and Water Agency over the period 2008-2010 have not resulted in information suggesting that they have been resurveyed in the intervening period. Data from the 1976, 1980, 1981 and 1984 resurveys were provided to Inter-Fluve by Water Agency in electronic format.

A selection of the degradation ranges was resurveyed in 2010 to support the feasibility assessment. In planning the resurvey of the ranges, several inquiries were made to the Corps of Engineers to recover the coordinates of the ranges with no success. Thus, the locations of the ranges were digitized by the Water Agency from scanned paper copies from their archives which showed the locations of the ranges in plan. The estimated horizontal accuracy of the digitized range locations is 50 feet +/-. In the field, the survey crew then navigated to the digitized locations using a GPS unit with sub-meter accuracy, and surveyed cross section topography at the designated locations.

Of the 20 ranges planned for resurvey in 2010, 14 ranges were resurveyed for comparison with historical survey data provided by the Water Agency. The remaining 6 ranges could not be resurveyed due to limitations on permission to enter private property. Figure 11 to Figure 16 show comparisons of the repeat cross section surveys. Due to anomalous data in the excel spreadsheet provided to Inter-Fluve, it was not possible to correlate the 2010 data to the earlier data for 3 of the 14 ranges, resulting in the 11 repeat cross section plots shown.

When reviewing the repeat cross section plots, it is important to keep in mind the variability that may be introduced purely through the method of relocating the cross sections. However, the repeat surveys at the ranges which bracket Lambert Bridge (18, 22, 24 and 27) suggest bed lowering of approximately 2 feet (approximately 5 feet for range 27) since the 1984 survey. These trends are consistent with local landowner observations of local degradation in the vicinity of Lambert Bridge since dam closure. Likewise, the ranges in the downstream end of the study reach (45, 47) suggest potential for approximately 2 feet of bed lowering. The remainder of the cross sections show variability in channel position over time, but do not suggest ongoing bed degradation.

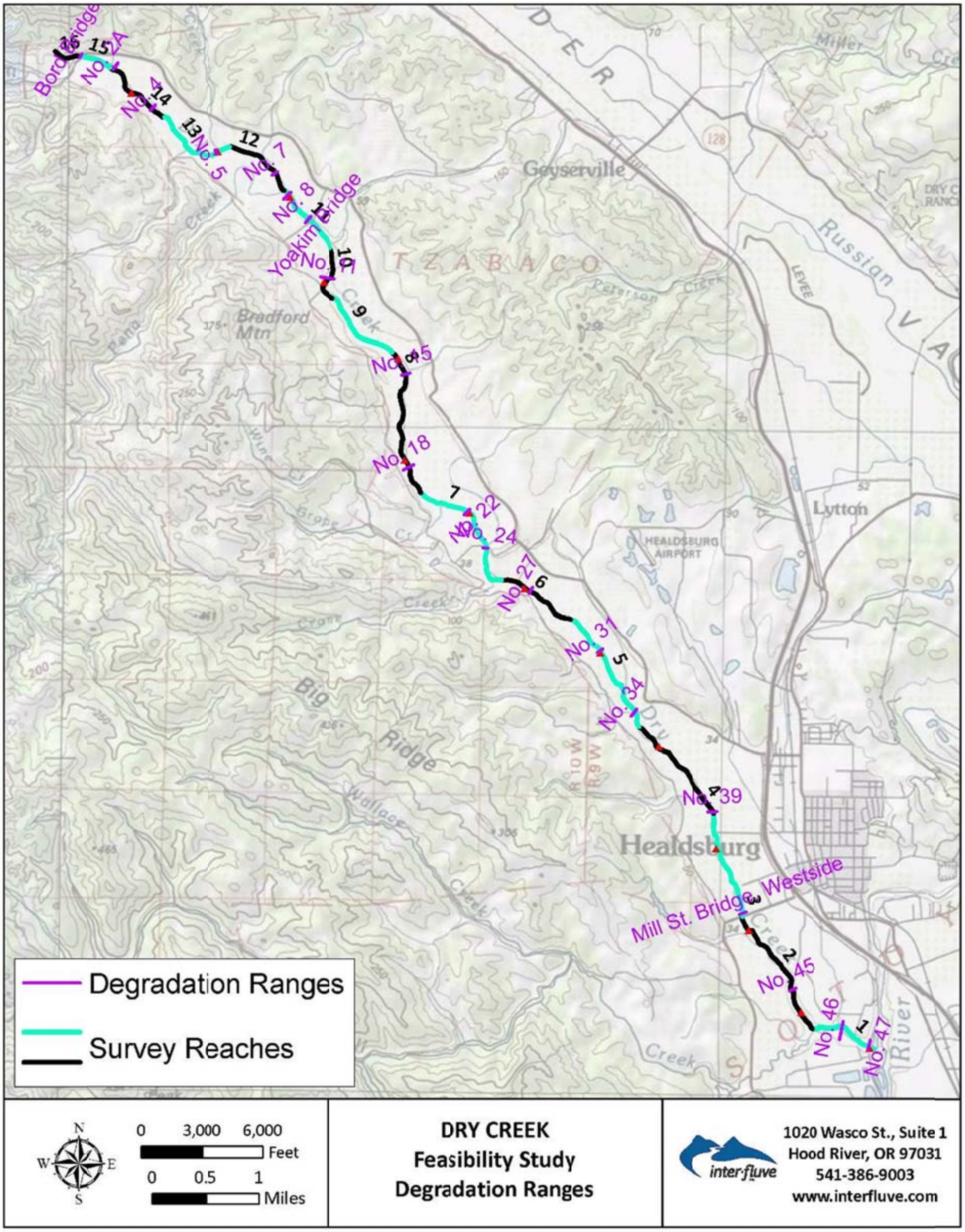
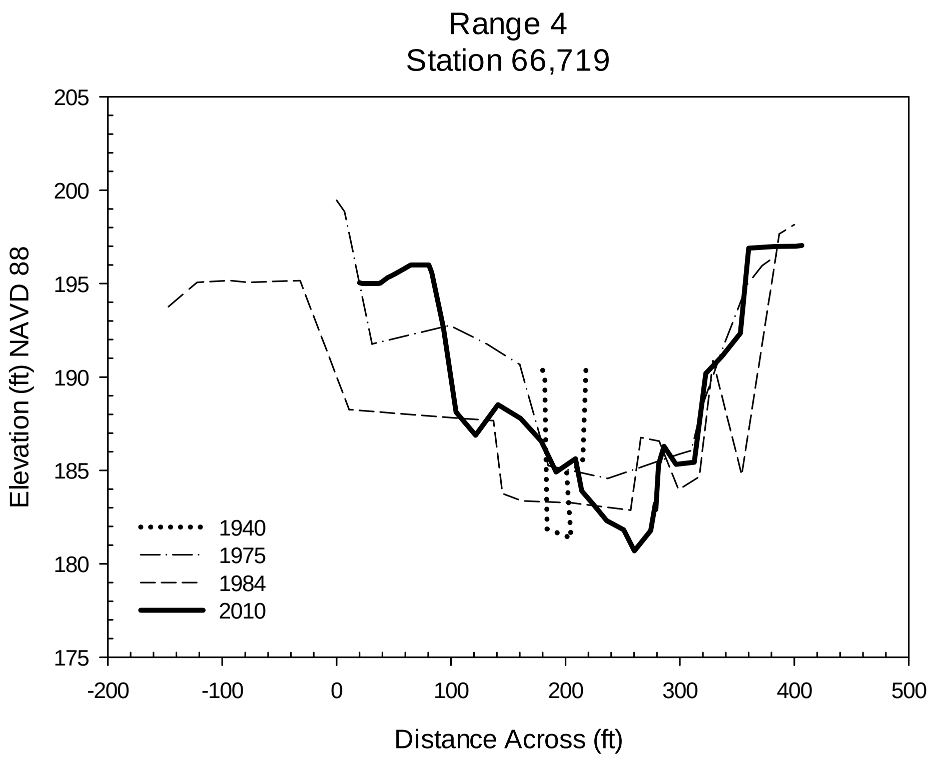


Figure 10. Locations of degradation ranges.



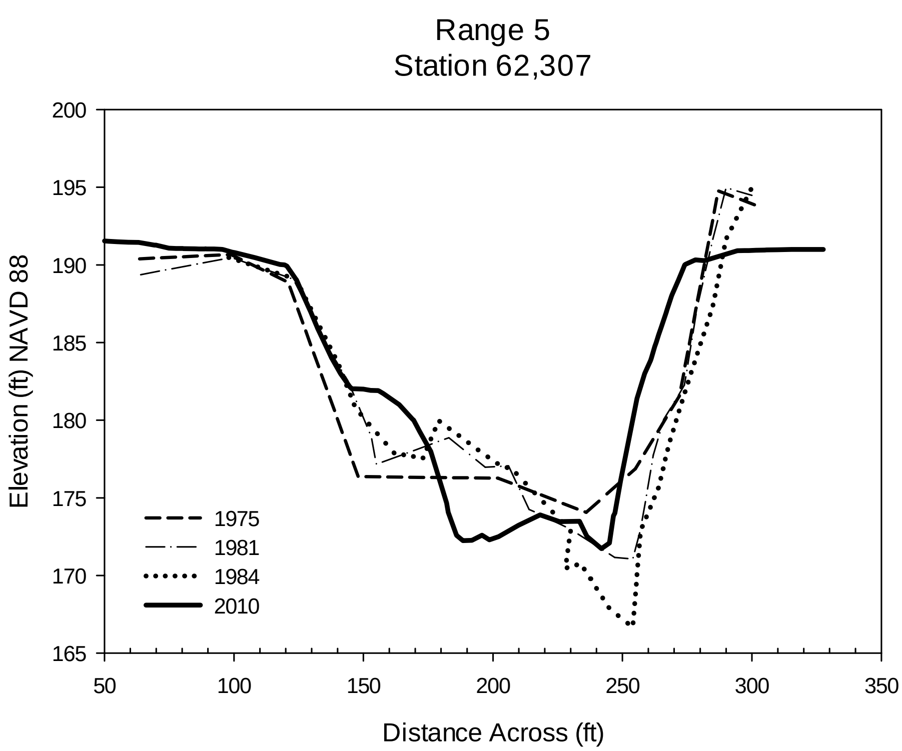


Figure 11a-b. Repeat surveys of degradation ranges 4 and 5. Station is distance upstream of the Russian River confluence, in feet.

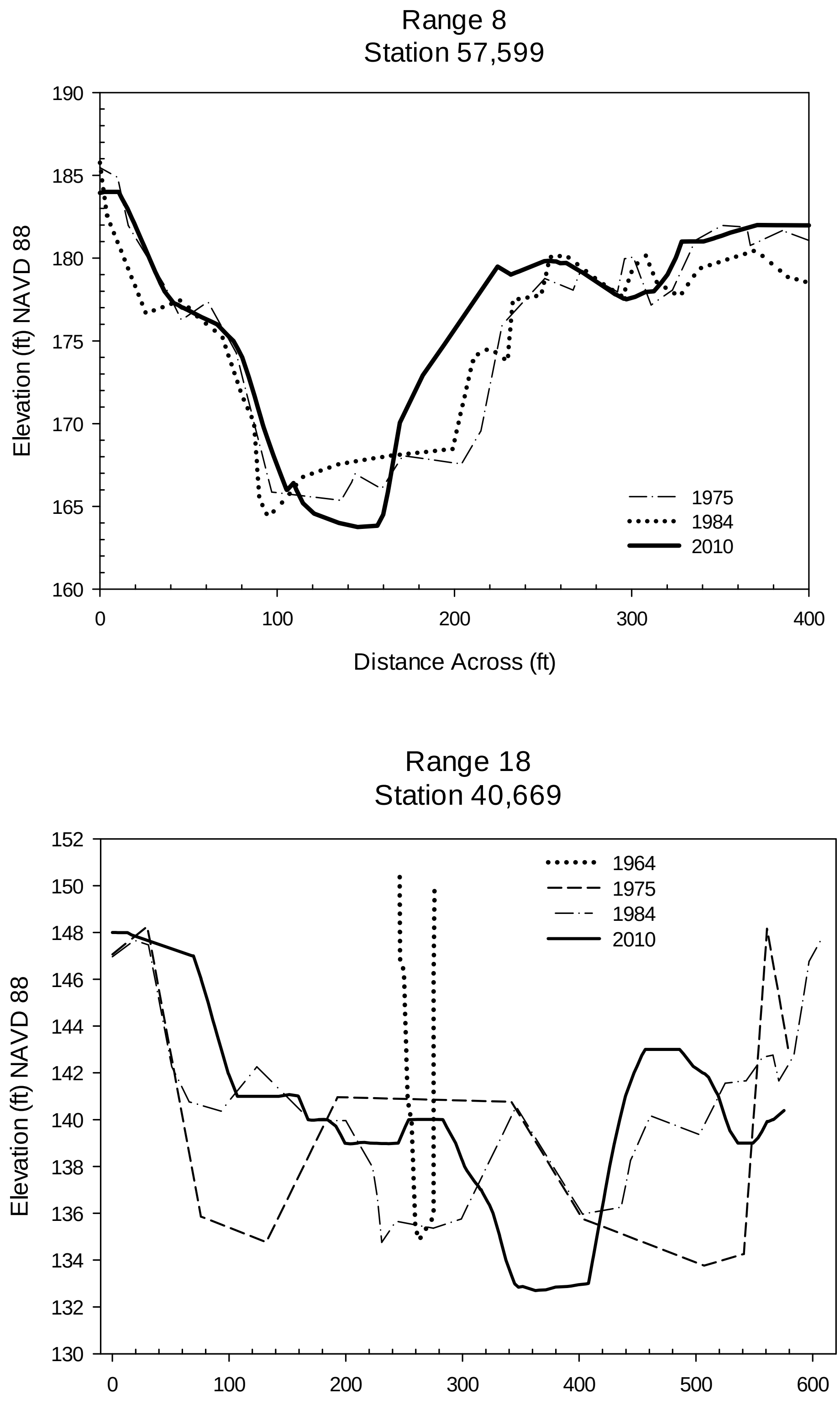


Figure 12a-b. Repeat surveys of degradation ranges 8 and 18. Station is distance upstream of the Russian River confluence, in feet.

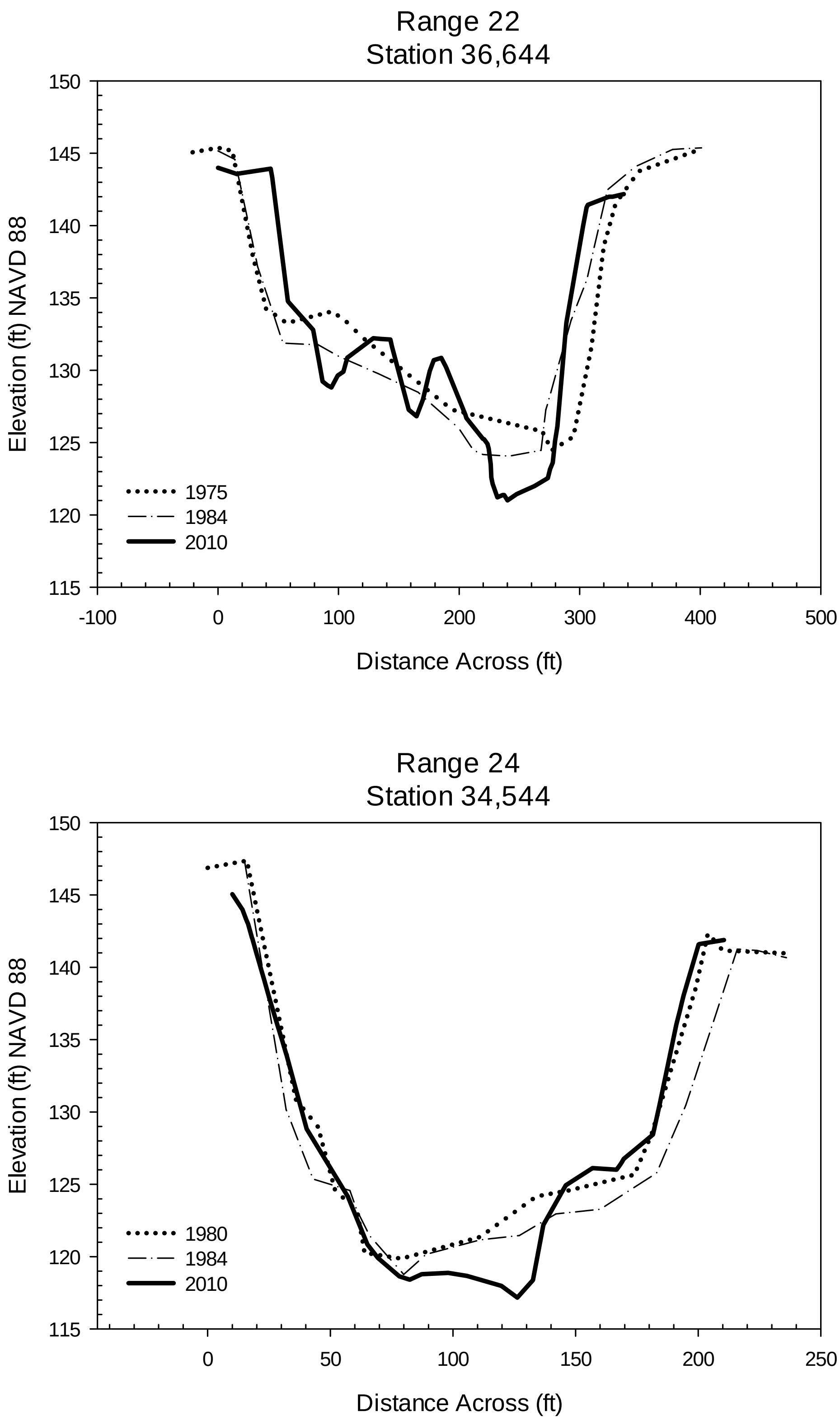


Figure 13a-b. Repeat surveys of degradation ranges 22 and 24. Station is distance upstream of the Russian River confluence, in feet.

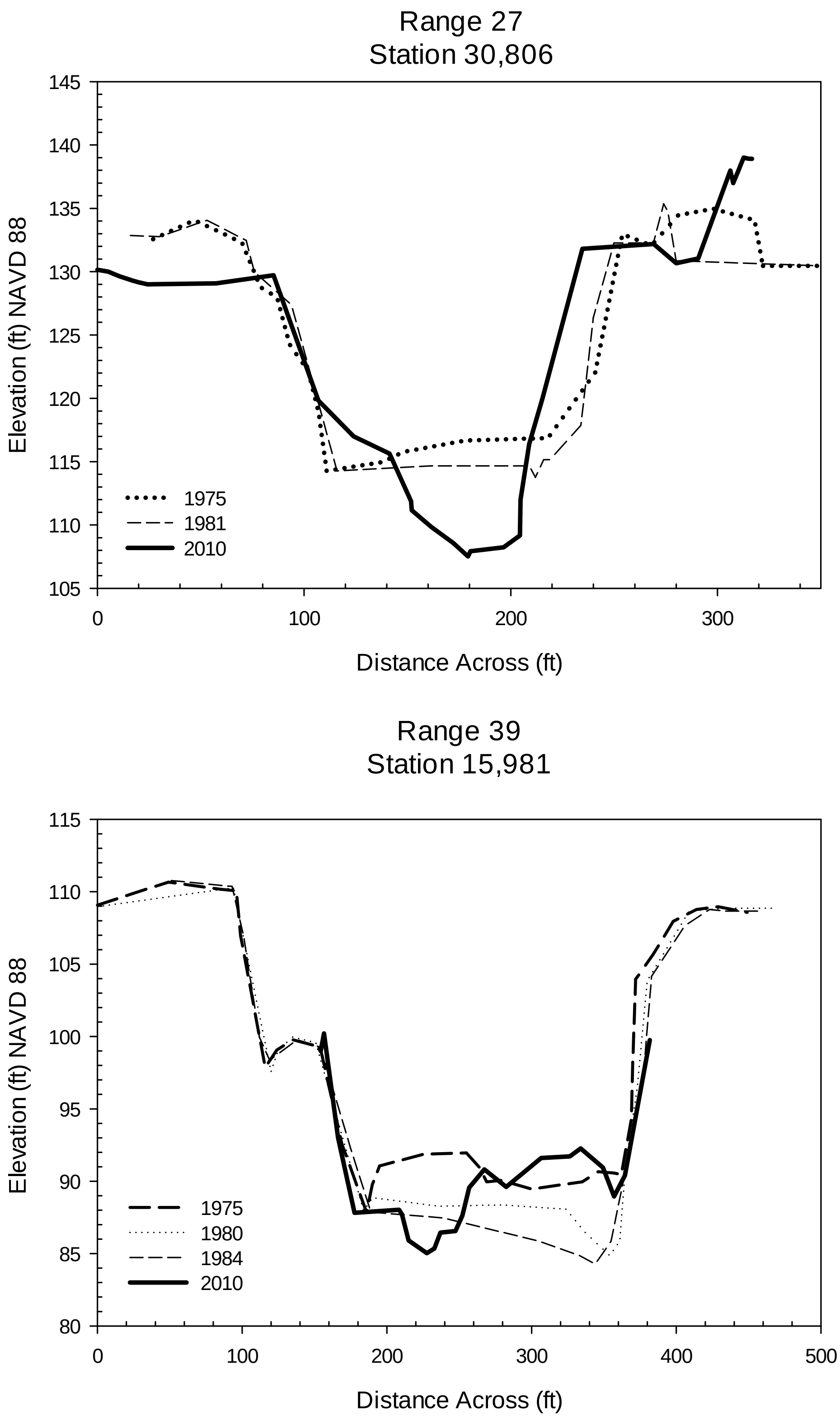


Figure 14a-b. Repeat surveys of degradation ranges 27 and 39. Station is distance upstream of the Russian River confluence, in feet.

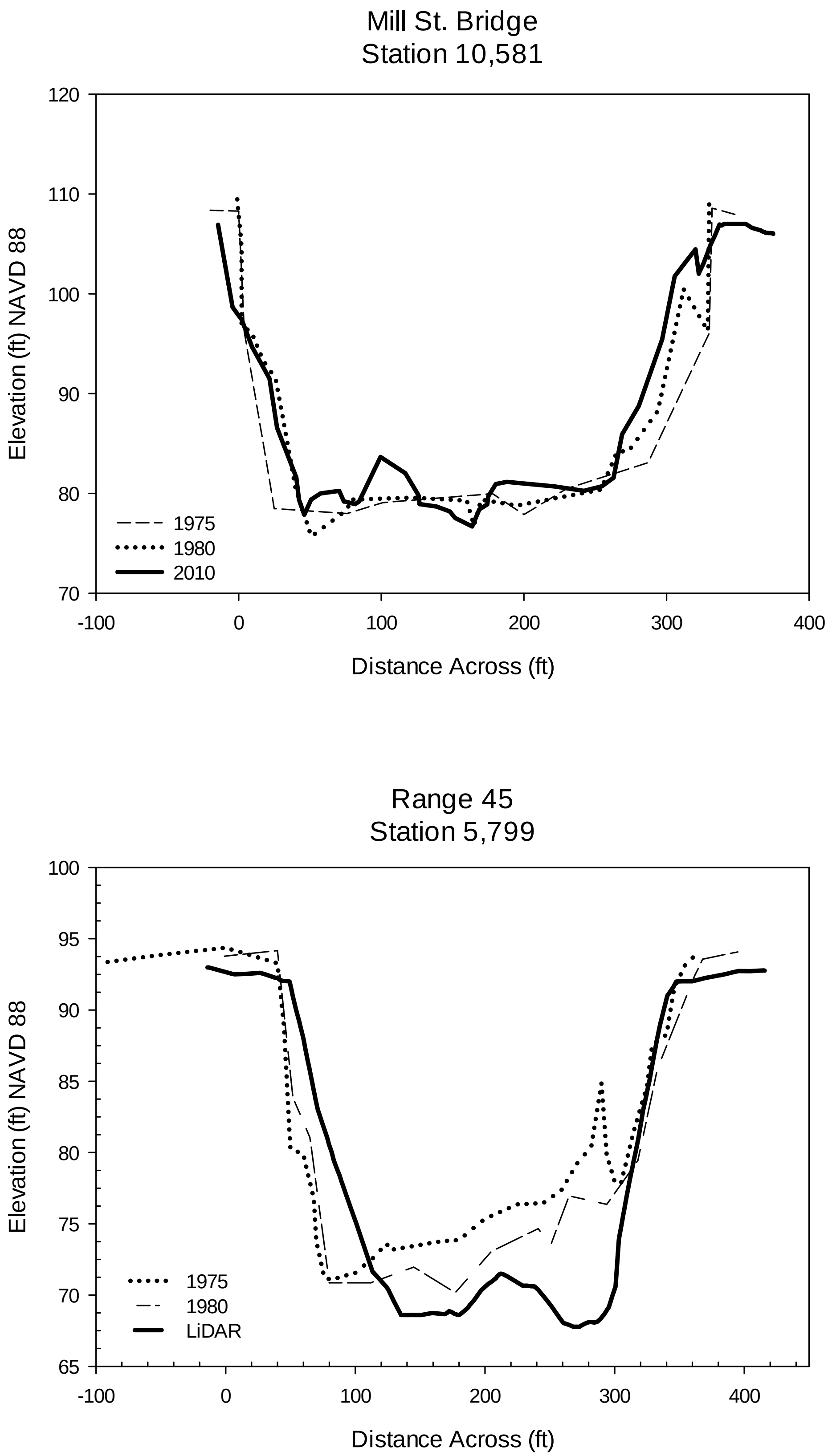


Figure 15a-b. Repeat surveys of degradation ranges Mill St. Bridge and 45. Contemporary topography at Range 45 was extracted from ground-truthed LiDAR data. Station is distance upstream of the Russian River confluence, in feet.

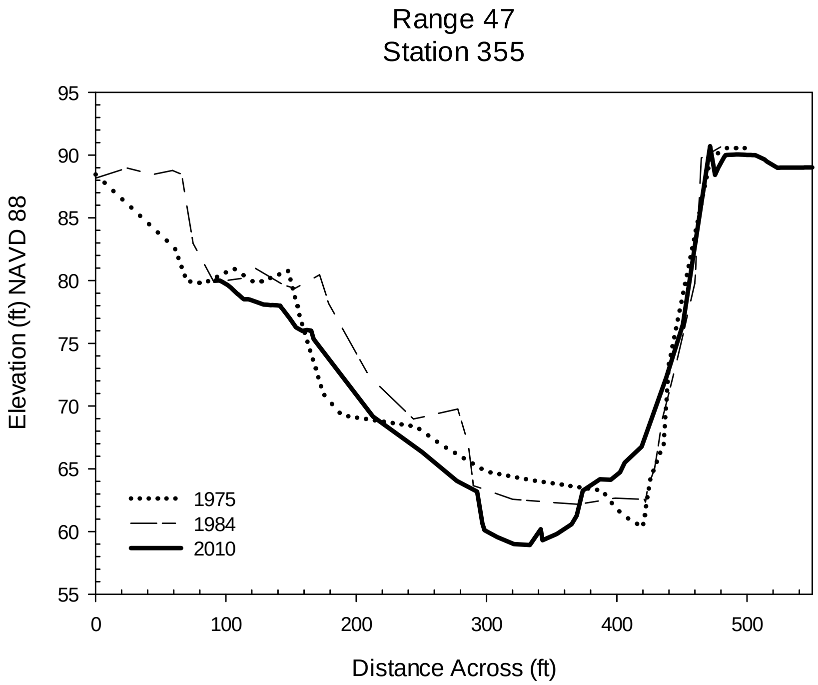


Figure 16. Repeat surveys of degradation range 47, located 355 ft upstream of the Russian River confluence.

4.5.1.1.2 Repeat longitudinal profiles

Using the same repeat survey data as the degradation range locations, the evolution of the Dry Creek bed level was also reviewed in terms of a longitudinal thalweg profile. Based on this comparison, Figure 17 suggests that the bed level may have lowered by approximately 2 feet in locations along the middle of the study reach, from upstream of the grade control sills to near the Grape Creek confluence, and again upstream in the reach one to two miles below Yoakim Bridge. However, when reviewing the repeat profile plots, it is important to keep in mind the variability that may be introduced purely through the method of relocating the cross sections upon which the comparisons are made, as described above.

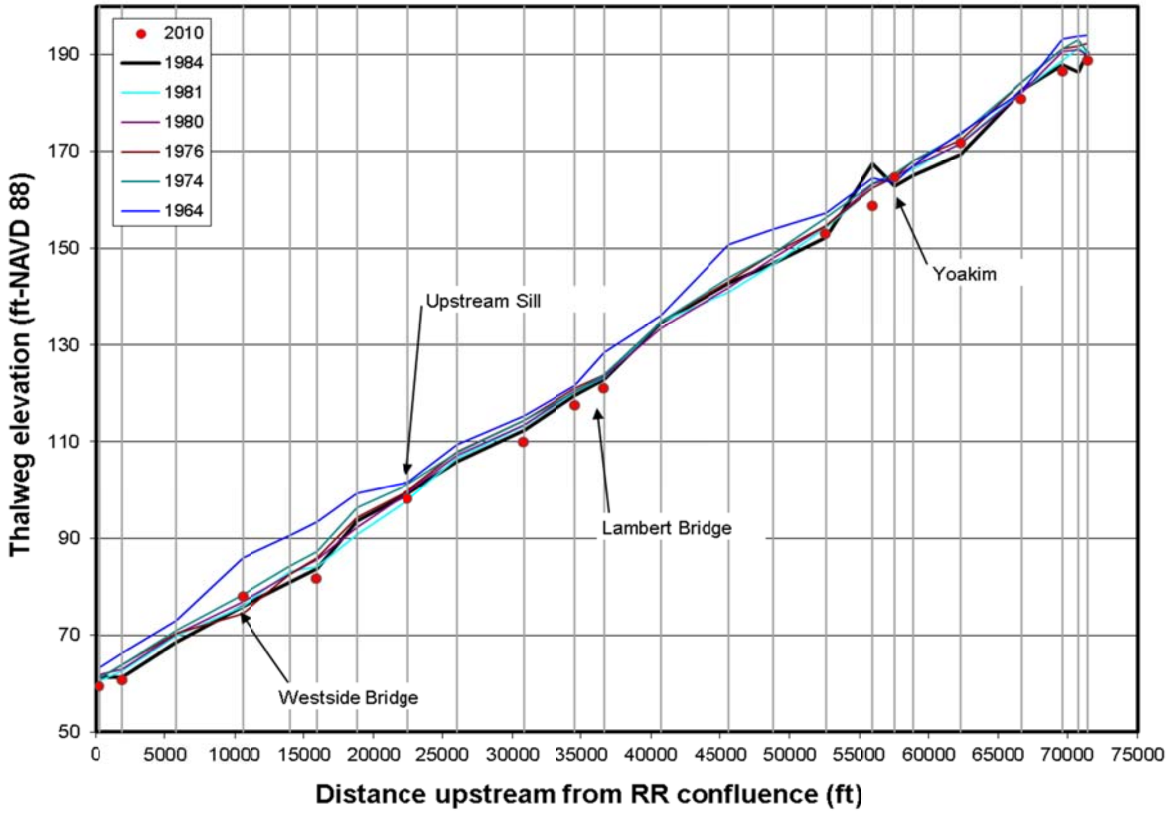


Figure 17. Repeat longitudinal thalweg profiles based on the degradation range resurveys. Note that vertical gray lines represent locations of degradation ranges. No data is plotted between these locations.

4.5.1.1.3 Stage-Discharge Rating curves

In addition to the repeat surveys described above, the available stage-discharge rating curves for the USGS stations at Yoakim Bridge and at the mouth of Dry Creek were reviewed for indications of channel adjustment since dam closure. At each gage, the rating curve is used to convert automated observations of river stage to river discharge. Manual physical flow measurements are typically made monthly at each gaging station to calibrate the stage-discharge rating curve for that station. With changes in the river channel in the vicinity of a stream gage, the plots of stage against discharge for the monthly manual measurements will tend to systematically diverge from the prevailing rating curve, leading to development of a new curve (Figure 18).

For each gage, all of the available rating curves were obtained USGS electronic National Water Information System (NWIS) database. At the Yoakim Bridge gage, the available rating curves extend back to 1979, approximately 5 years before dam closure (Figure 18). Starting in 1979, the progression of rating curves shows a systematic increase in stage at discharges above 500 cfs through 1998. This trend suggests progressive reduction of hydraulic capacity primarily in the overbank areas. Beginning in 1998, an opposite consistent trend is clear at discharges below 1000 cfs which suggests progressive increasing hydraulic capacity in the active flowing channel. These trends are consistent with the observed evolution of Dry Creek since dam closure. As riparian vegetation became established and proliferated in the overbank areas outside the active flowing channel, hydraulic capacity in the channel corridor was reduced. As vegetative colonization caused the overbank to become hydraulically rougher, proportionally more water is forced into the active flowing channel during peak flows, which has likely resulted in subsequent degradation of the channel bed in certain sub-reaches of lower Dry Creek. This indication of degradation below Yoakim Bridge also appears consistent with the trend seen in the comparison of longitudinal thalweg profiles discussed above, and in field observations of degradation adjacent to the Yoakim Bridge piers.

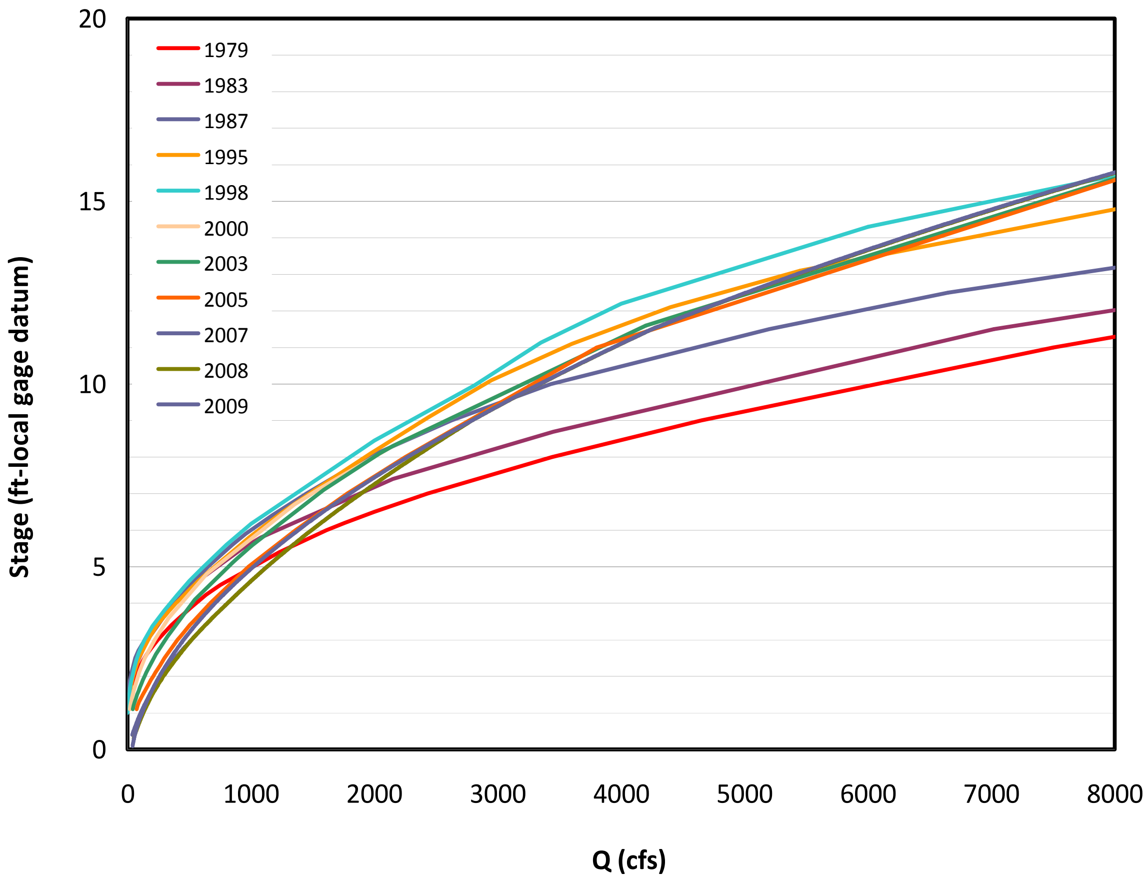


Figure 18. Time series of stage-discharge rating curves for USGS gage 11465200 Dry Creek near Geyserville (Yoakim Bridge).

At the gage near the mouth of Dry Creek, the available rating curves extend back to 1989, approximately 5 years after dam closure (Figure 19). This is a low-flow only gage which is located in a sub-reach that is influenced by backwater from the Russian River during winter and flood flows. Thus, the rating curves span the low flow range only. A cyclic trend is apparent in the progression of the rating curves, with increasing channel capacity 1989-1993, 2000-2004 and 2007-2009, and reduced channel capacity 1993-2000 and 2004-2007. This pattern is consistent with the backwater-influenced location of this gage. During high water events, bed aggradation is likely due to backwater from the Russian River, which has the effect of reducing hydraulic capacity. In the periods between high events, the channel is likely to degrade back down through the recent aggradation, subsequently increasing hydraulic capacity. The trend reverses again with the next flood event. The important trend to take away from the series of rating curves for the gage near the mouth is that these cycles of aggradation and degradation are occurring around a central mean condition, suggesting that the lower portion of Dry Creek is generally at grade with the downstream Russian River, and progressive trends in degradation or aggradation are not indicated based on this data.

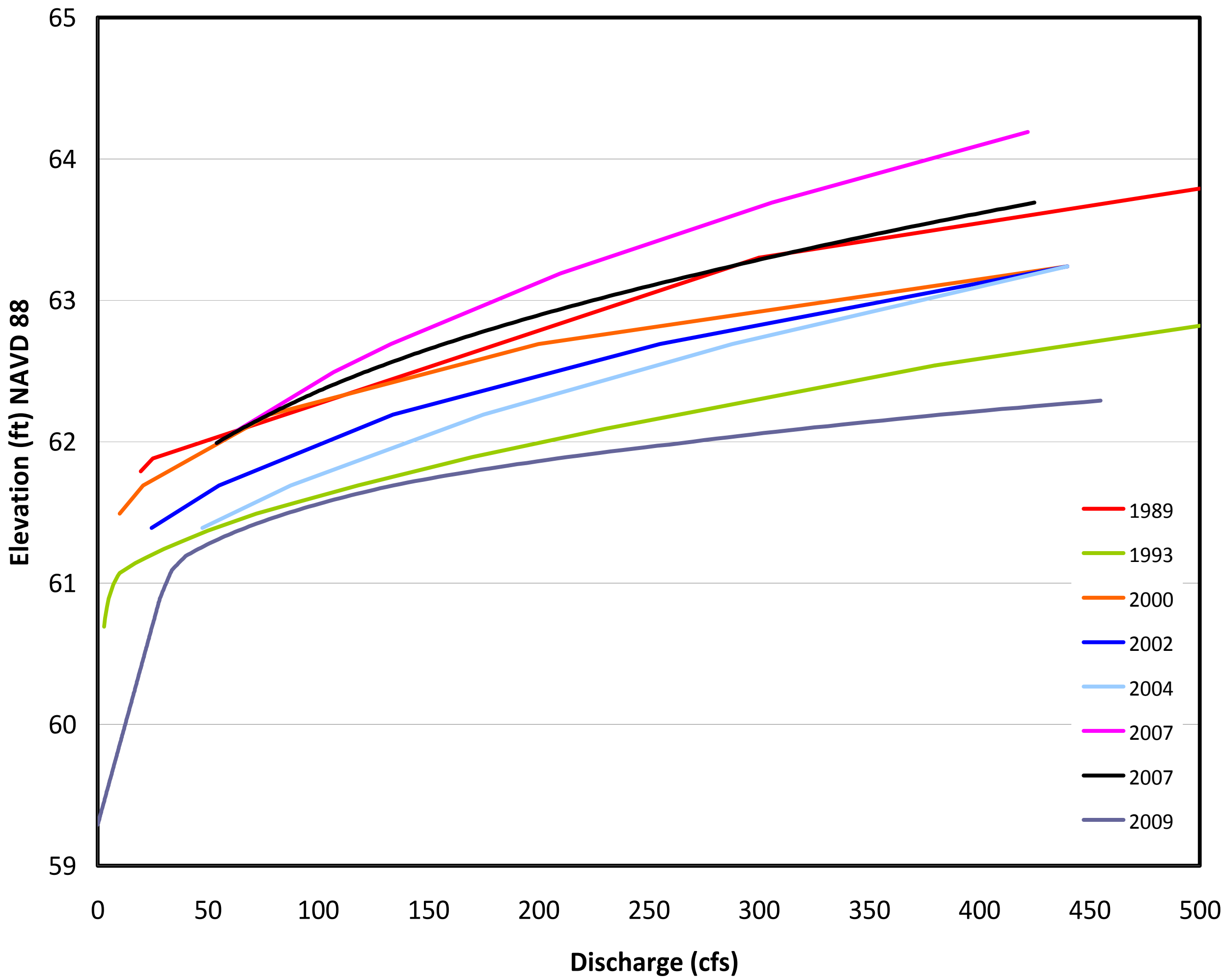


Figure 19. Time series of stage-discharge rating curves for USGS gage 11465350 Dry Creek near Mouth.

4.5.1.2 Vegetation

As described in the CCIR, regulation has resulted in elevated summer baseflow conditions that when combined with the local Mediterranean climate produce near ideal conditions for growth of riparian trees and shrubs (Figure 20 - Figure 23. Comparison of photos taken looking downstream from Yoakim Bridge. The top photo was taken in October 1970, bottom photo taken in July 2010. In 1970, lower summer flows limited encroachment of vegetation, while the post-dam era has provided excellent conditions for vegetation growth on bar surfaces.).

Riparian vegetation succession typical of the region is described by McBride and Strahan (1984b). Primary succession typically commences with colonization of red willow and cottonwood on point bars and cut banks, with alder also becoming established at the base of banks in contact with the streambed. Cottonwood and willow dominate initially, then trap fine-grained sediment resulting in aggradation of point bars, allowing alder to establish. As alder becomes established, it typically becomes the dominant canopy species. Shade-intolerant willows and cottonwood cannot survive beneath the dense canopy, and with time, alder dominates the interior downstream portions of point bars, reproducing primarily by layering or propagation via existing root biomass (McBride and Strahan 1984b).

As a point bar advances laterally and the stream bed moves further from the channel banks, the distance from the surface water in the stream to the root systems of alders (and other vegetation) often becomes too great for effective water transport. Under these conditions, alders will be replaced by species better adapted to terrace environments such as Hinds walnut, box elder, oak and bay with significant variations in basal area and relative density in relation to swales and floodplain terrace location. As the terrace builds in height or extends into the stream channel, more drought tolerant species such as oaks and bay increase in importance. These species will dominate the higher elevations of the floodplain woodland and those sites most removed from the stream channel, achieving a late-successional steady state is typically achieved only for brief intervals because of the continuous migration of the stream channel. Thus, left undisturbed by humans, the pioneering cottonwood/willow floodplain woodland community will ultimately trend towards a late-successional condition dominated by walnut, box elder, oak and bay, which will be subsequently reset to an early successional stage through channel migration, restarting the evolutionary pattern (McBride and Strahan 1984b).

However, in the case of Dry Creek, the late-successional and regeneration steps in the trajectory described above may be unlikely to occur. The elevated baseflow condition which occurs through the summer in Dry Creek provides a sharp contrast to unregulated riparian systems where the floodplain becomes progressively drier over time, leading to decline of the alder community and enabling establishment of the late-successional walnut/oak/bay community.

Instead, elevated baseflow in combination with curtailed flood hydrology, may support the dense alder community in perpetuity, effectively stalling the successional trajectory. This limits the potential for channel migration, which sequesters gravel within the system and limits the re-creation of lateral habitats such as alcoves, backwaters, and side channels. The mature vegetation and dense understory growth hydraulically roughen over overbank areas and concentrate high flow velocities in the channel during high flow events, which results in an active channel that is efficient at moving gravel supplied to the stream despite the reduced flood flow hydrology.


Figure 20: Vegetative colonization of bar surface, RM 12.3

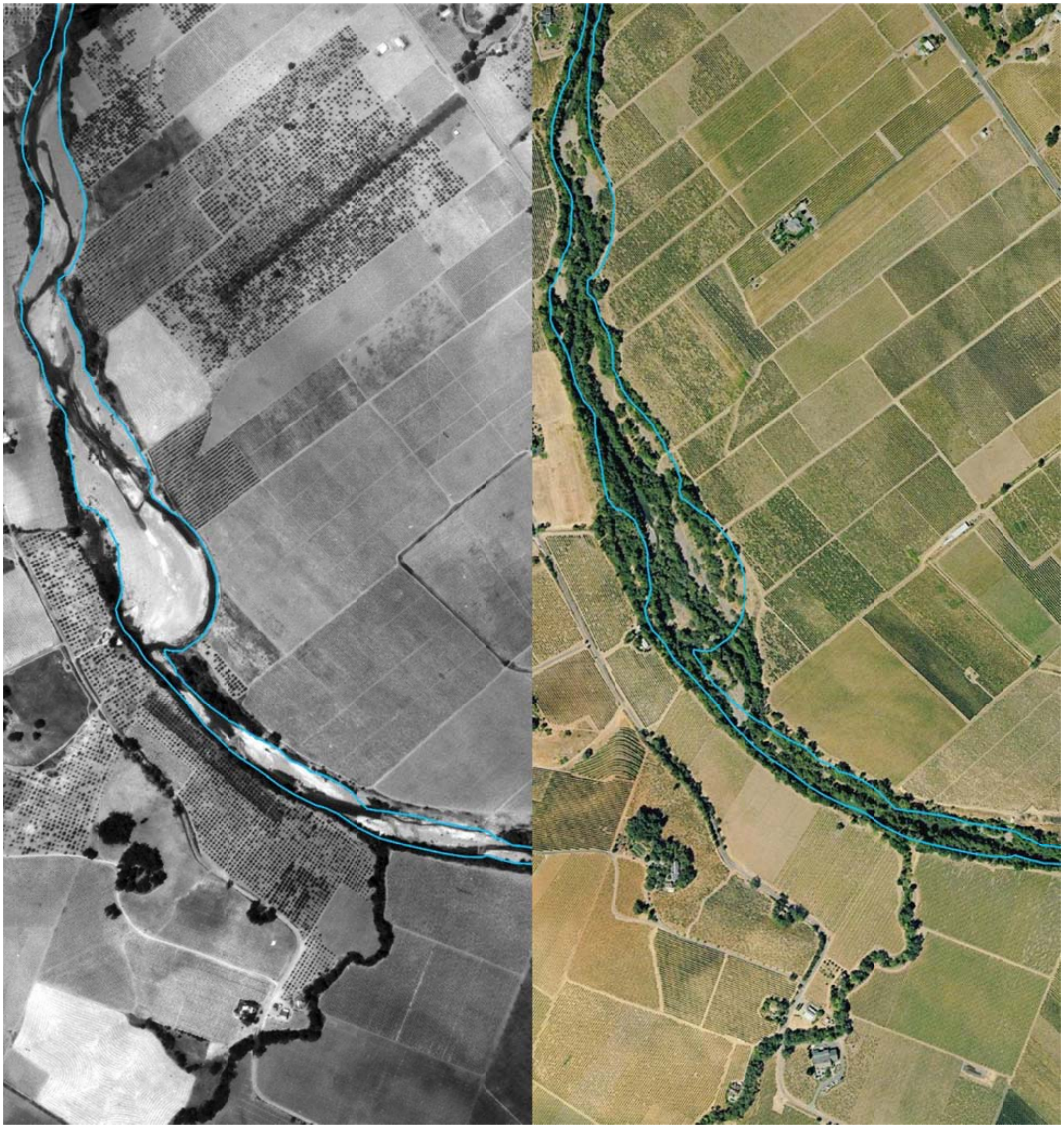


Figure 21: Example of vegetative establishment in relatively wider area of channel corridor leading to a narrowed active channel near confluence of Grape Creek (RM 7.3). Grape Creek is seen at bottom center of each frame. Dry Creek flow is from top to bottom. Left frame is from 1976, right frame is from 2004. Light blue line is estimated limit of active fluvial features in 1976.

Figure 22: Example of vegetative narrowing of channel corridor near Lambert Bridge (RM 6.6). Lambert Bridge is seen at lower right of each frame. Dry Creek flow is from top to bottom. Left frame is from 1976, right frame is from 2004. Light blue line is estimated limit of active fluvial features in 1976.

Figure 23. Comparison of photos taken looking downstream from Yoakim Bridge. The top photo was taken in October 1970, bottom photo taken in July 2010. In 1970, lower summer flows limited encroachment of vegetation, while the post-dam era has provided excellent conditions for vegetation growth on bar surfaces.

4.5.2 Bed and Bank Materials

Alluvial terrace and channel deposits in lower Dry Creek are comprised of sand, gravel and cobbles of varying rock types derived from tributaries extending into the adjacent Coast Range ophiolite, Great Valley Complex, and Franciscan Complex. With the exception of sandstone outcrops observed at Bord bridge (sub-reach 15), bedrock outcrops observed along the active stream channel were generally limited to Reach 7, beginning just upstream of Grape Creek, continuing downstream past the bedrock exposures at Lambert Bridge, and ending near the confluence with Crane Creek.

The alluvial bed of Dry Creek is primarily composed of coarse gravel, but ranges from sand to boulders and bedrock. The sand is generally concentrated in the pool bottoms and other backwatered areas, whereas the flatwaters and riffles are dominated by gravel and cobbles.
In 2009, the surface grain sizes of riffles throughout Lower Dry Creek were specifically measured to provide a general representation of trends in surface sediment in the study reach. Riffles in each reach were analyzed as well as the riffles downstream of tributaries and of the major tributaries themselves (Figure 24; Table 5). The 16^{th}, 50^{th}, and 84^{th} percentiles of the grain sizes found in the riffles were calculated. Though the surface grain sizes found in riffles does vary throughout Dry Creek, the median grain size primarily ranges between 20 and 30 mm. Based on the 2009 data, there is a slight trend towards decreasing median grain size with downstream distance from the dam, but this relationship is weak ($R^2 = 0.07$) (Figure 25). Similarly, the larger grains decrease in size downstream ($R^2 = 0.36$), ranging from 50 to 70 mm in the upstream half of Lower Dry Creek and 40 to 60 mm in the downstream half. D16 grains are fairly uniform in size throughout Lower Dry Creek at approximately 10 mm.

The bed material contributed to Dry Creek from tributaries does not appear to have a substantial effect on the measured surficial grain size in downstream riffles. The tributaries with larger bed material likely increase the size of bed material in Dry Creek, but a strong relationship is not exhibited in the data. The larger material from Pena Creek may contribute to the spike in grain size about 1.5 miles downstream of the confluence, but at the mouth of Pena Creek, the size of the material is smaller than elsewhere (Figure 25). The 84^{th} percentile of bed material in Grape Creek is much greater than elsewhere because of the predominance of bedrock. Large material delivered from Crane Creek may result in a slight increase in size of the 84^{th} percentile of the downstream riffle. Elsewhere, however, there is little impact of tributary bed material input on surficial grain sizes measured at downstream riffles on Dry Creek.

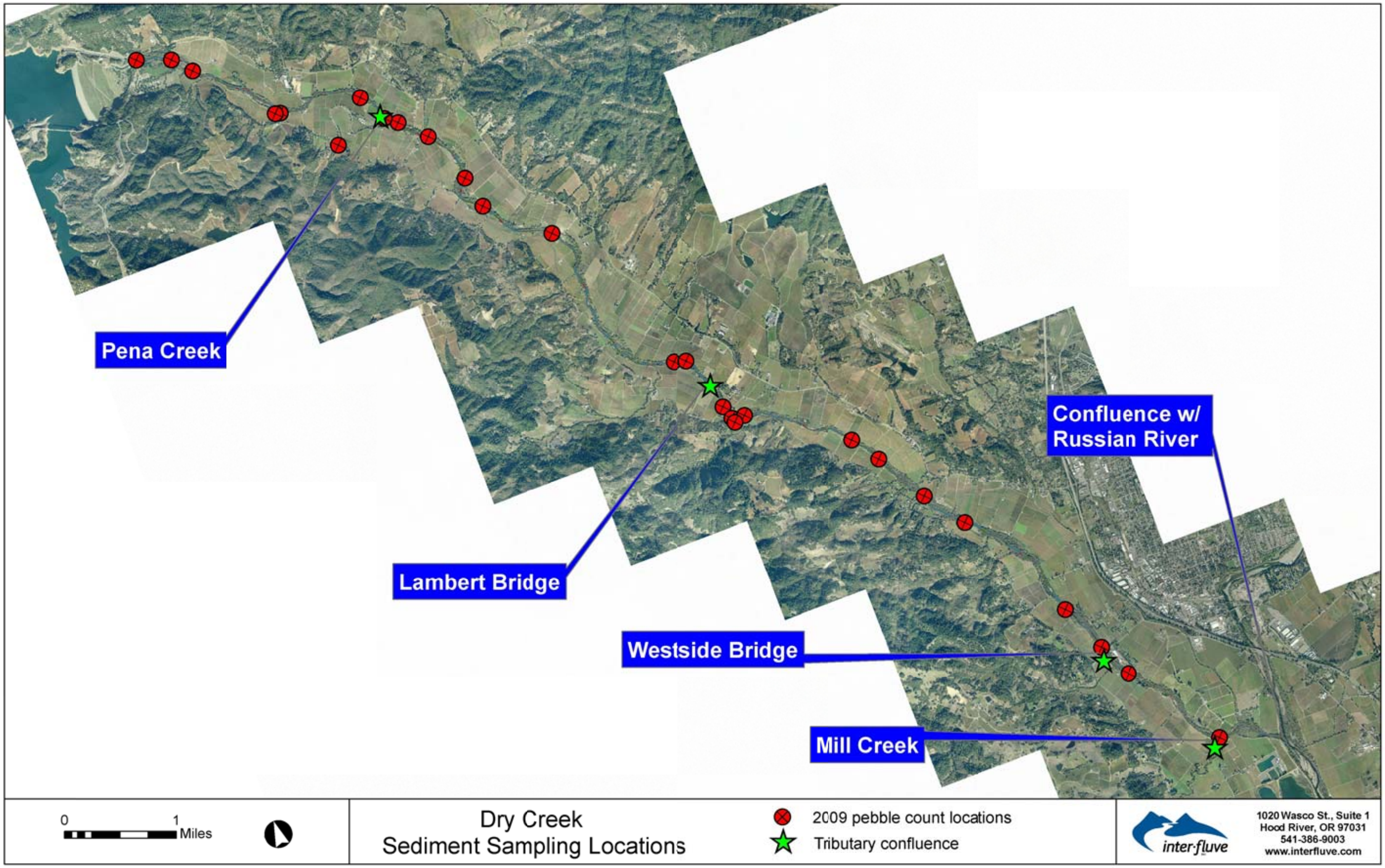


Figure 24. Locations of surface substrate pebble counts completed in conjunction with habitat inventory in 2009.

Table 5: Grain sizes for three percentiles of the surficial bed material in riffles throughout lower Dry Creek measured in 2009.

Reach	Unit #	Description	D16	D50	D84
1	D358	Downstream from Mill Creek	11.4	25.9	47.3
2	D320	Downstream from unnamed tributary	9.4	23.2	45.8
3	D305	Upstream of Westside Road Bridge	11.3	30.9	54.2
3	D289	Middle of reach	9.0	24.0	48.6
4	D256		14.4	31.4	59.8
5	Kelly Creek	Near mouth	4.5	11.4	21.48
5	D228		12.0	30.4	58.5
5	D219		5.7	21.8	49.5
6	D199	Downstream of Crane Creek	11.7	29.7	53.9
7	Crane Creek	Near mouth	1.6	9.7	82.7
7	D196	Upstream of Crane Creek	10.7	29.7	59.9
7	D191		10.8	25.0	52.7
7	D171		7.1	16.2	34.7
7	D167		11.3	25.4	53.7
7	Grape Creek	Near mouth	1.6	26.2	256
8	D123		10.7	34.9	71.7
9	D110		11.3	26.4	61.1
10	D099		11.2	44.3	123.9
11	D088	Downstream of Yoakim Bridge	12.3	30.2	80.5
11	D080		6.9	18.4	42.1
11	Peña Creek	Near mouth	8.0	27.6	70.5
11	Peña Creek	Near West Dry Creek Road bridge	14.5	34.9	62.7
12	D072	Downstream of unnamed tributary	9.4	32.8	77.8
13	D044	Downstream of Fall Creek	10.5	35.0	74.2
13	Fall Creek	Near mouth	3.8	16.0	54.4
14	D013		11.4	28.8	61.9
14	D004	Near mouth of Schoolhouse Creek	3.3	25.4	129.9
15	D001	At Bord Bridge	7.4	31.2	85.7

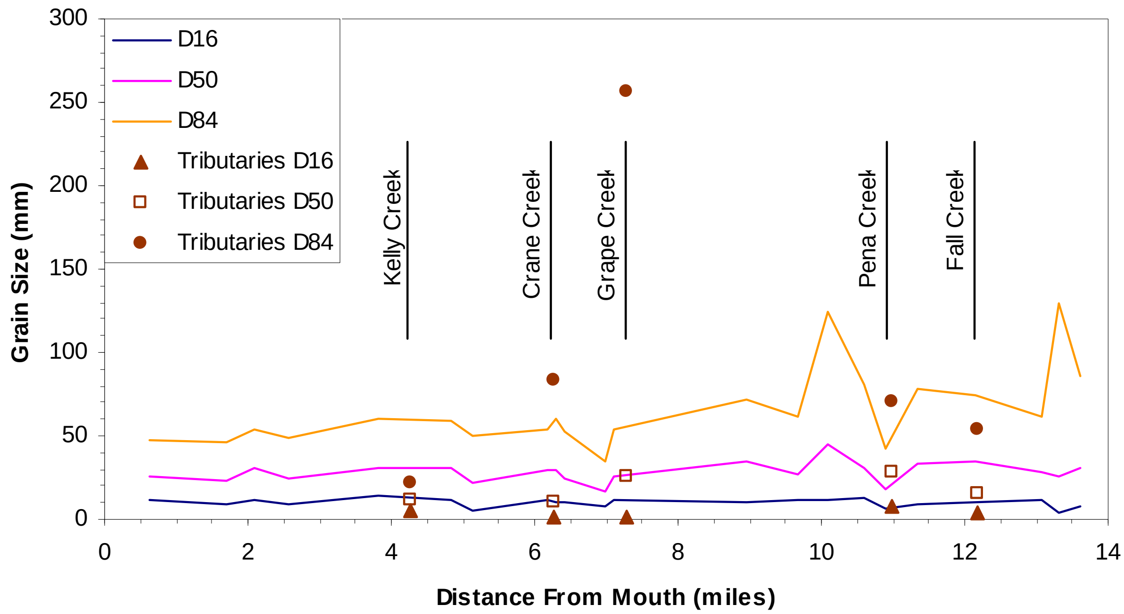


Figure 25: 16th (D16), 50th (D50) and 84th (D84) percentiles of surficial grain size distributions in riffles along Dry Creek and in five tributaries sampled in 2009.

In 2010, a supplemental substrate sampling program was conducted to support the feasibility analysis (Figure 26). The objectives for the supplemental sampling program were to develop a better understanding of the bed material load transported by Dry Creek, and to develop a better understanding of the limitation of sediment supply to Dry Creek reaches downstream of WSD.

The program consisted of collecting surface pebble count measurements to characterize the surface substrate, paired with bulk samples of the subsurface bed sediment which were retained and delivered to a testing lab for sieve analysis. The program was carried out at 14 riffle locations in lower Dry Creek. The sample locations (Figure 26) were selected to bracket the primary sources of sediment to Dry Creek downstream of WSD. Data sheets for the 2010 supplemental substrate sampling program can be found in Appendix B.

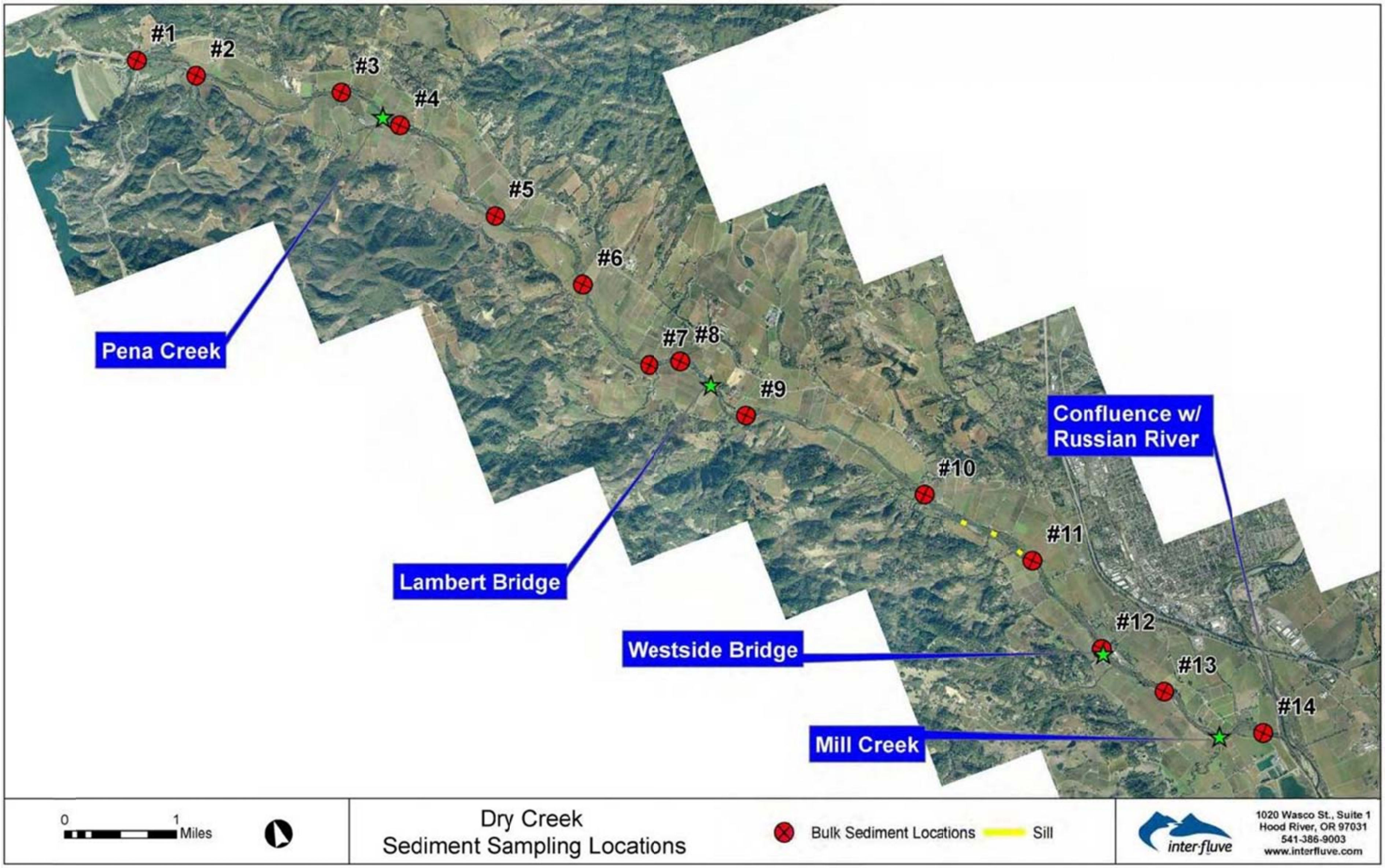


Figure 26. Locations of subsurface substrate bulk samples and surface pebble counts completed in 2010. Green star shows tributary confluence.

4.5.2.1 Dry Creek bed material load characteristics

Gravel bed streams tend to develop a surficial ‘armor’ layer where the materials found on the surface are coarser than those found deeper in the bed. The grain size distribution of the subsurface materials is considered to be representative of the bed material load that is delivered by floods, whereas the grain size distribution of the surface layer tends to be coarser because smaller particles are selectively removed by subsequent flows after a flood has passed (Dietrich et al. 1989).

The 2010 subsurface sediment gradations were assessed for trends in the size distribution of the likely bed material load (Figure 27). The data suggest an increase in the D84 and D50 sizes in response to the contributions of Pena, Crane and Mill Creeks, with a downstream fining trend below these tributaries. Conversely, the D16 values remain essentially constant over the project reach. In general, the median (D50) bed material sediment transported by Dry Creek is medium gravel (10 to 20 mm).

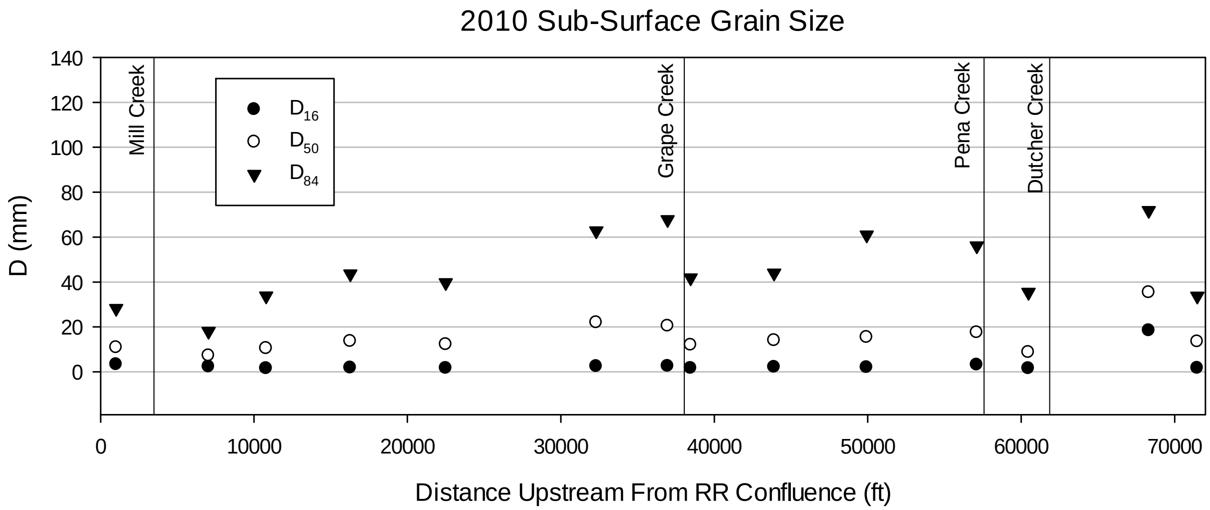


Figure 27: 16th (D16), 50th (D50) and 84th (D84) percentiles of subsurface grain size distributions in riffles along Dry Creek sampled in 2010.

4.5.2.2 Dry Creek relative sediment supply

The comparison of the sizes of the surface to the subsurface sediments is often termed an armoring ratio, and is considered indicative of the relative supply of sediment to the reach. Here the surface median size is denoted as D_s50 and the subsurface median size is denoted as $D_{ss}50$. The surface is said to be armored when $D_s50/ D_{ss}50 > 1$, with larger ratio values generally indicative of increasing sediment supply limitations. Accentuated armoring of the streambed is a common observation of streams below dams which significantly reduce the amount of sediment flowing to the reach. This ratio also provides a rough estimate of ability of the stream to move its own gravel. Low values of $D_s50/ D_{ss}50$ (e.g. < 1.3, i.e. relatively weak armoring) are generally indicative of relatively high mean annual sediment transport rates, whereas high values of Ds50/Dsub50 (e.g. > 4, relatively strong armor) are generally indicative of relatively low mean annual sediment transport rates (Dietrich et al., 1989).

The armoring ratio estimates are shown in Figure 28. In general, armoring ratio estimates range from 1 to 4 over the study reach with many locations less than 3. This is indicative of a moderately armored condition, which would suggest that the sediment supply deficit coming out of the dam is in part moderated by downstream tributary contributions. Additionally, the data suggests a correlation between tributary watershed contributions and reductions in armoring ratio, particularly downstream of Pena, Grape and Mill Creeks. This reinforces the role that the downstream tributaries play in moderating WSD's effects on sediment supply.

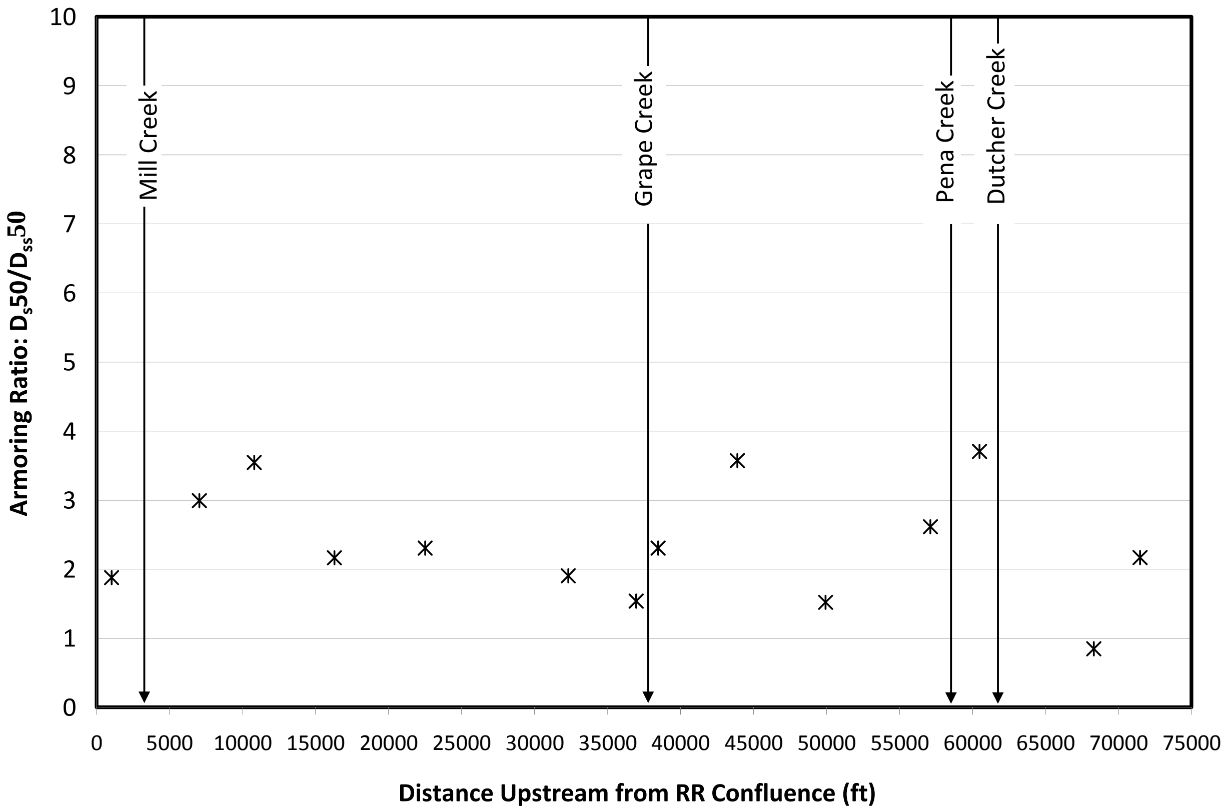


Figure 28: Armoring ratio along Dry Creek, sampled in 2010.

4.5.3 Dry Creek Hydraulics

4.5.3.1 Development of one-dimensional hydraulic model

A steady-state, one-dimensional hydraulic model that simulates current hydraulic conditions in Dry Creek was developed using the U.S. Army Corps of Engineers Hydraulic Engineering Center River Analysis System (HEC-RAS 4.1.0). The purpose of the model development was to enable evaluation of broad scale trends in the flow of water and sediment through the project reach. As such, the model was generally developed to a planning study level of resolution, though was developed to a detailed level in the 1.1-mile demonstration reach between Crane Creek and Grape Creek (discussed below). As such, the model can be considered as a planning-level model, with a detail-level sub-model nested within it.

HEC-RAS is a computer program that models the hydraulics of water flow through natural rivers and other channels. The program is one-dimensional, meaning that there is no direct modeling of the hydraulic effect of cross section shape changes, bends, and other two- and three-dimensional aspects of flow. These components are principally accounted for through energy loss and boundary roughness coefficients. The hydraulic model calculates channel and floodplain water surface elevations, velocities, depths, shear stresses and other variables for various input flows.

Model Geometry

The model geometry was developed using bathymetric, topographic and bridge data obtained for the study. The existing conditions model geometry includes 177 cross sections, which extend from the Russian River confluence upstream to several hundred feet below Warm Springs Dam (Figure 29). The cross sections were surveyed in summer 2010 (May-September). Two areas have a denser grouping of cross sections. These include the 1.1 mile demonstration project reach between Grape and Crane Creeks (53 cross sections) and the 0.75-mile segment which brackets the Westside Bridge (15 cross sections). Finer resolution was desired in these locations for two reasons. In the demonstration project reach, channel geometry was measured to a level of detail adequate to support detailed design of habitat enhancements. Slightly denser coverage was collected near Westside Bridge than other locations because the area is thought to contain the best existing coho rearing habitat over the entire reach, and it was desired to understand the hydraulic function of this area in more detail. As planning for habitat enhancement moves past the feasibility stage in areas outside the demonstration reach, survey efforts specific to the subject sub-reach will be required to refine model precision in that area to support detailed design.

At the time of the survey, permissions to enter (PTE) could not be secured for private properties on which several desired cross sections were located. In some cases, access could not be obtained for the entire cross section. In other cases, access could not be obtained for the overbank area on one side of the channel. For the locations where PTEs could not be secured, the cross sectional geometries were estimated from the available LiDAR[1] data, which was collected in November 2008. Comparison of ground surveyed elevations to LiDAR elevations at several locations suggested that the LiDAR elevations were on average 2.4 feet higher than the actual elevations within the stream channel. Therefore, the channel bottoms (not overbanks) were lowered by 2.4 feet for the locations where the geometry was defined through the LiDAR data exclusively. Of the 177 cross sections, 30 were based wholly on the LiDAR data set. After the cross sections were added to the model, an

[1] LiDAR, also known as Light Detection And Ranging, is derived from data collected using a specialized aircraft-mounted instrument which can collect high precision topographic data over large areas.

additional 15 cross sections were added through interpolation in order to provide additional resolution over certain stream reaches.

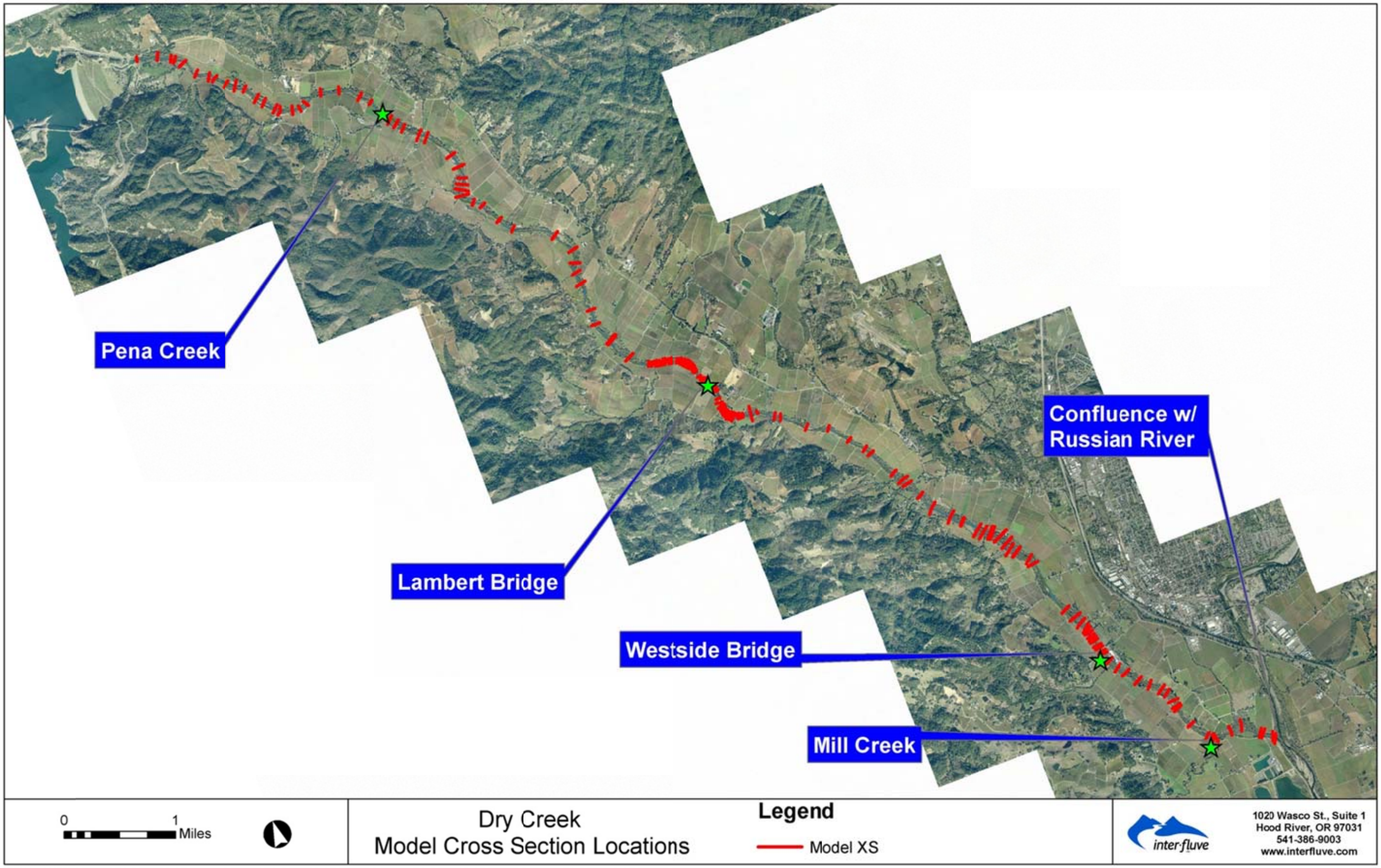


Figure 29. Locations of cross sections in one-dimensional hydraulic model.

Roughness coefficients (Manning's n values) applied at each model cross section were estimated from field observations, aerial photography and published methods (Arcement & Schneider 1989). The initially assigned values were adjusted during model calibration. Summarized in Table 2, the roughness values utilized in the model fall within the range of values used in the 2006 FEMA study (Federal Emergency Management Agency 2006).

Table 6. Roughness coefficients used in the existing conditions model.

Description	Manning's n values
Channel, high roughness (bedrock, vegetation, LWD)	0.04 – 0.06
Channel, low roughness	0.03 – 0.04
Floodplain, heavily vegetated, LWD	0.1-0.12
Floodplain, mixed residential/lawns/landscape trees/minor structures	0.11
Floodplain, cleared surfaces and roads	0.04-0.09

Inflow Hydrology

The inflow hydrology for the hydraulic model was based on the peak flow estimates discussed in Section 4.4.2 above. For the purposes of the current modeling effort, the updated estimates based on the available gage data were assumed.

Downstream Boundary Condition

During major floods, the backwater influence from the Russian River may extend over 3 miles up Dry Creek (to the downstream check dam-discussed further below). In order to evaluate the hydraulic function of the lower three miles of Dry Creek, a range in downstream Russian River water levels were considered in the analysis. Water surface elevations in the Russian River at the mouth of Dry Creek were obtained from a HEC RAS model of the Russian River developed by Swanson Hydrology and Geomorphology (2008) under contract to Syar Industries. The Russian River model had been calibrated to high water marks surveyed by Syar Industries following the 2008 peak flow event (Roberts 2010).

Model Calibration

Model input parameters were adjusted within a range of reasonable values so that simulated water surface elevations within the project reach approximately match observed water surface elevations. Three different sets of data were available for model calibration:

- Water surface elevations measured at time of ground survey at each cross section. Dry Creek discharge ranged from 100 to 217 cfs during the periods of survey in summer 2010 (May-September).
- Recent high water marks (HWM) were surveyed at cross section locations. The high water marks were assumed to correspond to the highest flow during the 2009-2010 winter period (March 3, 2010 – discharge of 2620 cfs at the USGS gage at Yoakim Bridge). These consisted primarily of drift lines observed in riparian vegetation or along stream banks.
- The most recent shift-adjusted rating curve for the Yoakim Bridge gage.

The model calibration results are summarized in Table 7 and Figure 30 - Figure 32. The goals of the calibration process were to minimize root mean square errors (RMSE), while obtaining median error values as near to 0 as possible. By doing so, errors in the simulated values are minimized and the simulated values represent the central tendency of the observed water surface elevation data.

In general, model calibration is reasonable for use in the present study, given the relatively sparse concentration of cross sections over much of the reach, and considering the gaps in the surveyed cross section data set due to property access restrictions. It should be noted that a portion of error range reported for the high water mark data is attributable to variability in the HWM data itself. There is a certain degree of imprecision inherent in field identification of HWM as the effort occurred several months after the high flow event, and may include HWM on flexible materials such as riparian vegetation which may partially deflect during the high flow event. Additionally, the HWM are assumed to be attributable to the peak of the last high flow event, which may not be accurate at all locations.

Nevertheless, in the absence of direct observations during the high flow event, the HWM provide useful information for evaluation of the general accuracy of the hydraulic model. As enhancement planning moves past the feasibility stage, model calibration will be improved by collection of additional cross section data to fill the data gaps described above and to densify the representation of creek geometry in the model. Additionally, direct observations of water surface elevations during high flow events will enable improved model calibration.

Table 7. One-dimensional hydraulic model calibration results

Data Source	Flow Range (cfs)	Application	Number of Values	Median Error (ft)	RMSE (ft)	Error Range (ft)
Surveyed Water Surface Elevations	100 - 220	Base flow calibration	91	0.0	0.37	
Surveyed High Water Marks	2620 cfs at Yoakim Bridge Gage	Moderate to High Flow Calibration	41	0.08	1.9	
USGS Rating Curve @ Yoakim Bridge gage	100 - 11000					+/- 1

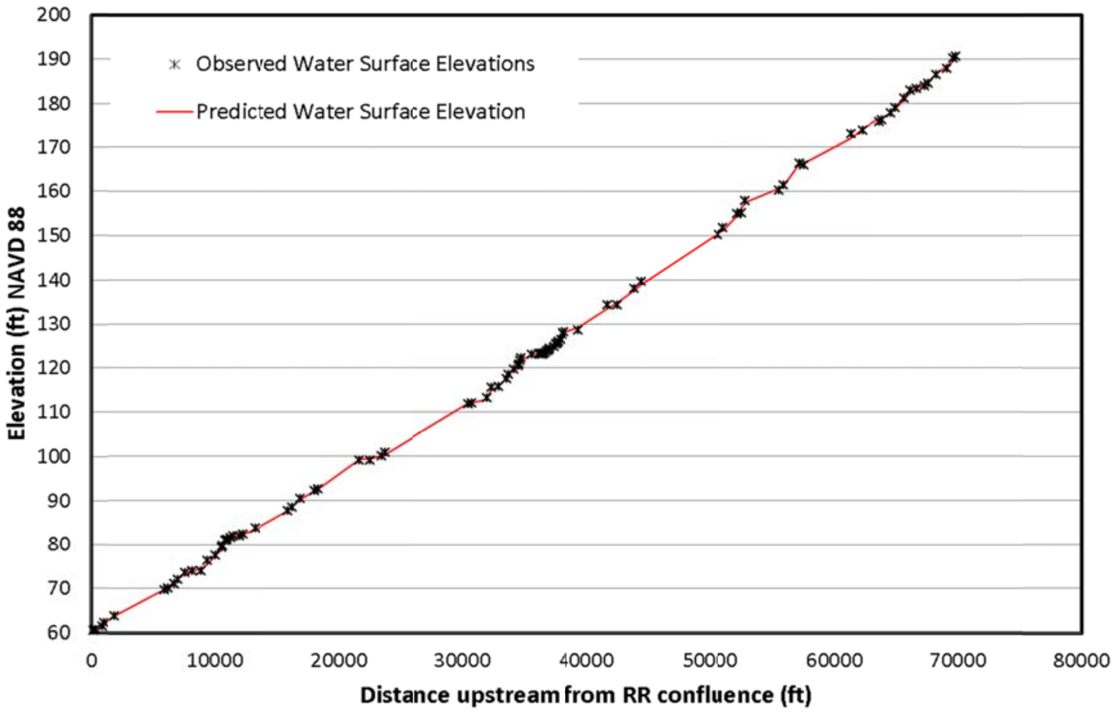


Figure 30. Comparison of water surface elevations predicted by the one-dimensional hydraulic model to water surface observations surveyed in 2010 at flows between 100 and 220 cfs.

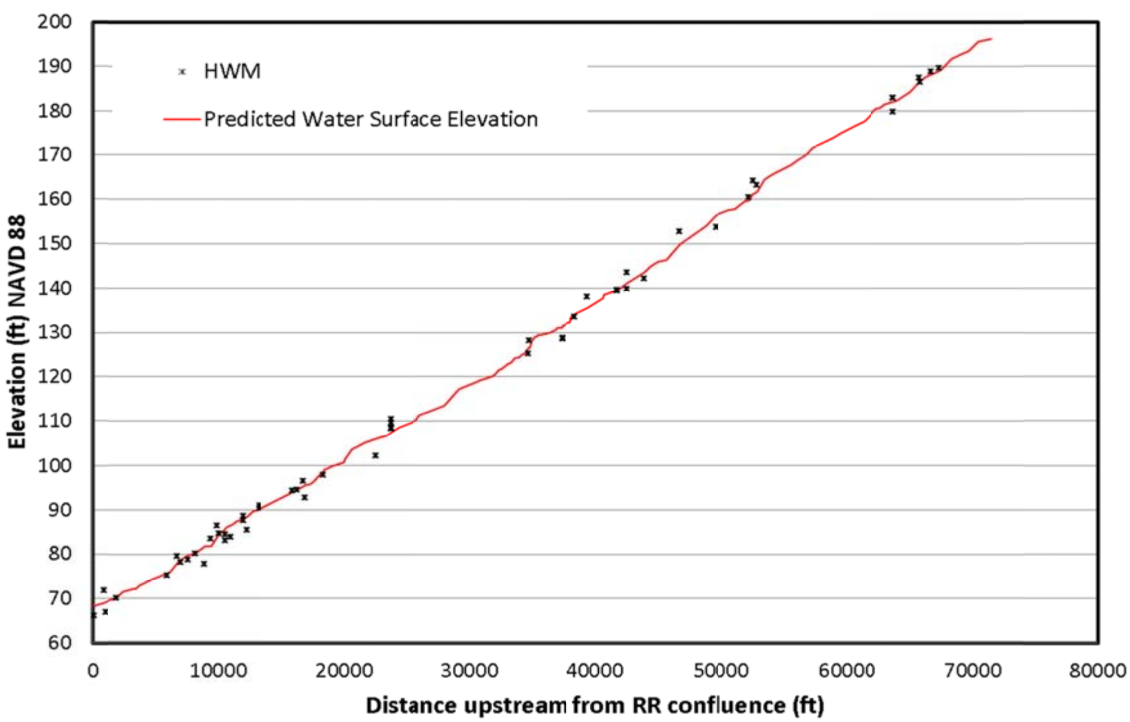


Figure 31. Comparison of water surface elevations predicted by the one-dimensional hydraulic model to surveyed high water marks interpreted to represent peak flow conditions in March 2010.

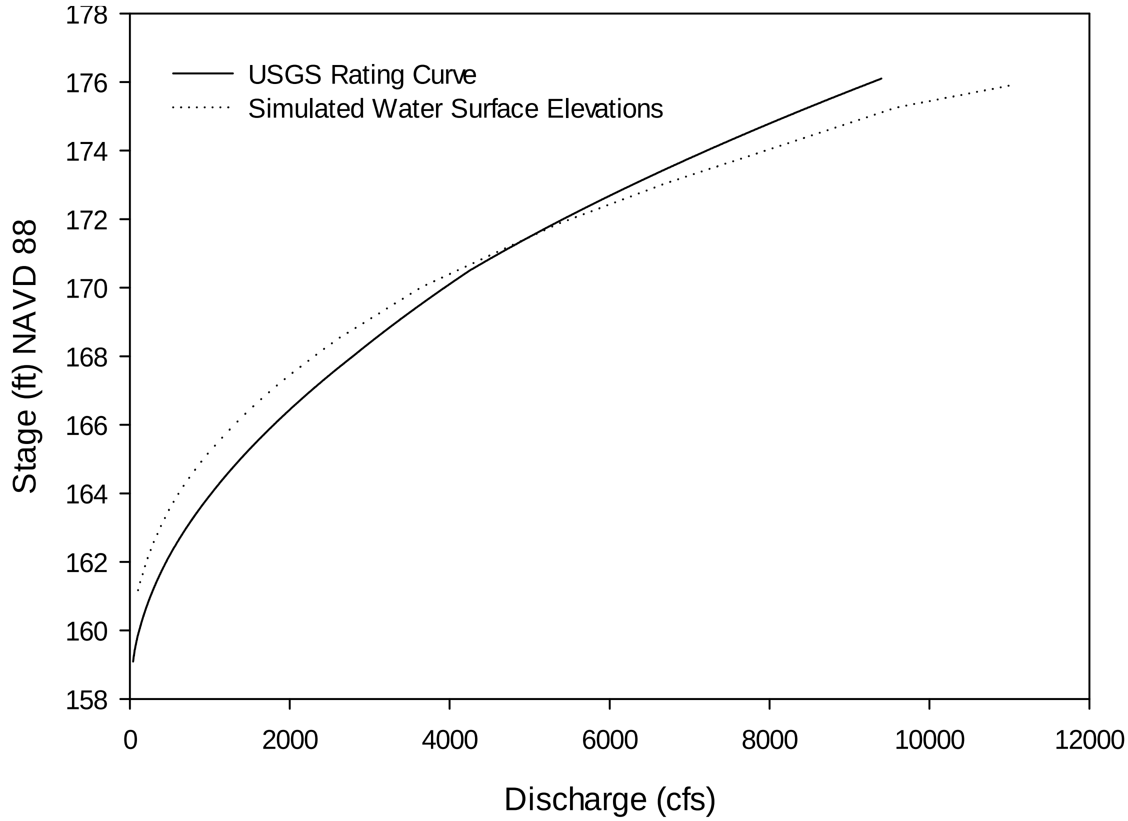


Figure 32. Comparison of water surface elevations predicted by the one-dimensional hydraulic model to the most recent stage-discharge rating curve for USGS gage 11465200 Dry Creek near Geyserville.

4.5.3.2 Selected Model Results – Current Conditions

The following paragraphs provide an overview of the model simulation results of current conditions in Dry Creek.

4.5.3.2.1 Effect of backwater from the Russian River

As depicted in Figure 33, the backwater from the Russian River provides a significant control on the hydraulics of lower Dry Creek. The backwater profile influences Dry Creek hydraulic conditions up to the Westside Bridge, the downstream grade control structure, and the upstream grade control structure for the Q1.5, Q10 and Q100 peak flow events in the Russian River, respectively. As discussed later in the document, the character of the lower 3 miles of Dry Creek is more alluvial than the upstream reaches as a result of the backwater effect.

4.5.3.2.2 Water Surface Profiles

Simulated water surface profiles for a range of flow events in Dry Creek with the Russian River at a low flow level (i.e., no backwater effect) are shown in Figure 35 -Figure 38. The grade control sills and Lambert Bridge provide the most significant flow contractions in the lower half of the study reach. Flow contractions also result from select key riffles near Yoakim Bridge, and downstream of Bord Bridge.

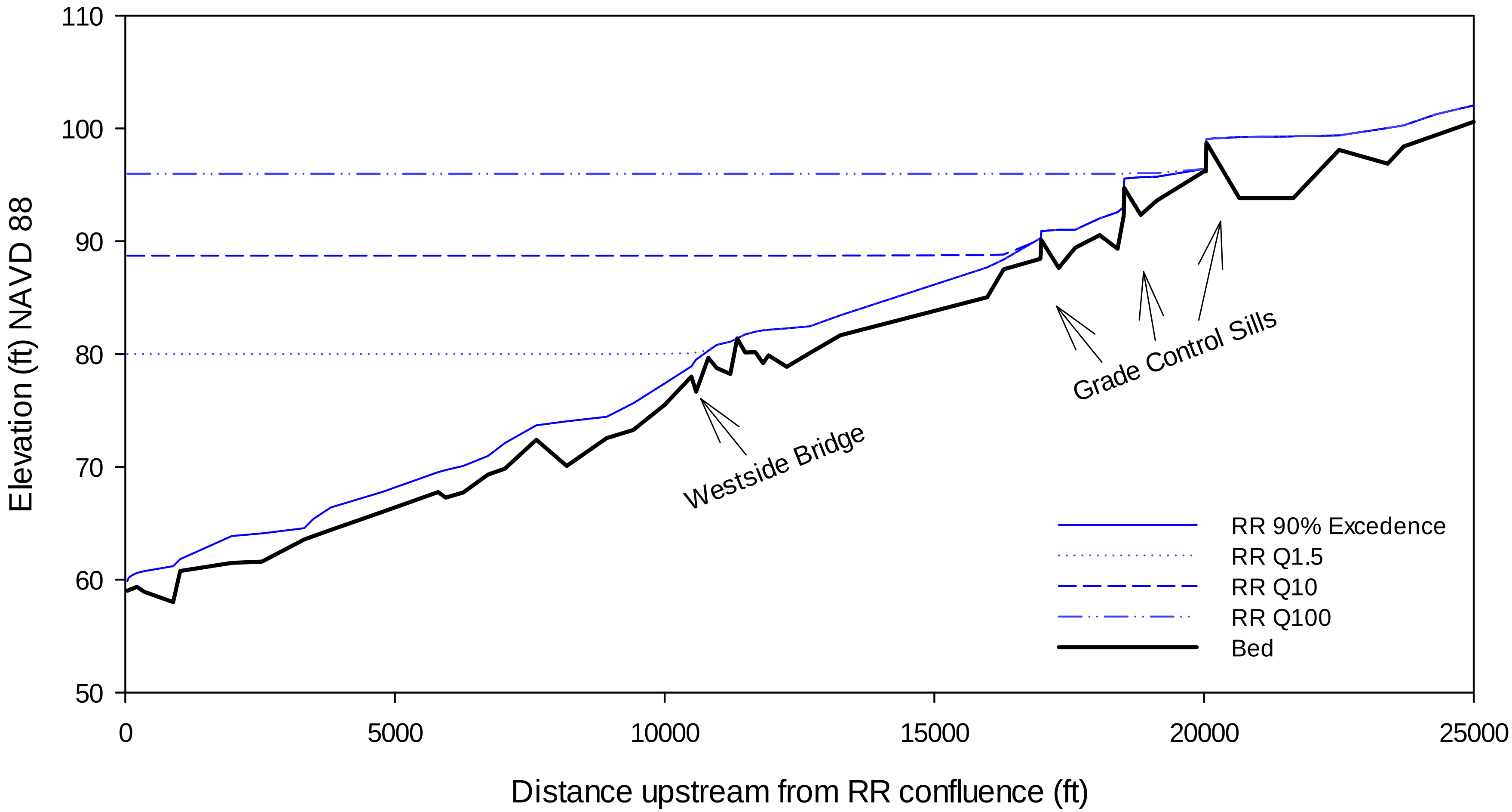


Figure 33. Model results predicting Dry Creek water surface elevations at 105 cfs for 4 different flow levels in the Russian River (RR).

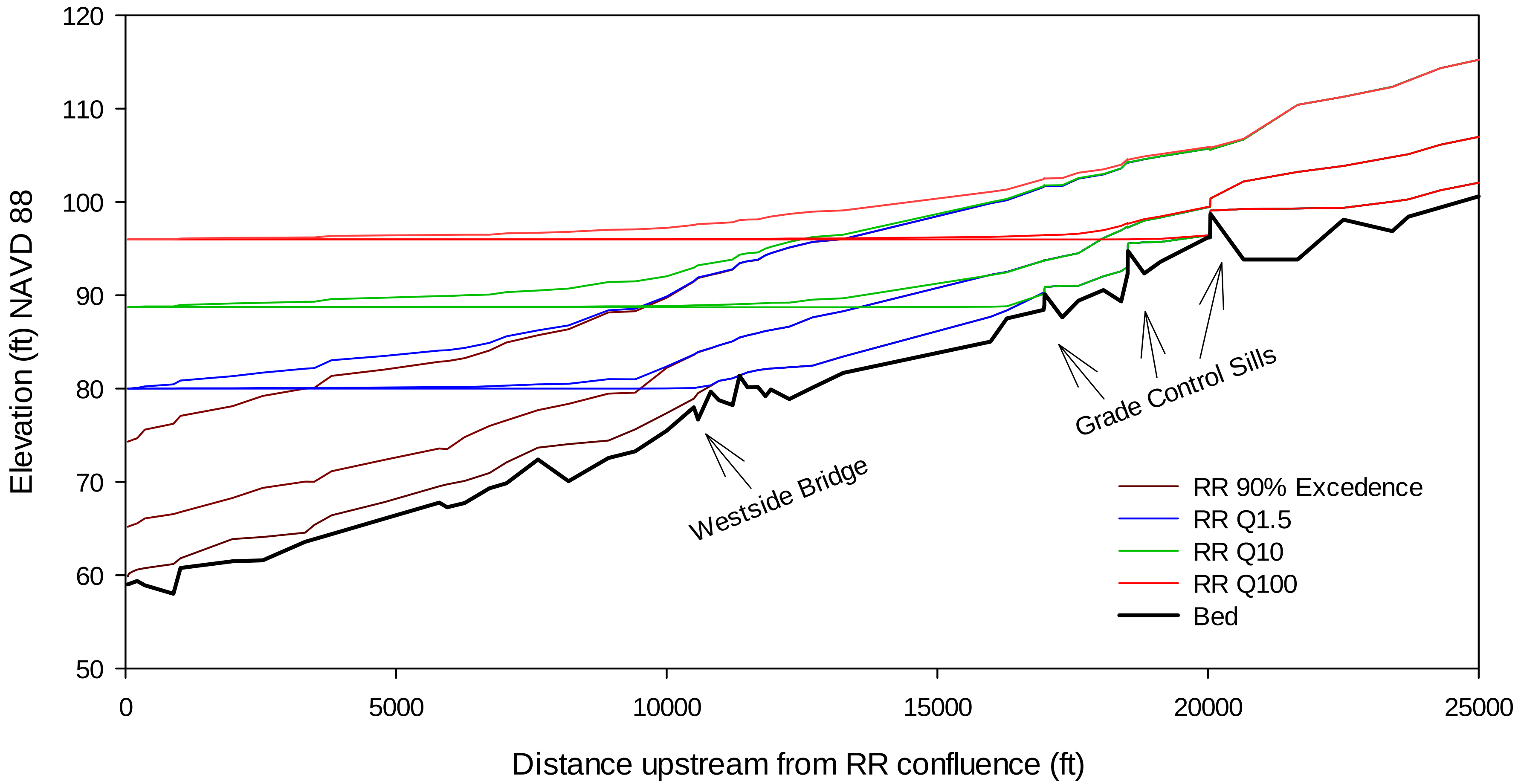


Figure 34. Model results predicting Dry Creek water surface elevations at 105 cfs, Q1 and Q10 in Dry Creek for 4 different flow levels in the Russian River (RR).

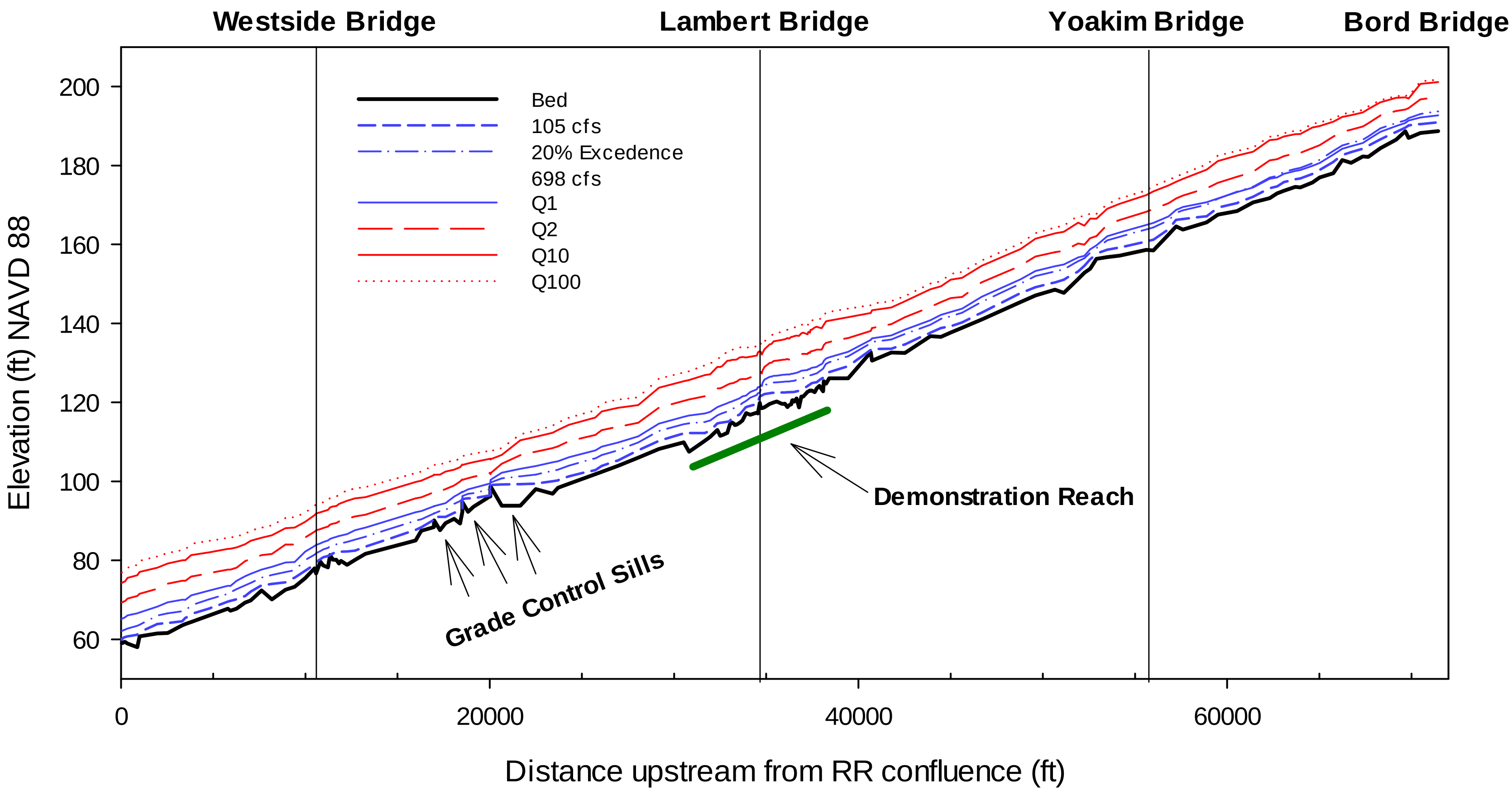


Figure 35. Simulated water surface profiles for a range of flow events in Dry Creek with no backwater influence from the Russian River, over the entire project reach.

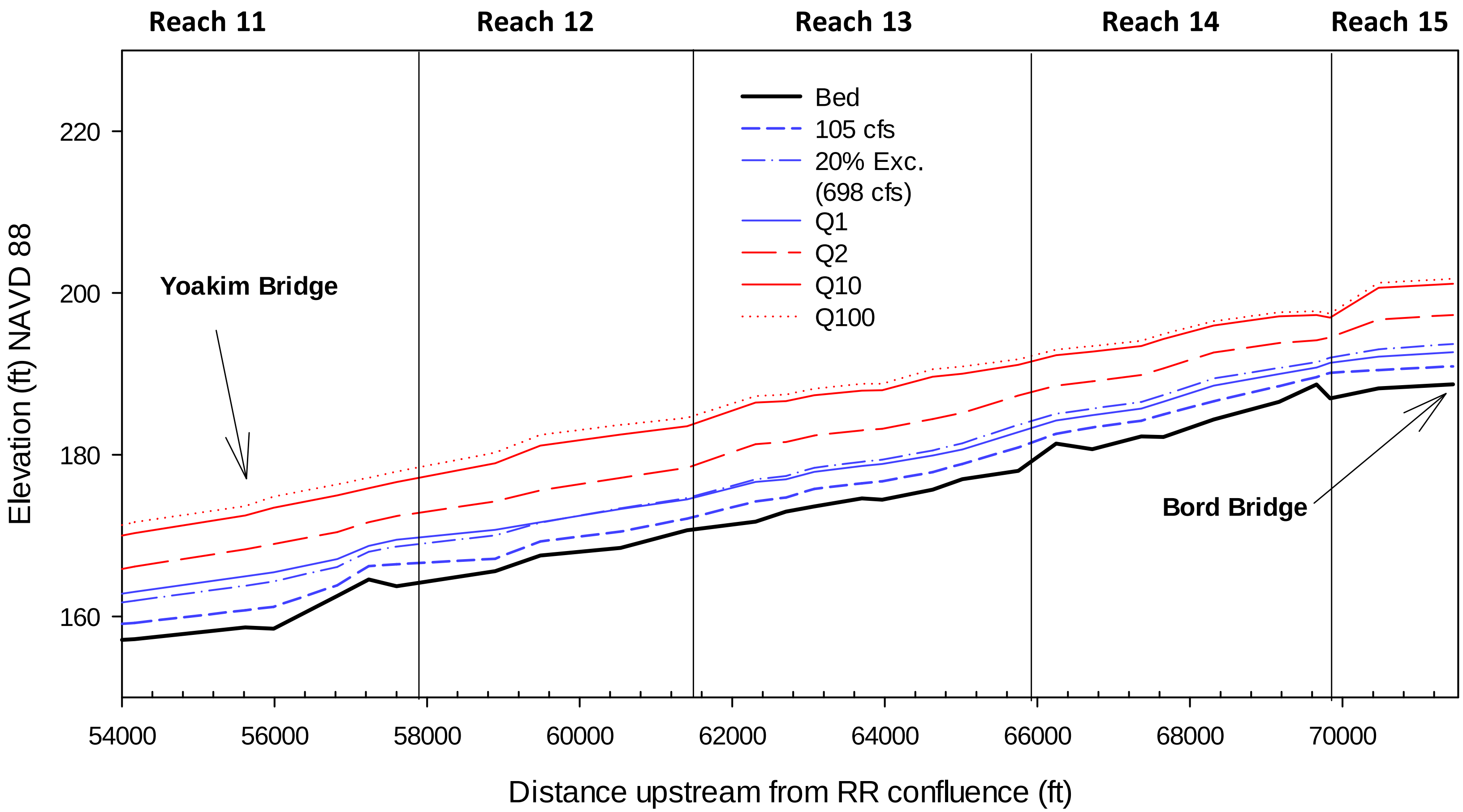


Figure 36. Simulated water surface profiles for a range of flow events in Dry Creek with no backwater influence from the Russian River, over the upper third of the project reach. (Note: 20% Excedence discharge is 698 cfs).

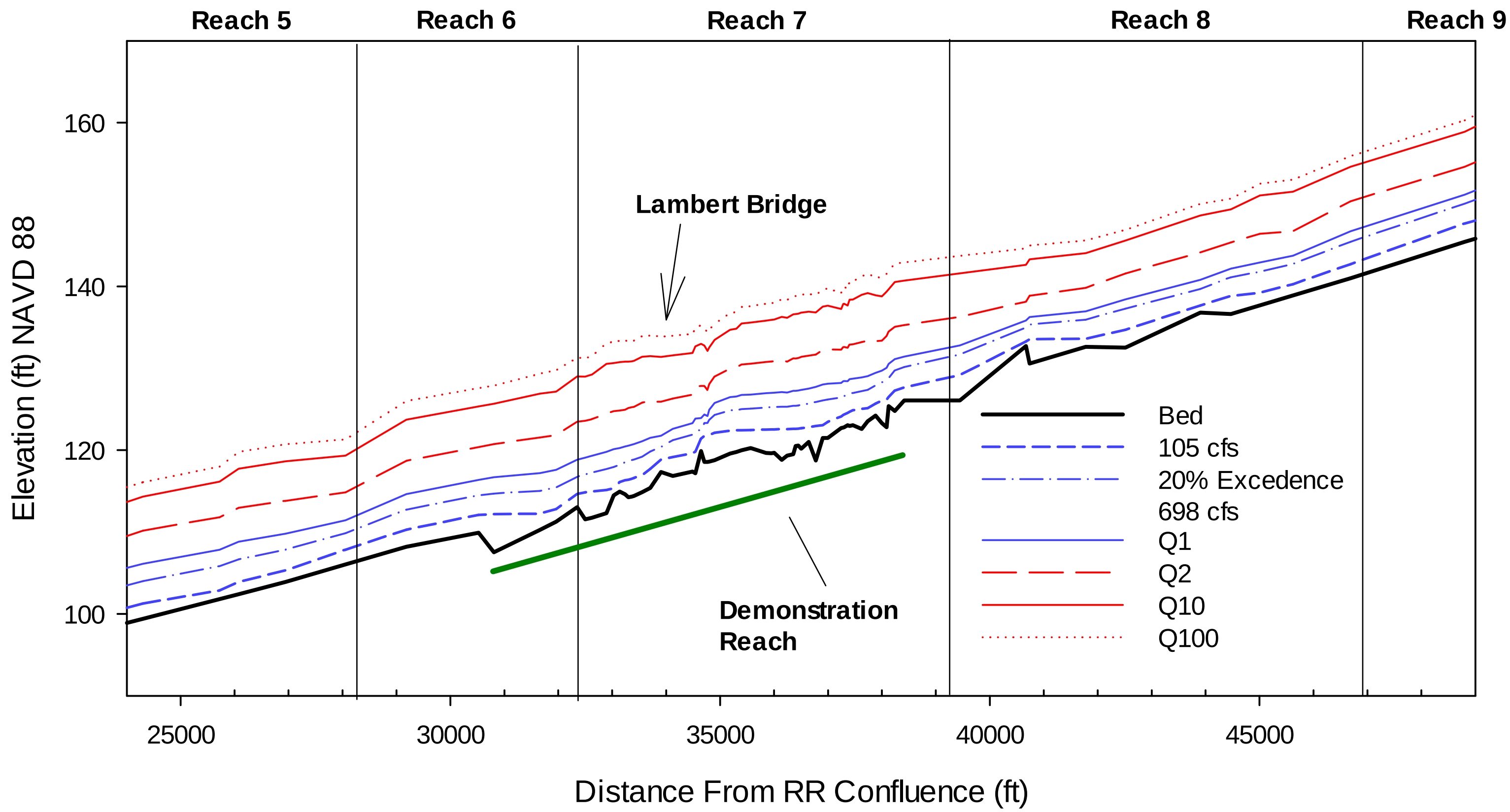


Figure 37. Simulated water surface profiles for a range of flow events in Dry Creek with no backwater influence from the Russian River, over the middle third of the project reach.

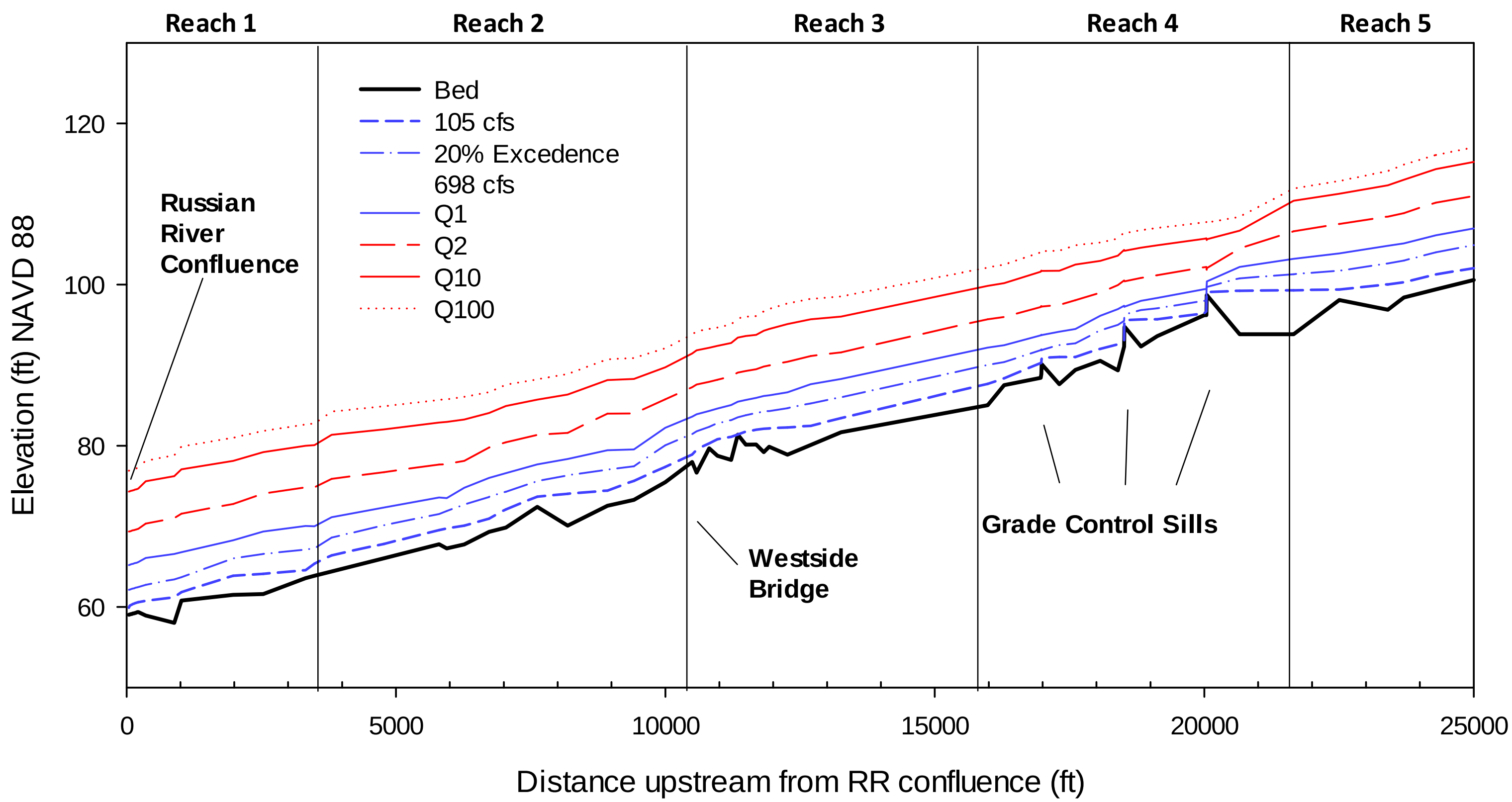


Figure 38. Simulated water surface profiles for a range of flow events in Dry Creek with no backwater influence from the Russian River, over the lower third of the project reach.

4.5.3.2.3 Inundation Mapping

To examine the spatial patterns of surface water distribution in Dry Creek during the simulated flows for existing conditions, the ArcGIS extension HEC GeoRAS was utilized to prepare inundation maps for selected flow events (See Section 5.3). As can be seen, flow begins to spill out of the existing active channel at roughly the 2-year return period flood. The 100-year return period flow is contained within the creek corridor. The inundation maps also give a good representation of the relative channel corridor widths as one moves along the project reach.

4.5.3.3 Channel competence

To evaluate general trends in the ability of Dry Creek to mobilize and convey sediment, channel competence-based calculations were conducted in the study reach. Channel competence refers to the size of sediment that can be transported for a given flow. The Shields (1936) equation was used for this analysis – a comparison between shear stress applied to the bed:

$$\tau = \rho g R s$$

And the shear stress needed to mobilize bed sediments, or critical shear stress:

$$\tau_c = \tau^*_{c50}\left(\rho_s - \rho\right) g D_{50} \qquad \text{where,}$$

τ	= bed shear stress	ρ	=	density of water (kg/m³),
g	= gravity (m/s²),	R	=	hydraulic radius
s	= slope	ρ_s	=	density of sediment (kg/m³),
τ^*_{c50}	= critical dimensionless shear stress (Shields parameter),			
τ_c	= critical shear stress (N/m²),	D_{50}	=	median grain size (m)

There is inherent uncertainty in selection of a critical Shields parameter (τ^*_{c50}), with values applicable to gravel-bedded rivers cited in the literature ranging from 0.03 to 0.1 (Buffington and Montgomery 1997). Recent studies suggest that 0.03 is a reasonable value for true incipient motion in gravel bed rivers, whereas 0.047 corresponds to a low but measurable transport rate (i.e., the bed is already in motion) (Buffington and Montgomery 1997).

In the current analysis, the Shields equation was used for two applications. The first application was to assess at which flow the surface substrate at riffles in the project reach would be mobilized (i.e., incipient motion), signifying the onset of sediment transport from within channel sources. For this application, the critical Shields parameter was estimated at 0.03. In the second application, the objective was to assess the flow rate at which the sediment that was already in motion and delivered to the reach in question would continue to be transported. For this application, the critical Shields parameter was estimated at 0.047.

To complete the analysis, an excess shear stress form of the Shields equation was used, which is defined by the ratio of the bed shear stress to the critical shear stress, or τ^*:

$$\tau^* = \frac{\tau}{\tau_c} = \frac{\rho R s}{\tau_c^* D_{50}\,(\rho_s - \rho)}$$

When τ^* <1, the shear stress is insufficient to mobilize or transport the sediment. If $\tau^* > 1$, sediment mobilization or transport is indicated. Based on the discussion above, and using a Shields value of 0.03, very low but measurable rate of transport would be indicated by τ^* between 1.0 and 1.5. At $\tau^* > 1.5$, bed adjustment could ensue following initiation of bed transport.

4.5.3.3.1 Surface substrate mobility results

To assess the mobility of the surface substrate in the study reach, the surface pebble count data collected in 2009 and 2010 (Figure 39) were combined with the shear stresses simulated by the one-dimensional hydraulic model to evaluate the relation above for τ^*. As stated above, a Shields parameter of 0.03 was selected for this analysis. Figure 40 and Figure 41 demonstrate the results of the analysis based on three flow events in Dry Creek, including Q2, Q10, and the flow that is exceeded at least 20 percent of the time in the winter months (Dec-March), for two separate flow levels in the Russian River (low and moderate backwater influence).

The results suggest that the surface substrate may be mobilized at all of the locations that were evaluated for the Q2 and Q10 events. In general, channel competence increases with increasing flood magnitude, which is consistent with the morphology of the incised channel corridor. The channel corridor lacks an effective flood plain in many areas (either due to lack of an overbank area, or due to dense vegetation if an overbank area does exist) which if present would cause shear stresses to plateau during overbank events as flood waters spread across the overbank area. Also notable is that the excess shear values are in the 1 to 1.5 range for many locations associated with the discharge that is exceeded 20% of the time in the winter. This is a sub-annual flow at which the bed begins to move in many locations, which suggests that the effective discharge for Dry Creek is associated with moderate sustained winter flows as opposed to an annual or bi-annual peak discharge. This result is also consistent with the active channel capacity estimates summarized in the CCIR, which suggested this flow was in the 500 cfs to 900 cfs range.

Finally, Figure 41 demonstrates the manner in which channel competency is affected by backwater from the Russian River in the reach of lower Dry Creek downstream of the grade control sills. Figure 41 represents a moderate backwater condition where the Russian River is experiencing a 1.5-year return period flood. The backwater effect from the Russian River curtails channel competency in Dry Creek below Westside Bridge over a range of flows, leading to shear stresses that are not sufficient to mobilize bed sediments, (i.e., Excess Shear Ratio < 1, incipient motion is not reached)

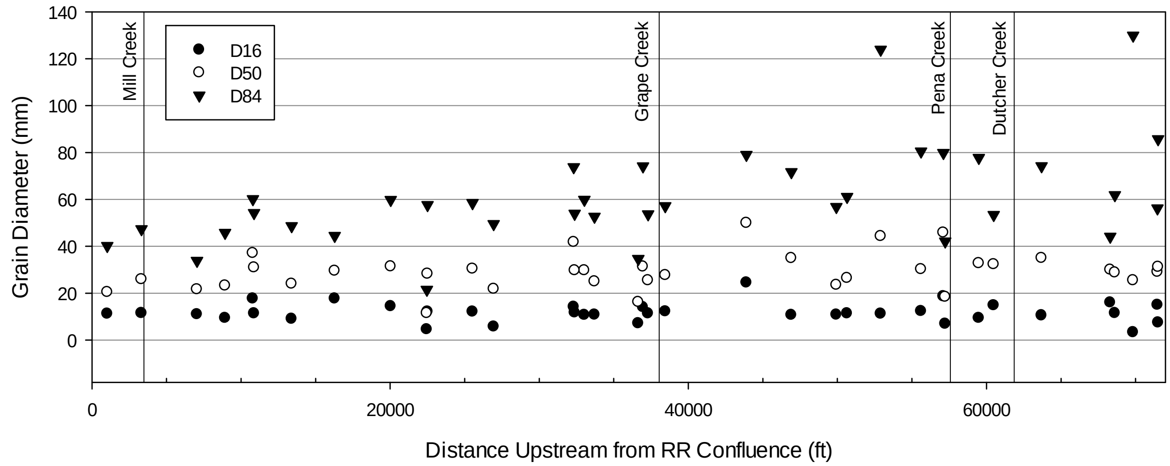


Figure 39: 16th (D16), 50th (D50) and 84th (D84) percentiles of surficial grain size distributions in riffles along Dry Creek sampled in 2009 and 2010.

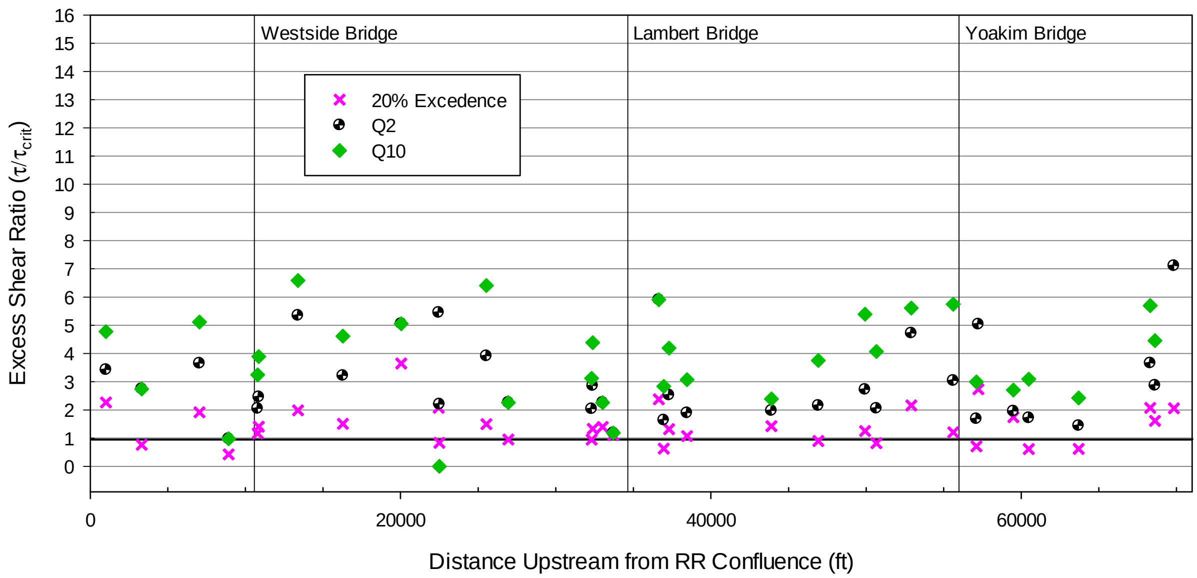


Figure 40: Excess shear ratio for median (D50) surface grain size at three flows in Dry Creek, and low flow condition in the Russian River (no backwater influence).

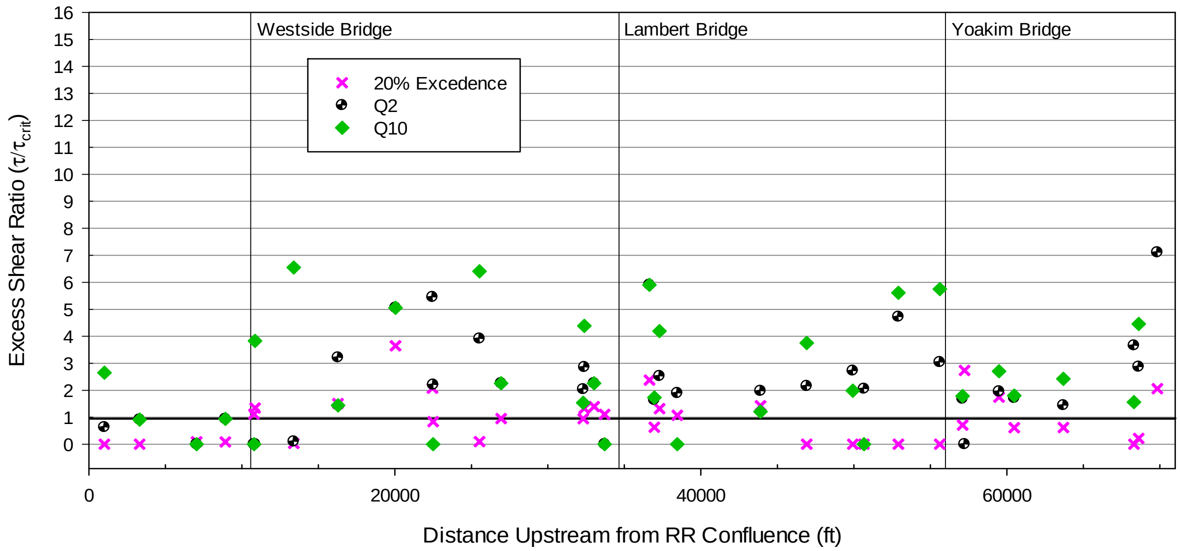


Figure 41: Excess shear ratio for median (D50) surface grain size at three flows in Dry Creek, and Q1.5 in the Russian River (moderate backwater influence).

4.5.3.3.2 Subsurface sediment transport results

To assess the ability of Dry Creek to convey the sediment that was already in transport, the subsurface substrate data collected in 2010 (Figure 42); used as a surrogate for measurements of the sediment during a transport event) were combined with the shear stresses simulated by the one-dimensional hydraulic model to evaluate the excess shear stress relationship for $\tau*$. As stated above, a Shields parameter of 0.047 was selected for this analysis. Figure 43 demonstrates the results of the analysis based on three flow events, including Q2, Q10, and the flow that is exceeded at least 20 percent of the time in the winter months (Dec-March). The assumed boundary condition is that the Russian River is at a flow level which does not cause backwater into Dry Creek.

The results suggest that the channel is capable of transporting the supplied bed sediment at or above the flow which is exceeded approximately 20% of the time in the winter period. In general, channel competence increases with increasing flood magnitude, which is consistent with the morphology of the incised channel corridor as described earlier.

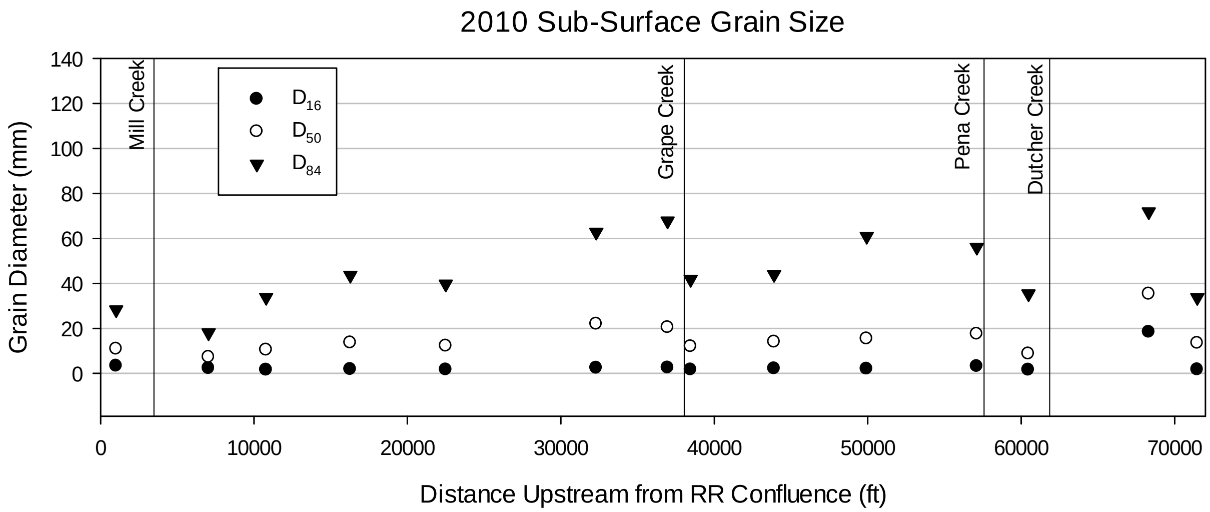


Figure 42: 16th (D16), 50th (D50) and 84th (D84) percentiles of subsurface grain size distributions in riffles along Dry Creek sampled in 2010.

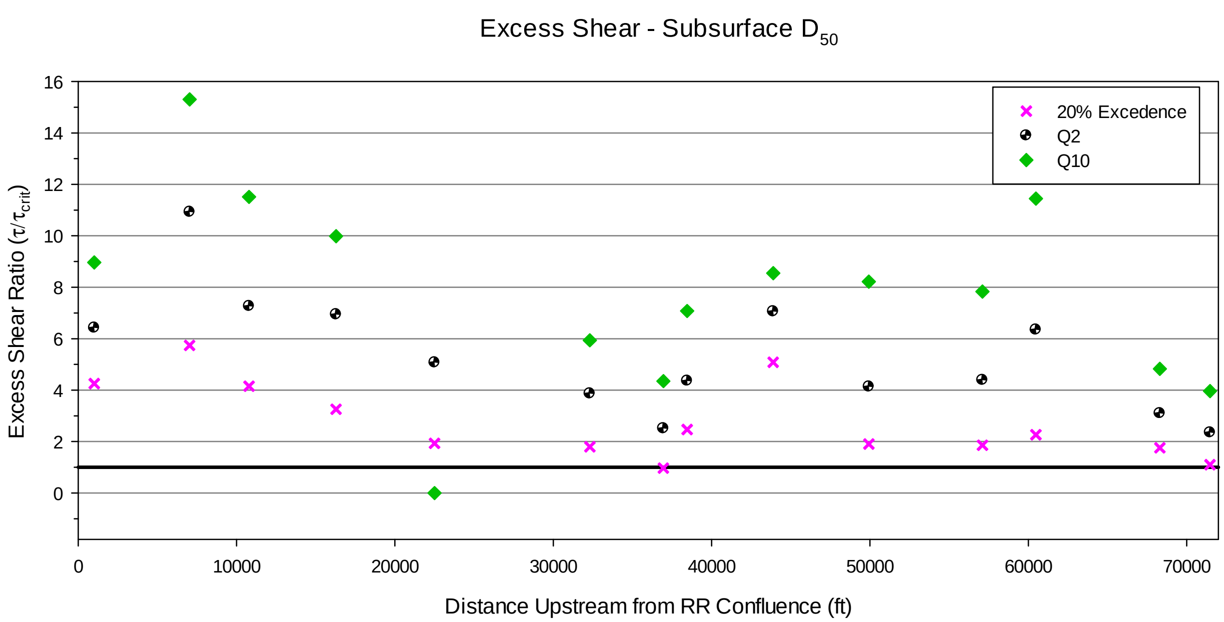


Figure 43: Excess shear ratio for median (D50) subsurface grain size at three flows in Dry Creek, and low flow condition in the Russian River (no backwater influence).

4.5.3.3.3 Synthesis of channel competence assessment

The results of the channel competence analysis for surface and subsurface substrates corroborate the conclusions that were drawn in the CCIR with respect to channel hydraulic geometry and evolution. Dry Creek has evolved a channel condition that is effective at transporting the sediment that is supplied to it, given the regulated flood hydrology. The adjustment in channel size is in large part attributable to vigorous growth of riparian vegetation. In addition, Dry Creek also appears to be effective at mobilizing its bed. This characteristic has led to relatively infrequent, small riffles and frequent, long flatwater and pool habitats that have relatively swift velocities. Finally, it appears that the discharge that is primarily responsible for maintaining channel characteristics is associated with relatively frequent, sub-annual, sustained, moderately high winter flows as opposed to a peak flow event that fits the classic model of the effective discharge falling somewhere between the Q1 and Q10 events.

4.5.4 Effective Discharge Analysis

An additional analysis was completed to estimate the effective discharge at several locations in the study reach. In essence, the effective discharge is considered to be that discharge (or range of discharge) which is responsible for transporting the largest volume of bed sediment load over the long term for a given stream system (Goodwin 2004). This discharge has been shown to play an essential role in maintaining the form and geometry of the stream given relatively stable boundary conditions (e.g., climate, sediment supply), allowing rivers to be "architects of their own geometry" (Leopold 1994). The methodology to estimate the effective discharge at any given location on a stream integrates the long-term distribution of flow (in terms of a flow duration curve) and a bed sediment discharge rating curve (Biedenharn et al. 2000). The sediment discharge rating curve may be developed based on many field measurements collected over a wide range of flows, or calculated using a sediment transport equation if relevant empirical data is not available (Beidenharn et al. 2000). The latter was the case for Dry Creek.

The effective discharge is estimated using the following equation, from Goodwin (2004):

$$\Phi_i = [Q_{s_i} * f(Q_i)]$$

$\Phi = \alpha Q^{\beta} f(Q) \Phi_i$ = total sediment transported (volume) at discharge *i*

Q_{s_i} = sediment discharge (volume/day) at discharge Q_i

f(Q) = period of time at discharge Q_{s_i} (days)

The effective discharge is that where Φ reaches a maximum (see Figure 44), or where:

$$\partial\Phi / \partial Q = 0$$

As shown in Figure 42, the effective discharge is essentially a convergence of relatively frequent floods that are also able to transport bed sediment. Smaller flows may occur much more frequently, but are not able to transport sediment. Conversely, larger floods may transport more sediment per any one event, but are so infrequent as to not add up to as substantial of a volume over the long term.

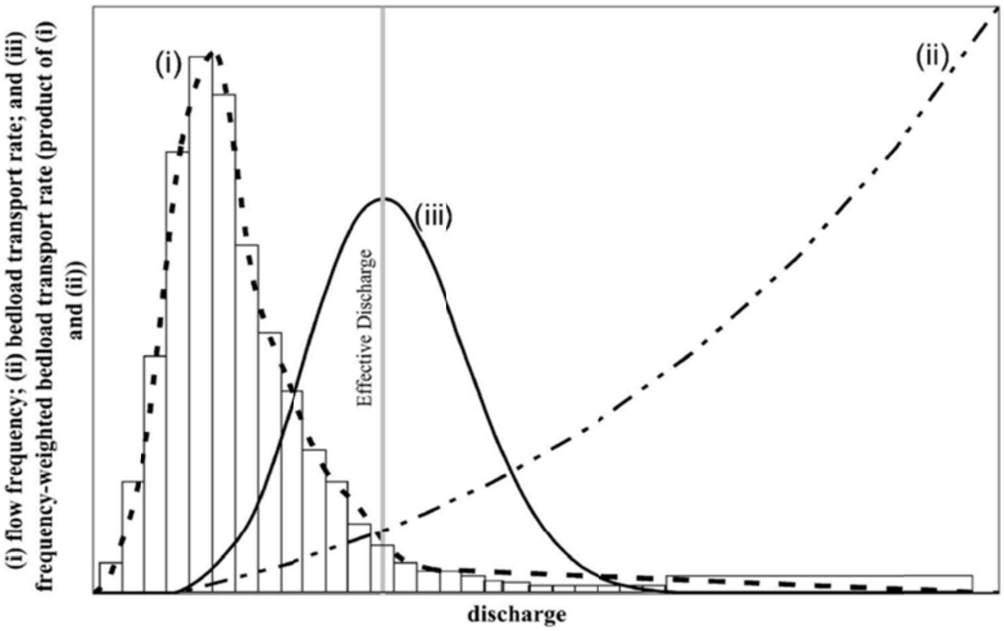


Figure 44. Effective discharge conceptual diagram. (i) flow frequency; (ii) bedload transport rate; (iii) frequency-weighted bedload transport (product of (i) and (ii)). Source: Barry et al. 2008.

As in many river systems, there was a lack of applicable direct bedload observations along Dry Creek. Instead, a sediment transport equation was used to estimate the sediment rating curve at each location of interest based on the local channel hydraulics and the sampled bed substrate gradation. Because the effective discharge concept is based on the bed sediment load, the calculation was completed at locations where subsurface bed sediment gradation data was available. As described in Section 4.5.2.1, the subsurface gradation is assumed to approximate the bed sediment gradation transported by Dry Creek.

Using the Sediment Transport Capacity module in HEC-RAS, the hydraulic model developed for this study was used to estimate bed sediment transport capacity. This module allows sediment transport calculations to be made at each cross section of interest, applying a user-selected sediment transport equation. Of the six bed sediment transport equations available in the Sediment Transport Capacity module, the most appropriate for use in Dry Creek was assessed to be the Meyer-Peter Muller equation (Meyer-Peter & Muller 1948).

The results of the effective discharge analysis are shown graphically in Figure 45. Upstream of Pena Creek, the effective discharge was estimated to approximately equal the 2-year return period flood (2500-3500 cfs). Downstream of Pena Creek, the effective discharge was estimated to have return frequency less than the one-year return period flood in many locations (750-1500 cfs). The results of the effective discharge analysis are consistent with the excess shear analysis and synthesis of field indicators. Even though Dry Creek's flood hydrology has been severely curtailed by operation of WSD, Dry Creek has evolved to a condition which is efficient at transporting the sediment supplied to the creek by the tributaries downstream of WSD. This is in large part due to the channelizing effect of the riparian vegetation that has become established in the overbanks. Even though large floods rarely occur, moderately high flows in the range that enable sediment transport occur relatively frequently (up to multiple times each year below Pena Creek) and for sustained duration (Figure 9– winter flow duration curve). It is these frequent and moderately high flows which are estimated to transport the largest volume of bed sediment over the long term.

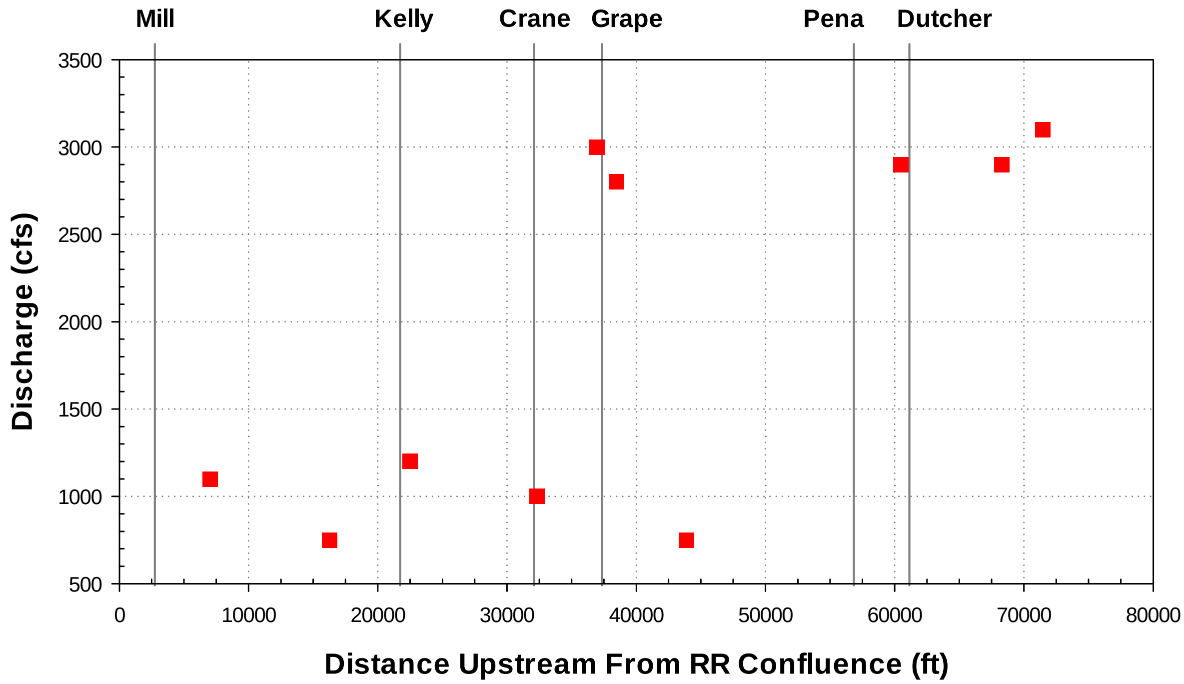


Figure 45. Effective discharge calculated for Dry Creek downstream of WSD.

4.6 FISH HABITAT IN DRY CREEK

4.6.1 Overview of 2009 Habitat Inventory

A comprehensive inventory of fish habitat in lower Dry Creek was completed in 2009, with the results summarized below and detailed in the CCIR (Inter-Fluve 2010). The goals of the habitat inventory were to census existing fish habitat in lower Dry Creek as a means of providing context for the development of fish habitat enhancement alternatives, and to establish a basic pre-treatment baseline against which to measure the effects of future fish habitat enhancement projects. Habitat conditions were documented at the summer steady-state operational discharge of approximately 100 cfs.

Dry Creek historically supported populations of coho and steelhead, although it only provided marginal salmon habitat when compared to other Russian River tributaries closer to the coast (Hopkirk and Northen 1980) due to very low summer flow. Today, coho and steelhead are present in Dry Creek year-round. Adult coho and steelhead enter Dry Creek to spawn in the late fall and winter. Eggs deposited in gravel nests called redds incubate through the winter and early spring, and fry emerge in the spring. Juvenile coho and steelhead rear in Dry Creek for a minimum of one year before migrating to the sea the following late winter or spring. Furthermore, it should be noted that Dry Creek currently supports a robust population of Chinook salmon (O. tshawytscha). Habitat enhancement efforts will need to consider interactions with this important population.

The results of the habitat inventory are summarized in Figure 46 and Table 8, with habitat unit mapping and detailed results for each sub-reach included in Appendix A. The current inventory found that Dry Creek is composed of 44% flatwaters, 26% riffle, 23% pool, 7% scour pool, and less than 1% cascade based on the relative frequency of mainstem habitats. Pool depths generally decreased in the downstream direction, with a greater proportion of scour pools in the middle to upstream end of the survey area. Overall, there was far more flatwater than riffle habitat (44% of mainstem habitats by frequency versus 26% for riffles). Although Dry Creek is composed of 26% riffles by frequency, riffles represent only 12% of mainstem habitats by length. A total of 44 alcoves and 27 side channels were measured, with a relatively greater number of off-channel habitats in the lower half of the study reach. The percent cover ranged from 27% associated with pools to 14% associated with riffles.

Pebble counts were conducted at riffles in all surveyed reaches. The substrate sizes in these riffles meet coho and steelhead spawning requirements. The predominant substrate sampled in riffle, flatwater and pool habitats was gravel. In side channel pools, dominant substrate was most often fine sediment, gravel, or sand.

Instream woody debris (small, medium and large) totaled an average of 183 pieces of wood per mile in lower Dry Creek, with variability from reach to reach, including 63 pieces per mile in Reach 14 to 362 pieces per mile in Reach 10. We also classified wood as living or dead. 46% of all the pieces counted were living, with 44% of the large pieces living, and 46% of the small and medium pieces living.

A moderate amount of cover provided by overhanging terrestrial vegetation (within 6" of the water surface) was found in the 2009 habitat inventory. Average cover in pools (27%) was higher than in flatwaters (22%), and cover was greater in flatwaters than riffles (14%). Off-channel habitats generally had much higher cover than main channel units. Additionally, the present inventory found channel complexity values to be high, but moderate to low shelter ratings. Overall, edge habitat was present in 41% of all habitat units. Although we did not specifically measure bank erosion, eroding banks were observed in Reach 1 and in Reach 7. There were a large number of bank stabilization efforts observed in the creek, including riprap, cars, creosote-preserved wood fences, steel I-beams, and chain-link fence.

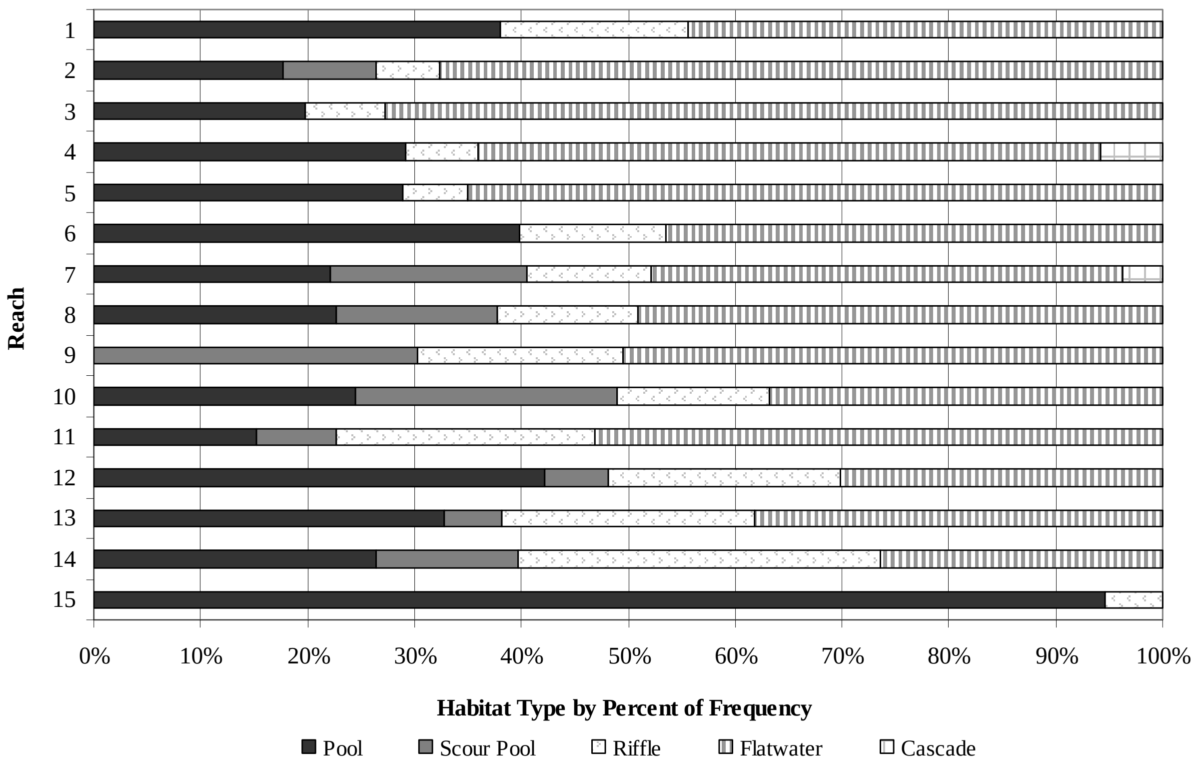


Figure 46: Distribution of habitat types by relative frequency for Reaches 1 through 15.

TABLE 8: LOWER DRY CREEK HABITAT INVENTORY RESULTS SUMMARY, REACHES 1 THROUGH 15.

		REACH 1	REACH 2	REACH 3	REACH 4	REACH 5	REACH 6	REACH 7	REACH 8	REACH 9	REACH 10	REACH 11	REACH 12	REACH 13	REACH 14	REACH 15
	river miles	0 to 0.7	0.7 to 2.0	2.0 to 3.0	3.0 to 4.1	4.1 to 5.4	5.4 to 6.2	6.2 to 7.5	7.5 to 9.0	9.0 to 9.8	9.8 to 10.3	10.3 to 11.0	11.0 to 11.7	11.7 to 12.6	12.6 to 13.3	13.3 to 13.6
	length (miles)	0.7	1.3	1.0	1.1	1.3	0.8	1.3	1.5	1.0	0.6	0.7	0.7	0.8	0.7	0.3
% total l frequency	**main channel pools**	32	16	17	25	26	35	19	19	0	20	13	37	29	25	50
	scour pools	0	8	0	0	0	0	16	13	23	20	7	5	5	13	0
	riffles	32	14	22	20	16	24	23	26	38	30	33	32	33	38	50
	flatwaters	37	62	61	50	58	41	39	42	38	30	47	26	33	25	0
	cascades	0	0	0	5	0	0	3	0	0	0	0	0	0	0	0
	# side channels	2	3	8	3	1	0	3	0	0	1	1	3	0	1	0
	# alcoves	4	6	4	8	2	0	8	1	1	3	1	1	3	2	1
% total length	**main channel pools**	39	18	25	59	30	60	45	36	0	26	13	49	41	26	97
	scour pools	0	3	0	0	0	0	22	21	49	25	2	7	6	12	0
	riffles	15	5	6	6	6	12	10	11	15	12	21	19	21	32	3
	flatwaters	47	73	69	34	64	28	22	32	37	38	64	25	33	30	0
	cascades	0	0	0	1	0	0	1	0	0	0	0	0	0	0	0
avg. width (feet)	**wetted channel**	45.6	45.6	47.7	51.9	48.4	48.6	47.7	45.8	51.1	47.6	46.5	46.0	43.5	48.1	39.0
	active channel	62.5	68.0	82.0	52.0	69.0	n/a	58.5	58.5	57	78	56.6	54.0	41.0	65.0	45
	floodprone	137.5	140.0	110.0	112.0	86.5	n/a	81.0	70.5	95	87.0	78.0	93.0	62	139.0	126
	avg. active channel depth	2.1	2	1.35	2.15	1.8	n/a	2.5	2.4	2.8	2.4	2.6	2.6	2.3	2.6	2.9
	width:depth	30	40	48	19	39	n/a	24	24	21	32	22	21	18	25	15
	entrenchment	2.2	2.02	1.4	2.2	1.3	n/a	1.6	1.2	1.7	1.1	1.4	1.7	1.5	2.1	2.8
avg depth (feet)	**pools max**	4.0	4.3	4.6	5.3	4.9	5.5	4.8	4.7	4.2	6.3	5.1	5.5	5.7	5.7	7
	pools residual	2.7	2.8	2.4	3.8	3.4	4	3.5	3.4	3.0	5.0	4.3	3.9	3.8	4.4	4.5
	riffle	1.1	0.9	1.1	1.2	1.0	0.9	1.0	1.0	0.9	1.1	1.0	1.4	1.2	1.1	2
	flatwaters	1.4	1.5	1.4	1.3	1.5	1.5	1.4	1.4	1.5	1.9	1.8	2.0	2.2	2.3	
	cascade				0.9			1.1								
	side channel	0.6	1.3	1.8	0.9	0.5		0.8			0.3	1.0	1.6		1.1	
	alcove max	1.0	2.0	1.4	1.7	1.0		2.0	2.0	1.5	2.6	2.3	2.5	2.2	3.5	3
	% cover (mainstem habitats)	17	26	24	22	24	23	26	18	20	25	19	24	19	20	19
	complexity value (mainstem habitats)	2.1	2.7	2.7	2.5	2.6	2.6	2.6	2.6	3.0	3.0	3.0	2.8	2.7	2.7	2.0
	shelter rating (mainstem habitats)	35	69	65	55	61	59	67	47	59	74	56	67	51	54	37
	edge habitat frequency (mainstem habitats)	38%	39%	60%	58%	40%	29%	43%	47%	31%	36%	12%	26%	33%	19%	33%
wood	**pieces per mile**	96.9	141.9	165.4	184.9	233.9	195.6	190.5	193.6	192.8	361.8	269	176.6	159.9	117	62.9
	% live wood	42%	50%	43%	37%	31%	38%	34%	23%	19%	17%	29%	37%	51%	66%	70%
	# pieces S, M, L	41, 14, 9	158, 71, 13	174, 54, 30	177, 66, 15	229, 47, 20	110, 29, 15	231, 57, 8	233, 55, 8	124, 22, 9	171, 55, 9	132, 52, 12	122, 36, 3	100, 35, 6	64, 29, 0	13, 7, 0
	# pebble counts	1	1	2	1	2	1	4	1	1	1	2	1	1	2	1
% frequency in riffles	**spawning gravels** (11.4 to 128 mm)	84%	79%	81%	89%	80%	84%	80%	82%	81%	69%	73%	77%	83%	69%	67%
	fry rearing gravels (32 to 128 mm)	39%	33%	42%	49%	41%	45%	36%	53%	36%	45%	33%	51%	55%	37%	37%

4.6.2 Existing rearing habitat characteristics

The availability of existing rearing habitat is limited in Dry Creek, particularly for coho salmon. Instream rearing habitat is limited primarily by the presence of swift velocities in the main channel of Dry Creek (Figure 47) and relatively limited habitat structure and complexity (Table 8). The primary instream rearing habitat is associated with overhanging and emergent vegetation along the margins of the channel in select sub-reaches.

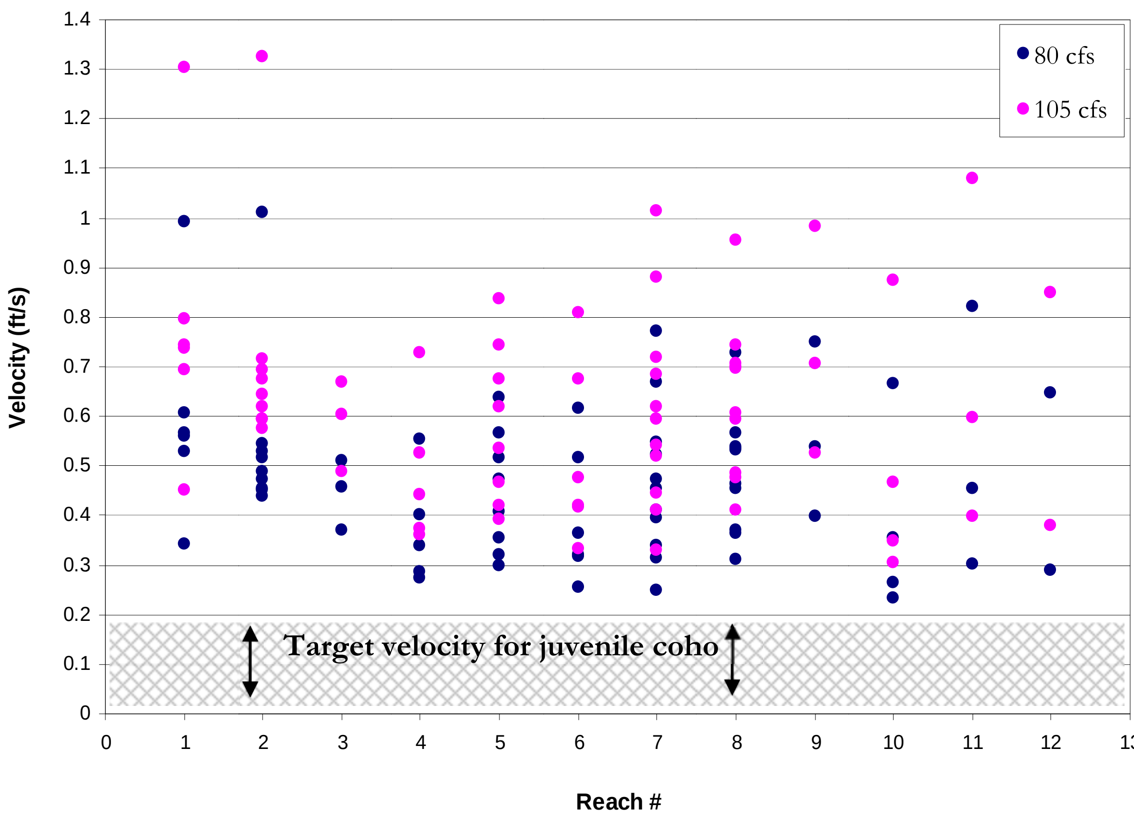


Figure 47: Estimated velocities for lower Dry Creek pools based on 2009 habitat inventory data. Velocities were calculated at 80 and 105 cfs to capture the typical range of discharge in Dry Creek during the time of the habitat inventory. The cross-hatched area is the target velocity range for coho rearing habitat (< 0.2 ft/s) per the RRBO.

Off-channel rearing habitat is also limited. The habitat inventory documented a total of 44 alcoves and 27 side channels. These features are found primarily in the lower half of the study reach. The alcoves that were found were relatively small, with 80% of them less than 100 feet in length, and 34% of them less than 50 feet in length.

Ironically, the area of Dry Creek which appears to have the best rearing habitat and greatest concentration of off-channel habitat is located in an area where in-stream gravel mining occurred in the 1950s to 1970s. This area is located about 2,000 feet upstream of Westside Bridge. Based on examination of historic ground-level and aerial photos of the site following the culmination of gravel mining, the site appears to have been left nearly flat across the channel corridor bottom without a readily discernable channel. The mining operation occurred near the upstream end of the backwater zone created by high flows on the Russian River, and is in a depositional zone. It is likely that the existing concentration of backwater channels has resulted from the interaction of depositional sedimentary processes and vegetative colonization, as opposed to erosive and scouring processes associated with channel migration. The processes which are thought to have created this complex habitat 2,000 ft upstream of the Westside Bridge contrast with the processes which have shaped other segments of lower Dry Creek.

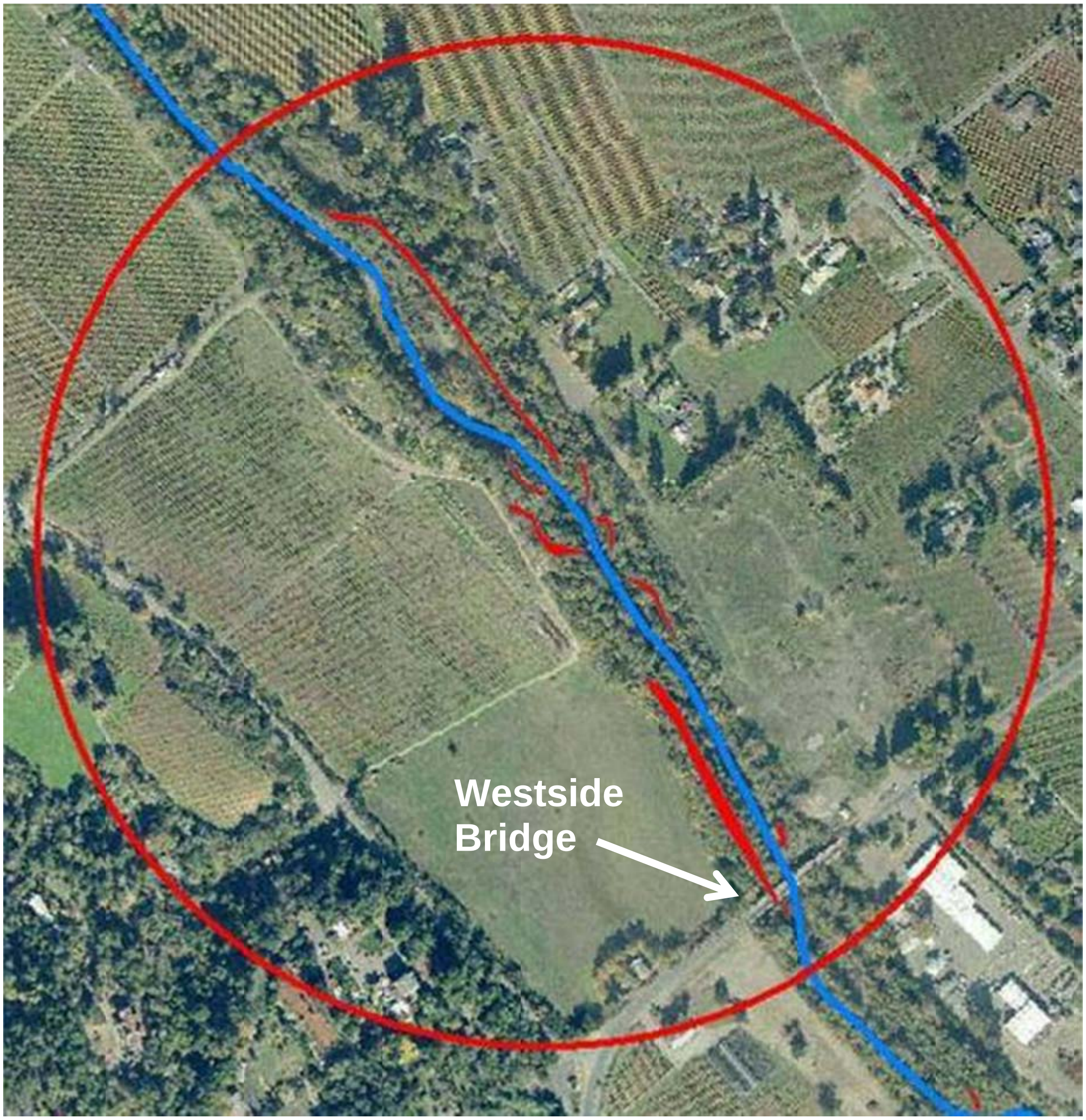


Figure 48. Concentration of off-channel rearing habitat upstream of Westside Bridge.

Figure 49. Looking upstream from Westside Bridge at an area that was mined for gravel from the 1950s to the 1970s, which now has good rearing habitat. Date of picture is 1981. Source: Bill Cox, CDFG – retired.

4.7 Dry Creek Evolutionary Trajectory

At the time of closure of WSD, Dry Creek was heavily altered due to 125 years of impacts. Based on assessments made near the time of dam closure (Harvey and Schumm 1985), Dry Creek appeared to have reached its maximum level of alteration and had started on a geomorphic recovery trajectory (Figure 52). The construction and operation of WSD changed the course of that trajectory. The modified hydrology and sediment regimes diverge substantially from that which had sustained Dry Creek in the pre-development era and created the form and function of the channel corridor present at the time of dam closure.

In a classic pool-riffle channel, at low or baseflow conditions, the water surface will typically exhibit a moderately stepped profile with a very low slope through the pool, and a relatively steeper slope through the riffle section. As flow increases, the water surface slope through the pool-riffle sequence tends to be become more consistent, to the point where at high flow there is little or no break in the water surface slope over a pool-riffle sequence. In a pool-riffle channel that has reached an equilibrium condition with its hydrology, sediment supply and floodplain, the slope of the water surface at the bankfull flow will match the slope of the adjacent floodplain surface. Prior to European settlement, Dry Creek likely exhibited these characteristics.

While a pool-riffle channel was the historic morphology of Dry Creek, several factors challenge the ability of Dry Creek to self-form this type of morphology in the classic sense today. Historical incision of Dry Creek left the system without a floodplain and high flood conveyance capacity (see stage II, Figure 46) for many decades. As the system was recovering to the extent of beginning to develop a new inset floodplain within the channel corridor along much of its length (see stage V; Figure 52), many stabilization projects were implemented to limit the lateral expansion of the channel corridor in order to protect property and infrastructure which curtailed the development of a new effective floodplain in many locations.

WSD's operation today creates flood hydrology that is significantly reduced from historical conditions, and flow characteristics are generally consistent with a much smaller stream. This decreased flood hydrology effectively increases the relative size of the inset overbank areas. However, WSD operation elevates baseflows that, in conjunction with reduced peak flow magnitude, enable extensive vegetative growth on the floodplain areas which were present at the time of dam closure. The altered hydrology has led to overbanks that are very hydraulically rough acting to stabilize the floodplain, to limit channel migration, and to focus flow in the narrow active channel. This effectively creates inset channelization for the stream within the incised channel corridor. The typical locations where Dry Creek is actively migrating through the floodplain deposits are locations where riparian vegetation is absent (Figure 51).

The altered hydrologic regime and vegetative crowding of the channel make Dry Creek competent at moving the coarse sediment that is supplied to it at relatively low discharges as compared to an undisturbed stream. Ultimately, this combination of factors has led to the conditions that are observed today. Because of the ability of Dry Creek to transport the coarse sediment delivered from tributaries, riffles (which are depositional features) are limited in frequency and size, and the intervening sections of stream, while possessing some residual depth, lack other characteristics of pools and are far out of balance in terms of size relative to the riffles.

As summarized in section 4.5.1.2, the altered hydrology has created ideal conditions for riparian vegetation growth while failing to provide large enough flood events to erode vegetated bars and expose bare surfaces for primary vegetation succession. Geomorphically, the combination of altered hydrology and vegetation growth patterns has curtailed the fluvial processes which erode and deposit bars ,in the active channel, while also creating lateral habitats such as alcoves, backwaters, and side channels. These factors will also likely continue to limit development and maintenance of pool-riffle morphology through time.

Figure 50. Dry Creek downstream of Lambert Bridge in 1970 and 2010. The geomorphic response of the channel to both gravel mining downstream and the completion of WSD has resulted in dramatic changes in both the channel and the adjacent riparian area.


Figure 51. Active channel meandering in a typical location where Dry Creek is lacking riparian vegetation at RM 6.4.

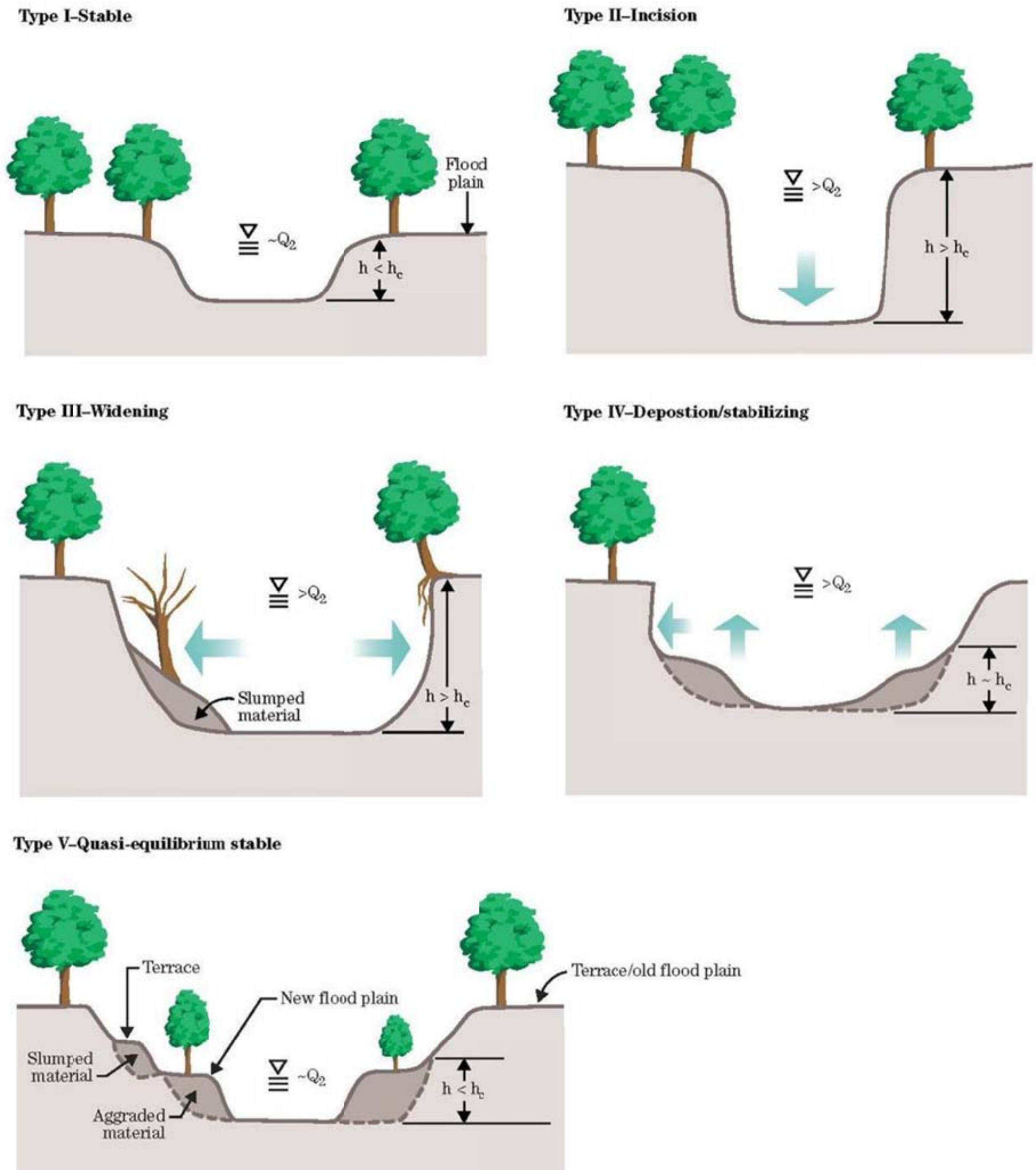


Figure 52: Conceptual model of incising channel evolution developed by Schumm, et al. 1984. Reprinted from USDA-NRCS 2008.

5 HABITAT ENHANCEMENT FEASIBILITY ASSESSMENT

As noted in Section 3, the primary Project Goal is to:

- Enhance channel and riparian conditions on lower Dry Creek to benefit juvenile life stages of ESA-listed coho salmon and steelhead trout, which will aid in their recovery within the region.

Attendant to the project goal, the following are the primary objectives for the Dry Creek Habitat Enhancement Project:

- Enhance summer rearing habitat for coho salmon and steelhead to 'near-ideal' conditions,
- Create refugia from winter high-flow releases for both coho salmon and steelhead,
- Enhance habitat while, to the extent feasible, minimizing impacts on adjacent property and infrastructure
- Enhance habitat without adversely affecting Chinook salmon.

The task of the present study is to assess whether it is feasible to accomplish the goal and objectives listed above. In order to assess feasibility, it is first necessary to define these objectives more specifically.

5.1 HABITAT ENHANCEMENT DEFINED

The following paragraphs characterize the spatial, temporal and desired physical characteristics of habitat enhancement in Dry Creek.

5.1.1 Spatial Characteristics

Lower Dry Creek extends 13.9 miles between WSD and the Russian River. At present, all flows are contained within the historical incised channel corridor (channel corridor) which evolved between the time of European contact (1850s) and the 1980s. Beyond the edges of the channel corridor, agricultural lands (primarily vineyards) extend to either edge of the lower Dry Creek valley.

The RRBO (NMFS 2008) requires that habitat enhancements be distributed over the study reach, including at least 8 sections of improvements distributed over the upper, middle, and lower sections. The estimated area of habitat enhancements is 96,500 m^2 over the life of the project. The RRBO also includes installation of 20 isolated habitat structures (boulder clusters) in areas outside of those that are intensely treated. It should be noted that the final approach to measurement of enhanced habitat area is being developed collaboratively by the Water Agency and Army Corps of Engineers (the 'action agencies'), NMFS and CFDG (Wieckowski et al. 2010).

To date, the most realistic approach has been to endeavor to locate areas of habitat enhancement within the channel corridor because of the perceived challenges of attempting to locate enhancements that would impact the private agricultural (vineyard) lands that border the channel corridor. The stream segment (study sub-reach 16) between Bord Bridge (RM 13.7) and the WSD outlet (RM 13.9) has not been included in consideration for enhancements as it contains the dam outlet infrastructure and tailwater channel. Since nearly all lands bordering Dry Creek are privately owned, habitat enhancements will ultimately be implemented at locations where private landowners have granted permission for the work to be completed on their property.

5.1.2 Temporal Components

The RRBO lays out a timeline for implementation of the habitat enhancements, which will ultimately result in six miles of habitat enhancement in Dry Creek by 2020. The timeline dictates that the first mile of habitat enhancement will be completed by 2014, and miles 2-3 by 2017. If habitat enhancements in the first three miles are found to be successful, the remaining three miles of enhancement will be completed by 2020 (NMFS 2008). In general, the instream component of the habitat enhancement work will need to be completed during the period June 15 to October 15, which is the typical in-water work period for the region (designed to minimize impacts on adult anadromous salmonids and coincide with low flow conditions).

Although the RRBO is a 15 year guiding document, NMFS and CDFG will likely require the Water Agency to maintain functioning coho and steelhead habitat beyond this time frame. It is anticipated that the habitat enhancements will continue to provide habitat benefits and be maintained in approximately similar quantities for 25 years. The Water Agency, NMFS, and CDFG are engaged in an adaptive management planning process that will specify goals, objectives, and monitoring methods to verify the effectiveness and longevity of habitat enhancements (Wieckowski et al. 2010). The habitat enhancement approaches described below will be designed to meet the expectations described in this adaptive management plan.

5.1.3 Physical Criteria

The RRBO lays out criteria which define 'near ideal' rearing habitat conditions for coho salmon and steelhead trout. The criteria in the RRBO focus on enhancement of mainstem pool-riffle habitat with the following attributes in the target flow range of 110 to 175 cfs:

- Pool abundance in the stream: 33% to 67% of habitats,
- Pool:Riffle ratio: 1:2 to 2:1,
- Water depth: 2 to 4 feet,
- Water velocity: substantial areas with mean column velocities of 0.1 to 0.2 ft/s,
- Cover: more than 30% of the pool bottom obscured due to depth, surface turbulence, or presence of structures such as logs, debris piles, boulders, or overhanging banks and vegetation,
- Alcoves: Should be present to provide high quality shelter during both low and high flow events, and
- Installation of 20 boulder clusters (as defined in Flosi et al. 1998).

As with the spatial and temporal characteristics listed above, it should be noted that the final approach to measurement of enhanced habitat area is being developed collaboratively by the action agencies, NMFS and CFDG (Wieckowski et al. 2010).

5.2 Habitat Enhancement Alternatives

5.2.1 Approaches to Habitat Enhancement – General perspectives

The practice of habitat enhancement and restoration in rivers and streams is an evolving field. To date, enhancement projects have been designed and implemented based on a wide range of fundamental approaches. A certain degree of variability in approach is unavoidable, and appropriate, given the differences between the streams and rivers in which the work is conducted, and the associated constraints that act on each fluvial system.

In general, the restoration philosophy that is the underpinning of any particular project falls within a continuum between fully process-based and direct habitat construction-based approaches. With the fully process-based approach, the overarching concept is that fluvial systems are inherently resilient 'living' systems, and given sufficiently unconstrained space and time will revert towards a fundamental behavior, form and pattern. In doing so, inherent habitat characteristics will emerge which will support the life history needs of native flora and fauna as it is within these stream systems that they have evolved..

With this approach, little focus is placed on creating late-successional habitat conditions[2] that species of concern occupy immediately following project implementation. The crux of the fully process-based approach is the need to understand the trajectory of evolution of the system at present, to be assured that the physical processes which shape the system are sufficiently intact in order to enable recovery towards a desired habitat condition (i.e., the 'stage must be set'). Additionally, the project proponents must confirm that the timeframe to achieve the desired habitat characteristics is acceptable in light of the needs of potentially declining populations of focus species which may serve as the primary motivation for restoration efforts. This approach also becomes increasingly relevant as project scale increases to the point where it may not be practical to construct each piece of habitat.

At the other end of the spectrum is the direct habitat construction approach, which may focus on development of habitat 'features', 'structures' or units. These elements are intended to provide late-successional habitat characteristics immediately following project implementation. Depending on the desired longevity for the constructed habitat, the crux of this approach is to understand whether the context in which the habitat is constructed will support the habitat features through time, and that the habitat will not be destroyed by the inherent dynamic processes of the fluvial system. In highly altered systems in particular, it simply may not be feasible to rely on the physical processes to create habitat and enhancement may need to follow such a feature-based approach.

In practice, most restoration or enhancement projects fall somewhere in the middle of this continuum. As the restoration field has matured, an increasing number of implemented projects have attempted to define the restoration trajectory for the system, implement focused habitat enhancements to jumpstart the site along the trajectory providing provide near-term habitat value, and then rely on processes to evolve the created habitats into a mature state through time. In many

[2] The concept of "late-successional habitat" refers to an area which has been shaped by channel and riparian processes (vegetative growth and large woody debris recruitment) to provide mature, complex, high quality habitat for native fauna.. Maturation of habitat in a newly disturbed area of a river system to a late-successional condition may occur over years to decades.

cases, it may be acceptable or expected that individual constructed habitats may be replaced through time, but that the overall quantity or volume of habitat is approximately similar over the restoration timeframe.

5.2.2 Approaches to Habitat Enhancement in Dry Creek

The preceding section provides perspectives on the two overarching questions with respect to the feasibility of habitat enhancement in Dry Creek (construction-related and other logistical questions not withstanding):

- Are fluvial processes sufficiently intact to provide Dry Creek with the potential to create suitable habitat through a primarily process-based approach?
- If suitable late-successional habitat is constructed directly, will it be destroyed and not replaced within a timeframe that is acceptable?

As with many heavily modified stream systems, a range of habitat enhancement philosophies should be considered on Dry Creek. Because there is variability in terms of dominant processes and dynamics at different locations along the creek, differing philosophies may be used in different stream segments. Key to the consideration of enhancement approaches in response to the RRBO are the range of variability that may be embraced after the habitat is constructed, sensitivity to dynamics in the composition of habitat, and the timeframe over which the habitat function must be provided. These key questions are among those being collaboratively addressed by the action agencies, NMFS and CDFG in the adaptive management process (Wieckowski et al. 2010). It is necessary to have some resolution on these topics to fully conclude whether the habitat enhancement will meet the goals and objectives (and thus be considered feasible), because the manner in which project performance and change are measured and interpreted dictates whether the goals and objectives have been met. Nevertheless, the following sections discuss aspects of habitat enhancement that provide perspectives towards conclusions regarding feasibility.

Two primary types of habitat are considered for enhancement in Dry Creek: mainstem in-channel habitat and off-channel habitat. Following the recommendations in the RRBO, pool-riffle habitat is the primary desired in-channel habitat, with additional boulder clusters installed in stream reaches where other work will not occur. Potential off-channel habitats include alcoves, backwater channels, and side channels. After initial characterization and discussion of these habitat types, they will be evaluated for applicability in each of three primary segments of Dry Creek over which the feasibility assessment is characterized. The three primary segments include 1) upstream of Pena Creek, 2) Pena Creek to the grade control sills, and 3) grade control sills to the confluence with the Russian River. This delineation was made based on differences in the dominant hydrologic, sedimentary, and hydraulic boundary conditions. Study sub-reaches 1 – 15 are grouped into these primary stream segments as shown in
Table 9.

Table 9. Delineation of Upper, Middle and Lower Segments for evaluation of feasibility alternatives.

Feasibility Assessment Segment	Study Sub-reaches	River Miles	River Stations (distance upstream in feet)	Description
Lower	1 to 3	0 to 3	0 to 15,800	Downstream of grade control sills. Receives sediment and water contributions from tributary watersheds which partially offset flow regulation impacts. Segment influenced by backwater from Russian River during high flow events
Middle	4 to 11	3 to 11	15,800 to 58,000	Grade control sills upstream to Pena Creek. Receives sediment and water contributions from tributary watersheds which partially offset flow regulation impacts.
Upper	12 to 15	11 to 13.7	58,000 to 73,300	Upstream of Pena Creek. Lacks notable sediment supply, peak flow hydrology is most substantially altered.

5.2.3 Instream Habitat General Feasibility Considerations

5.2.3.1 Pool-Riffle Habitat

Pool-riffle morphology is typically found in fully alluvial stream channels with slope between 0.1% and 2%. This channel type is characterized by alternating pool and bar topography caused by oscillating lateral flow that forces local flow convergence (pool scour) and divergence (bar deposition). These are typically moderate- to low-gradient, unconfined channels, with readily available supplies of coarse bed material and attendant floodplains. In these streams, the effective discharge[3] is typically similar to the bankfull discharge[4] (Montgomery and Buffington 1997). By definition, pools have residual depth, and the streambed elevation loss through a stream reach is made up almost entirely by the riffle sections.

As described earlier in the report, in a classic pool-riffle channel at low or baseflow conditions, the water surface will typically exhibit a moderately stepped profile with very low slope (and hence velocity) through the pool, and relatively steeper slope (and hence greater velocity) through the riffle section (Figure 53). As flow level increases, the water surface slope through the pool-riffle sequences tends to be become more consistent, to the point where at high flow there is little or no break in the water surface slope over a pool riffle sequence,. In a pool-riffle channel that is in an equilibrium

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[3] Effective discharge (Qeff) is the discharge which over time will transport the greatest amount of sediment in a stream, and has been shown to be correlated with the size of the stream channel that is maintained over time.
[4] Bankfull discharge (Qbf) is the discharge at which water will spill from an alluvial stream channel onto its associated floodplain.

condition with its hydrology, sediment supply and floodplain, the slope of the water surface at the bankfull flow will match the slope of the adjacent floodplain surface. Prior to European settlement, Dry Creek likely exhibited these characteristics.

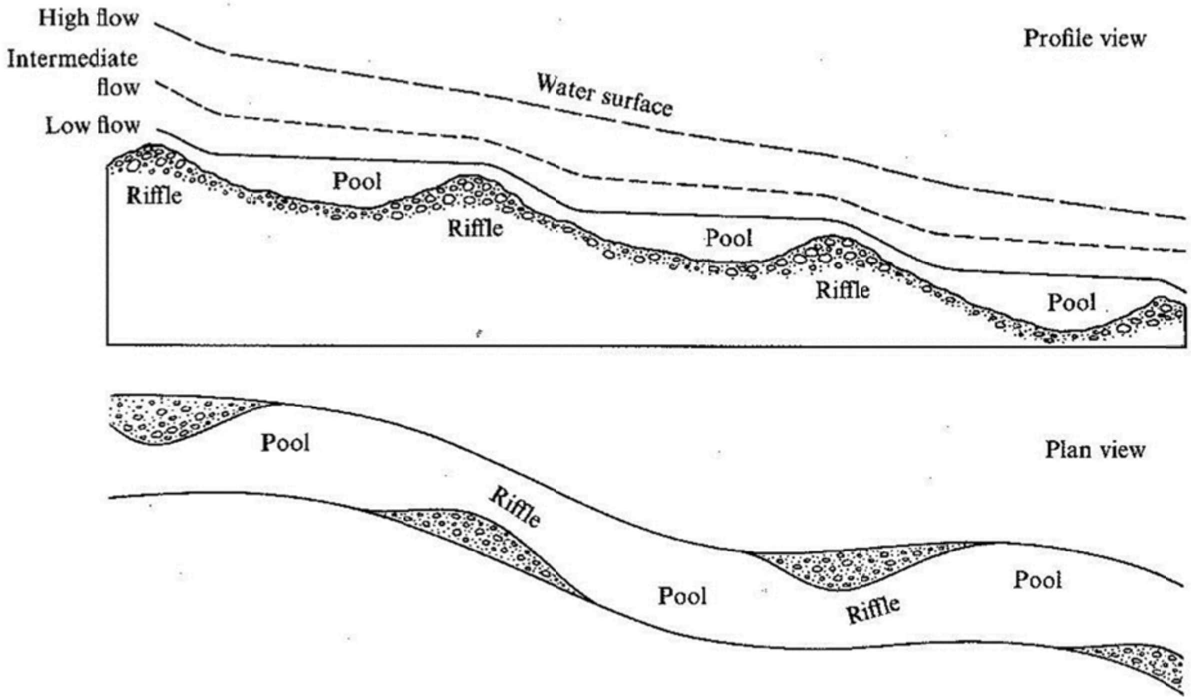

Figure 53. Conceptual depiction of water surface profiles through intact pool-riffle morphology at various flow levels. Source: Dunne and Leopold 1978.

WSD's operation creates flood hydrology that is significantly altered from historical conditions, and is overall consistent with a much smaller stream with a more narrow range of flow conditions. This altered hydrology has led to floodplains that are very hydraulically rough and limit channel migration while focusing high flows in the open portion of the stream channel. These factors make Dry Creek competent at moving the coarse sediment that is supplied to it at relatively low discharges as compared to the pre-WSD stream. Because of Dry Creek's ability to transport coarse sediment supplied to it, riffles (which are depositional features) are limited in frequency and size, and the intervening sections of stream, while possessing residual depth, lack other characteristics of pools and are far out of balance in terms of size relative to the riffles. Since the intervening habitats are so long relative to the riffles, the resultant water surface slope at the low water condition is actually more akin to the intermediate flow profile in Figure 53 than the low flow profile. It should be acknowledged that while 'low flow' is used here to describe the lowest flows of the year in the regulated condition, the 110 to 175 cfs flow range is a greater than intermediate flow condition compared to unregulated flow patterns. This flow range equates to the approximate 30% excedence flow in the unregulated era (Figure 4), or the flow that is exceeded only 30% of the time on an annual basis.

The RRBO cites evidence of habitat preference criteria for coho salmon and steelhead as guidelines for pool enhancement in the desired pool-riffle habitat. These include water depths of 2 to 4 feet and significant areas with mean water column velocities that are less than 0.2 ft/s. Assuming these criteria pertain to water column depth (not pool residual depth) and cross section-averaged water velocity, Table 10 includes estimates of the channel width that would be required to attain these characteristics. These required widths can be compared to the channel widths that were measured in Dry Creek at the time of the 2009 habitat inventory (Table 8) which was accomplished when the flows were approximately 105 cfs. The habitat inventory resulted in measured wetted and active channel widths that averaged 47 and 61 feet respectively. Additionally, GIS measurements of the width across the bottom of the historical incised-channel corridor using available topographic data result in an average width of 173 feet (median width of 143 feet and standard deviation of 92 feet). These existing channel corridor widths are further illustrated in Figure 54 to understand their distribution, which range from 61 to 700 feet. Thus, the required widths to attain the desired velocities and depths are substantial relative to both the existing stream channel and the channel corridor itself.

Table 10. Estimates of channel width required to attain various depth and maximum velocity criteria included in the RRBO.

Discharge (cfs)	Desired Depth (ft)	Desired Maximum Velocity (ft/s)	Required Channel Width (ft)
110	2	0.2	**275**
110	4	0.2	**138**
175	2	0.2	**438**
175	4	0.2	**219**

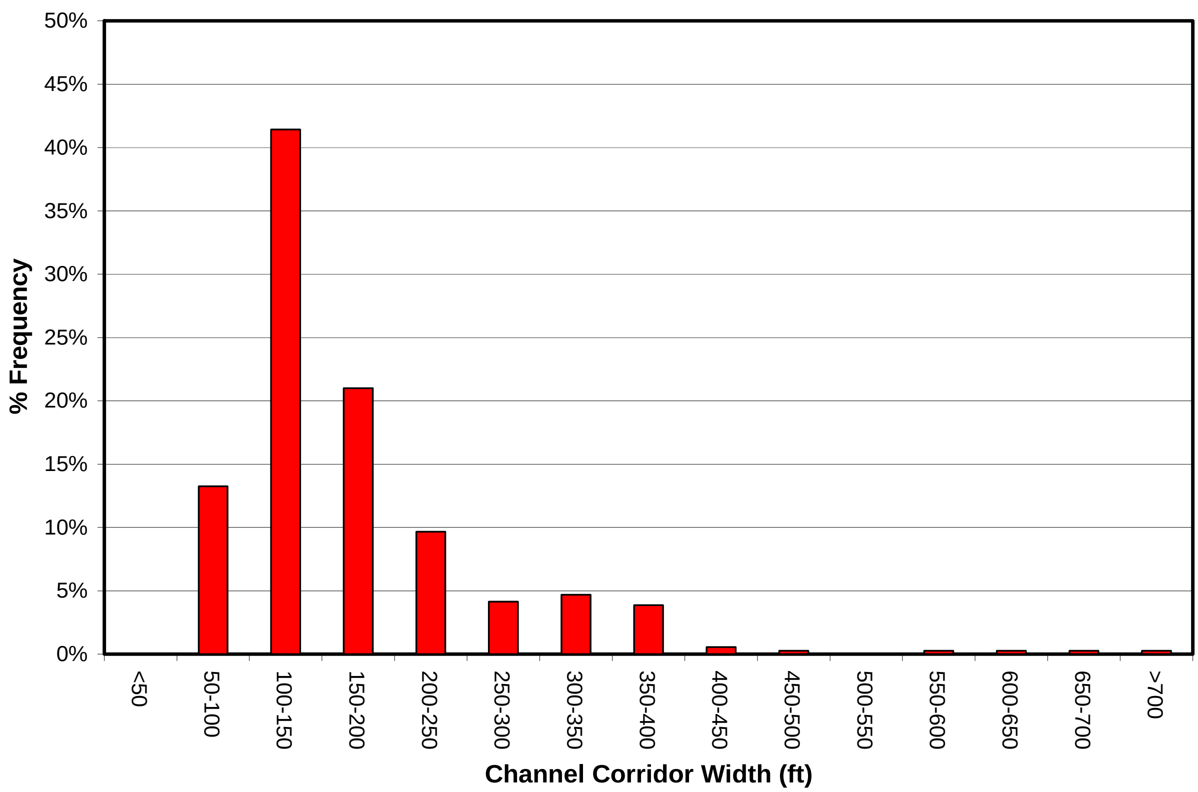

Figure 54. Relative distribution of incised-channel corridor bottom width, measured in GIS at 200' intervals along Dry Creek channel alignment

Assuming an unlimited channel corridor width was available, two separate approaches were used to estimate the potential flood hydrology that would be required to maintain a channel cross section with the required widths. First, Soar and Thorne (2001) assembled a comprehensive database of empirical hydraulic geometry measurements for gravel bed rivers collected by many researchers across North America. Their relationship was used to estimate the bankfull discharge that would be required to maintain the channel widths included above, based on the empirical data. Clearly, relationships specific to Dry Creek would differ from this broad data set, but the relationships nonetheless provide an idea of the order of magnitude in discharge that may be required.

The second method applied was a deterministic approach that used the Manning's and Shields' equations to estimate the discharge and bankfull geometry that would be required to transport the approximate median grain size (1") of the sediment load in Dry Creek during a bankfull event. With this approach, two cases were evaluated. The first case involved estimation of boundary roughness based solely on the typical substrate size. The second case increased the boundary roughness moderately for the anticipated presence of large woody debris. The results of these two approaches for bankfull flows are summarized in Table 11 below.

Table 11. Preliminary estimates of effective discharge required to maintain channel widths listed in Table 10. Q = discharge; W/D = width/depth

Width (ft)	Method	Flow	Mannings n	Q (cfs)	Depth at Riffle Crest (ft)	W/D ratio
275	Mannings	Bankfull	0.032	4,028	3.3	86
	Mannings	Bankfull	0.04	3,222	3.3	86
	Soar & Thorne	Bankfull		15,015		
138	Mannings	Bankfull	0.032	1,951	3.3	43
	Mannings	Bankfull	0.04	1,561	3.3	43
	Soar & Thorne	Bankfull		4,088		
438	Mannings	Bankfull	0.032	6,402	3.3	134
	Mannings	Bankfull	0.04	5,122	3.3	134
	Soar & Thorne	Bankfull		36,136		
219	Mannings	Bankfull	0.032	3,137	3.3	68
	Mannings	Bankfull	0.04	2,510	3.3	68
	Soar & Thorne	Bankfull		9771		

Based on the existing regulated hydrology, and channel and corridor characteristics, the only alternative that seems marginally realistic is the 138 foot wide channel. The other options require bank-full flow releases that are either unrealistic under today's regulation or even impossible given the constraints of the dam's infrastructure. However, even the 138 foot wide alternative has substantial limitations.

First, to attain this width, the channel corridor would need to be widened in some locations. Second, because the entire length of Dry Creek would not be similarly widened (the RRBO only requires 6 miles of the 13.9 miles of channel to be modified), significant hydraulic transitions would exist between the target width and the existing widths in neighboring reaches at either end of each treatment reach. At the upstream end of a widened reach, this type of transition would be susceptible to sediment deposition associated with flow expansion. At the downstream end of a widened reach, the neighboring reach would create a flow constriction which would create backwater into the widened reach, also creating a condition prone to sediment deposition. Third, due to the increased width, streamside shading in the widened reach would be less influential, which may lead to increased stream temperatures. Finally, while the calculations above provide a first order approximation of the geometry and hydrology that may be required, additional issues regarding the potential influence that re-colonizing riparian vegetation and nuisance deposition may have at flows less than the bankfull discharge should be considered. Unless monitored closely and managed as necessary, a widened channel may ultimately revert back to a condition similar to what is seen in Dry Creek today: a 50-60 ft channel crowded by dense riparian vegetation.

While there are limitations to consider in widening the active channel to meet the target velocity criteria, less intensive approaches can be considered which will in part address the swift velocities through pools that exist in Dry Creek today. As discussed previously, Dry Creek is able to efficiently transport the sediment load that is supplied to the creek from tributary watersheds, and has limited depositional features like bars and riffles. This has led to the presence of habitat units that have residual depth, but do not possess other pool-type attributes. Due to the lengths of these units, energy is expended over their length with a sloping water surface and swift velocities (analogous to the intermediate flow profile in Figure 53).

One approach to address these limitations is to construct intermediate riffles in these habitat units, which is essentially one form of focused sediment augmentation to offset the sediment supply that is lost due to the presence of the dam. With this approach, the caliber of the sediment can be controlled to enable the features to persist over an extended period. As a result of the proposed riffle construction, multiple pool-riffle units will be created, energy expenditure will shift to concentration in the new riffles, and the water surface through the pools will be flattened leading to reduced stream velocities. While this approach is unlikely to lead to the velocity criteria highlighted above being explicitly met, conditions will be improved. Through additions of large woody debris (LWD), quiescent zones can be created along the margins of these pools. The actual magnitude of velocity reduction will vary by location, but the improvements can be estimated using the hydraulic model in the design stage.

5.2.3.2 Boulder Clusters

The RRBO includes installations of 20 boulder clusters in stream reaches that are not otherwise treated with habitat enhancements, to provide additional resting and cover opportunities. Described in Flosi et al. (1998), a boulder cluster is a triangular arrangement of three large boulders placed in the middle of a riffle in a reach with intact and robust streambanks (Figure 55). The boulders will need to be sized for stability under the full range of Dry Creek flows, but are typically in the 4-5 foot diameter range.

Boulders of this size do not naturally occur in Dry Creek, though there are some boulders of this size at select locations where bank stabilization structures have fallen in the creek. There are no primary feasibility limitations with boulder cluster installation. In other streams, boulder clusters have been seen to adjust through time to flows, which will need to be considered in the monitoring and evaluation criteria. One primary mechanism for boulder movement is that the relatively finer gravel materials which surround the boulders will be preferentially removed, creating scour pockets that may cause the boulders to roll or settle over time, which will reduce their effectiveness.

As an alternative to boulder clusters, stakeholders may want to consider LWD additions in suitable locations to provide similar habitat functions.

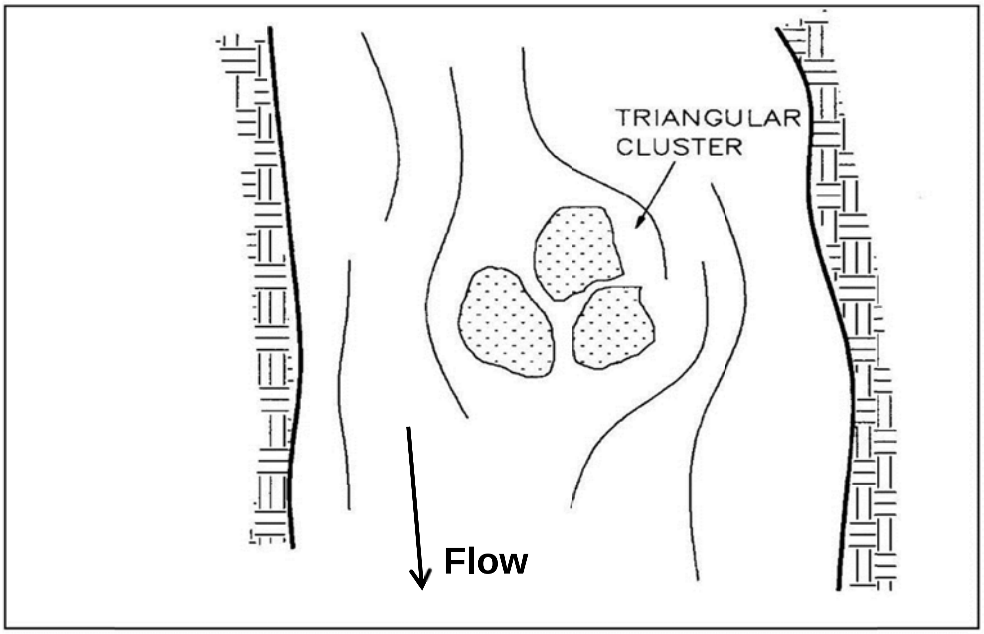

Figure 55. Conceptual depiction of boulder cluster. Adapted from Flosi et al. 1998.

5.2.4 Off-Channel habitat general Feasibility Considerations

Side channels, backwater channels and alcoves are habitats that provide good potential for rearing and refugia habitat enhancement in Dry Creek. As discussed above, it may be difficult to obtain the preferred velocity criteria in the mainstem Dry Creek. However, constructed habitats that occur off the main channel of Dry Creek can be designed to meet the velocity, depth, cover and complexity described in the habitat preference criteria listed above. In addition to providing benefits during the low flow period, these lateral features can also provide refugia habitat during high flow periods.

5.2.4.1 Side channels

Side channels are lateral stream features which may be formed through one of several mechanisms. As an alluvial stream channel migrates across its floodplain and down the valley through time, the active stream channel may become less dominant in preference for an alternative alignment, leaving the original stream channel with only a portion of the flow. Alternatively, a side channel may develop where a meander cuts off through an avulsion process. Side channels may also develop instead through island building processes, which may occur in areas of high sediment load through braiding, in response to extraordinary floods, or in oversized stream channels that were formed through historic geologic processes, and are now oversized to the current sediment and hydrology. By definition, a side channel will maintain a surface water connection at both upstream and downstream ends, with flow through the channel even during baseflow periods.

Figure 56. Conceptual depiction of side channel habitat.

Though often characterized as transitory in the riverine landscape, the persistence of side channels in alluvial systems will vary depending on the mechanisms by which they are formed and the prevailing sediment, hydraulic and hydrologic regimes. In streams with low sediment supply and regulated hydrology, side channels may persist for a long time. In streams with moderate to high sediment supply and intact flood hydrology, or highly mobile beds, they may be more transitory, though the specifics of each site may moderate the influence of these factors. In incising streams, side channels may transition to flood overflow channels if the downstream base level is lowered, dropping the hydraulic control for the feature.

In Dry Creek, there are numerous locations where side channels may be considered for habitat enhancement. The primary feasibility considerations for side channels would be their persistence in the light of potential for nuisance sedimentation, blockage of the inlet with debris, or unanticipated lateral or vertical channel change leaving the habitat stranded during the summer period. Nuisance sedimentation or debris blockage at the inlets to these features may ultimately result in a transition from a side channel to a backwater channel.

With regard to both side channels and backwater/alcoves, the means by which the enhanced habitat will be measured, monitored and tracked through time is key to the success of these habitats at meeting the goals and objectives for the effort (and thus being characterized as feasible). In some instances, these habitats may be more transitory than mainstem habitats, while in other instances they have a high likelihood of long-term persistence. In many cases where a side channel may be abandoned, it may transition to a backwater channel, or a new side channel may be created elsewhere in the same vicinity during the same flood, resulting in an overall net balance of habitat area. The means to account for and accommodate this type of dynamism is a topic of collaborative discussion at present by the action and resource agencies (Wieckowski et al. 2010).

In order to develop an understanding of the persistence of these habitats where they exist in Dry Creek today, a qualitative field assessment was completed in June 2010. The assessment followed the high flow events of January – March 2010, in which flow exceeded 2000 cfs on 5 separate occasions and 2500 cfs (Q1.5 to Q2) on 4 separate occasions at the Yoakim Bridge gage. In addition, there was a period in January where over 2000 cfs (Q2) was coming out of the unregulated tributaries between WSD and Lambert Bridge during a period where release from WSD was low. It was reasoned that this series of events should be reasonably representative of the dynamics of sediment supply from the tributary watersheds. The assessment consisted of floating the length of the study reach, and observing how side channels and backwater channels fared following the high water events. Visual observations were made of the changes that had occurred to the side channels and backwater channels during the high water events throughout the study reach.

Contrary to expectations, little or no evidence of fresh tributary deltaic deposits was seen and little or no evidence of sedimentation was seen until a mile upstream of Grape Creek, where the presence of new localized bed sheets of medium gravel estimated at 1.0 to 1.5' thick were observed. More evidence of sedimentation was observed between Grape Creek and the Russian River.

Three side channels were observed to be altered by the high flow events, with two of the sites receiving nuisance sedimentation. In addition, two of the sites were altered as a result of mainstem channel changes in response to log jam blockages: one of these resulted in removal of a controlling downstream riffle which left the channel dry, and one of these deflected the main channel into a new alignment, scouring a new side channel in the process. The side channels which received nuisance sedimentation were located laterally very close to the main channel, below a bend in the planform alignment of the main channel, and were oriented directly in line with the upstream channel. During the high flow conditions, the down valley flow inertia was oriented directly into the side channel inlets transporting gravel into these areas.

Based on the field review and observations of the evolution of constructed side channels elsewhere, Table 12 summarizes several key considerations for design of side channel enhancements. More specific discussion of applicability is included in Section 5.3.

Table 12. Consideration for design of side channels on Dry Creek, based on observations of similar habitats on Dry Creek following a high water event, and observations of constructed side channel evolution on other project sites.

Consideration	**Relevant Failure Mode**
Inlets and Outlets should not be located in depositional zones (e.g., riffles)	Nuisance sedimentation
Side channel inlet alignment should be oblique to upstream main channel alignment	Nuisance sedimentation, debris blockage
Sediment competency should be balanced with the main channel	Nuisance sedimentation
A robust control on channel grade should be located downstream of the outlet (e.g., riffle)	Abandonment by loss of hydraulic control.

5.2.4.2 Backwater channels and alcoves

Similar to side channels, backwater channels and alcoves are lateral stream features which may be formed through several mechanisms. These include channel migration, when the active stream channel may become less dominant in preference for an alternative alignment, leaving the original stream channel only connected at the downstream end. Alternatively, backwater and alcove channels may develop in relation to avulsion processes or floodplain scouring during large over-bank flood events. By definition, alcoves and backwater features maintain a surface water connection at the downstream end during base flow (Figure 57 - Figure 58).

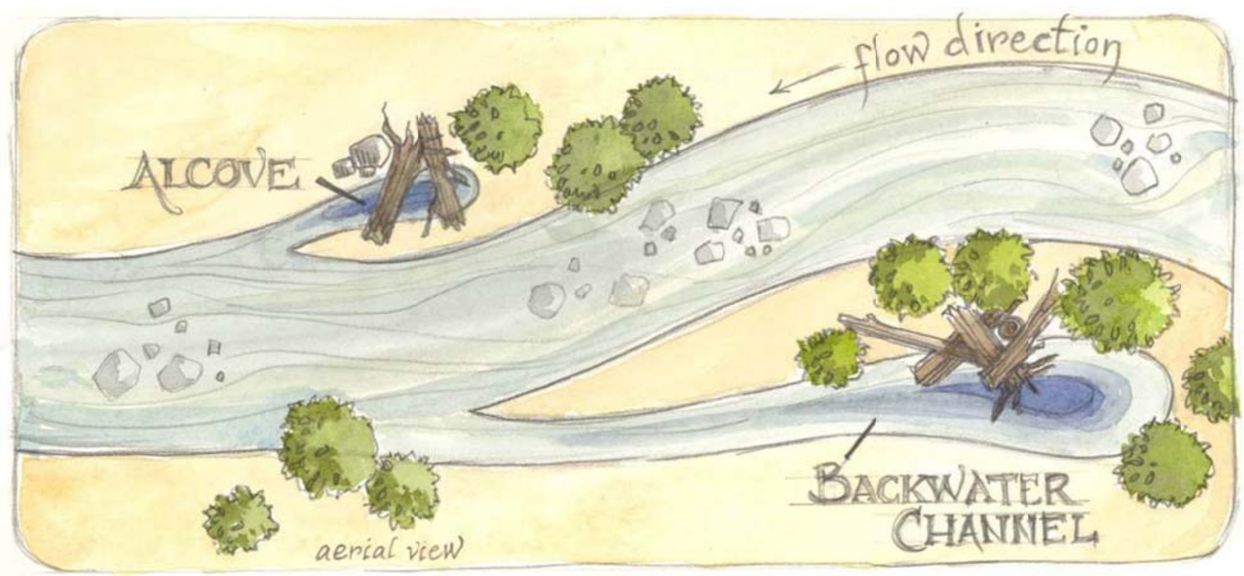

Figure 57. Conceptual depiction of backwater channel and alcove features.

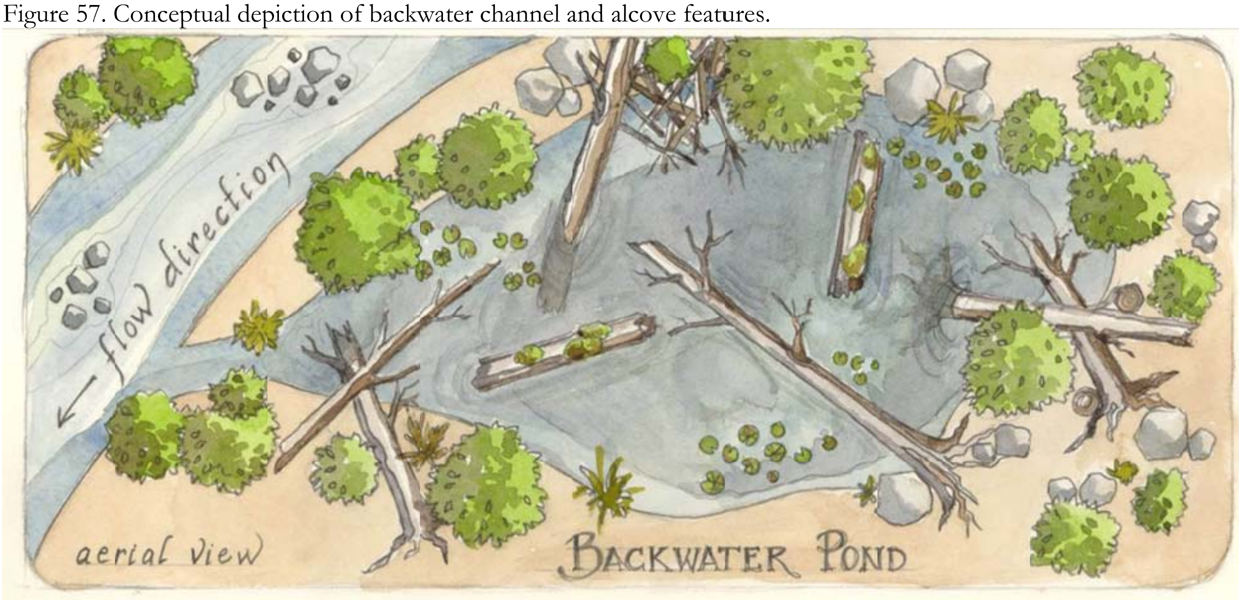

Figure 58. Conceptual depiction of backwater pond feature.

Similar to side channels, the persistence of backwater habitat in alluvial systems will vary depending on the mechanisms by which they are formed and the prevailing sediment, hydraulic and hydrologic regimes. In streams with low sediment supply and regulated hydrology, they may persist for a long time. In streams with moderate to high sediment supply and intact flood hydrology, or highly mobile beds, they may be more transitory, though the specifics of each site may moderate the influence of these factors. In incising streams, the habitat may be lost if the downstream base level is lowered, dropping the hydraulic control for the feature.

In Dry Creek, there are numerous locations where backwater habitat may be considered for habitat enhancement. The primary feasibility considerations include their persistence in the light of potential for nuisance sedimentation, or unanticipated lateral or vertical channel change leaving the habitat stranded during the summer period.

With regard to backwater/alcove habitat, the means by which the enhanced habitat will be measured, monitored and tracked through time is key to the success of these habitats at meeting the goals and objectives for the effort (and thus being characterized as feasible). In some instances, these habitats may be more transitory than mainstem habitats, while in other instances they have a high likelihood of long-term persistence. In many cases where a backwater channel may be abandoned, a new similar feature may be created elsewhere in the same vicinity during the same flood, resulting in an overall net balance of habitat area. The means to account for and accommodate this type of dynamism is a topic of collaborative discussion at present by the action and resource agencies (Wieckowski et al. 2010).

Backwater habitats were also reviewed in the qualitative field assessment completed in June 2010 discussed in Section 5.2.4.1. The habitat in select backwater channels had been compromised following the winter-spring 2010 high flow events. Primary causes included nuisance sedimentation and downstream changes in the main channel which affected the hydraulic control for the backwater habitat. Of the backwater channels reviewed, those whose upstream ends were located a moderate distance from the active channel, and/or with a section of hydraulically rough floodplain between the upstream channel and the habitat were substantially less affected. Nevertheless, some degree of sedimentation in these habitats may be unavoidable, and this issue needs to be considered during design.

Based on the field review and observations of the evolution of constructed backwater channels elsewhere, Table 13 summarizes several key considerations for design of backwater/alcove enhancements. More specific discussion of applicability is included in Section 5.3.

Table 13. Considerations for design of backwater channels on Dry Creek, based on observations of similar habitats on Dry Creek following a high water event, and observations of constructed side channel evolution on other project sites.

Consideration	Relevant Failure Mode
Outlets should not be located in depositional zones (e.g., riffles)	Nuisance sedimentation
Moderate distance from the active channel at the upstream end	Nuisance sedimentation
Hydraulically rough zone between active channel and upstream end	Nuisance sedimentation
A robust control on channel grade should be located downstream of the outlet (e.g., riffle)	Abandonment by loss of hydraulic control.

5.2.5 Miscellaneous Habitat Enhancement Feasibility Considerations

It is anticipated that habitat enhancements will proceed through advancing enhancement 'reaches' through design. Each enhancement reach may comprise several enhancement 'sites' that may be pool-riffle enhancements, side channels, backwater channels/alcoves, or other. Each site may contain many 'features' such as log jams. The intent is for the collection of sites that comprise the reach to function cohesively and holistically to provide a continuity of fish habitat. Miscellaneous features that may be used at the sites scale are discussed below.

5.2.5.1 Large Woody Debris

Large woody debris (LWD) would be used in several applications. Log jams may be used to effectively act as non-mobile objects in desired locations, to prevent migration of the channel, or to initiate a turn in the channel planform (Figure 59). Habitat LWD may be used in instream and off-channel habitats to provide flow diversification, cover and habitat complexity (Figure 60). Floodplain LWD will be used to hydraulically roughen overbank zones to emulate mature riparian forest in key locations, in order to slow overland flows on the floodplain. LWD may also be used in select bank stabilization applications (Figure 61).

Because much of the LWD is likely to be fully submerged though the operational life of the project, ballasting will be required to retain the LWD. Typical ballasting methods include partial burial, cabling to buried deadmen or earth anchors, cabling to boulders, or cabling to existing mature trees.

Figure 59. Conceptual depiction of a log jam.

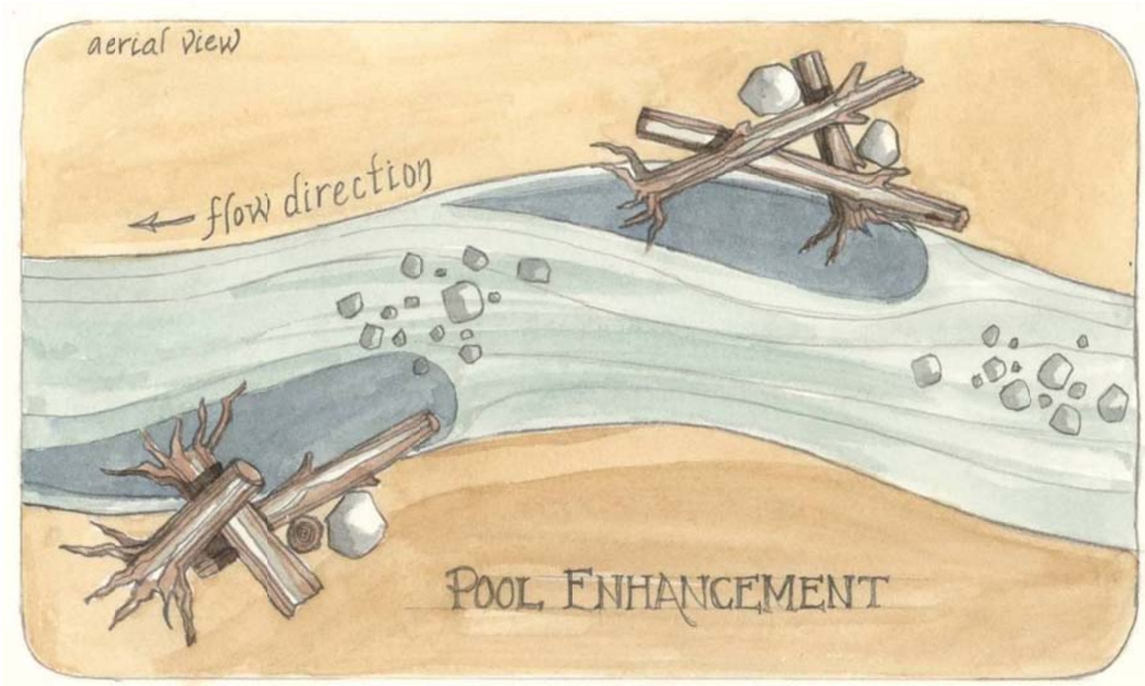

Figure 60. Conceptual depiction of LWD placed for habitat.

Figure 61. Conceptual depiction of bank stabilization utilizing LWD to also provide habitat.

5.2.5.2 Bank Stabilization

Bank stabilization will be required at select locations to establish an outside boundary for adjustments that may result following project completion, or to protect critical infrastructure. Bank stabilization will be tailored to each site. The design team will endeavor to optimize the bank stabilization approach at each location, both to incorporate habitat elements to the extent practicable and to result in the most efficient design at each location.

5.2.5.3 Riparian Habitat Enhancement

Dry Creek has extensive vegetative growth along the channel, much of which is comprised of many non-native weed species. In some areas, overly dense stands of vegetation impair stream function by channelizing the flow of the creek and acting like a levee, which forces energy into the creek bed, and results in pools that are too long, with water that moves too swiftly. Riparian vegetation management will include selective thinning of existing vegetation, removal of invasive weeds, and in some cases, replanting of native vegetation.

5.2.6 General Project Planning Feasibility Considerations

As mentioned previously, lower Dry Creek flows through private property and ultimately the habitat enhancements will occur in locations where the landowners are willing to have the work occur on their property. Additional project planning considerations include USACE coordination and project permitting.

5.2.6.1 Project permitting

To implement the habitat enhancements, permits or authorizations are likely to be required from the following entities:

- USACE - Clean Water Act Section 404
- CDFG – Streambed Alteration Permit
- RWQCB – Water Quality Certification
- Sonoma County – Grading permit

Overarching these permits is the need to comply with and provide documentation regarding potential impacts according to the California Environmental Quality Act.

Additionally, lower Dry Creek is within a FEMA-mapped floodplain (FEMA 2006). The local jurisdiction responsible for managing the floodplain will require documentation regarding the potential impact of the project on the mapped floodplain. Typically, if the potential rise in base flood (100-year return period) water surface elevations is less than 0.01 feet, then a Letter of No-Rise Certification will be filed with the jurisdiction. If more pronounced increases in the base flood elevations are anticipated, documentation of the changes under FEMA Conditional Letter of Map Revision / Letter of Map Revision (CLOMR/LOMR) may be required. Early coordination with the local jurisdiction will be required.

5.2.6.2 Existing USACE-constructed stabilization works

Between 1981 and 1989, USACE constructed several projects to aid in stabilization of Dry Creek (Table 14. Stabilization structures installed by Army Corps of Engineers between 1981 and 1989. Source: Army Corps of Engineers 1991).; Army Corps of Engineers 1991).

It is conceivable that the habitat enhancement efforts may interact with these structures, or may even endeavor to modify these structures. The programmatic logistics associated with potential modifications of these structures are presently unknown. Early coordination with the USACE is advisable.

5.2.6.3 Enhancement work in existing right-of-way corridors

Public right-of-way corridors cross Dry Creek at four bridges (Bord, Yoakim, Lambert and Westside) and one buried pipeline crossing located 1200 feet upstream of the Russian River confluence. Encroachment permits would likely be required to implement enhancement work in these corridors.

Table 14. Stabilization structures installed by Army Corps of Engineers between 1981 and 1989. Source: Army Corps of Engineers 1991).

Feature	Location	Bank	Length
Grouted Riprap Grade Control Sill	10.5 mi. DS of Dam	Channel spanning	
Grouted Riprap Grade Control Sill	10.3 mi. DS of Dam	Channel spanning	
Grouted Riprap Grade Control Sill	10 mi. DS of Dam	Channel spanning	
Rock Riprap Bank Protection	0.8 mi. DS of Dam	Left	600
Rock Riprap Bank Protection	0.9 mi. DS of Dam	Right	750
Rock Riprap Bank Protection	1.4 mi. DS of Dam	Left	200
Rock Riprap Bank Protection	2.1 mi. DS of Dam	Right	480
Rock Riprap Bank Protection	2.2 mi. DS of Dam	Left	450
Rock Riprap Bank Protection	10 mi. DS of Dam	Right	2,000
Rock Riprap Bank Protection	10.3 mi. DS of Dam	Right	200
Board Fence	1.3 mi. DS of Dam	Right	700
Board Fence	5.3 mi. DS of Dam	Right	900
Stone Toe Protection and low rock weir	4 mi. DS of dam	left	130

5.2.7 Construction Feasibility Considerations

The nature of land use and infrastructure constraints along lower Dry Creek present logistical challenges for constructing the enhancements, as discussed below.

5.2.7.1 Access and Staging

The existing transportation corridors in the Dry Creek valley consist of relatively narrow and winding two-lane roads with substantial recreational and farm traffic. Planning of truck routes to enable efficient delivery of the construction materials will be required to ensure an environment that is safe for the public. During periods of significant materials hauling, effective traffic control provisions will be required.

The narrow, incised creek corridor and proximity to vineyard operations limit available access corridors and staging areas. Proposed alignments of ingress/egress, access corridors and staging areas will need to be reviewed by the Agency and the landowners to verify consistency with vineyard operations. Dust control during construction will be an issue requiring particular attention, due to the damage that excessive dust may cause on the high-value grape crops in the valley. Once the stream is diverted (see below) and access into the creek bed is established, the creek bed itself may be utilized in part as an additional access corridor.

5.2.7.2 Timing and Duration of Construction

The in-water work period for Dry Creek is typically June 15 to October 15 (designed to minimize impacts on adult anadromous salmonids and coincide with low flow conditions). If necessary, this period could be potentially extended for two weeks on either end, dependent on year and circumstances of the work. In order to maximize the available construction window within the in-water work period, mobilization and site preparation efforts may commence around or before June 1. With planning of enhancements at each location, it will be necessary to identify whether there are periods between May and October during which construction work would adversely impact vineyard operations, such as the autumn crush period. If necessary, the available work window will need to be further constrained to accommodate vineyard operations.

5.2.7.3 Stream Diversion and Dewatering

The steady state operational discharge maintained by the Water Agency during the allowable in-water work period is typically 105 cfs, but may be as high as 175 cfs. In order to satisfactorily construct the enhancements and prevent excessive turbidity to the active flowing stream, it will be necessary to divert the stream around selected active work zones and/or dewater the active work zones while the construction work is completed.

Discharge of 105 (or 175) cfs is a substantial volume of water to divert in a stream with the physical characteristics such as Dry Creek, including relatively narrow and deeply incised stream corridor, high value adjacent land use, and in some cases a primary traffic corridor bisecting the work zone. Stream diversion options include gravity-driven and pumped systems. Due to the high transmissivity of the alluvium that comprises the substrate materials in Dry Creek, a gravity-driven system would require containing the flow in either pipes or a lined open bypass channel, or also dewatering the through gravel flow from each active work zone. Either piped or open-channel gravity systems require space within the channel corridor to convey the bypass flows. To deploy a gravity system may require sustained work in the active flowing stream, which may be unacceptable within the regulatory framework. Sensitivity to these considerations will need to be investigated further with applicable regulatory agencies prior to verifying gravity diversion as a feasible option.

Pumped diversion systems provide the benefits of moving the water out of the creek corridor, and maximize the available work space in the corridor, which will facilitate efficient and competent completion of the work, including concurrent completion of work at multiple sites within a reach. Due to the logistics of installing a pumped system to convey 105 (or 175) cfs, it may be most practical to bypass an entire project reach with a single system. Contrasted to the benefits described above, pumped diversion systems capable of diverting 105 cfs to 175 cfs will be very costly.

With a pumped diversion system, electric pumps may be more economical in terms of energy costs and rental fees than diesel pumps, and may provide a quieter environment while the work is being constructed. To power an electrical system, however, a temporary extension of the existing electrical system in the area will be required. The cost benefit tradeoffs between gravity- and pumped diversion technology, and between electrical and diesel pumps, can be evaluated as each project site is advanced towards design and implementation.

5.2.7.4 Fish Screening and Rescue

The diversion system will require screening to prevent aquatic life from entering the system. It is anticipated that a large perimeter screen will enclose the pump intake zone to allow approach water velocities to be within criteria established by the National Marine Fisheries Service. Screen mesh will meet established criteria.

Once the stream diversion commences, it will be necessary to relocate aquatic life from the project reach to adjacent reaches, in particular ESA-listed salmonids. Fish relocation will require a significant effort, accomplished through a combination of methods using nets and electrofishing techniques.

5.2.7.5 Working Hours

Given the high daily expense of the diversion systems, the Agency and landowners may wish to consider extended working hours to maximize the daily rate of production, to minimize the overall duration of construction and project cost. If feasible, expanded working hours that allow two shifts per day during the extended summer daylight hours will reduce overall project cost and impact.

5.3 Review of Habitat Enhancement Feasibility in Upper, Middle and Lower Segments of Lower Dry Creek

As highlighted in Section 5.2.2, because there is variability in terms of dominant processes and dynamics at different locations along the creek, differing enhancement philosophies should be considered in different stream segments. Lower Dry Creek was delineated into three broad feasibility assessment segments based on differences in the dominant hydrologic, sedimentary, and hydraulic boundary conditions. These three primary segments include 1) Upper - upstream of Pena Creek, 2) Middle - Pena Creek to the grade control sills, and 3) Lower - grade control sills to the confluence. Study sub-reaches 1 – 15 are grouped into these primary stream segments as shown in Table 8 and discussed below. The following sections discuss feasibility perspectives unique to each stream segment.

5.3.1 Upper Segment – River Miles 11 to 13.7

The upper segment extends from Bord Bridge (RM 13.7) to the Pena Creek confluence (RM 11). In this segment, sediment supply is the most limited and the hydrologic regime is the most regulated of the three stream segments. This segment contains study sub-reaches 12 to 15.
Figure 65 to Figure 62 demonstrate typical inundation patterns in these sub-reaches, while Appendix A contains detailed habitat and geomorphic inventory summaries for each subreach.

It is anticipated that habitat enhancements will proceed through advancing enhancement 'reaches' through design. Each enhancement reach may comprise several enhancement 'sites' that may be pool-riffle enhancements, side channels, backwater channels/alcoves, or other. Each site may contain many 'features' such as log jams. The intent is for the collection of sites that comprise the reach to function cohesively and holistically to provide a continuity of fish habitat.

While opportunities to develop off-channel habitat in Dry Creek are limited to specific locations, opportunities to enhance instream habitat are numerous throughout Dry Creek. Because the intent is to develop cohesive habitat reaches that contain both instream and off-channel habitats, the likely approach to identifying habitat enhancement reaches will be to first identify off-channel opportunities, and then locate instream enhancements to correspond. For this reason, and to simplify the figures, areas of interest for off-channel enhancements (labeled as 'OC-1', 'OC-2', etc.) are shown in Figure 62 to
Figure 65, while specific locations for instream enhancements are not shown. It should be noted that much of sub-reach 15 flows through public land administered by the Army Corps of Engineers. Past discussions with USACE have indicated that there may be complexities associated with authorizing habitat enhancement in this reach.

Based on the geologic and geomorphic reconnaissance completed in 2009 (Section 4), it was suspected that a few of the key riffles in sub-reaches 13 and 14 may be linked to shallow bedrock. To assess whether this was indeed the case, and whether this would provide any constraints on implementation of enhancements, a reconnaissance-level subsurface exploration was completed in fall 2010. The exploration consisted of test pit excavation and seismic refraction testing at selected locations. Based on the results of the exploration, it was concluded that the key riffles were not controlled by shallow bedrock. A draft summary of the subsurface exploration is located in Appendix C.

Sub-reaches 13 to 15 contain numerous opportunities for habitat enhancement, while opportunities are lacking in sub-reach 12. These opportunities are distributed over approximately 1.6 miles of stream. Because of the limited upstream sediment supply and regulated hydrology, habitat enhancements in this segment can be characterized as having low risk of failure relative to the other segments. In the Upper segment, late-successional habitat characteristics may be constructed with confidence that their quality will not be substantially altered by nuisance sedimentation and other detractors. While the limited sediment supply has its own connotations for instream habitat quality, this may be offset through focused, tactical sediment augmentation through construction of riffles (subject to the limitations described in Section 5.2.3) to break up the long habitat units that are present in the segment (Appendix A). In contrast, because fluvial processes are most constrained in this segment, an enhancement approach which relies on Dry Creek's processes to create quality habitat is unlikely to be successful in this segment without substantial periodic intervention.

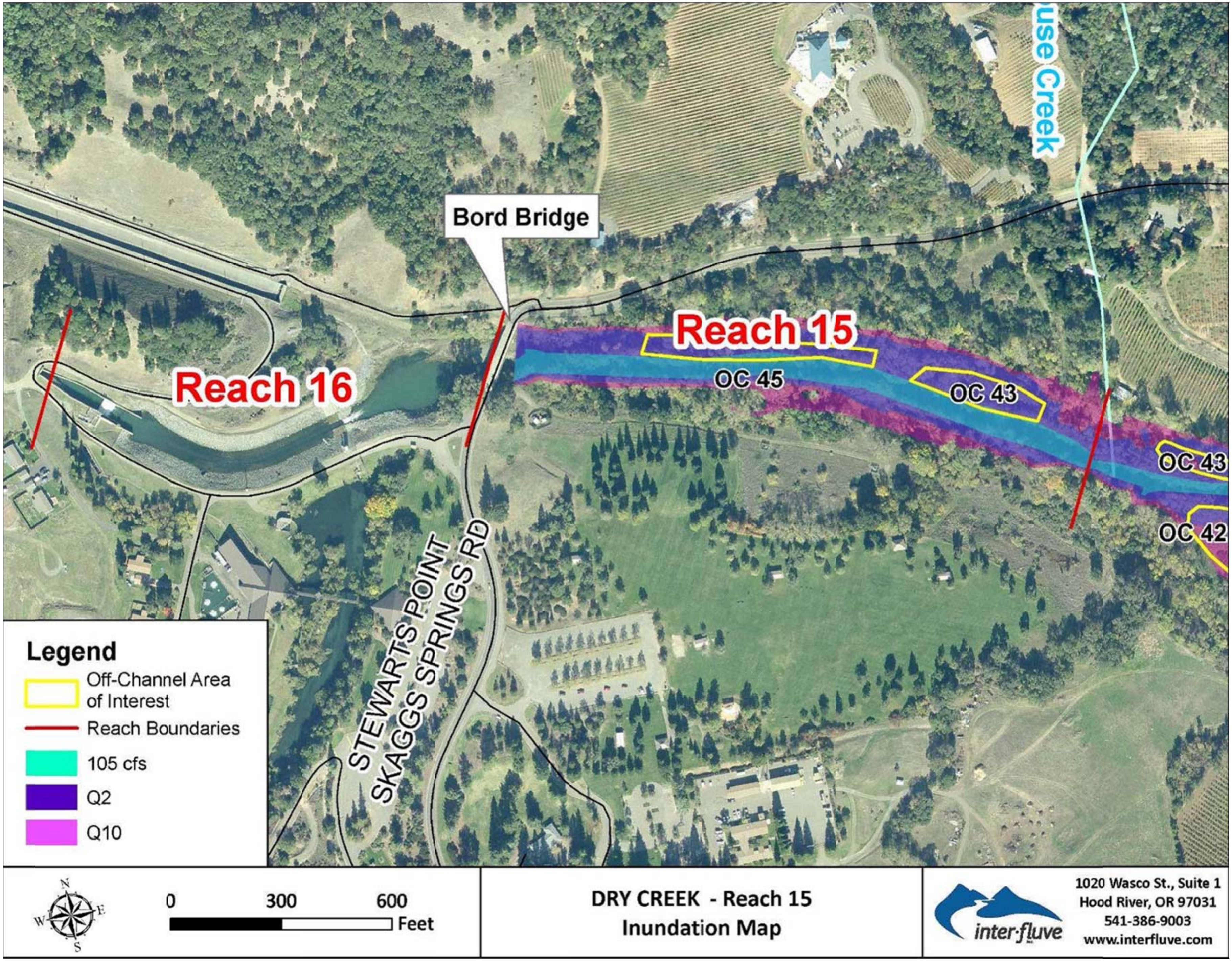

Figure 62. Sub-reach 15 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

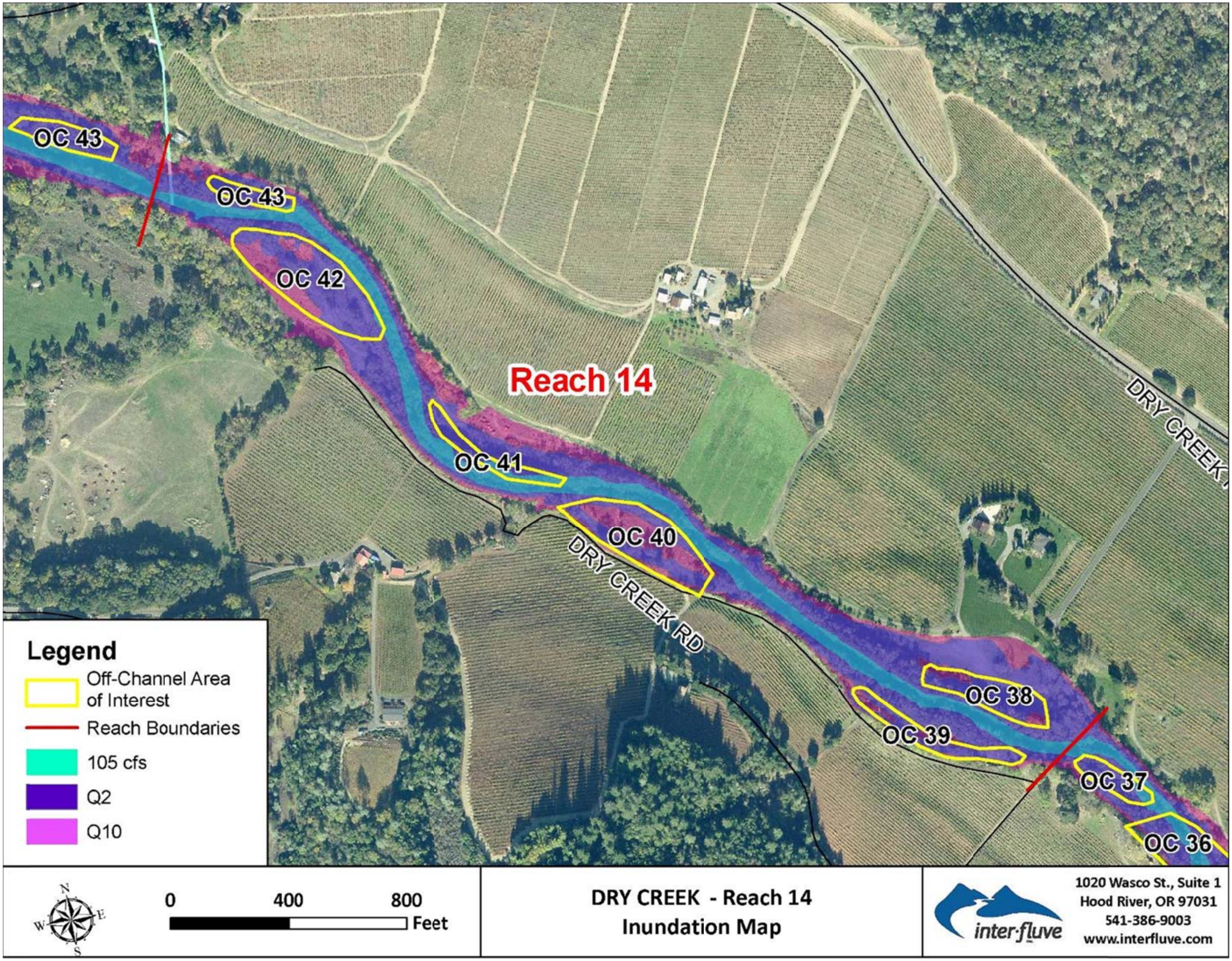

Figure 63. Sub-reach 14 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

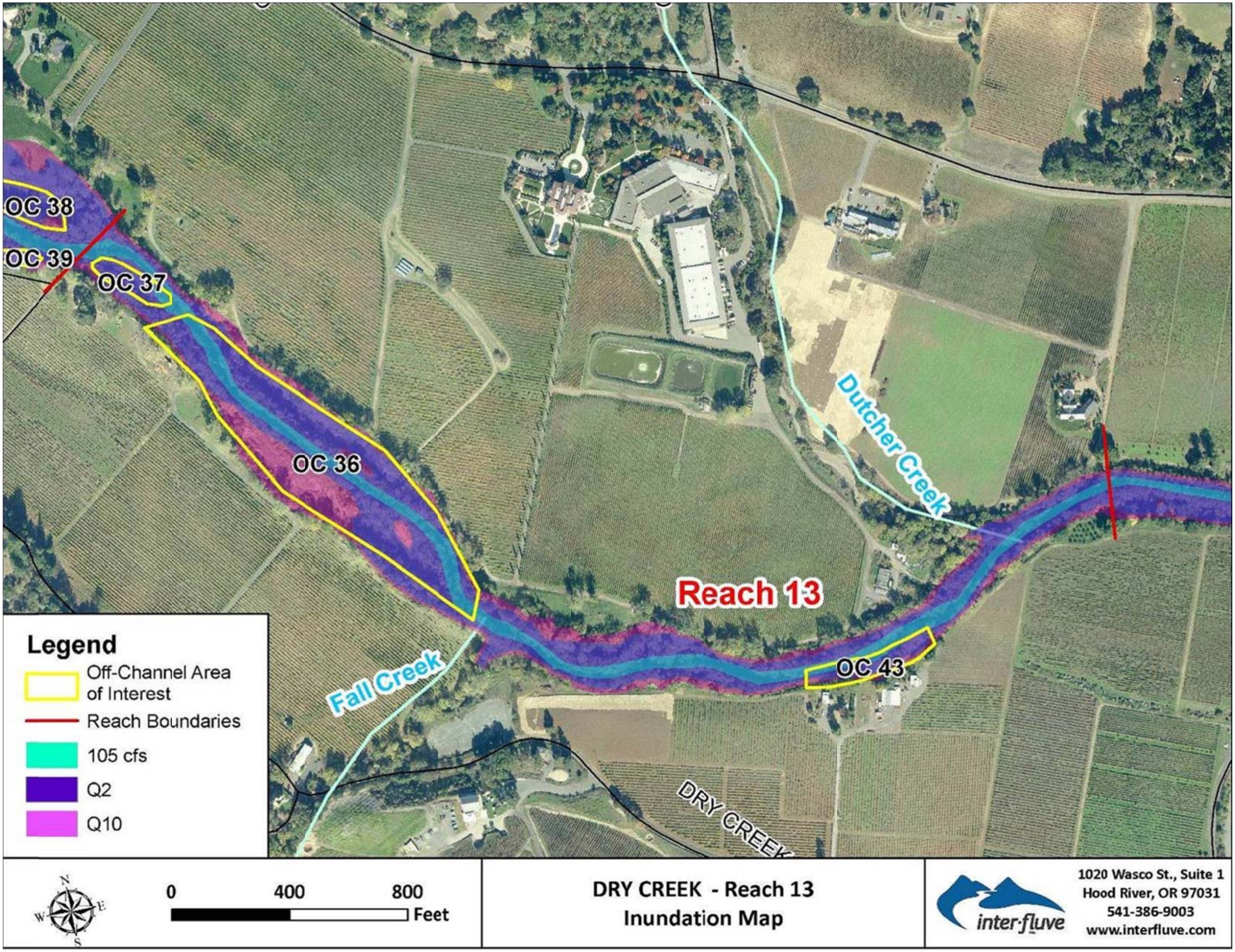

Figure 64. Sub-reach 13 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

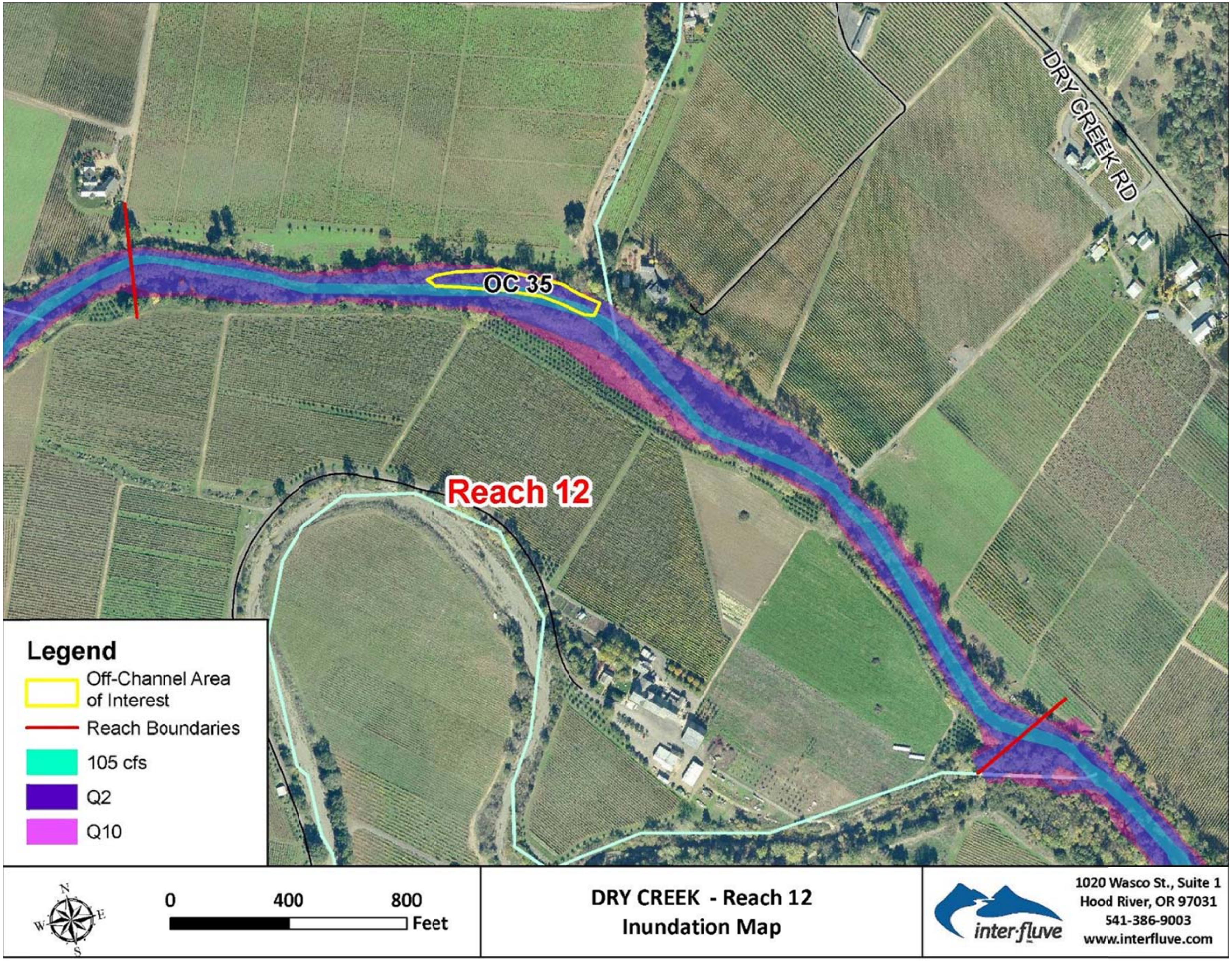

Figure 65. Sub-reach 12 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

5.3.2 Middle Segment – River Miles 3 to 11

The middle segment extends from the Pena Creek confluence (RM 11) to a location just downstream of the lowest grade control sill (RM 3). In this segment, sediment supplied by the unregulated watershed downstream of WSD begins to compensate for the sediment deficit immediately below the dam, in particular by Pena, Grape and Crane Creeks. These unregulated tributary watersheds also produce moderate rainfall runoff events. This segment contains study sub-reaches 4 to 11. Figure 66 to Figure 73 demonstrate typical inundation patterns in these sub-reaches, while Appendix A contains detailed habitat and geomorphic inventory summaries for each sub-reach.

As with the upper segment, it is anticipated that habitat enhancements will proceed through advancing enhancement 'reaches' through design. Each enhancement reach may comprise several enhancement 'sites' that may be pool-riffle enhancements, side channels, backwater channels/alcoves, or other. Each site may contain many 'features' such as log jams.

Similar to the upper segment, while opportunities to develop off-channel habitat in Dry Creek are limited to specific locations, opportunities to enhance instream habitat are numerous throughout the segment. Because the intent is to develop cohesive habitat reaches that contain both instream and off-channel habitats, the likely approach to identifying habitat enhancement reaches will be to first identify off-channel opportunities, and then locate instream enhancements to correspond. For this reason, and to simplify the figures, areas of interest for off-channel enhancements (labeled as 'OC-1', 'OC-2', etc.) are shown in Figure 66 to Figure 73, while specific locations for instream enhancements are not shown. It should be noted that much of sub-reach 7 flows through the 'demonstration reach' where the landowners have come together with the Water Agency to advance planning of a series of pilot projects to demonstrate the enhancement concepts.

Sub-reaches 4, 5, 8 and 10 contain numerous opportunities for habitat enhancement, while opportunities are moderate in sub-reaches 7 and 9, and lacking in sub-reaches 6 and 11. These opportunities are distributed over approximately 5 miles of stream. Relative to the Upper Segment, there is greater risk of constructed late-successional habitats in the Middle Segment being compromised, primarily due to nuisance sedimentation and the potential for downstream bed degradation to affect the water levels in the habitat. These risks can be mitigated through appropriate site selection and adherence to the other guidelines discussed in Section 5.2.4. However, it is likely that at some point the constructed off-channel habitats may shift in character, potentially being replaced by new habitat. As stated previously, it is key to understand the range of variability that may be embraced after the habitat is constructed, sensitivity to dynamics in the composition of habitat, and the timeframe over which the habitat function must be provided in terms of quantifying habitat enhancement.

Conversely, even though Dry Creek regains some of its unregulated attributes with the successive contributions of tributary watersheds, the processes are still likely too constrained to effect meaningful habitat development without substantial and ongoing intervention. However, there are several large off-channel opportunities (e.g., OC 24, 31, 32 and 34) in this segment which may lend themselves to a more dynamic, heavily process-focused approach, or a combined approach. In addition, the series of opportunities that bracket the grade control sills (OC 11 – OC 18) provide substantial lateral space, but also reasonable channel grade drop to work with in developing a comprehensive project. The intricacies of modifying or removing the grade control sills need to be understood before advancing too far with enhancement concepts at these sites. At a minimum, any retrofit through sub reach 4 would need to provide a similar level of service as the existing sills in terms of grade control for the upstream reach. This could likely occur by spreading the grade taken up by the three structures over a more uniformly graded pool riffle reach, subject to the discussion in Section 5.2.3.1. As with any approach that embraces dynamism of processes and habitat, it will be necessary to have a clear understanding of how that will be addressed in the monitoring and evaluation of the success of the enhancements.

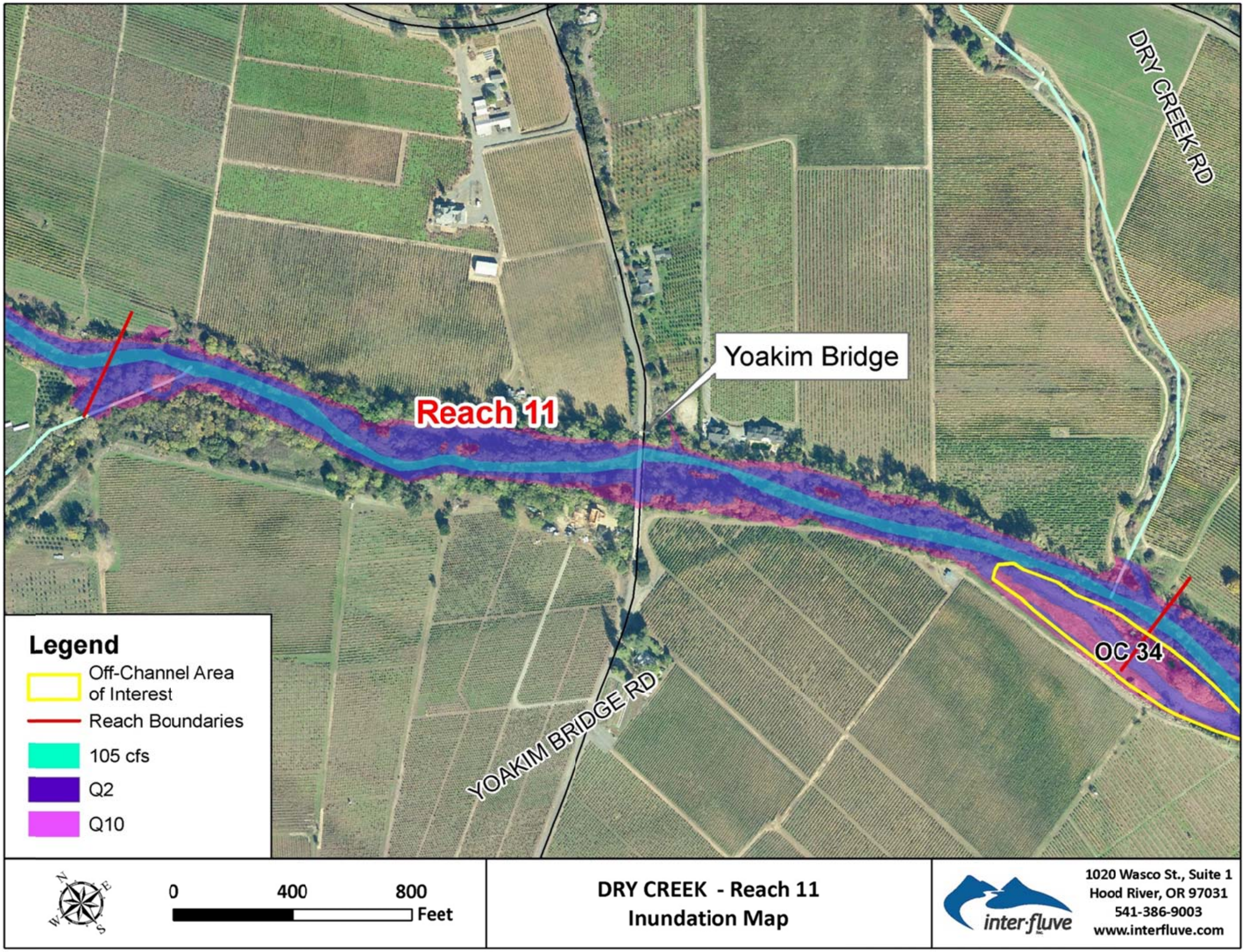

Figure 66. Sub-reach 11 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement

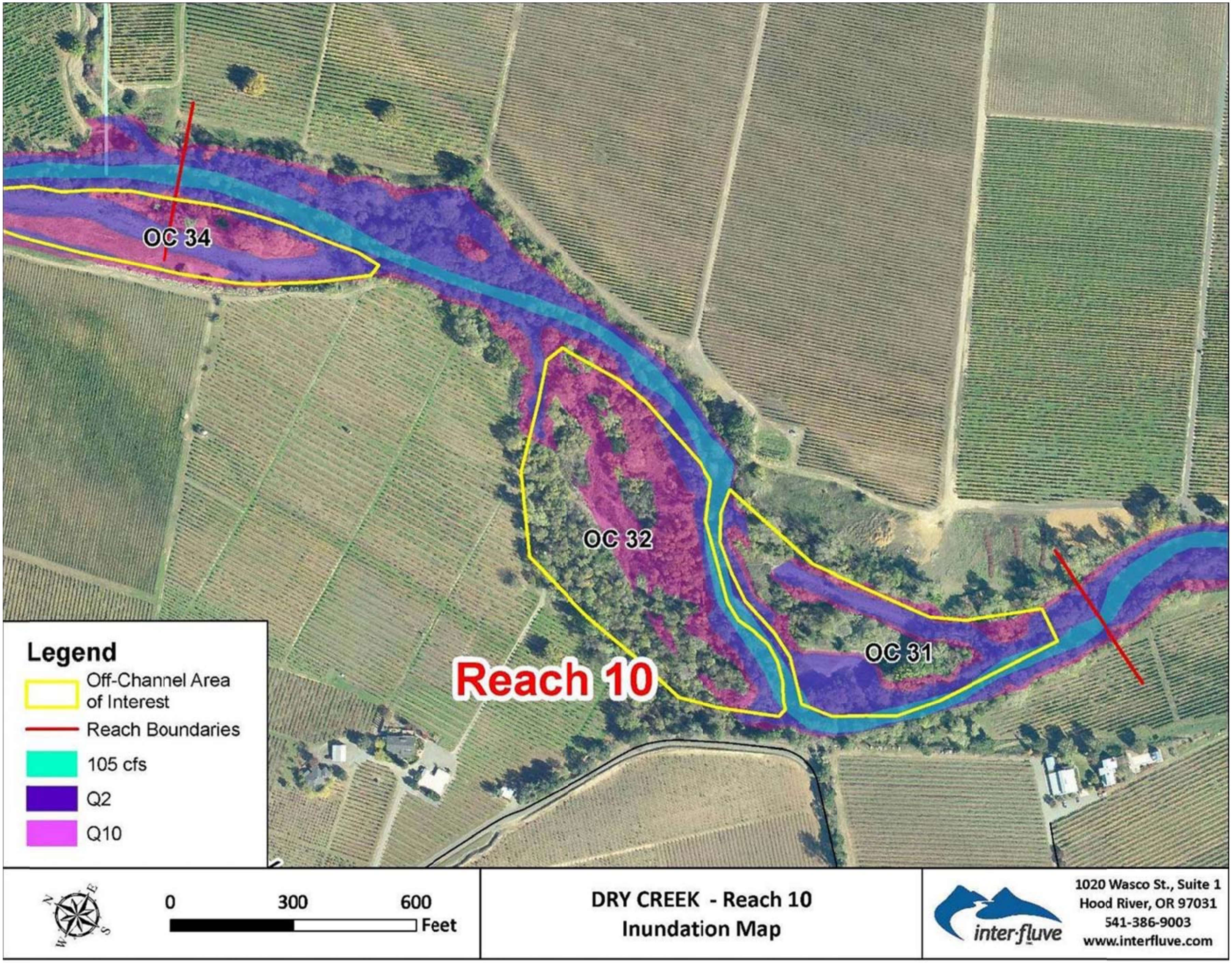

Figure 67. Sub-reach 10 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement

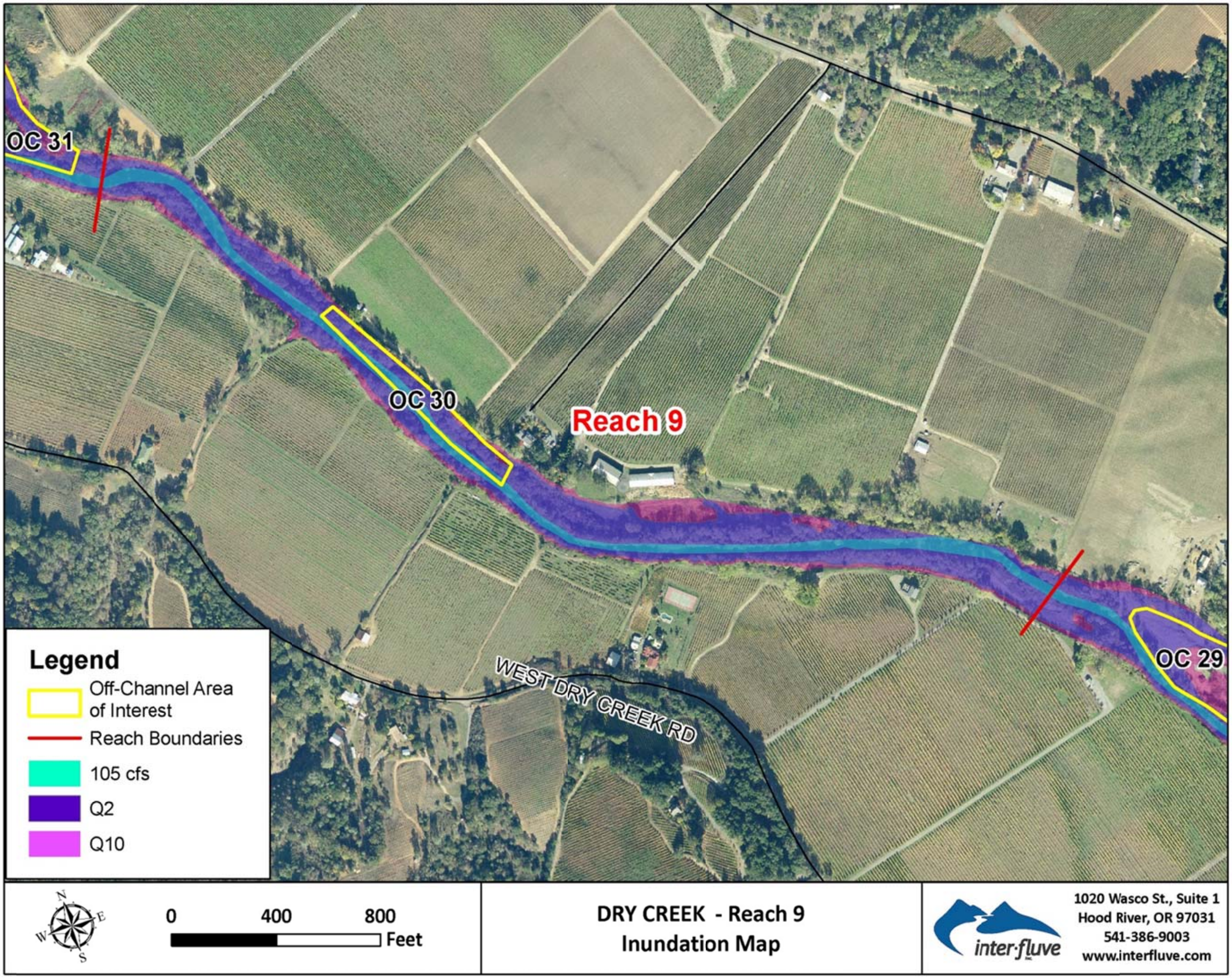

Figure 68. Sub-reach 9 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

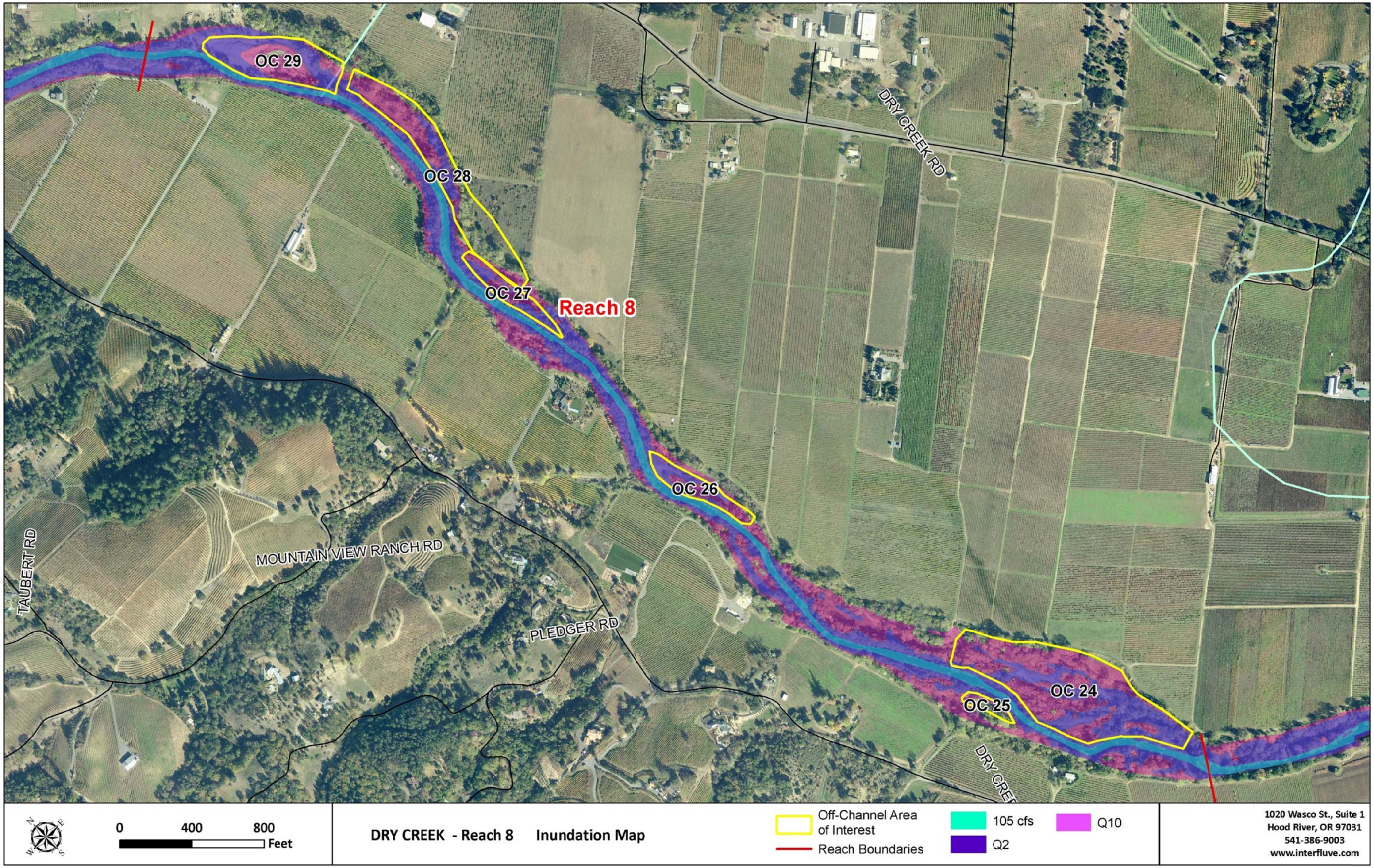

Figure 69. Sub-reach 8 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

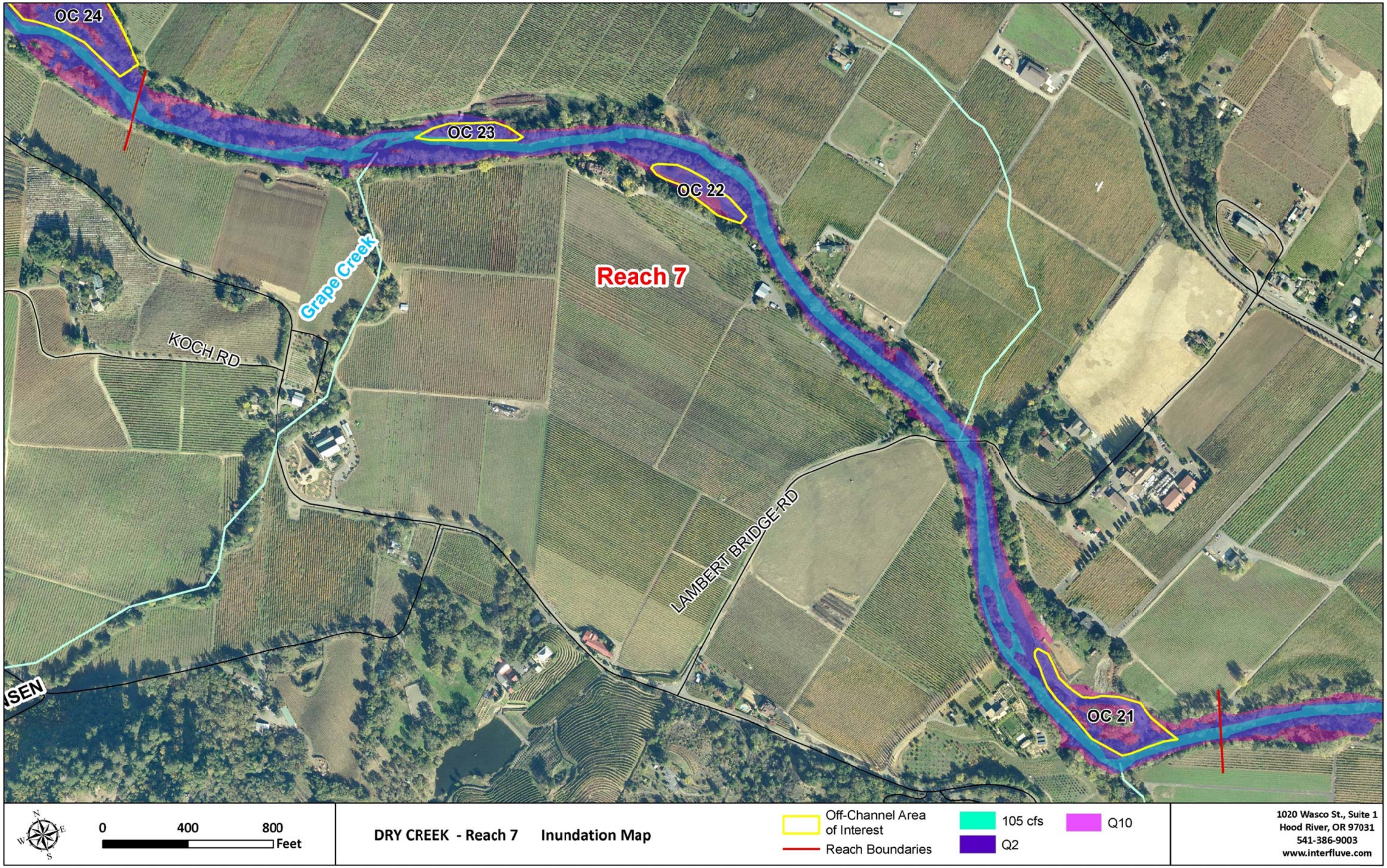

Figure 70. Sub-reach 7 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement

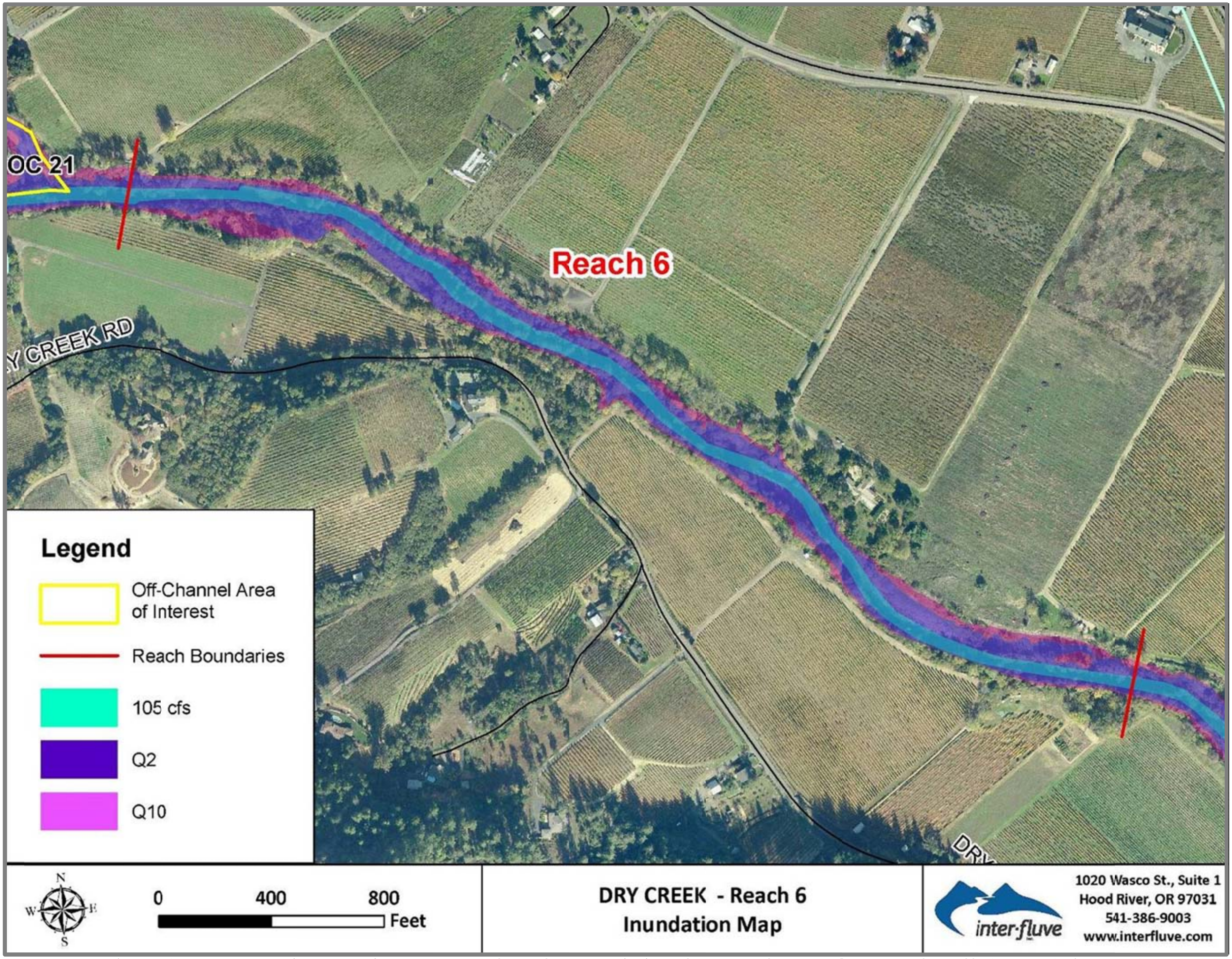

Figure 71. Sub-reach 6 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

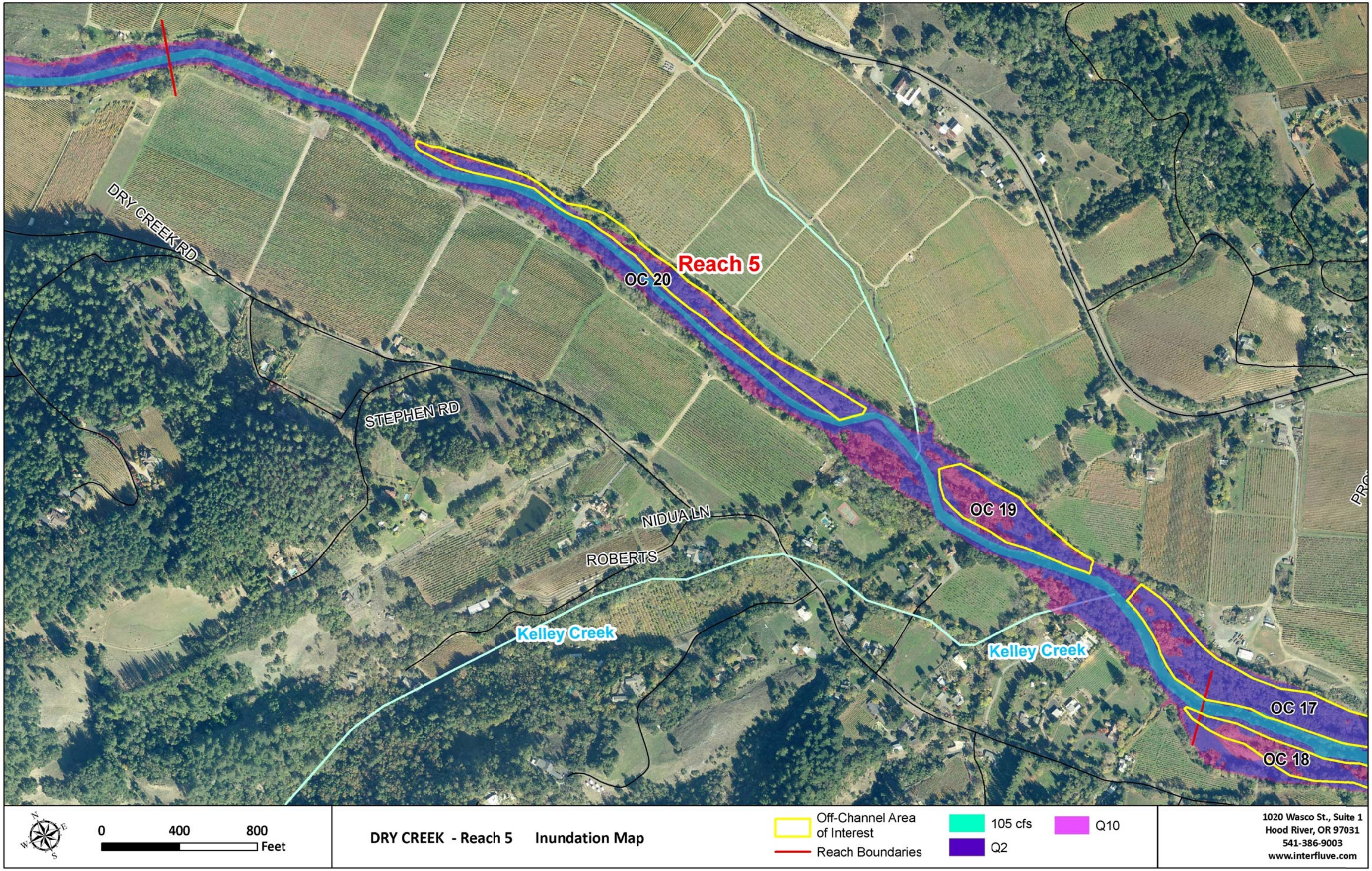

Figure 72. Sub-reach 5 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement

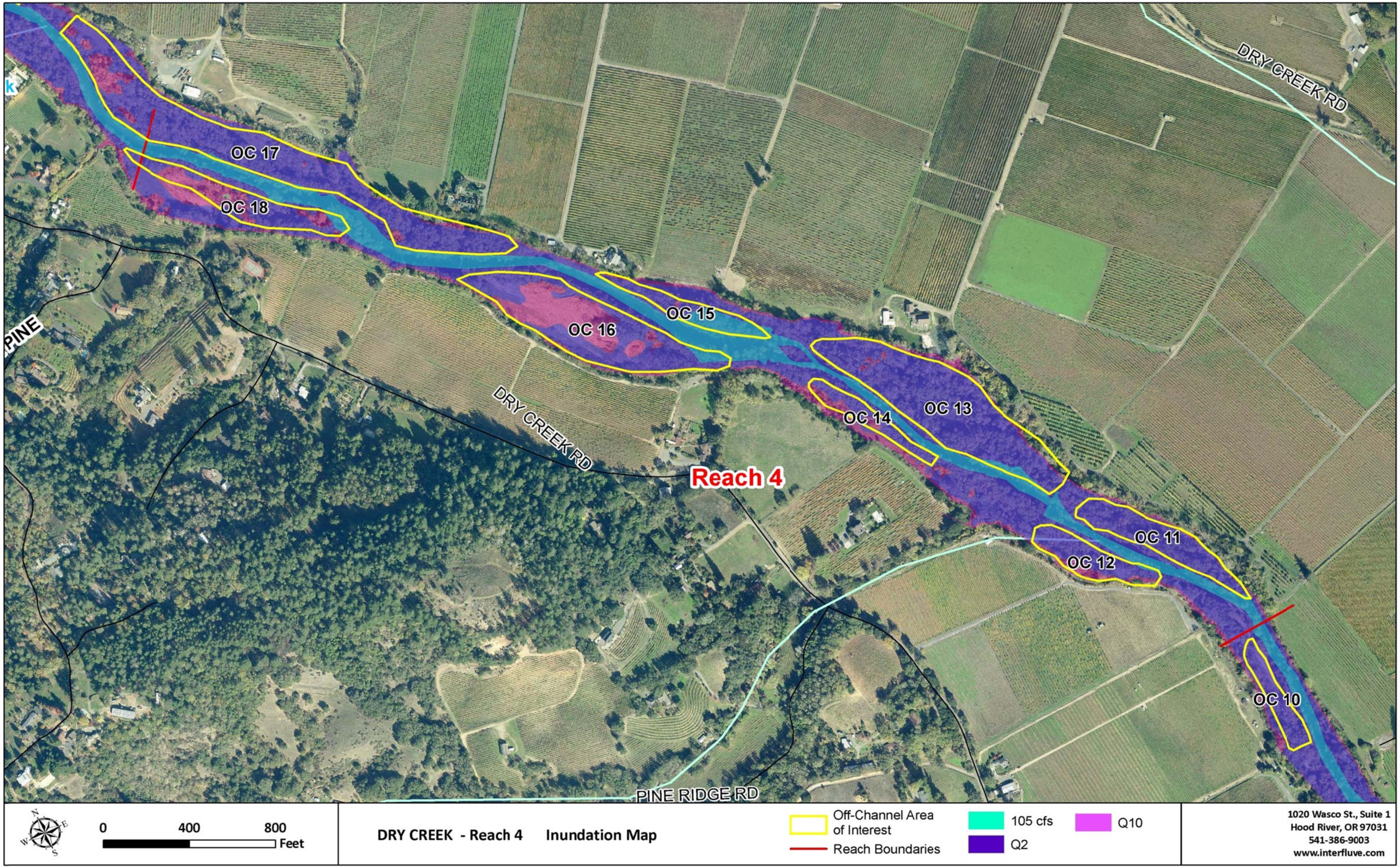

Figure 73. Sub-reach 4 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement

5.3.3 Lower Segment – River Mile 0 to 3

The Lower Segment extends from just below the downstream grade control sill (RM 3.0) to the confluence with the Russian River (RM 0). In this segment, Dry Creek continues to gain sediment supplied by the unregulated tributaries downstream of WSD. In addition, this segment is influenced by backwater from the Russian River during high flow events. These combined effects act to make this segment prone to deposition and make it the most alluvial segment in lower Dry Creek. This segment contains study sub-reaches 1 to 3. Figure 76 to Figure 74 demonstrate typical inundation patterns in these sub-reaches, while Appendix A contains detailed habitat and geomorphic inventory summaries for each sub-reach.

As with the other segments, it is anticipated that habitat enhancements will proceed through advancing enhancement 'reaches' through design. Each enhancement reach may comprise several enhancement 'sites' that may be pool-riffle enhancements, side channels, backwater channels/alcoves, or other. Each site may contain many 'features' such as log jams.

Similar to the other segments, the likely approach to identifying habitat enhancement reaches will be to first identify off-channel opportunities, and then locate instream enhancements to correspond. For this reason, and to simplify the figures, areas of interest for off-channel enhancements (labeled as 'OC-1', 'OC-2', etc.) are shown in Figure 74 to Figure 76, while specific locations for instream enhancements are not shown.

Sub-reaches 1-3 contain numerous opportunities for habitat enhancement. These opportunities are distributed over 2.1 miles of stream. Relative to the other segments, there is high risk of constructed late-successional habitats in this segment becoming compromised through sedimentation due to the backwater influence of the Russian River. Conversely, an enhancement approach that relies on a modified version of a fully process-driven approach likely provides the best option in this segment.

An analog of the modified fully process-driven approach is available in sub-reach 3. As described in Section 4.6.2, the 2,000 foot long area upstream of Westside Bridge contains the best existing rearing habitat and greatest concentration of off-channel habitats. The location is at the upper end of the backwater influence of the Russian River, and is in a depositional zone. It is likely that this concentration of channels has resulted from the interaction of depositional sedimentary processes and vegetative colonization, as opposed to erosive and scouring processes associated with an incising, migrating channel.

The essential components of this example provide the likely best approach to habitat enhancement in the Lower Segment. This would include essentially excavating the off-channel enhancement areas down to elevations in close proximity to the creek bed, and allowing existing alluvial and vegetative processes create habitat complexity over time. With this type of approach, it would be advised, however, to incorporate features such as log jams to help guide the channel planform development. Though, as with any approach that embraces dynamism of processes and habitat, it will be necessary to have a clear understanding of how that will be addressed in the monitoring and evaluation of the success of the enhancements.

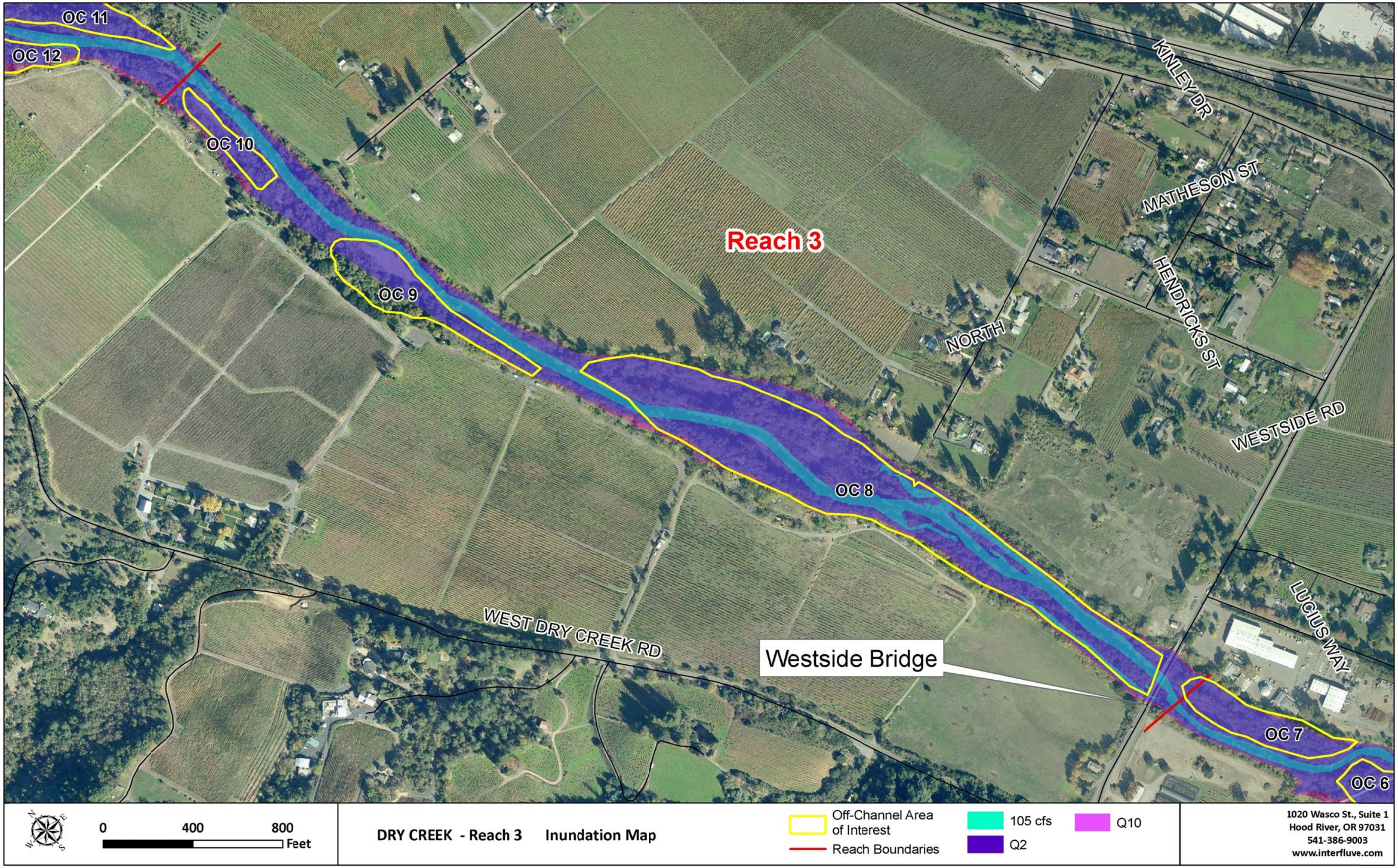

Figure 74. Sub-reach 3 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement

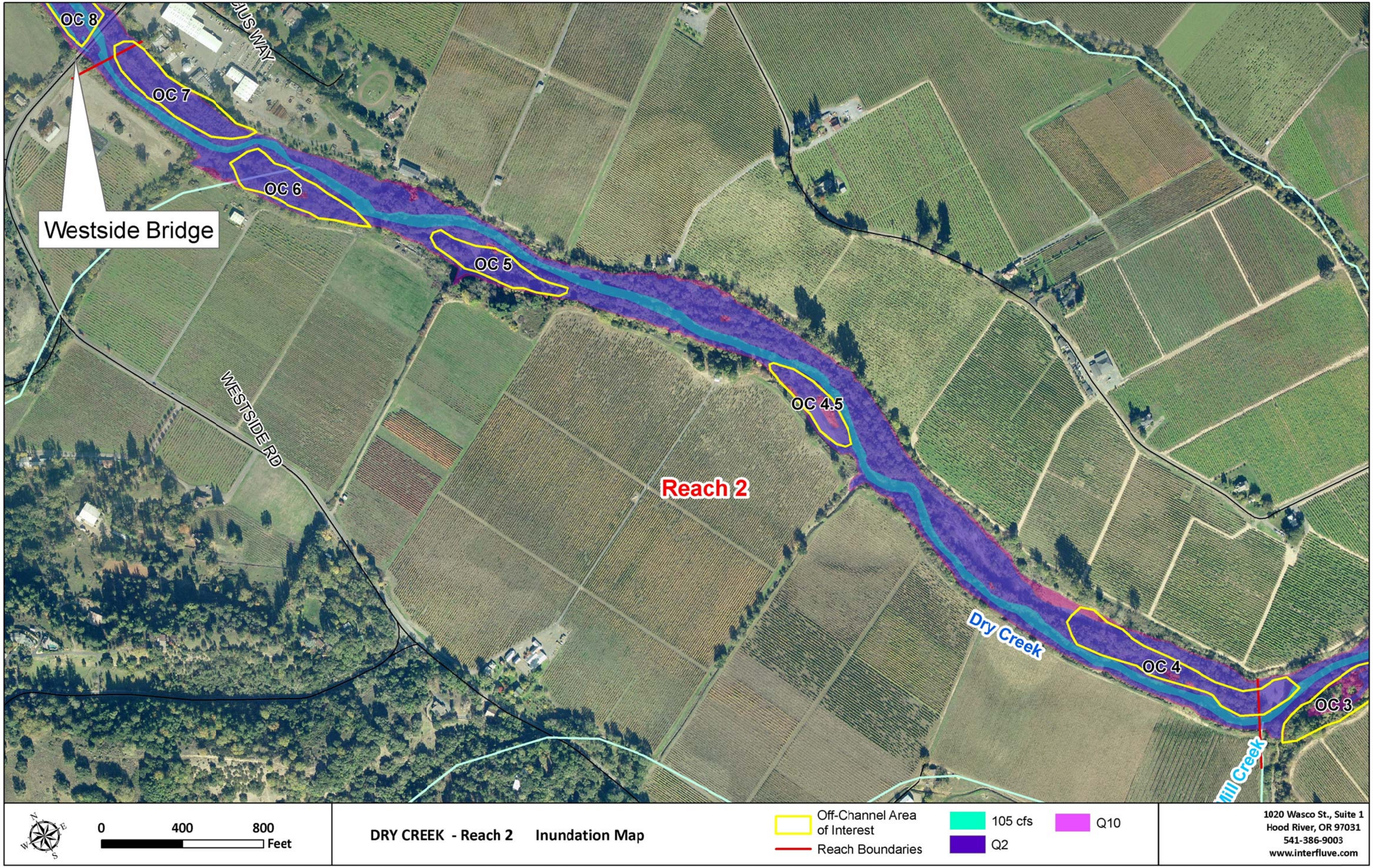

Figure 75. Sub-reach 2 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

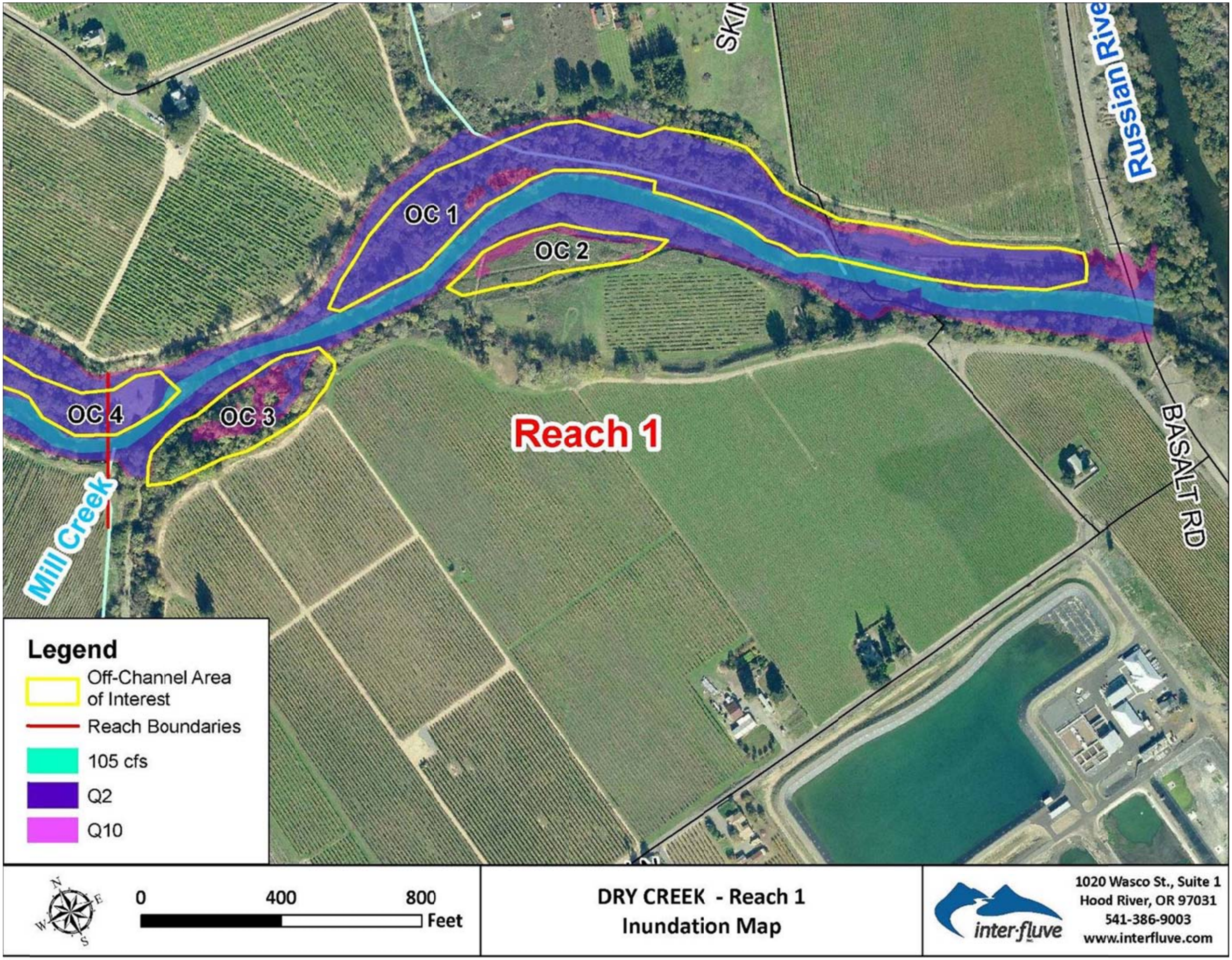

Figure 76. Sub-reach 1 map including inundation extents for 3 flows, and identification of areas of interest for off-channel habitat enhancement.

6 CONCLUSIONS

The following are the primary conclusions resulting from the study:

- Dry Creek has been profoundly affected by 150 years of settlement and management.
- The flood flow hydrology of Dry Creek has been substantially reduced from the pre-dam, unregulated area. Despite this, Dry Creek is efficient at transporting the bed sediment that is supplied to the study reach by unregulated tributaries below WSD. This is due to the characteristics of the channel corridor that have developed due to historical impacts, regulated hydrology, and vegetation characteristics.
- The Dry Creek segment upstream of Pena Creek (RM 11 to 13.9) exhibits the strongest effects of WSD regulation, in terms of limited sediment supply and altered hydrologic regime. Conversely, the Dry Creek segment downstream of the check dams (RM 0 to 3) exhibits the most alluvial characteristics, in large part due to the influence of the Russian River during large floods. Conditions are more variable and site specific in the middle segment (RM 3 to 11).
- Existing fish habitat in Dry Creek is deficient in terms of riffle frequency and size, and pool velocity and quality. This can be directly linked to the operation of WSD.
- It is feasible to enhance fish habitat in Dry Creek to benefit juvenile life stages of coho salmon and steelhead trout.
- The ability of fish habitat enhancement efforts to meet the targets spelled out in the RRBO will be influenced by the scoring methods developed to evaluate project success.
- Both instream and off-channel habitat enhancement can be considered.
- Off-channel habitats are likely best able to meet specific juvenile habitat preference criteria contained in the RRBO.
- Instream habitats can be improved, but are unlikely to meet habitat preference criteria contained in the RRBO if the criteria are narrowly interpreted.
- Because the dominant physical processes vary over the length of lower Dry Creek, the viable approaches to enhance fish habitat will also vary at each location. These approaches can be generally grouped as follows:
    - Above Pena Creek (RM 11 to 13.7)– Direct development of complex habitat is the most viable approach
    - Below the check dams (RM 0 to 3) – Direct development of complex habitat will have a high degree of risk. Instead, a process-based approach which embraces channel dynamics and is reliant on the dominant processes to create and sustain habitat is likely the best approach.
    - Between the check dams and Pena Creek – Conditions are more variable than the other two reaches, and the most appropriate approach at each location will be dictated by site characteristics, such as inundation patterns, relative confinement within the channel corridor, and planform geometry.
- Numerous fish habitat enhancement opportunities were identified. On the basis of adjacent stream length, these off-channel and mainstem opportunities are distributed over 1.6, 2.1, and 5

miles for the above Pena Creek, below the check dams, and middle channel segments. It should be noted that the length of enhancement that can be credited based on the identified opportunities will depending on the pending development of habitat benefit scoring methodology.

7 NEXT STEPS

7.1 CONCEPT DESIGN

Following the completion of the feasibility assessment phase, concept designs will be developed for fish habitat enhancement sites and reaches. The framework that will guide the development of concept designs will emerge from the analyses and approaches described in the above sections, and will incorporate feedback from action agencies, NMFS and CDFG. Concept designs are scheduled to be completed in mid-Summer 2011.

7.2 PROJECT RANKING & SELECTION

Following development of the concept designs, the enhancement opportunities will be ranked according to criteria developed collaboratively by the Action Agencies, NMFS and CDFG. A preliminary discussion of enhancement opportunity ranking was convened at the October 2010 adaptive management workshop (Wieckowski et al. 2010). These criteria will be further refined and a scoring method will be developed to complete the ranking. After the enhancement opportunities have been ranking, an enhancement site selection process will be completed by the stakeholders mentioned above. See Figure 77 for a general representation of the ranking and selection process.

The general ranking approach will be to first score each site on the basis of habitat enhancement potential. Factors which are considered include the proximity of a project site to other habitats (ability of linking up high quality habitats, for fish movement, ability to find refuge from high flow events), distance from WSD, proximity to tributary inputs, and the potential for off-channel habitat development. Subsequently, the opportunities will be scored in terms of the overall geomorphic risk associated with the habitat remaining viable of the project horizon. Scores based on habitat and geomorphic considerations will comprise the site ranking.

Once the opportunities have been ranked, socio-economic feasibility questions will be taken into account in the project selection phase. These include, such as cost, land ownership, and the overall distribution of implemented and future projects along lower Dry Creek.

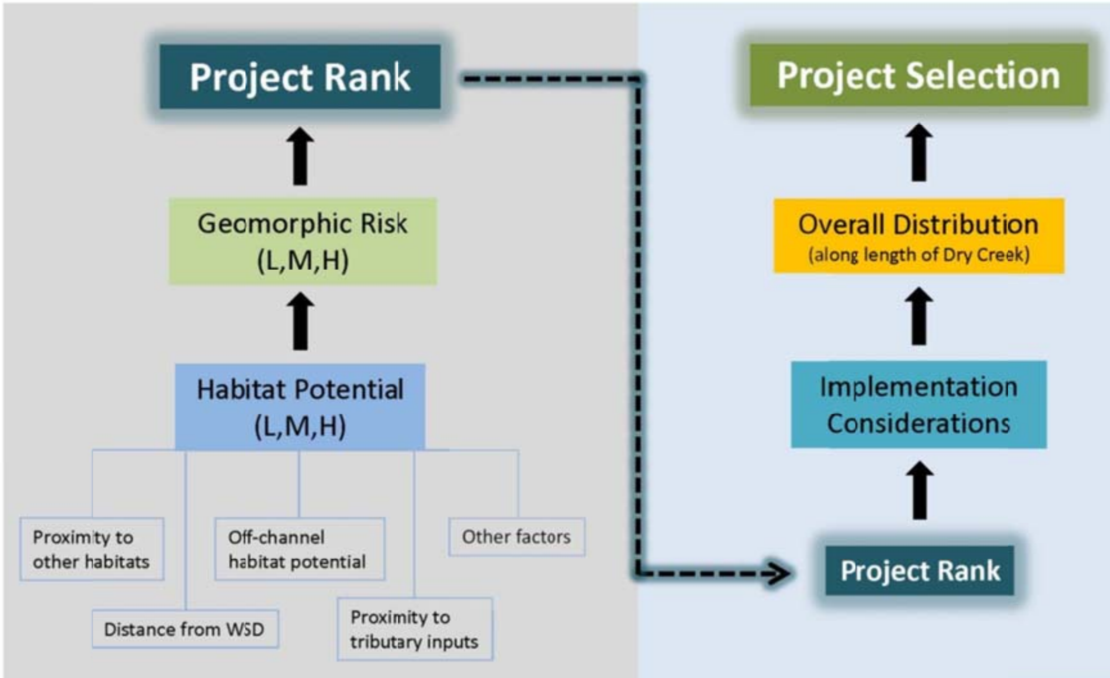

Figure 77. Project ranking diagram based on discussions between action partners, NMFS and CDFG in October 2010. Adapted from Wieckowski et al. 2010.

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Appendix A:

Reprint of Individual Study Sub-Reach summaries from current conditions report

REACH 1 (RM 0 to RM 0.7) **Russian River Confluence to Mill Creek Tributary Junction**

Reach 1 is defined by two major confluences: Dry Creek's confluence with the Russian River at Dry Creek river mile 0, and second the confluence of Dry Creek's second largest tributary, Mill Creek, on the right[1] bank at river mile 0.7 (Figure 1). Another confluence occurs at river mile 0.4, where an unnamed tributary enters on the left bank and has deposited small gravels at its mouth. Confluences are often ecological hotspots of diversity and productivity, due to the mixing of cold and warm waters, local heterogeneity in substrate, nutrient inputs, and hydraulics (Kiffney et al. 2006). In the Russian River watershed, Hopkirk and Northen (1980) emphasize the importance of tributary confluences: "Even if the tributary dries up during the summer, it forms an embayment on the mainstem, where water velocity is reduced and young fish and small prey species can seek shelter from mainstem predators. The roach, a small minnow native to the system, was recorded by Pintler and Johnson (1957) as being common on the mainstem [Russian River] only around the mouths of tributaries. Even the tuleperch, a native live-bearing species, enters the mouths of tributaries to deliver its young" (Hopkirk and Northen, 1980). Drastic differences in water temperature between the Russian River

Figure 1: (upper left) looking down the Russian River at the Dry Creek confluence, (upper right) looking up the mouth of Dry Creek, (lower left) the mouth of Mill Creek, and (lower right) the mouth of the unnamed tributary.

[1] In the individual reach summaries, right and left bank designation defined as looking downstream.

and Dry Creek provide cold water refugia for mainstem species.

Extending from the confluence with the Russian River upstream to the Mill Creek confluence, Reach 1 is a single-thread channel with a few vegetated gravel bars. The channel alternates primarily between pools and flatwaters. There are six main channel and two side channel riffles in this reach that range in length from 40 to 80 ft. Although historical incision has occurred (the terraces are 10 to 15 ft above the channel bed), the channel is currently vertically stable. The Russian River provides grade control for this reach, but the backwater created by the Russian River may cause some aggradation with the high sediment load from upstream and from Mill Creek.

Channel change suggested by results from historical aerial photograph analysis was corroborated during the geomorphic investigation. The channel in Reach 1 has been active since the dam was built. The channel has generally become narrower over time, but the channel has migrated frequently through the wide riparian area. The channel is currently less sinuous than in 1983 and 1998 but has a similar sinuosity to the channel in 1993. Some of the abandoned channels are still visible in the floodplain and riparian area and may provide opportunities for habitat enhancement.

Other remarkable features in Reach 1 include the active summertime USGS stream flow gage at river mile 0.16 and the abandoned seasonal Basalt Road crossing at river mile 0.05, where streambanks remain unvegetated. Another exposed area was recorded where Mill Creek enters Dry Creek. Last, a hand-built cobble dam at river mile 0.03 had been breached and did not block fish passage (Figure 2).

Figure 2: (left) A hand-built cobble dam across Dry Creek, (right) Unvegetated streambanks at the Mill Creek confluence.

Habitat Classification

The total length of Reach 1 is 0.7 miles and is comprised of 32% pools, 37% flatwater, and 32% riffles by relative frequency (Figure 3). Riffles comprise only 15% of Reach 1 by length. At the time of the survey, the average wetted width was 45.6 ft. The average active channel width was 62.5 ft and the flood prone width was 137.5 ft.

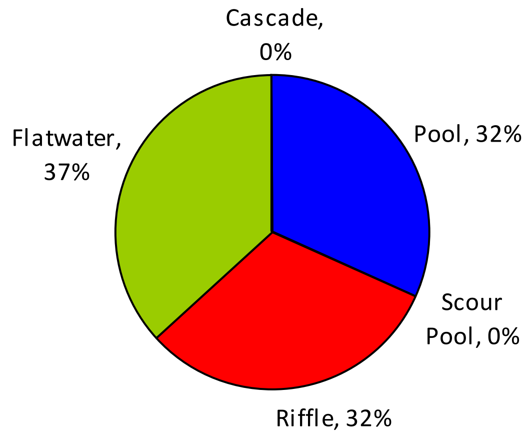


Figure 3: Proportion of Habitat Units by Relative Frequency in Reach 1

Based on a pool-riffle spacing, low confinement, and a gradient of 0.2%, Reach 1 appears to be an alluvial pool-riffle, response reach (Montgomery and Buffington, 1997). Reach 1 resembles a “C4” channel type, with a high active channel width-to-depth ratio of 30 and a moderate entrenchment ratio of 2.2 (Rosgen, 1996). Point bars and gravel islands are common in this reach, and most banks are vegetated with a maturing hardwood riparian forest.

Figure 4: (left) A typical pool in Reach 1 with overhanging vegetation, (right) the 150', glide-dominated side-channel.

Pools

Six pools were measured in Reach 1. The average maximum pool depth was 4.0 feet (Figure 5). Several of these pools resembled flatwaters for short reaches, and several of the flatwaters contained short pools. All of the pools had maximum depth greater than 3 feet. Residual pool depths averaged 2.7 feet, and pool crest depths averaged 1.3 feet. Substrate in pools was most often gravel with sand.

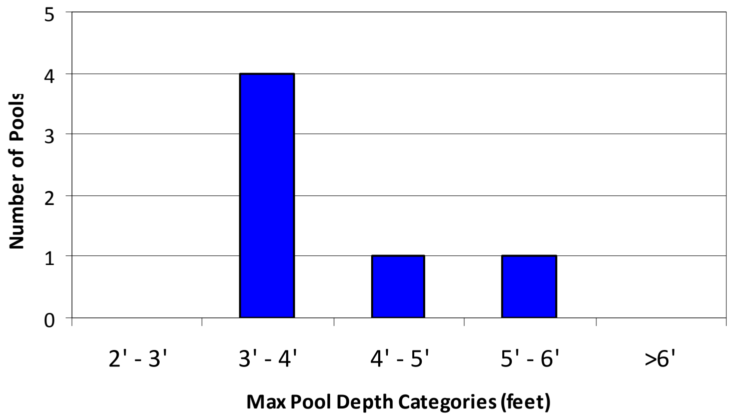


Figure 5: Maximum Pool Depths in Reach 1

Riffles & Flatwaters

There were 6 riffles and 7 flatwaters in Reach 1. The average riffle depth was 1.1 (st.dev. 0.2) and average flatwater depth was 1.4 (st.dev. 0.2). The riffles are composed of coarse gravel and small cobbles and the flatwaters are primarily gravel and sand. The D50 of the bed material in the riffle immediately downstream of Mill Creek is 26 mm, coarse gravel (Figure 6). The majority of the clast sizes were coarse gravel, with only 3% of the samples less than 2 mm (sand/fine sediment). In flatwaters, substrate was most often observed as gravel with small cobble. A greater portion of sand on the streambed was observed in this reach compared with others.

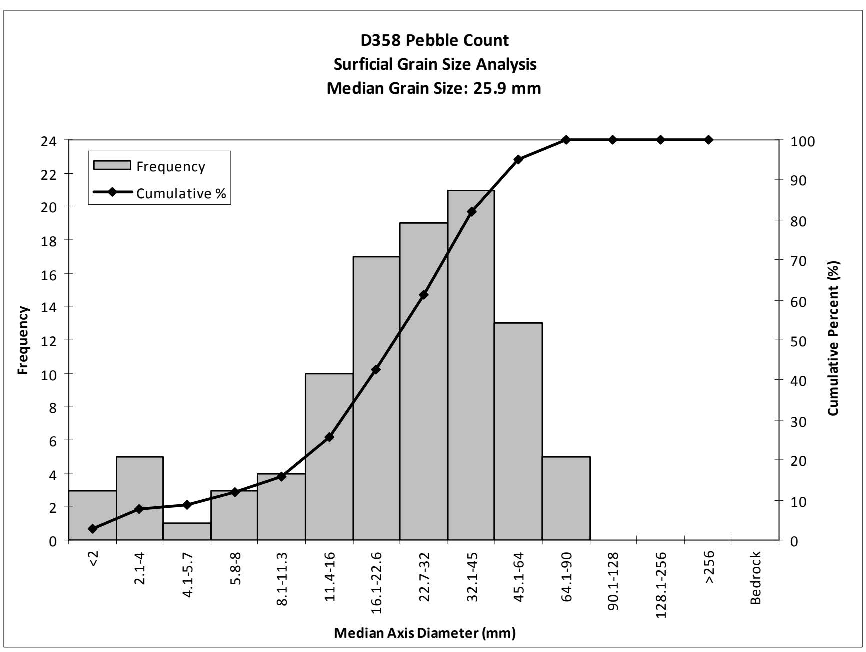


Figure 6: Grain size distribution for riffle downstream from Mill Creek (habitat unit #358).

Side Channels

We measured two side channels in Reach 1. The first side channel, a 150' flatwater, occurred just upstream of the USGS stream flow gage, where the river splits around a vegetated island. The other side channel, predominantly a riffle, connected a pool with a downstream riffle and was only 60 feet long. There was very little instream cover in either of these side-channels. Gravel with sand was the dominant substrate.

Alcoves

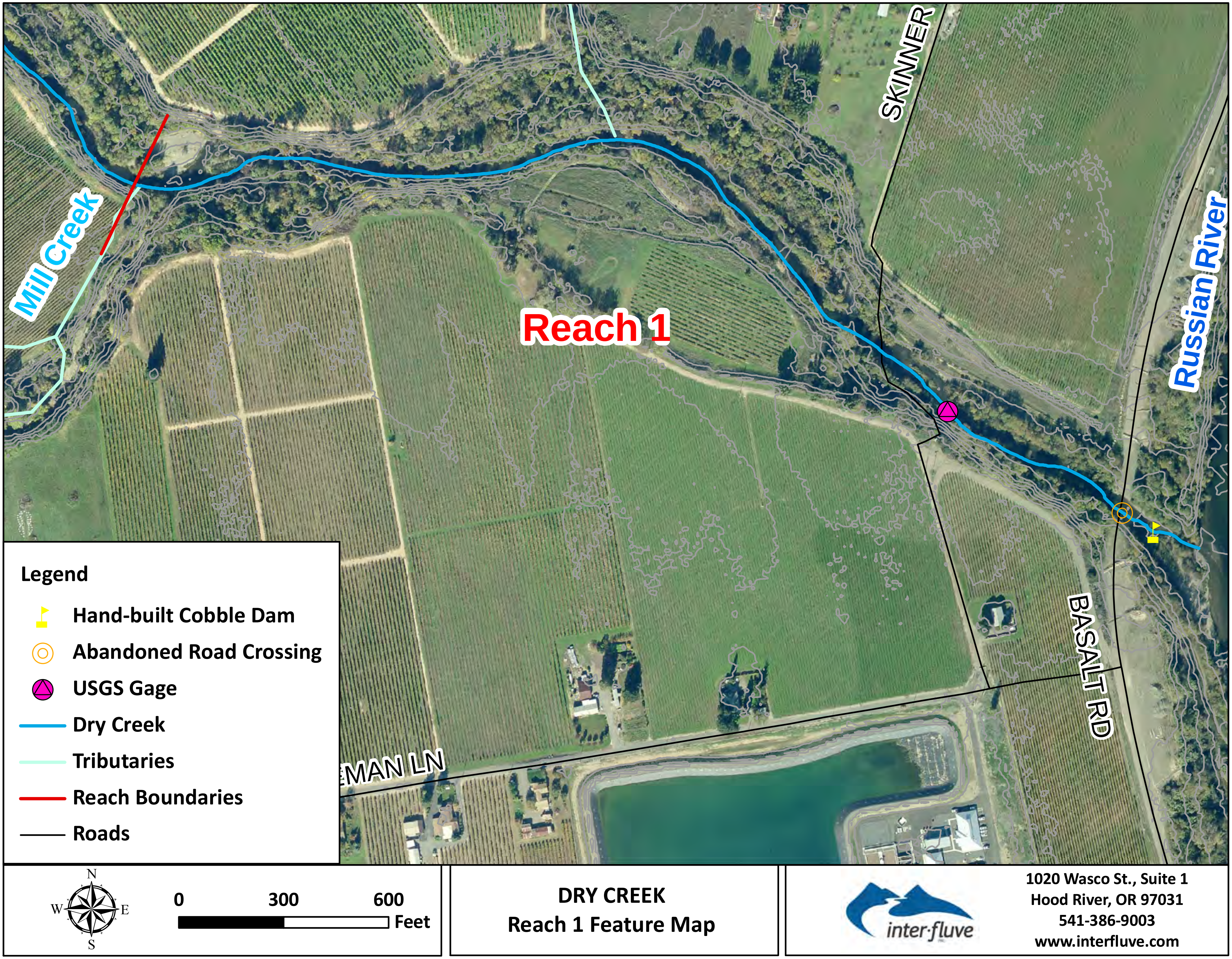
In the four alcoves measured in Reach 1, substrate was fine sediment with gravel. Two alcoves near the mouth of Dry Creek were associated with flatwaters, while the two others are located just downstream of Mill Creek's confluence, and were associated with pools. These four alcoves are all small and shallow, averaging 425 square feet in area (stdev. 99.8), with an average maximum depth of 1.0 feet (stdev. 0.6). Instream cover in the alcoves is provided by terrestrial vegetation, but also by aquatic plants and algae.

Instream Cover & Woody Debris

Compared with other reaches, Reach 1 contains much less wood (only 86 pieces per mile) and less instream cover and edge habitat. Of the 23 pieces of wood greater than 1' diameter observed in Reach 1, 13 were found in pools. Pools and alcoves have the highest number of pieces of wood per length. Flatwaters contained slightly more wood than riffles, greater instream cover, as well as a greater frequency of edge habitat. Most cover was provided by willows and other vegetation interacting with the water, and also by small woody debris. In alcoves, aquatic vegetation and algae provided additional cover. CDFG sets desirable criteria for instream cover and shelter rating at >40% and >70, respectively (Coey, 2002), and no habitat type except alcoves met these criteria. Relatively few of the mainstem habitat units contained edge habitat, although side channels and alcoves did provide similar habitat.

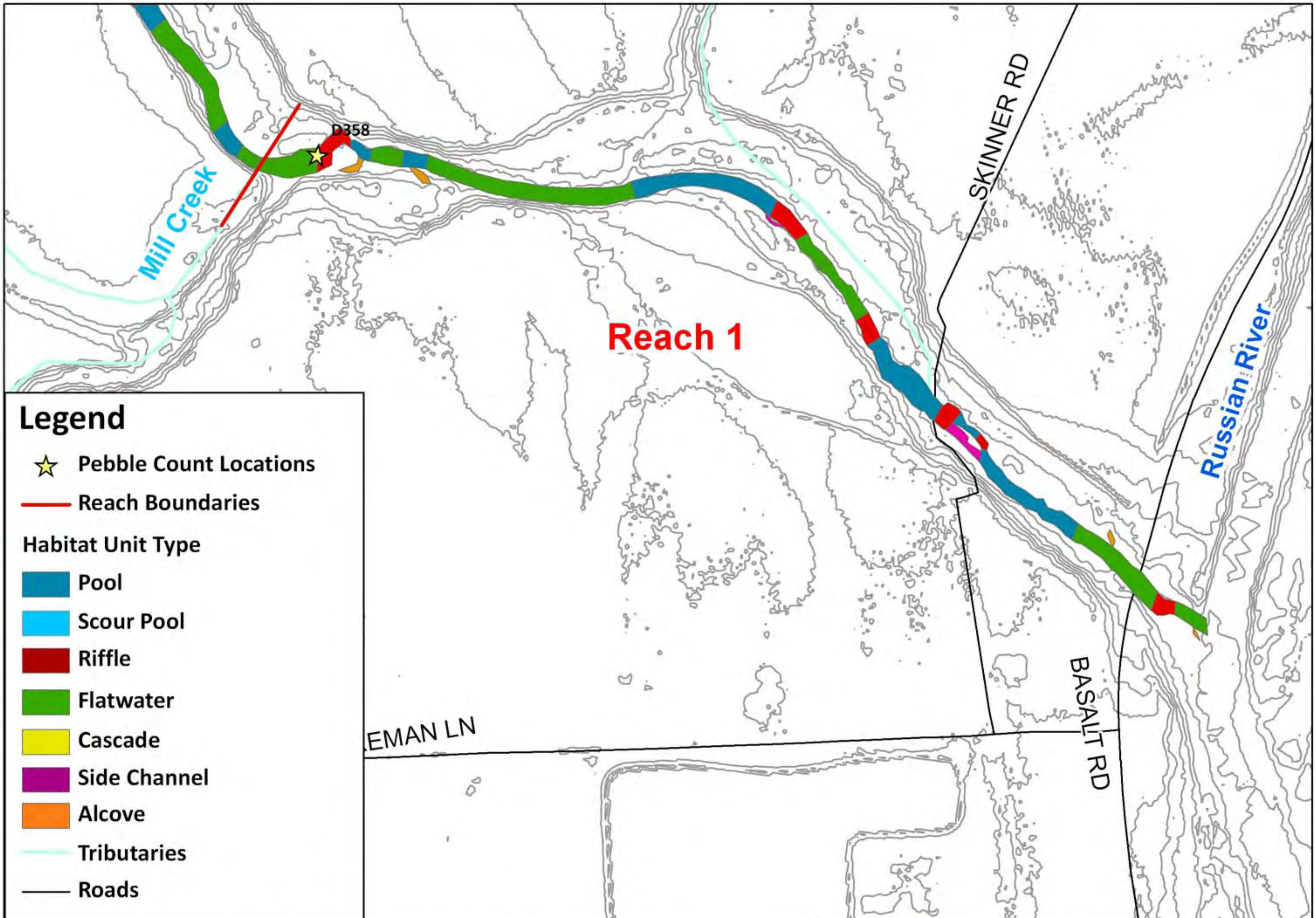
Table 1: Instream woody debris, cover, and edge habitat frequency for Reach 1.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	98.8	34.2	15.2	148.1	26%	64	33%
Riffles	10.1	20.2		30.2	8%	13	0%
Flatwaters	40.6	12.2	16.2	53.0	17%	36	43%
Side Channels	25.1			25.1	20%	30	100%
Alcoves	72.0		24.0	96.0	61%	184	75%
	mainstem wood pieces/mile			96.9			



DRY CREEK
Reach 1 Feature Map

inter·fluve
1020 Wasco St., Suite 1
Hood River, OR 97031
541-386-9003
www.interfluve.com



DRY CREEK
Reach 1 Habitat Units

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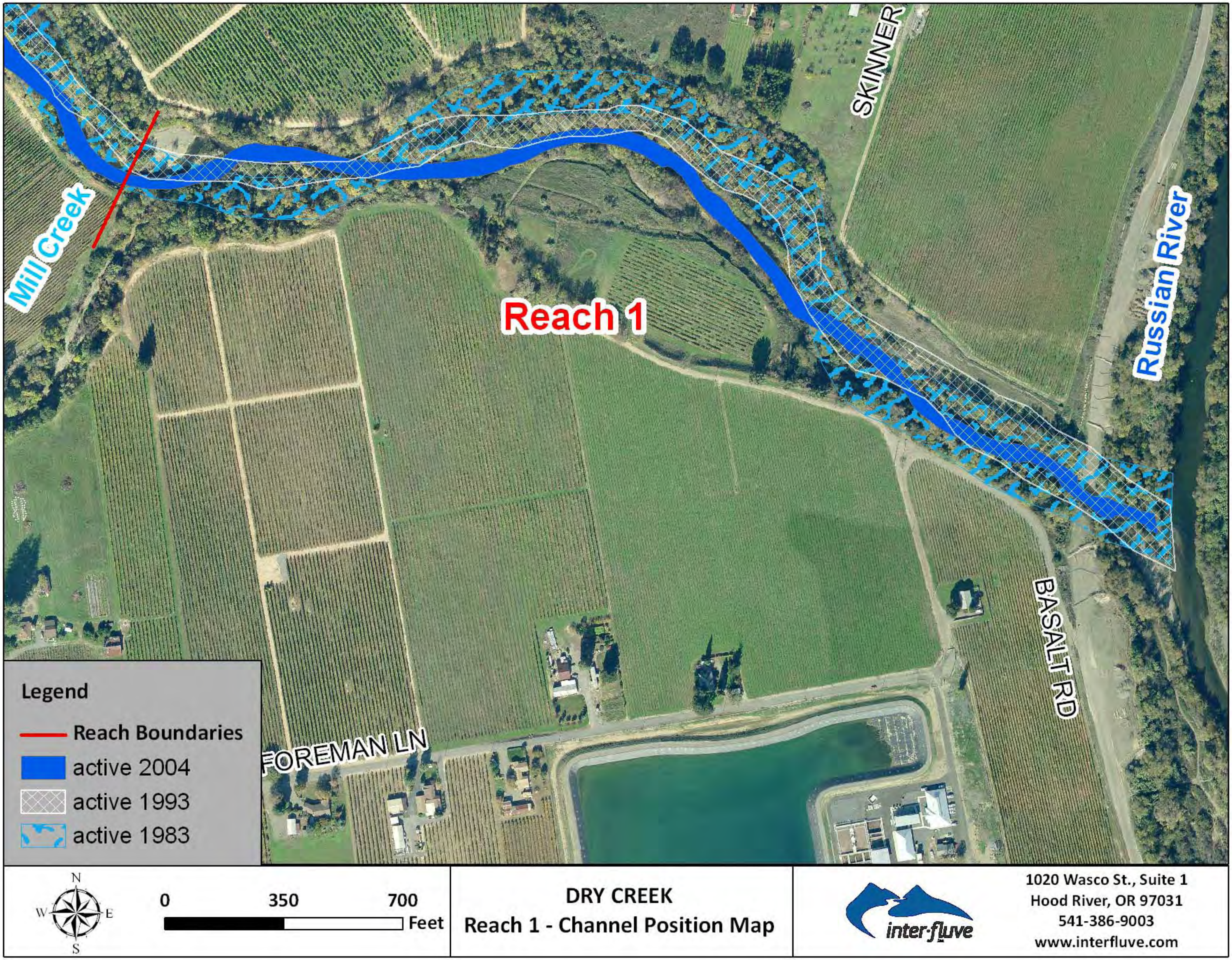

SKINNER
Mill Creek
Russian River
Reach 1
BASALT RD
FOREMAN LN
Legend
Reach Boundaries
active 2004
active 1993
active 1983
N
W
E
S
0
350
700
Feet
DRY CREEK
Reach 1 - Channel Position Map
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REACH 2 (RM 0.7 to RM 2.0) **Moderately Confined and Well Armored from Mill Creek to the Westside Road Bridge**

Reach 2 of Dry Creek extends from the Mill Creek confluence upstream to about 100 ft downstream from the Westside Road Bridge. Reach 2 was a relatively straight reach with many riprap-armored streambanks. There were several long, narrow side channels and six alcoves, one of which was associated with the inlet of a dry, unnamed tributary at river mile 1.9.

Over the last century the channel has become narrower, but there has been little channel migration. The only location with substantial channel change is from river mile 1.5 to the reach boundary at river mile 2.0. Here, the 1983 channel is now the floodplain and may provide opportunities for constructing backwater channels for habitat. Although the narrowing likely coincided with channel incision (the terrace is approximately 10 to 15 ft above the channel bed), the channel is currently relatively vertically stable. The sediment load through this reach, like Reach 1, is high and there may be some minor aggradation occurring.

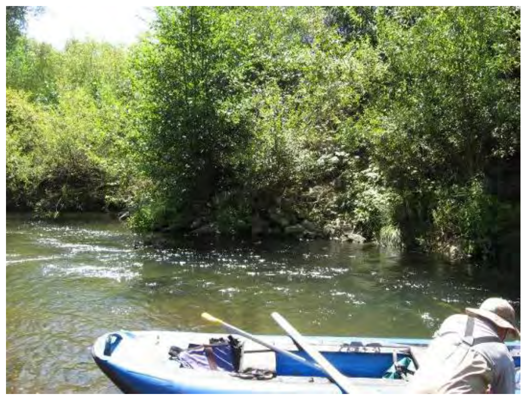



Figure 7: (left) Boulder riprap along streambanks, (right) a pool with riprap along the right bank.

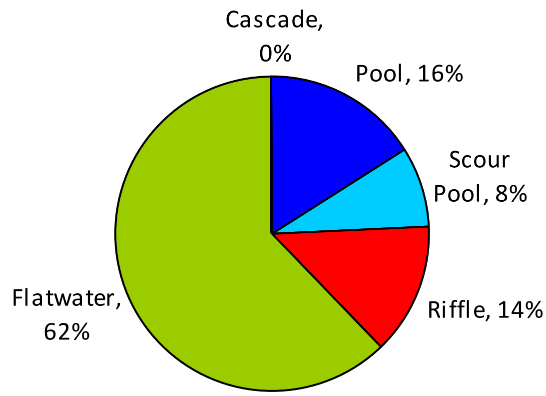


Figure 8: Proportion of Habitat Types by Relative Frequency in Reach 2

Habitat Classification

Reach 2 was 1.3 miles long, primarily comprised of flatwater habitat units (62%), with pools and scour pools representing 24%, and 14% riffles by relative frequency (Figure 8). Riffles comprise only 5% of the total length. There are five riffles with lengths ranging from 60 to 90 ft. The channel geometry is similar to Reach 1. The wetted width is 45.6 ft, and the active channel width is 68 ft with an active channel depth of 1.7 feet. The floodprone widths were 90 and 190 feet.

The average reach gradient was 0.2%. Reach 2 resembles a plane-bed channel morphology, with long stretches of relatively featureless bed and few gravel bars and no islands (Montgomery and Buffington, 1997). Two different entrenchment ratios were measured in riffles in Reach 2; at the upstream end of the reach entrenchment was 2.6, and in the middle of the reach, the entrenchment ratio was 1.4. A high active channel width:depth ratio was measured at both sites (35 and 46, respectively). Due to the constrained nature of the channel by bank stabilization measures along most of Reach 2, it more resembles an “F4” channel type (Rosgen 1996).

Figure 9: Glide habitat units in Reach 2, with riprap along the banks.

Pools

All of the 6 pools and 3 scour pools in Reach 2 were more than three feet deep, thus qualifying as CGFG primary pools (Coey 2002). The average maximum pool depth was 4.3 feet (st.dev. 0.8). The average residual pool depth was 2.8 feet, with an average pool crest depth of 1.5 feet. Substrate in pools was gravel with sand.

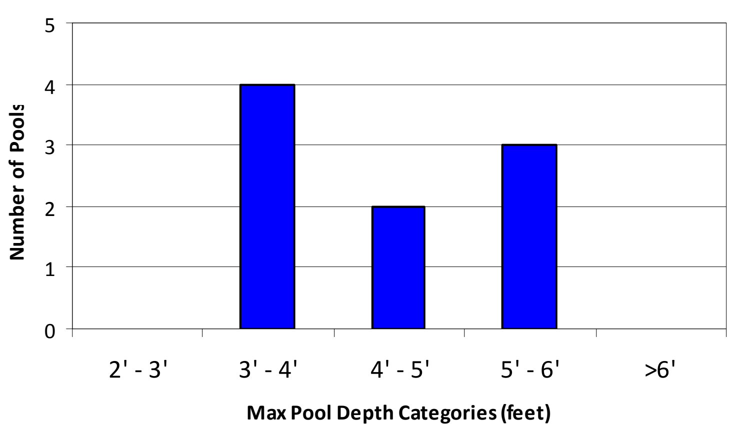


Figure 10: Maximum Pool Depths in Reach 2.

Riffles & Flatwaters

Average riffle depth in Reach 2 was 0.9 feet (st.dev. 0.3). Average flatwater depth was 1.5 feet (st.dev. 0.3). The flatwaters are composed primarily of gravel and sand and the riffles are composed of coarse gravel and small cobbles. The riffle below the tributary at the upstream end of the reach is dominated by medium to very coarse gravel with a median grain size of 23 mm. Substrate in both riffles and flatwaters was categorized as gravel with small cobbles and sand.

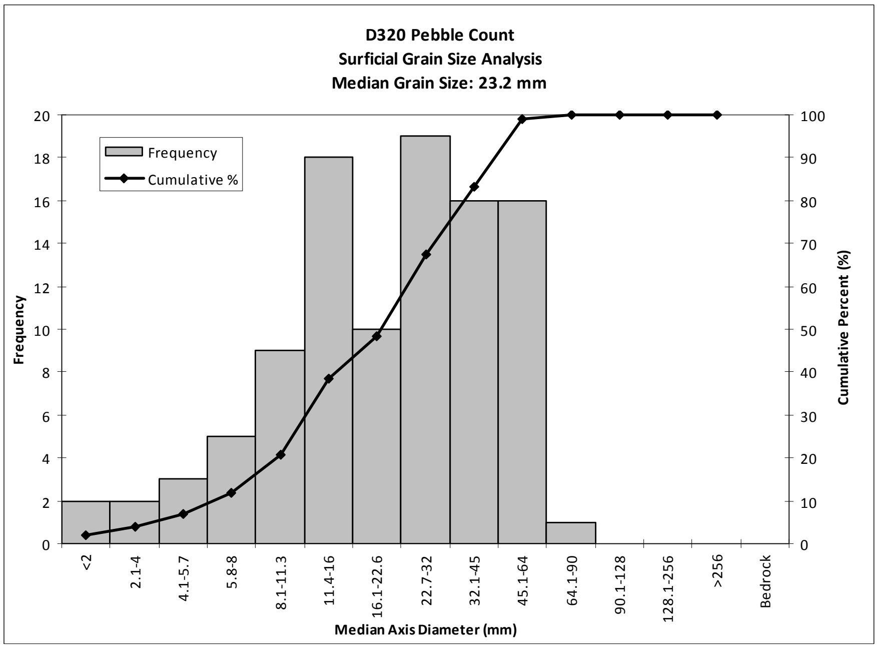


Figure 11: Grain size distribution for riffle downstream of the unnamed tributary, downstream from Westside Road (habitat unit #320).

Side-Channels

Of the three side channels in Reach 2, two were pool dominated, and the third consisted mainly of flatwater habitat. Each side channel was narrow (average 7 feet) and long (113 feet long on average). Substrate was gravel with sand and small cobble.

Alcoves

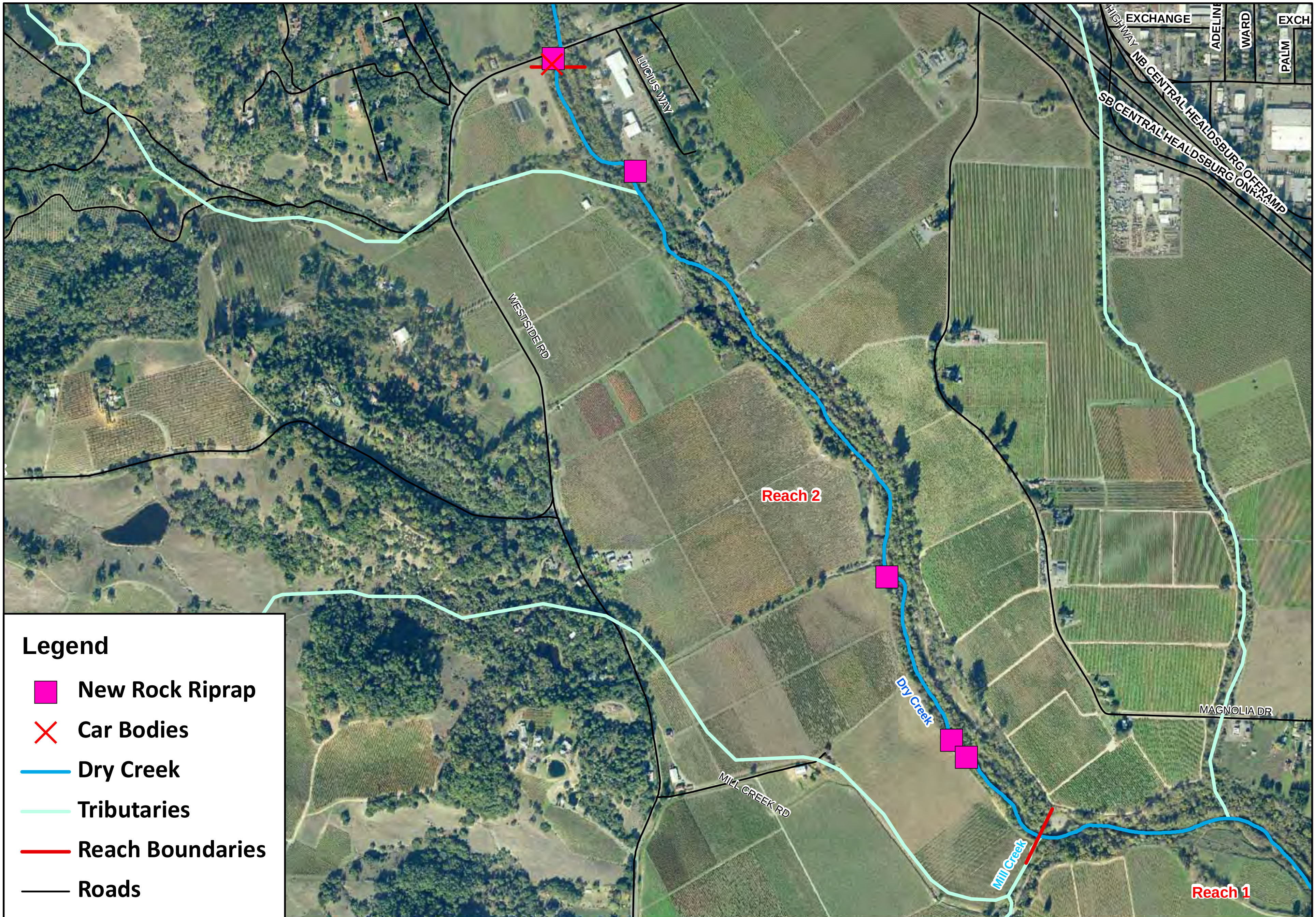
All six alcoves in Reach 2 were narrow (average width 11 feet), and most ranged from 40 to 90 feet long, with one exception. Near the unnamed tributary junction at river mile 1.9, one alcove was 250 long and followed the incised floodplain wall upstream. Substrate in the alcoves was mostly fine sediment, with sand and gravels.

Instream Cover & Woody Debris

Most instream cover in Reach 2 was provided by terrestrial vegetation interacting with the water or within 6" of the water surface, and secondarily by small woody debris. In the alcoves, abundant aquatic vegetation provided additional cover. More abundant and larger woody debris was found in scour pools (Table 2). The highest cover and shelter ratings were found in narrow side-channels, with thick overhanging vegetation and abundant small woody debris. All alcoves provided edge habitat, with an edge frequency of about 40% in other habitat types.

Table 2: Instream woody debris, cover, and edge habitat frequency for Reach 2.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	90.1	55.8	12.9	158.7	29%	87	50%
Scour Pools	93.5	46.7		140.2	27%	62	33%
Riffles	125.1	55.6	27.8	208.4	17%	48	40%
Flatwaters	96.2	45.0	7.2	148.4	27%	71	17%
Side Channels	248.5	46.6	15.5	310.6	77%	204	67%
Alcoves	138.2	49.3		187.5	61%	174	100%
	mainstem wood pieces/mile			141.9			



N W E S

0 750 1,500 Feet

DRY CREEK
Reach 2 Feature Map

1020 Wasco St., Suite 1
Hood River, OR 97031
541-386-9003
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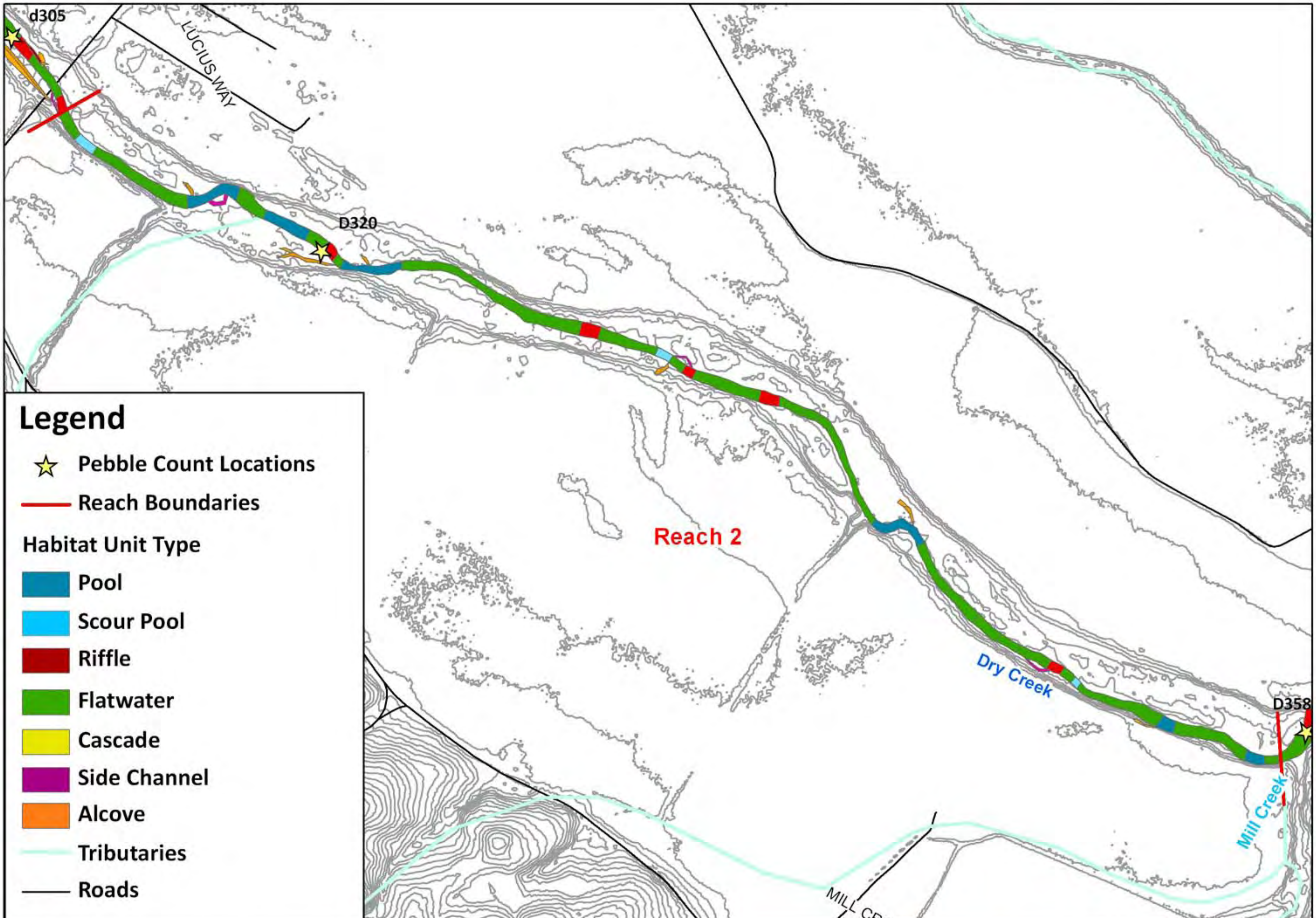

DRY CREEK
Reach 2 Habitat Units

1020 Wasco St., Suite 1
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541-386-9003
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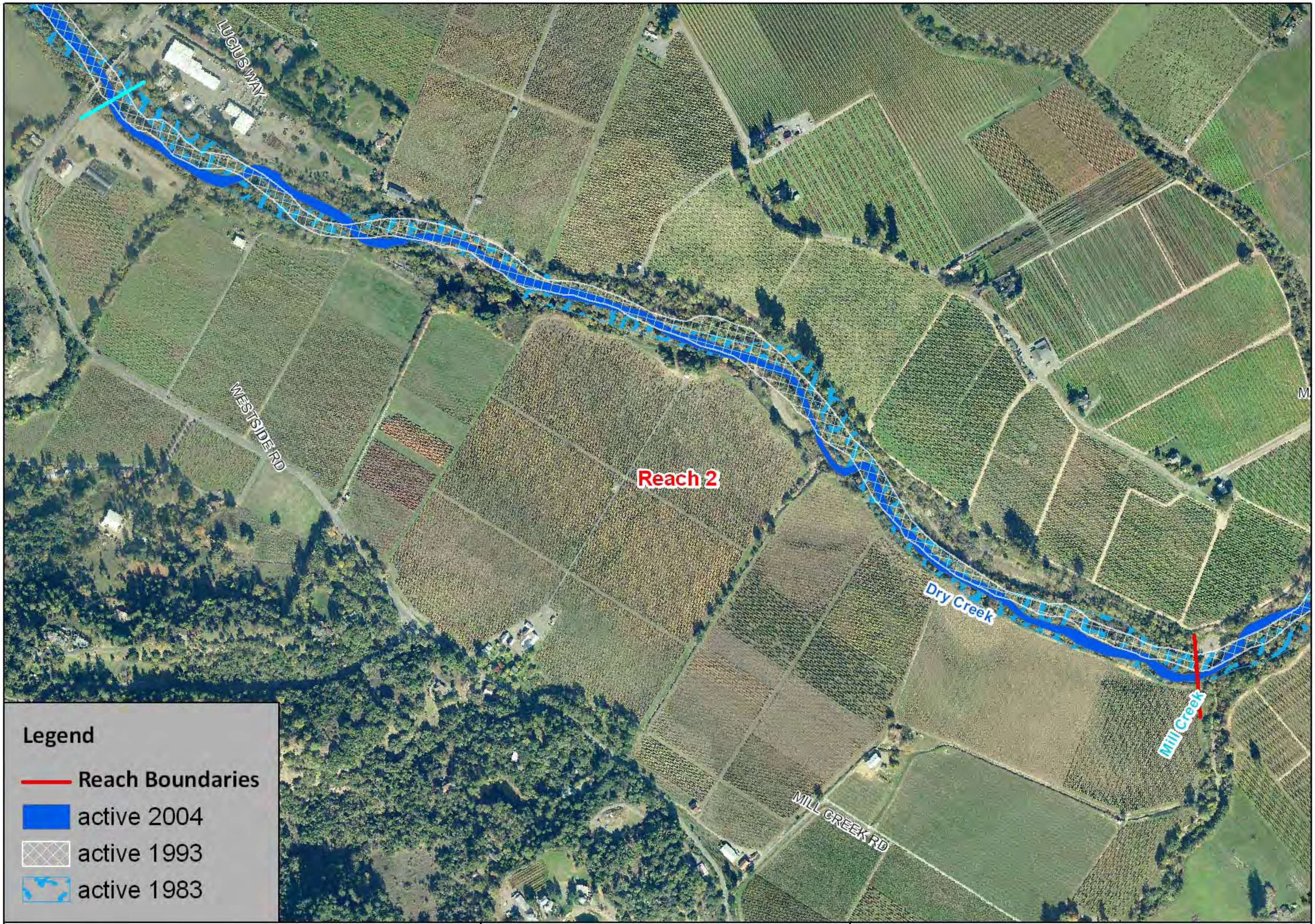

0 600 1,200 Feet

DRY CREEK
Reach 2 - Channel Position Map

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REACH 3 (RM 2.0 to RM 3.0) **Active Incised Floodplain, from the Westside Bridge to a fault lineament downstream of the gradient sills**

Reach 3 was less confined than Reach 2, and contains eight side channels, six of which are over 100 feet long. Abundant alcoves and side-channels may provide substantial channel and habitat complexity, and may serve as templates for off-channel habitat design and construction in other areas. One intermittent tributary enters at river mile 3.0 on the right[2] bank (unmapped). Stream stabilization efforts using I-beams and chainlink fence have failed at river mile 2.95. The Dry Creek screw trap is located at river mile 2.0, under the Westside Road bridge at the downstream end of the reach. A mapped levee runs along the right bank for 1300 feet in at the upper end of Reach 3, but the stream has meandered away from it, and it was not noted during the survey.

The upstream reach boundary is at the approximate downstream influence of the three grade control structures in Reach 4 and is where the southeast/northwest trending lineament intersects Dry Creek. Upstream of this point the lineament is located approximately along Dry Creek to river mile 5.35. It is unlikely that the lineament impacts the current processes shaping the channel and riparian corridor, but the historic location of the channel may have been influenced by the location of the lineament.

Figure 12: (upper left) Westside Road bridge and screw trap, (upper right) mouth of intermittent stream, (lower left) failed I-beam and chainlink bank armor, and (lower right) side channel pool.

[2] In the individual reach summaries, right and left bank designation defined as looking downstream.

The channel in this reach is active and has been migrating frequently since the dam was constructed. The current channel is slightly less sinuous than during the 1980s and 1990s, but the older channels are now productive side channels flowing through dense riparian vegetation. This is the case particularly downstream of river mile 2.5 where a side channel that is up to 75% of the width of the main channel splits and meanders along the left terrace edge. This channel maintains pools of varying depths and flatwaters and has substantial quantities of large and small woody debris. An alcove along the right bank extends from the Westside Road Bridge upstream to about River Mile 2.05. This is a long, narrow channel, but there is no upstream inlet. At high flows, this alcove likely becomes reconnected to the main channel at the upstream end.

Degradation has likely not occurred in Reach 3 since the dam was built and there may be some aggradation. There are extensive gravel bar deposits and some alders were observed to be slightly buried or closer to the water surface. During flood flows, bedload may be transported and deposited in large volumes, leading to the higher degree of channel change and lateral instability in this reach.

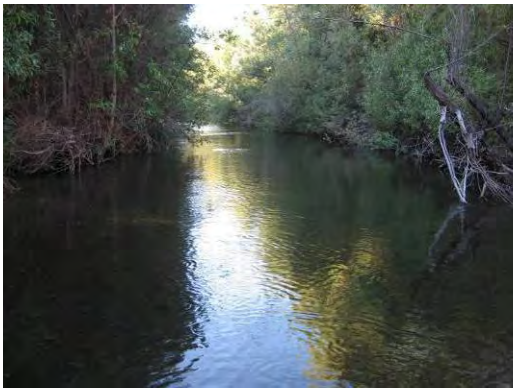


Figure 13: (left) a typical pool in Reach 3, (right) one of the three riffles in Reach 3.

Habitat Classification

Reach 3 is comprised of 61% flatwater habitat, 17% is mainstem pool (0% scour pool), and 22% riffle by relative frequency. Only 6% of the 1.0 mile length of Reach 3 is riffle habitat by length. Nearly 70% of the wetted channels are composed of flatwaters and pools and almost 25% are side channels and alcoves. It was noted that flatwaters often contained very short pool units and visa versa. There are four riffles ranging in lengths from 70 to 110 ft. The average channel wetted width in the single-thread portions of the channel is about 48 ft. The active channel and flood prone widths are 82 and 110 ft respectively; these widths would

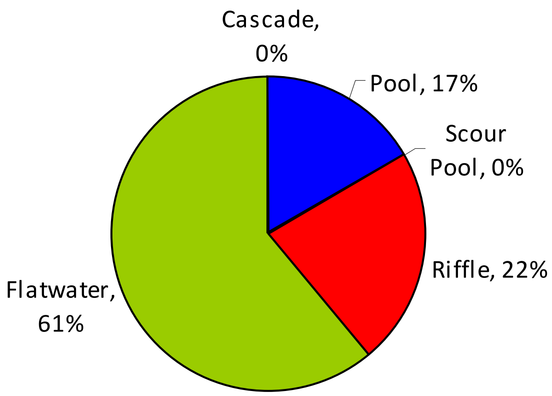


Figure 14: Proportion of Habitat Types by Relative Frequency in Reach 3

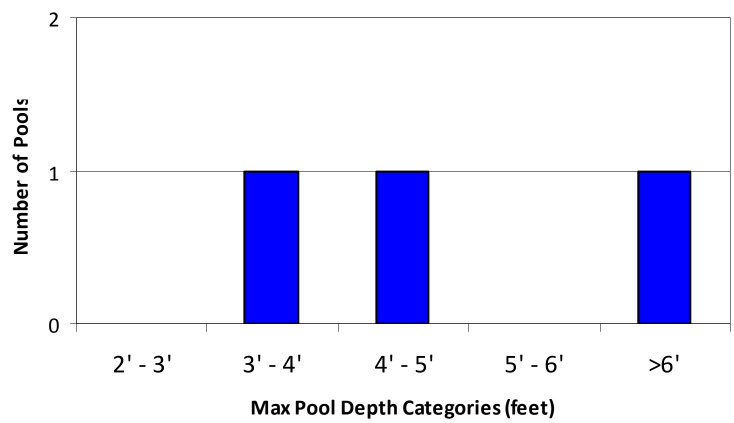
be greater in the multi-thread portions of the channel. The average active channel depth was 1.7 feet.

Reach 3 resembles plane-bed morphology based on long flatwater units and few riffles (Montgomery and Buffington, 1997). The entrenchment ratio was 1.35 and the average active channel width:depth ratio was 48. The incised nature of the floodplain caused this reach to resemble an "F4" type channel (Rosgen, 1996).

Pools

There were a total of three pools in Reach 3, with an average maximum depth of 4.6 feet (st.dev. 1.3). All three pools were greater than 3 feet deep (Figure 15). The average residual pool depth was 2.4 feet for main channel pools. The average pool crest depth was 1.3 feet. Observed substrates in pools were gravel with sand.

Figure 15: Maximum Pool Depths in Reach 3.

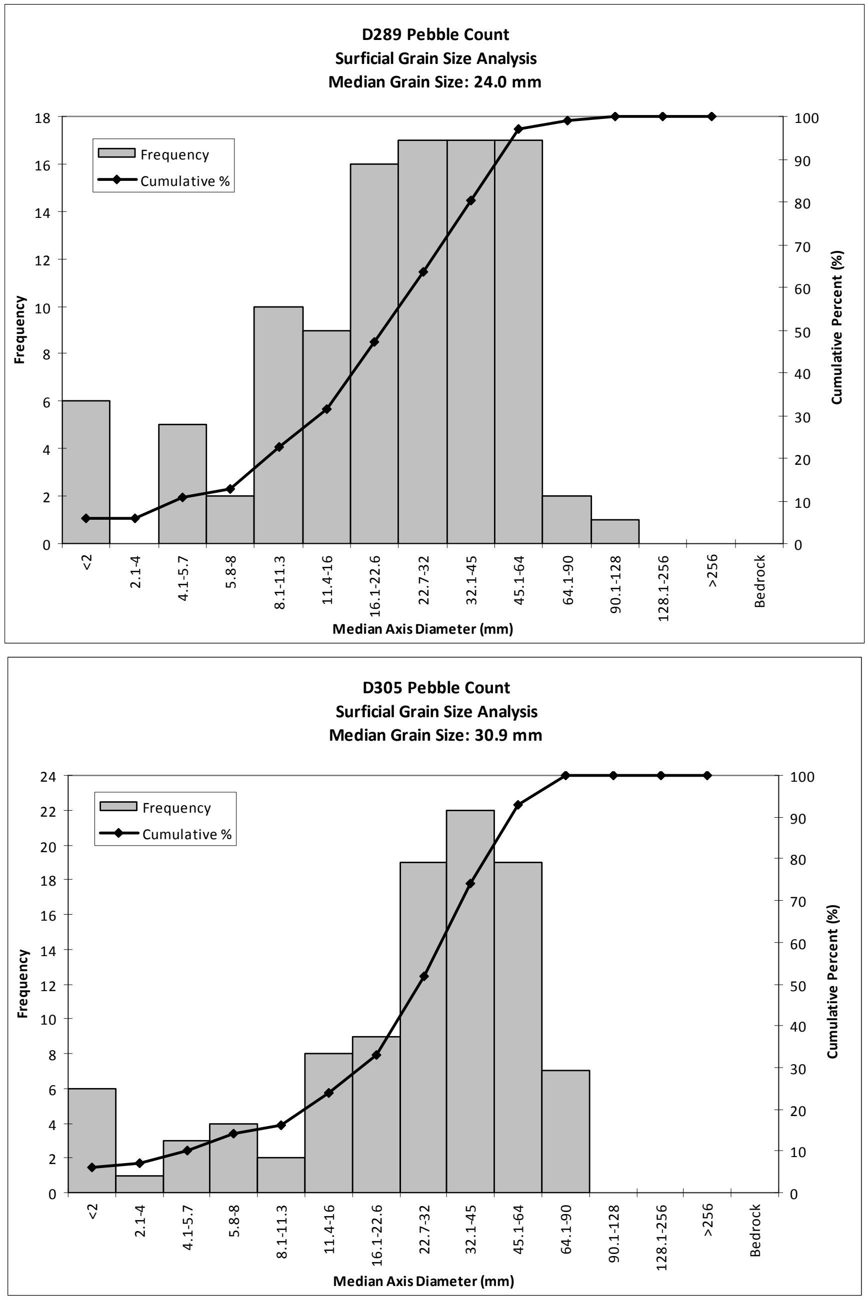


Riffles & Flatwaters

Average riffle depth was 1.1 feet (st.dev. 0.2), and the average flatwater depth was 1.4 feet (stdev 0.2). The bed material in reach 3 ranges from sand to small cobbles; flatwaters are primarily composed of gravel and sand and the riffles are composed of gravel and small cobbles.

Two pebble counts were conducted in riffles in Reach 3 (D305 and D289). One was the first riffle upstream of the Westside Road bridge, the second was about half-way through the reach. The median grain sizes of the two riffles in this reach were coarse gravel at 24 and 31 mm (Figure 16). 85% of the sediments were within desirable spawning gravel sizes (11.4mm to 128mm), and 42% within desirable coho/steelhead rearing sediment sizes (32mm to 128mm). 6% of the samples were fine sediment or sand (<2mm).

Figure 16: Grain size distribution for riffles in the middle of reach 3 (habitat unit #289) and just upstream of the Westside Road bridge (habitat unit #305).



Side-Channels

In the eight side channels, most of the substrate was fine sediment and sand, with some gravel. Seven out of the eight side channels were pool-dominated, with one flatwater-dominated. Maximum depths in pool-dominated side-channels averaged 2.9 feet, with only one over three feet deep. The flatwater-dominated side channel was 0.8 feet deep on average. There was one long side-channel on left side that extends for a few hundred feet with pools and flatwaters, woody debris and other cover. This side-channel is deep

(~3.5’) and wide (~30’) and abuts the terrace wall. A smaller side channel and alcove on the channel right side provides additional habitat.

Figure 17: (top row) side-channel habitat units, (bottom row) alcoves in Reach 3.

Alcoves

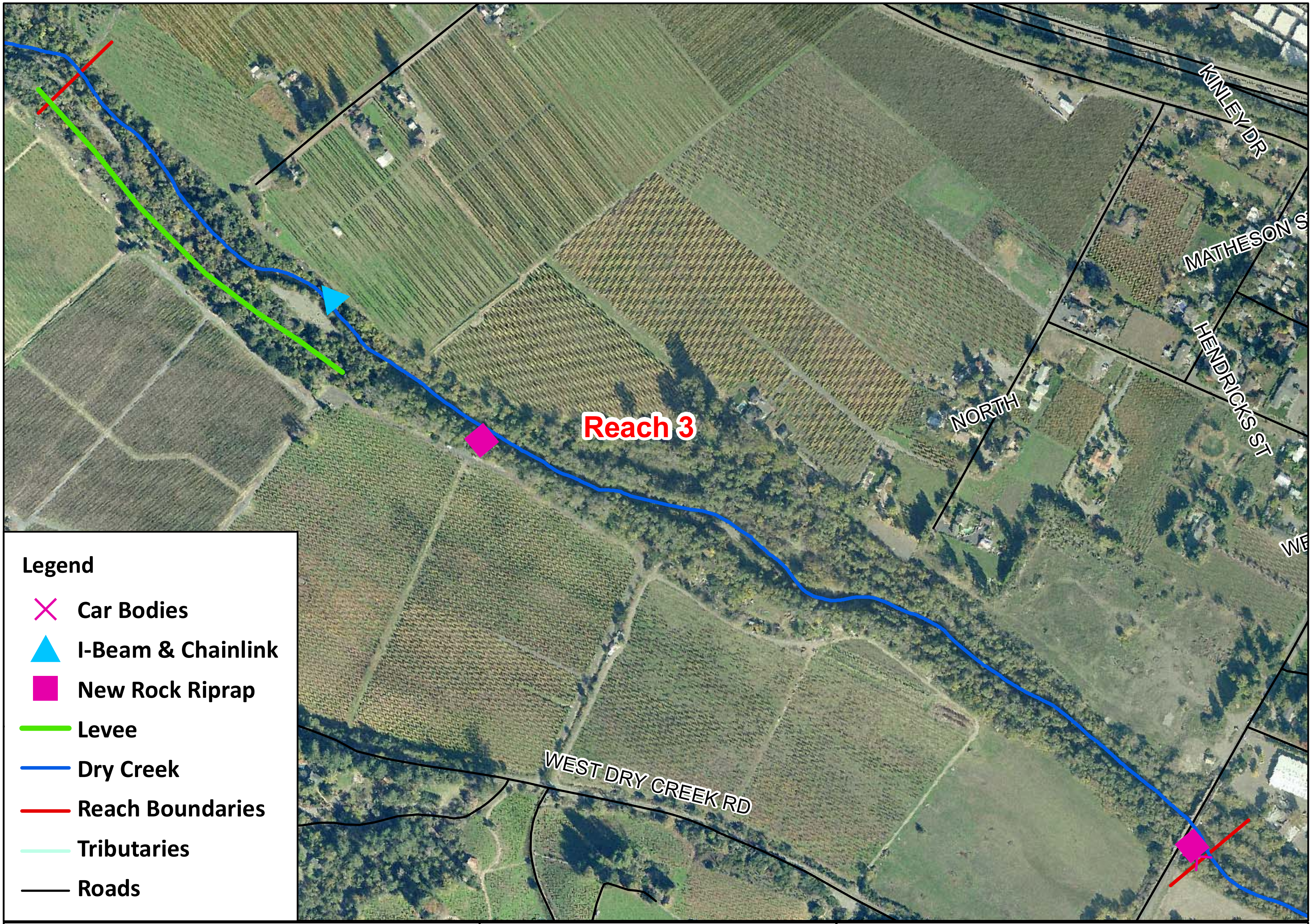
There were four alcoves in Reach 3. Substrate in alcoves is mainly fine sediments and sand, with some gravel. The average maximum depth of alcoves was 1.4 feet, with only one over three feet deep. There were several longer alcoves, including a 1500 foot alcove that flows along the base of a right bank terrace into a small side channel just downstream from the Westside Road bridge. A second very long alcove could not be fully investigated because we did not have landowner permission to access the area.

Instream Cover & Woody Debris

A total of 166 pieces of wood per mile were counted, with most pieces found in flatwaters and side channels (Table 3). While scour pools contained less small and medium sized wood than most other habitat types, the majority of large (>20” diameter) wood was observed in scour pools. Trees and shrubs interacting with the water provided the majority of cover in all habitat types, except for alcoves, where aquatic vegetation provided abundant cover. Additional cover was provided by small woody debris, root masses in riffles, aquatic vegetation in flatwaters and side channels, and large wood and boulders in scour pools. Edge habitat occurred in 18 out of 30 habitat units, primarily along the channel margins in flatwaters, and in side-channels, and alcoves.

Table 3: Instream woody debris, cover, and edge habitat frequency for Reach 3.

	wood pieces/mile				instream cover		
	small 6" - 12"	**med 12" - 20"**	**large >20"**	**total**	**% cover**	**shelter rating**	**% units with edge habitat**
Pools	120.0	23.2	11.6	154.8	27%	71	0%
Riffles	78.8	31.5	15.8	126.1	7%	14	25%
Flatwaters	118.5	38.6	15.7	172.8	30%	89	64%
Side Channels	76.6	39.6	26.4	142.7	63%	188	75%
Alcoves	74.6	8.6	14.3	97.6	84%	251	100%
	mainstem wood pieces/mile			165.4			



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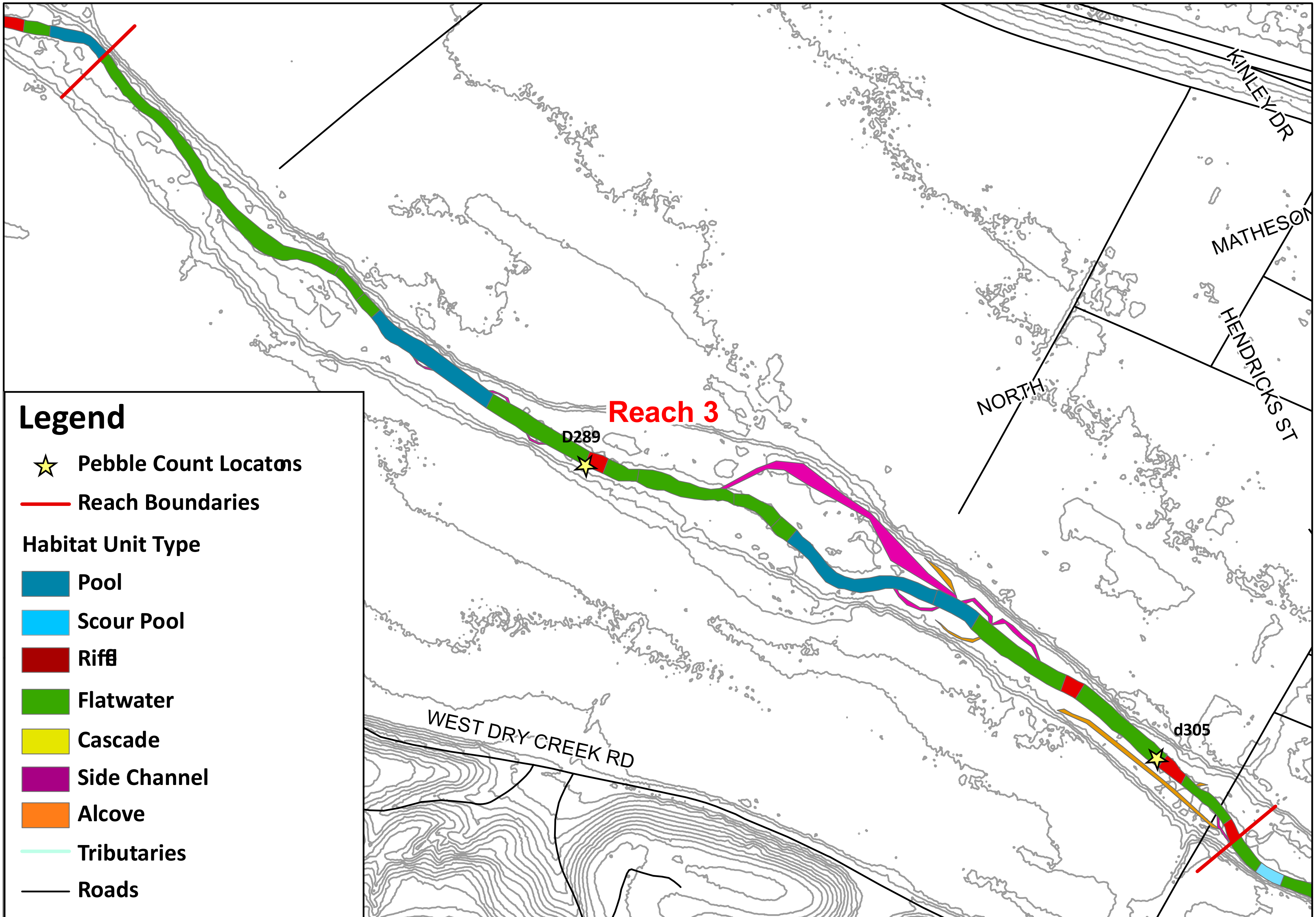

0 500 1,000 Feet

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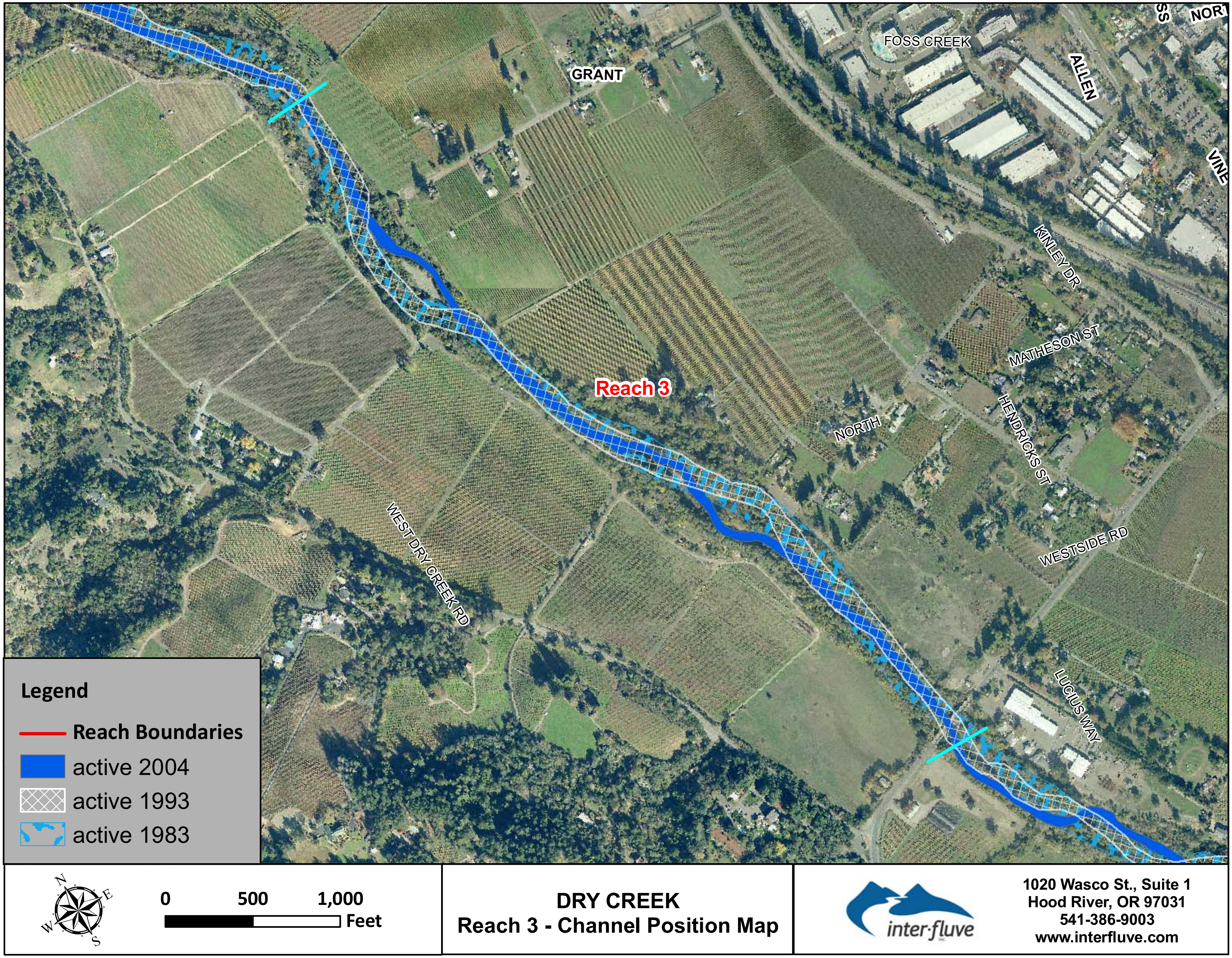

DRY CREEK
Reach 3 - Channel Position Map

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REACH 4 (RM 3.0 to RM 4.1) **Three Constructed Gradient Sills with a fault running alongside, to the top of the upper backwatered pool**

Three gradient sills were constructed in 1983 by the ACOE to slow migrating nick points and associated channel incision in lower Dry Creek. This reach is vertically stable due to the check dams. The backwatered pools created by each sill extended several hundred feet upstream, forming a pool-dominated reach. The upper sill (RM 3.8) consisted of a cascade down two sets of boulder falls, 2’ and 1’ in height. The middle sill (RM 3.5) was 200’ long, 10’ wide, and 3’ in height. The lower sill (RM 3.3) was 100’ long, 10’ wide, and 1 foot tall. Each sill has a fish ladder to provide passage through the short cascades. Rock riprap covers than right bank between the upper and middle sill, and short sections of boulder riprap cover both banks upstream and downstream of each sill. An unnamed tributary enters Dry Creek just downstream of the lower sill at river mile 3.25.

Through Reach 4, the channel has become less sinuous since the dam was built, though minor channel migration has continued. Three side channels and eight alcoves were identified in this reach, and these are located primarily along previous channel paths.

Figure 18: (upper left) lower sill, (upper right) upper sill,
(lower left) ladder on middle sill, (lower right) middle sill.

Habitat Classification

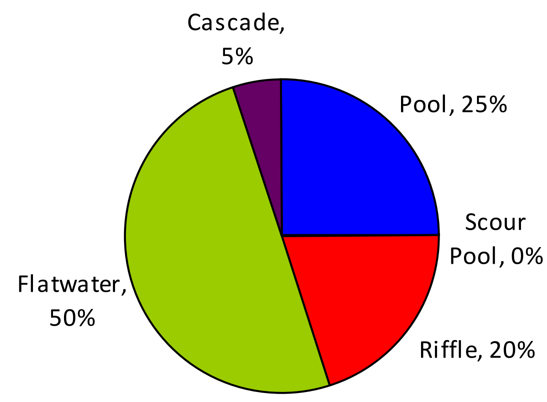


Figure 19: Proportion of Habitat Types by Relative Frequency in Reach 4

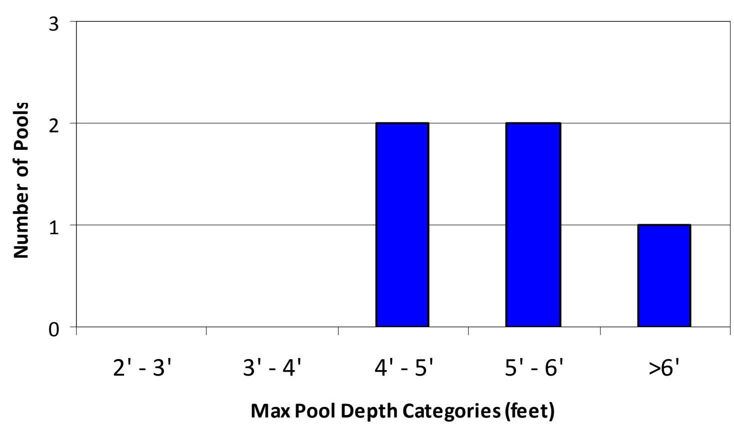
This reach is primarily composed of flatwaters (50%) pools (25%) backwatered behind check dams, and riffles (20%) at and just downstream of the dams. Four riffles were identified ranging in length from 50 to 80 ft and comprise 6% of the 1.1 mile mainstem length for the reach on a length basis. At each sill, a short cascade of water pours over the structure.

The channel in this reach has steep banks as the average wetted width and active channel widths are the same at 52 ft. The active channel depth was 2.7 feet. The average flood prone width is more than double at 112 ft. The floodplain in Reach 4 is approximately 3 to 4 ft above the bed and adjacent terraces are 10 to 15 ft above the channel bed.

Pools

All five pools in Reach 4 were greater than 3 feet deep (Figure 20). The average maximum pool depth was 5.3 feet (st.dev. 0.6). The average residual pool depth was 3.8 feet, and the average pool tail crest depth was 1.6 feet. Substrate observed in pools was gravel with sand.

Figure 20: Maximum Pool Depths in Reach 4.



Riffles, Flatwaters & Cascades

In Reach 4, the average depth of riffles was 1.2 feet, 1.3 feet in flatwaters, and 0.9 feet in cascades. The bed material in Reach 4 ranges from sand to small cobbles, but is primarily composed of coarse to very coarse gravel. Gravel and some sand make up the majority of the channel bed in the pools and flatwaters and the riffles are composed primarily of gravel with a few small cobbles. In cascades, most of the substrate was boulders with large cobbles. The dimensions of the riffle downstream of the upper check dam, where the pebble count was conducted (D256), partly resembled a flatwater. The median grain size of the riffle below the most upstream check dam was 31 mm, coarse gravel (Figure 21). The frequency of fine sediment was 1%. 89% percent of the surface substrate was within ideal spawning sizes for coho and steelhead (11.4 to 128 mm), and 49% was within ideal juvenile rearing clast sizes (32 to 128 mm).

Figure 21: Grain size distribution for riffle below the most upstream check dam (habitat unit #256).

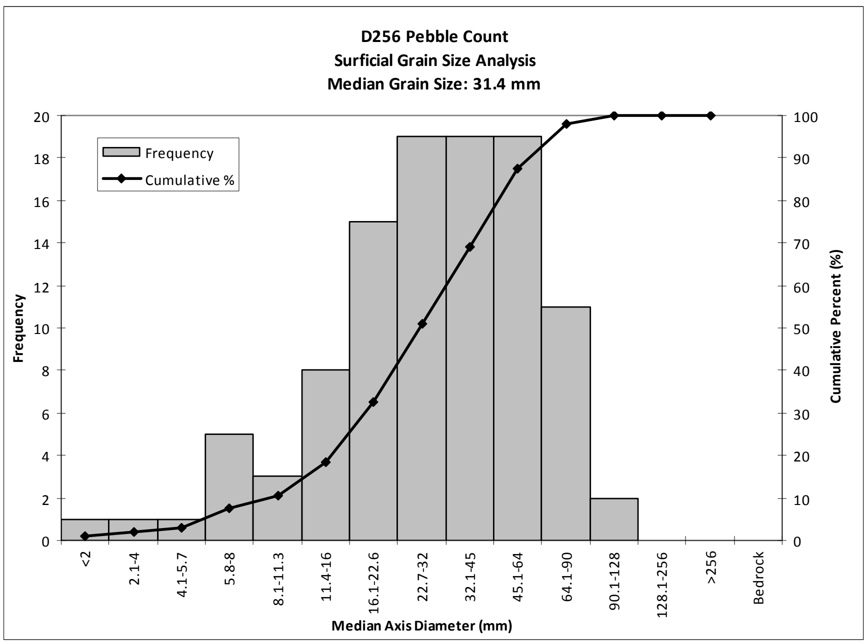


Figure 22: (upper left) long pool above upper sill, (upper right) alcove off upper sill, (lower left) side-channel habitat, (lower right) aquatic vegetation in alcove near middle sill.

Side-Channels

In Reach 4, three side channels were observed. Two of the side-channels were on the right side between the upper and middle sills, each with a pool in the middle and riffles and their entrances and exits. Their average depths were 0.5 and 0.7 feet. The third size-channel occurred where the creek split around an island downstream of the middle sill. The left channel, which was primarily flatwater habitat, was slightly smaller than the main channel to the right, with an average depth of 1.5. Substrates observed in side channels were classified as gravel with small cobbles and sand.

Alcoves

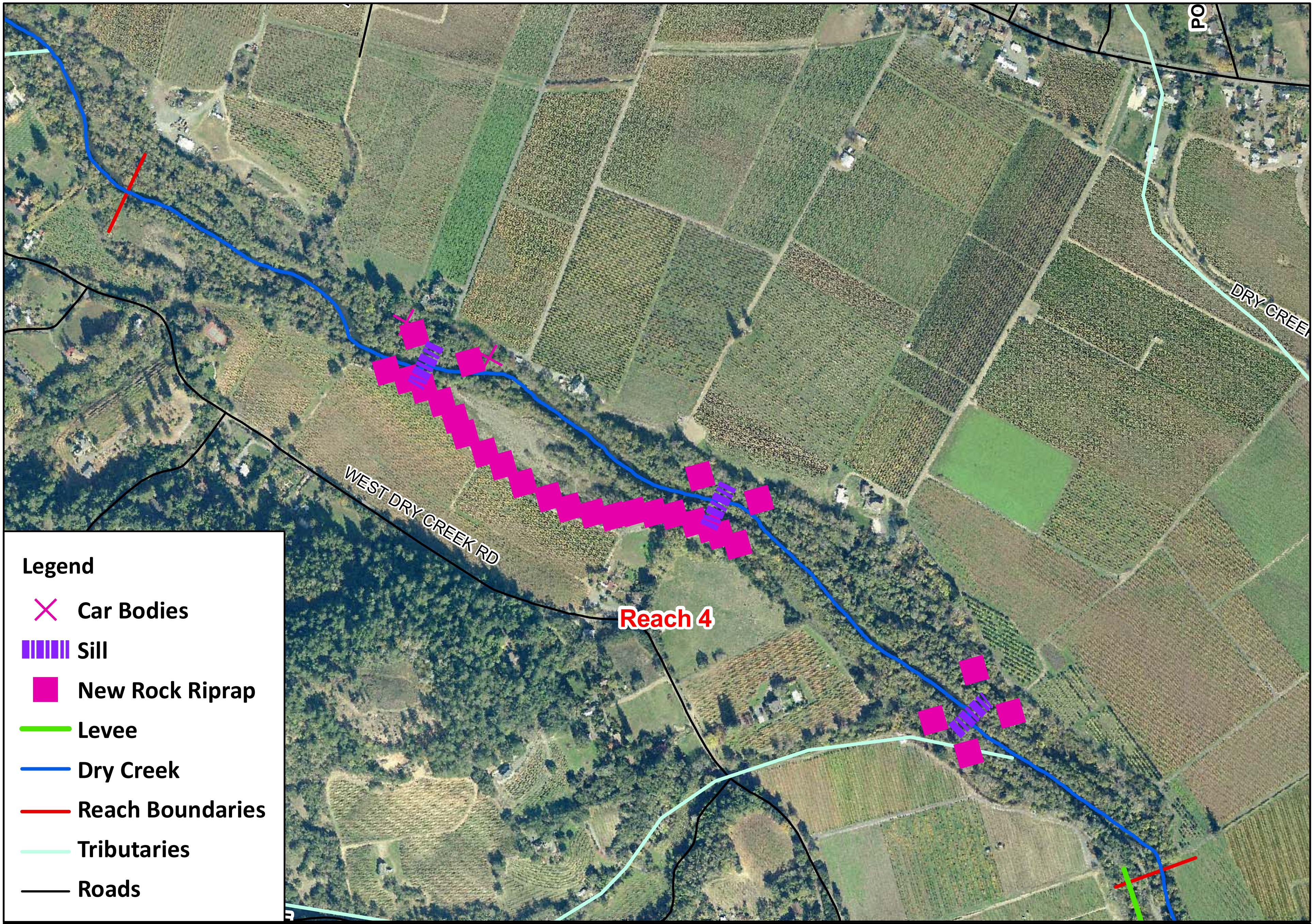
There were eight alcoves in Reach 4. Several were associated with the areas around the sills. There were two alcove pools on the right side of channel near the middle sill, with one upstream and the other downstream of the structure. The average maximum depth of the alcoves was 1.7 (st.dev. 0.9), with only one over three feet deep. Substrate in the alcoves was fine sediment and gravels with sand.

Instream Cover & Woody Debris

Overall, Reach 4 contained 185 pieces of wood per mile, with the greatest densities in pools, riffles, and side channels. Eight of the fifteen large pieces of wood were found in pools. The cascade and alcove habitats had more instream shelter and cover than ,riffles, and flatwaters. The side-channels in Reach 4 offered lower than ideal instream cover. Cover was provided in pools by terrestrial vegetation and small woody debris. In riffles, most cover was provided by woody debris, and secondarily by root masses and overhanging vegetation. In flatwaters, overhanging vegetation and root masses provided cover, along with some small woody debris. In cascades, cover was provided by boulders, with some overhanging terrestrial vegetation. Cover in alcoves was mainly provided by aquatic vegetation, with root masses, terrestrial vegetation, and some small woody debris. In side-channels the limited cover was mainly provided by small woody debris and root masses. Edge habitat was present in 5 pools, 5 flatwaters, and the majority of side-channels and alcoves.

Table 4: Instream woody debris, cover, and edge habitat frequency for Reach 4.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	145.3	66.6	10.6	222.5	38%	114	60%
Riffles	168.8	61.4	15.3	245.6	12%	26	0%
Flatwaters	88.8	15.7	7.8	112.3	16%	37	70%
Cascade	0	0	0	0.0	50%	100	0%
Side Channels	196.1	90.5	30.2	316.8	12%	23	67%
Alcoves	138.8	36.2	12.1	187.1	43%	101	75%
	mainstem wood pieces/mile			184.9			



0 500 1,000 Feet

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Reach 4 Features

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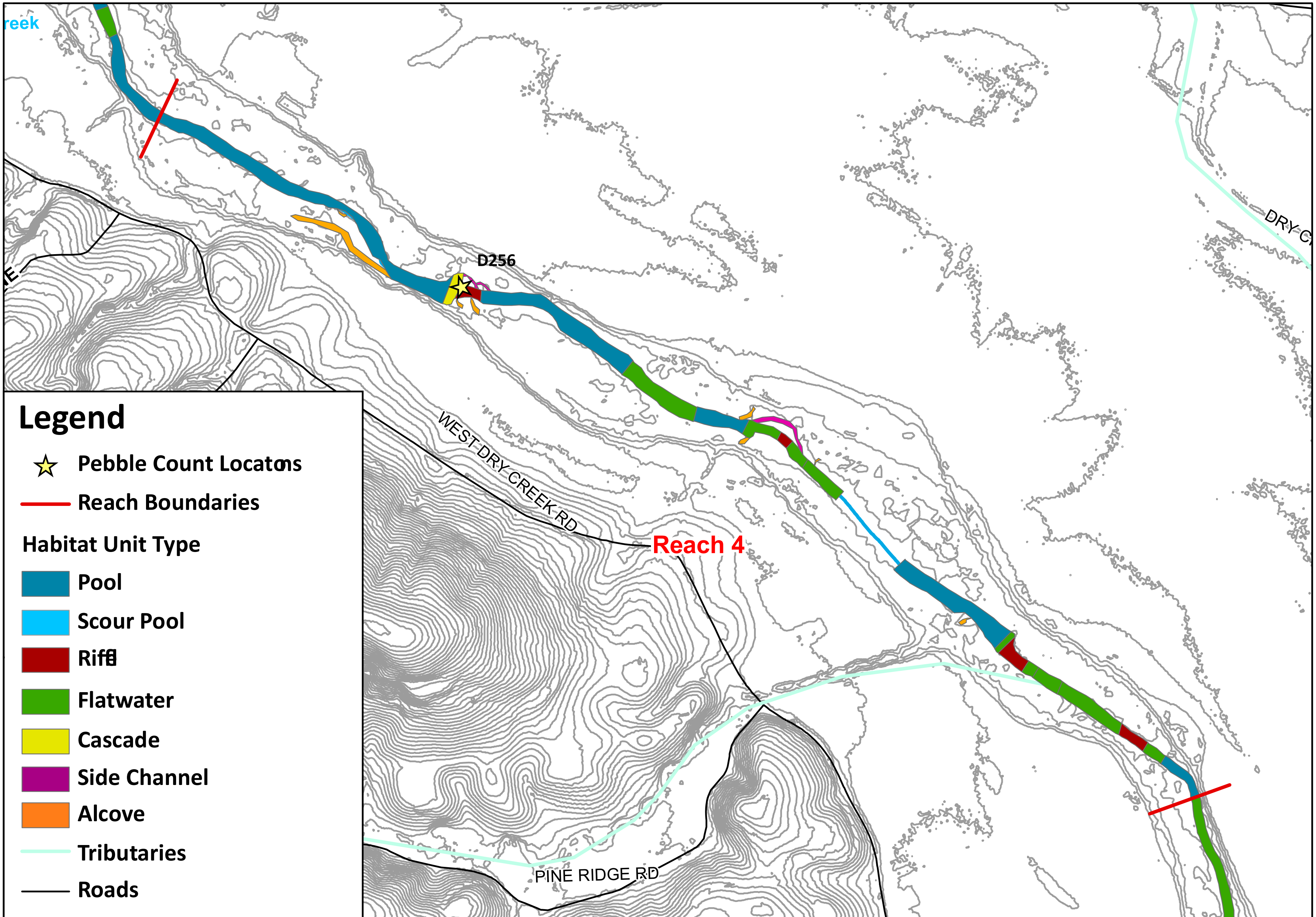

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Feet

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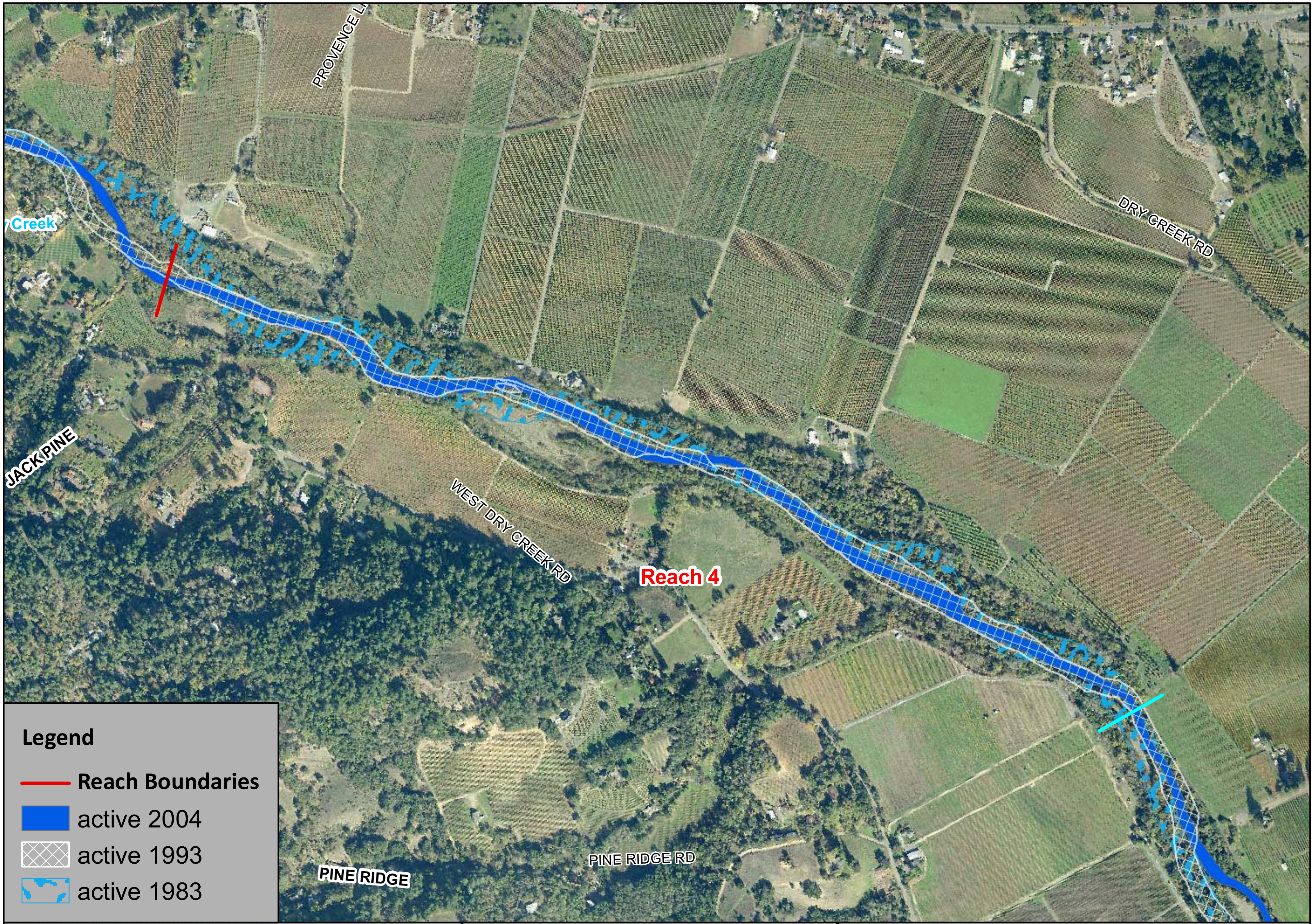

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Reach 4 - Channel Positon Map

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REACH 5 (RM 4.1 to RM 5.4) **Kelley Creek and Hidden Concrete Slabs, upstream of the sill-influenced pool to the end of the adjacent fault lineament**

A fault lineament runs along most of Reach 5, which is a single-thread channel extending upstream from the upper check dam pool to river mile 5.4, just upstream of where the channel diverges from the lineament. It is a fairly straight reach composed of long pools, with two tributary junctions. Kelley Creek enters Reach 5 at on the right[3] bank at river mile 4.3 in the lower end of the reach. Upstream from the Kelley Creek junction, an unnamed tributary enters Dry Creek on the left bank at river mile 4.6. The mouth of Kelley Creek is covered in fine sands with small gravels (Figure 23). The unnamed tributary is steep and dry, except for mouth. 20 feet up the unnamed creek channel from its confluence, a 3 foot nick point was observed. The riparian zone in this reach is narrow, especially upstream of the two tributaries.

Figure 23: (left) mouth of Kelley Creek, (right) mouth of unnamed tributary.

The channel has narrowed since the earliest aerial photographs in 1942, but there has been little channel migration upstream from the unnamed tributary at approximately river mile 4.6. The 10 to 15-ft terraces relatively close to the channel banks limit the degree of channel migration. Also limiting channel migration are the bank stabilization projects that have been implemented, particularly the concrete slabs lining both banks in the upper half of this reach. Even with these channel modifications, bank and terrace erosion does occur as was observed at river mile 4.55 where the channel meanders east.

Downstream from this unnamed tributary junction at river mile 4.6, the influx of water and bed load from the unnamed tributary on the left bank and Kelley Creek on the right bank has likely resulted in the frequent channel changes that have occurred in the last three decades.

[3] In the individual reach summaries, right and left bank designation defined as looking downstream.

Habitat Classification

Reach 5 is primarily composed of flatwaters (58%) and pools (25%) with a few riffles (16%) by relative frequency, Figure 24). Riffles represent only 6% of this 1.3 mile-long reach on a length basis. The wetted width at the time of the survey was 48 ft. There are five riffles ranging in length from 45 to 90 ft.

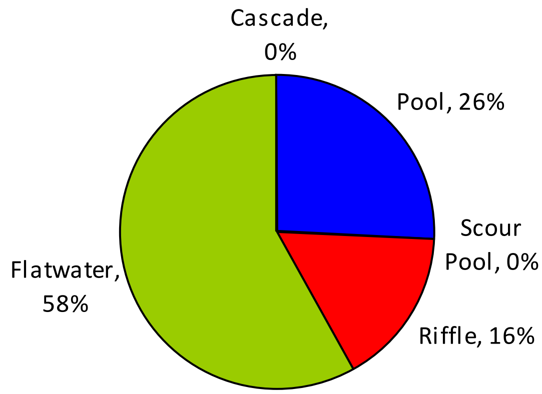


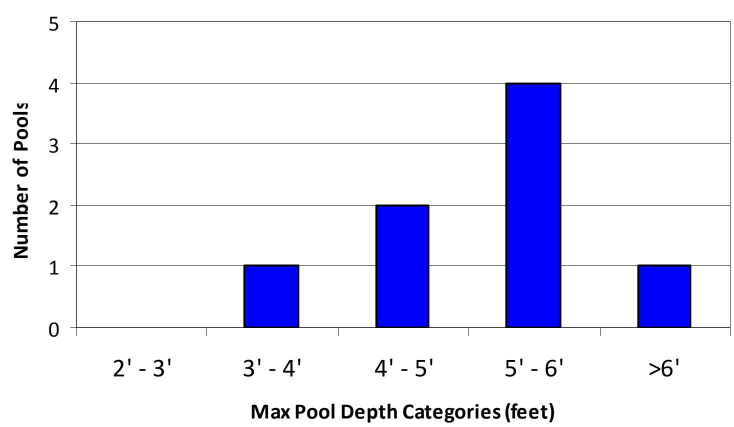
Figure 24: Proportion of Habitat Types by Relative Frequency in Reach 5

Reach 5 is typified by plane-bed morphology with long flatwaters and an entrenched floodplain (Montgomery and Buffington, 1997). The average active channel width was 69.0 feet, the active channel depth 1.8 feet, and the average floodprone with was 86.5 feet. With a active channel width:depth ratio of 39 and an entrenchment ratio of 1.25, Reach 5 resembles an "F4" channel type (Rosgen 1996).

Pools

There were 8 pools in Reach 5 with an average maximum depth of 4.9 feet (stdev 0.9). All pools in Reach 5 were greater than 3 feet deep (Figure 25). The average residual pool depth was 3.4 ft, with an average pool crest depth of 1.5 ft. Substrate in pools was gravel with sand.

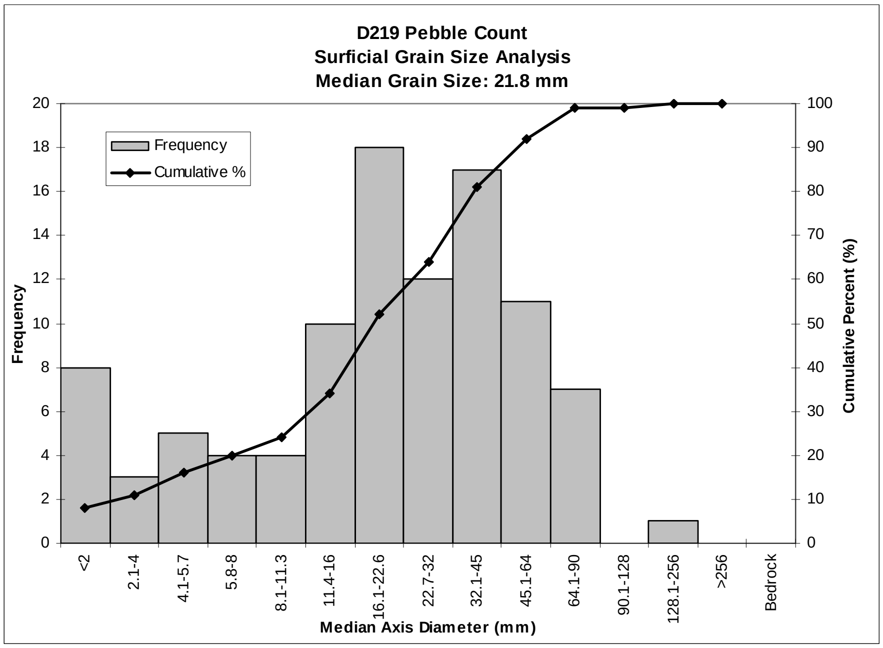
Figure 25: Maximum Pool Depths for Reach 5.

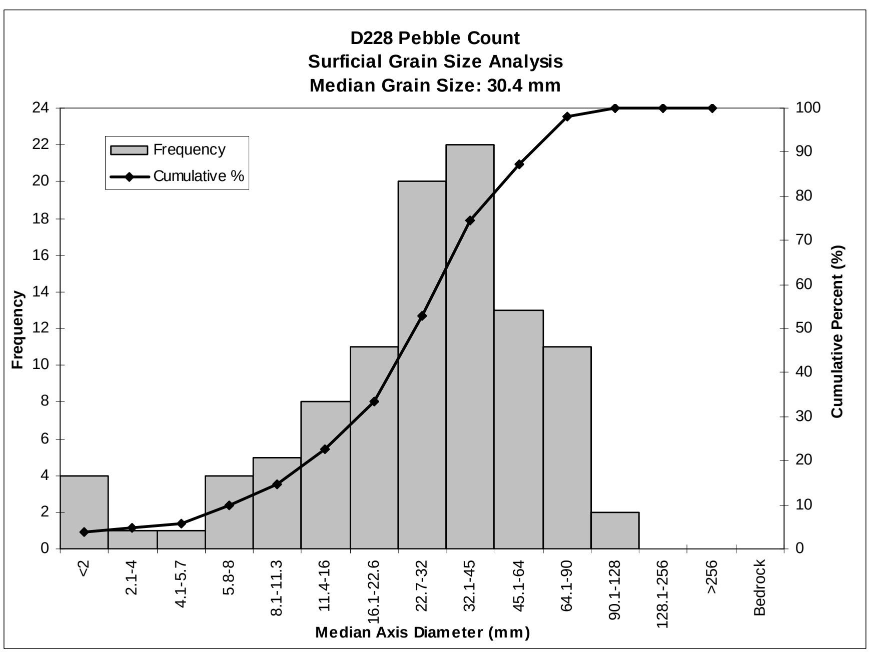


Riffles & Flatwaters

The average depth of riffles in Reach 5 was 1.0 feet, and the average depth of flatwaters was 1.5 feet. The bed material in this reach is primarily gravel with some sand in the pools and small cobbles in the flatwaters and riffles. Two pebble counts were conducted in riffles within Reach 5, both upstream of Kelley Creek. The riffles are primarily composed of coarse to very coarse gravel with median grain sizes of 22 and 30 mm (Figure 26). 4% and 8% of the substrate was sand/fine sediment (<2mm). 80% was coho and steelhead spawning gravel (11.4 to 128mm), and 42% was ideal juvenile rearing size (32 to 128 mm).

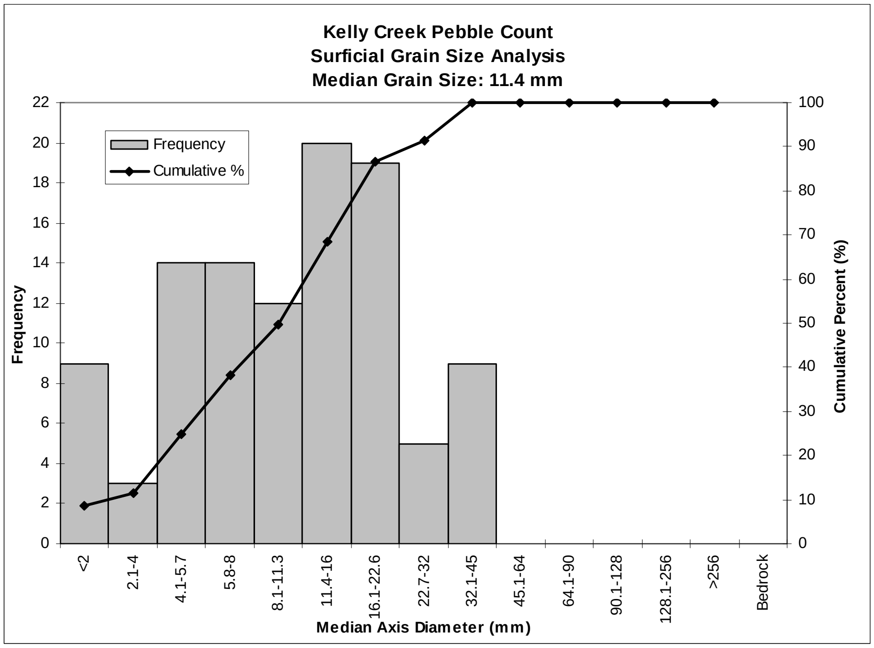
Figure 26: Grain size distribution of two riffles in the stable section of reach 5 upstream of both tributaries (habitat units #219 and 228).





The bed material in Kelley Creek is primarily fine to medium gravel but ranges from sand to very coarse gravel. The median grain size near the mouth of Kelley Creek is 11 mm, medium gravel (Figure 27). The smaller grain sizes being discharged by Kelley Creek are likely transported readily during higher flows on Dry Creek.

Figure 27: Grain size distribution for the channel bed of Kelley Creek near its confluence with Dry Creek.



Side-Channels

There was one short, riffle-dominated side channel in Reach 5. It was 60 feet long, 12 feet wide, with an average of 0.5 feet deep. Observed substrate was gravel with small cobble.

Figure 28: (left) riffle habitat unit, (right) long, deep pool with woody debris.

Alcoves

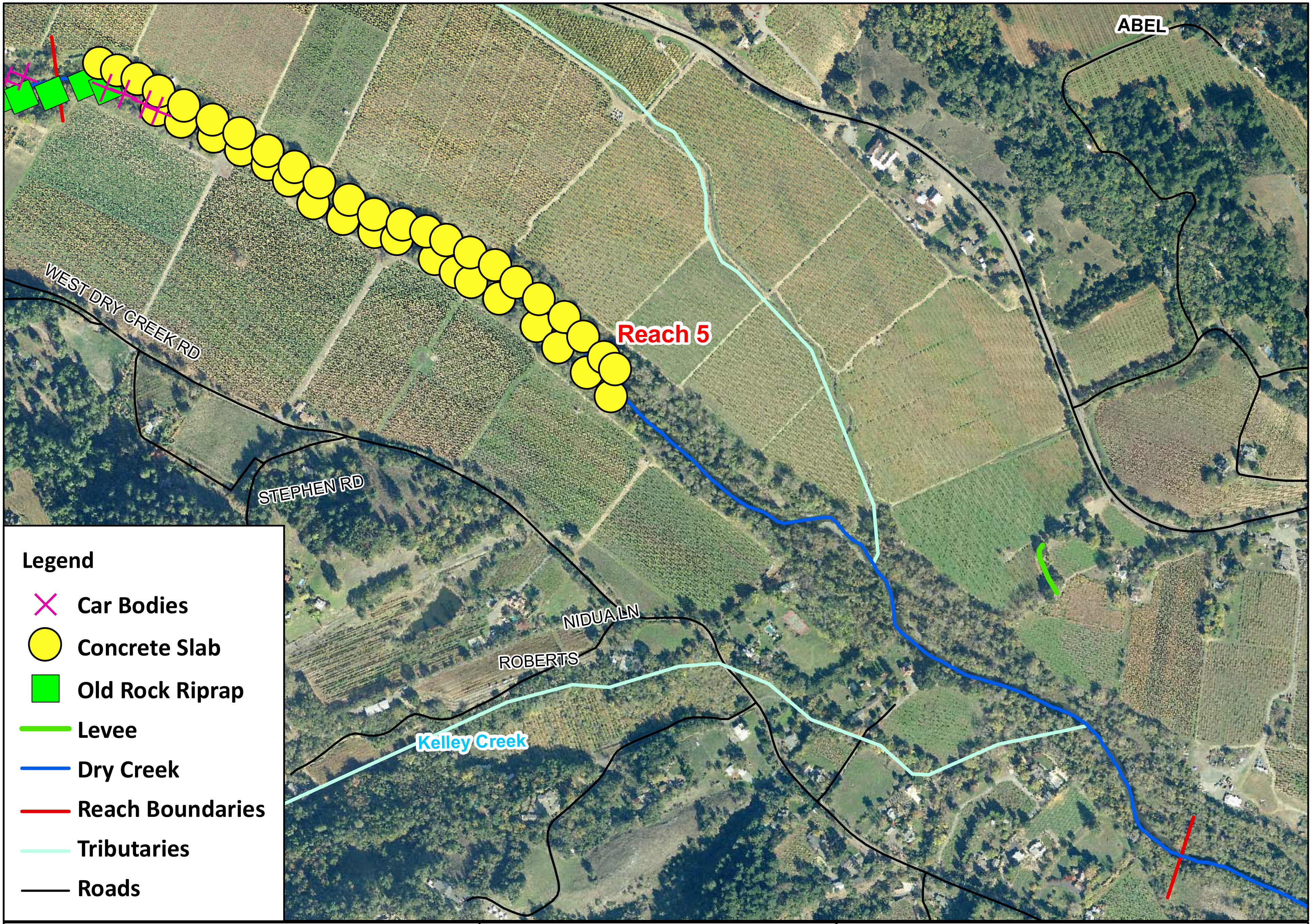
There are two medium-sized alcoves in Reach 5, one was 45 by 5 feet and 0.5 feet deep, and the other was 60 by 10 feet and 1.5 feet deep. Observed substrate was fine sediment with gravels.

Instream Cover & Woody Debris

In Reach 5, there were an average of 234 pieces per mile of wood in the mainstem channel (Table 5). Overall, pools contained the highest densities of wood pieces, followed by side channels and alcoves. Out of 20 large wood pieces (>20" diameter) counted, sixteen were found in mainstem pools. Cover was provided by terrestrial vegetation and small woody debris, with some root mass cover in riffles and flatwaters, and some cover in alcoves provided by aquatic vegetation. Edge habitat was observed in four flatwaters and six pools, and in the side-channel and alcoves.

Table 5: Instream woody debris, cover, and edge habitat frequency for Reach 5.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	224.8	40.1	26.8	267.1	22%	60	50%
Riffles	103.0	44.1	0.0	147.1	16%	36	0%
Flatwaters	166.3	35.3	12.6	214.2	26%	69	33%
Side Channels	264.0			264.0	20%	40	100%
Alcoves	150.9	50.3		201.1	55%	165	100%
	mainstem pieces/mile			233.9			



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Reach 5 Features

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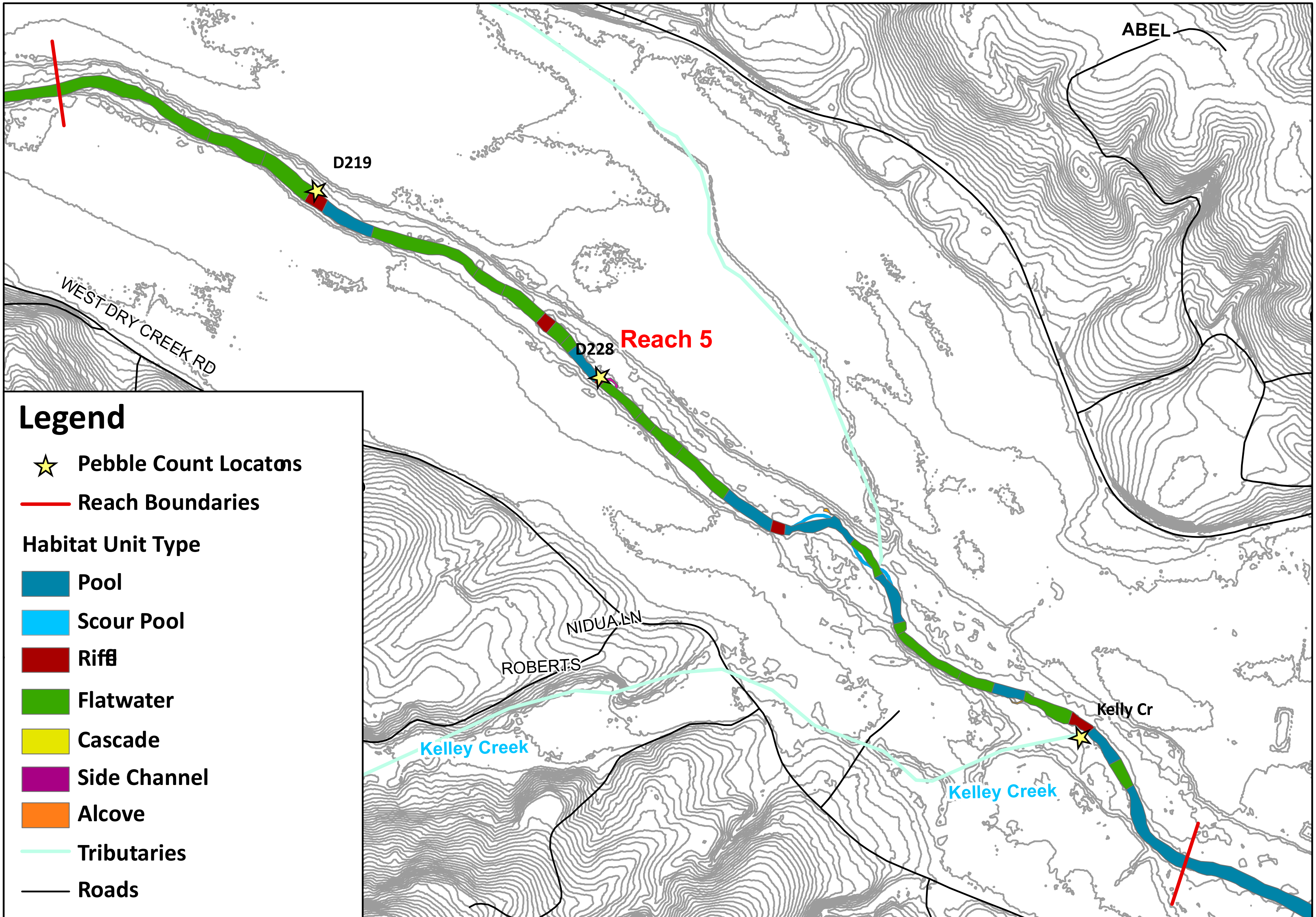

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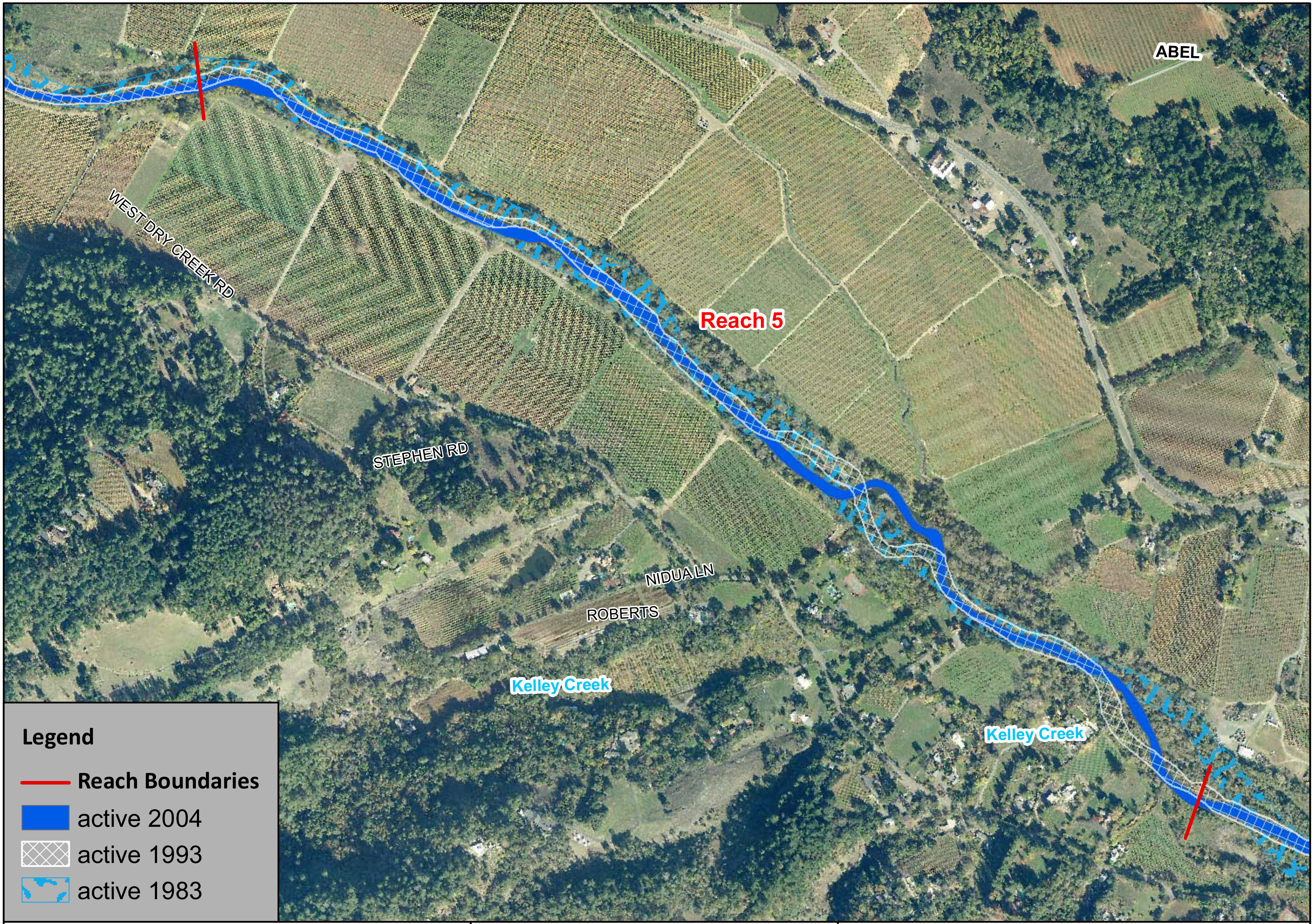

N E S W

0 500 1,000 Feet

DRY CREEK
Reach 5 - Channel Positon Map

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REACH 6 (RM 5.4 to RM 6.2) **Moderately confined from the end of fault influence to the first bedrock outcrop**

Reach 6 is a single-thread channel that has narrowed over time but has not experienced substantial amounts of channel change. It extends upstream from reach 5 to river mile 6.2, about 500 ft downstream from the confluence of Crane Creek on the right[4] bank. Access to the floodplain was restricted through much of this reach due to landowner concerns, so information regarding this reach is limited. No tributaries flow into Dry Creek in this reach.

A PIT tag antenna was located in the middle of the reach at the time of the survey (Figure 29). Car bodies and riprap were observed for 500 feet along the streambanks at the downstream end of the reach. The upstream end of this reach terminates at the first visible expression of bedrock in the channel.

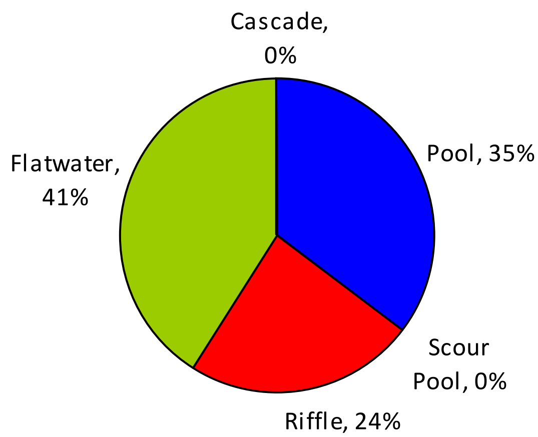
Figure 29: (left) adult fish monitoring station, (right) scour pool.

Habitat Classification

By relative frequency, Reach 6 is composed of 35 % pools, 41% flatwaters, and 24% riffles (Figure 30). Riffles range in length from 60 to 120 ft and account for 12% of the main channel on a length basis. The average wetted width at the time of the survey was 49 ft.

It was plane-bed morphology with an low gradient, with four of the seven pools longer than 300 feet long. Due to concerns over landowner permissions, no active channel or floodprone measurements were made.

Figure 30: Proportion of Habitat Types by Relative Frequency in Reach 6

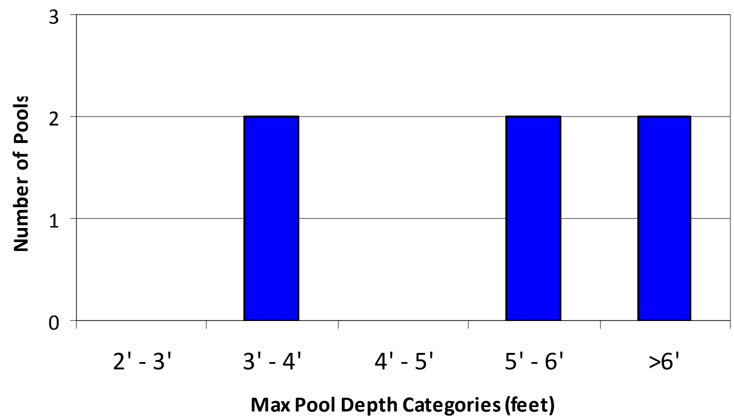


[4] In the individual reach summaries, right and left bank designation defined as looking downstream.

Pools

The average maximum pool depth was 5.5 (stdev. 1.8), and average residual pool depth was 4 feet. All of the six pools were greater than 3 feet deep (Figure 31). Substrate in pools was gravel with sand and some small cobble.

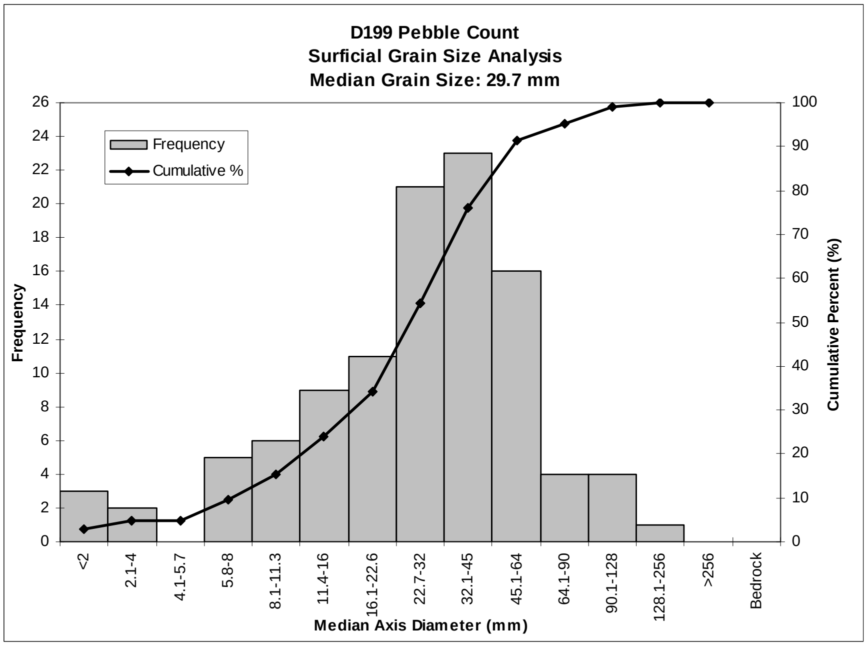
Figure 31: Maximum Pool Depths in Reach 6.



Riffles & Flatwaters

The average depth of riffles was 0.9, and the average depth of flatwaters was 1.5. Bed material in Reach 6 is primarily gravel with some sand in the pools and small cobbles in the flatwaters and riffles. The bed material in the riffle at the upstream extent of the reach ranges from sand to large cobbles but is primarily coarse to very coarse gravel. The median grain size is 30 mm, coarse gravel (Figure 32). The majority of samples fell within the very coarse gravel and coarse gravel size categories. 84% of the substrate was within desirable size classes for coho/steelhead spawning (11.4 to 128mm), and 45% fell within desirable sizes for juvenile rearing (32 to 128mm). 3% of the samples were fine sediment and sand (<2mm).

Figure 32: Grain size distribution for riffle about 500 ft downstream from Crane Creek (habitat unit #199).



Side-Channels & Alcoves

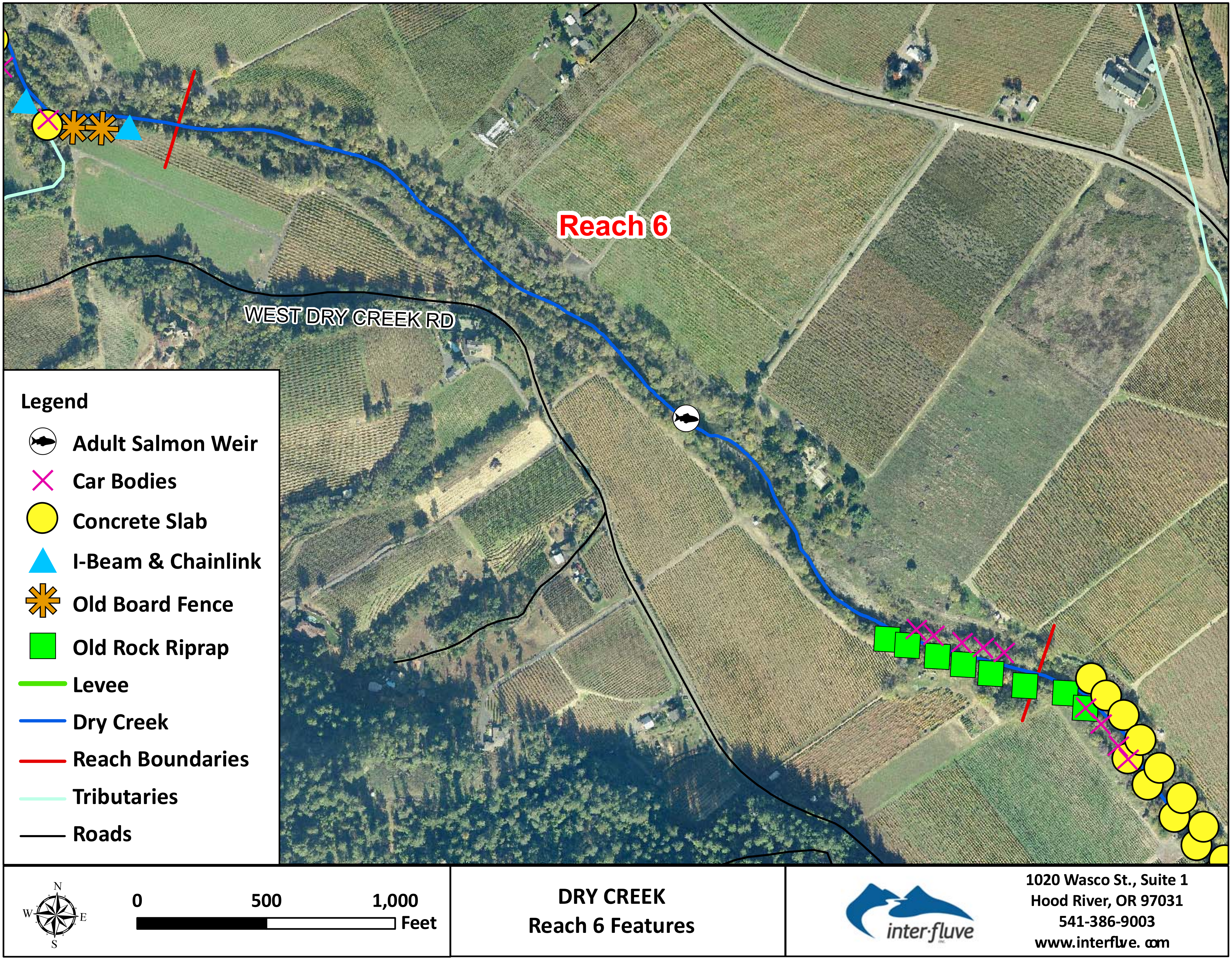
There were no side-channels or alcoves observed in Reach 6.

Instream Cover & Woody Debris

There were 196 pieces of wood per mile in Reach 6 (Table 6). The highest density of wood was found in pools, and 8 out of the 14 large wood pieces (>20" diameter) in Reach 6 were also found in pools. Most of the cover was provided by terrestrial vegetation and small woody debris, with some cover provided by large woody debris and root masses. Edge habitat was present in two pools and three flatwaters.

Table 6: Instream woody debris, cover, and edge habitat frequency for Reach 6.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	123.1	25.5	17.0	165.5	35%	98	33%
Riffles	72.8	10.4	20.8	103.9	16%	31	0%
Flatwaters	204.8	72.8	22.8	300.4	17%	47	43%
	mainstem pieces/mile			195.6			



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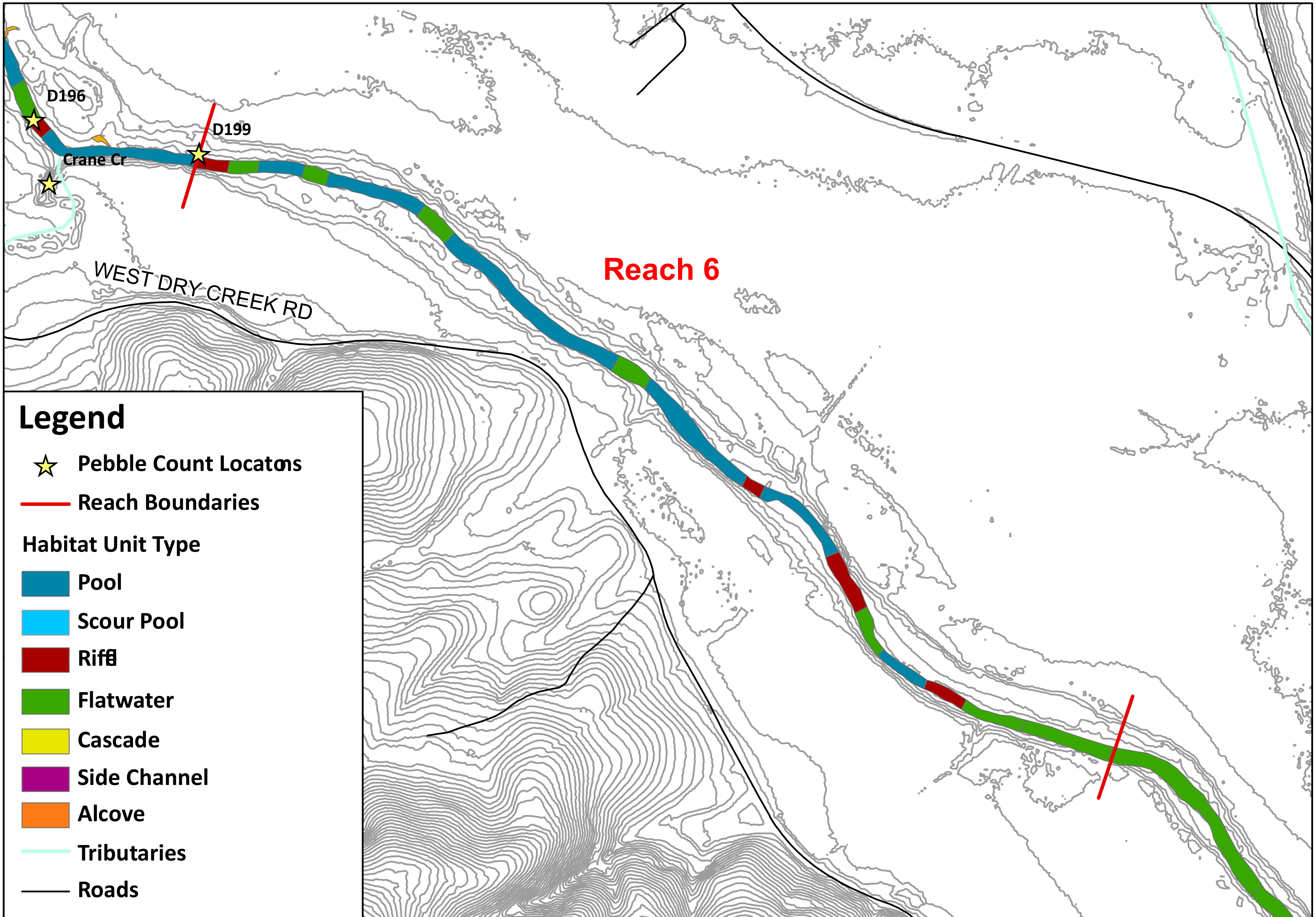

N S E W

0 500 1,000 Feet

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N
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REACH 7 (RM 6.2 to RM 7.5) **Crane Creek to Grape Creek, from the beginning of Bedrock Outcrops to the end of Bedrock Outcrops**

Reach 7 extends upstream from below Crane Creek to about 1000 ft upstream of Grape Creek at river mile 7.5. Two important tributaries, Grape Creek and Crane Creek, enter Reach 7 at river miles 7.2 and 6.3, respectively. Crane Creek is a steep, deeply incised tributary with exposed bedrock at its mouth and compacted sands and gravel on its steep banks. A mapped, unnamed tributary enters Dry Creek at river mile 6.6, but was not noted in the survey. A valley landmark, Lambert Bridge, crosses Dry Creek at river mile 6.6.

Multiple bedrock outcrops are visible along the channel bed in this reach and the reach boundaries were located to encompass all of these outcrops. Though the channel has narrowed as it has incised through this reach, there have been only minor amounts of channel migration since the 1940s. The channel is more sinuous than downstream, but the riparian corridor is narrow, and there is little room for substantial channel migration. Although the riparian corridor is narrow through this reach there is some room for habitat enhancement upstream from Crane Creek and downstream from Grape Creek where minor channel changes have occurred historically.

Figure 33: (upper left) cascade under Lambert Bridge, (upper right) mouth of Crane Creek, (lower left) bedrock outcrop, (lower right) riffle where Grape Creek enters Dry Creek.

Substantial incision has occurred through this reach, but the bedrock outcrops have limited further degradation. The most apparent bedrock outcrop is the bedrock cascade under the Lambert Bridge, but there are also outcrops at river mile 6.4 between the unnamed tributary and Crane Creek, at the mouth of Grape Creek and upstream of Grape Creek. These occasional bedrock extrusions provide cover for fish, influence pool formation, and control stream gradient. Despite the bedrock outcrops, the dominant substrate is gravel, followed by sand.

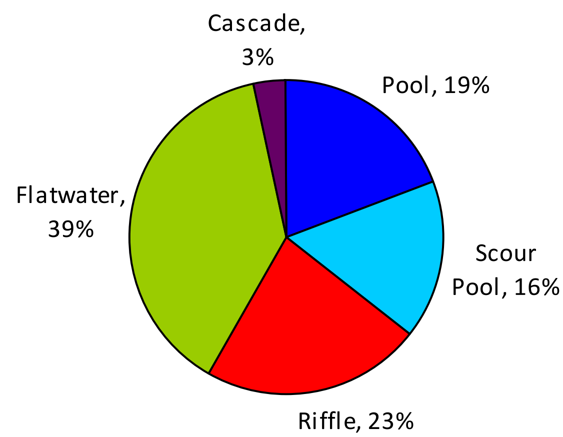
Bank stabilization efforts in Reach 7 include boulder riprap, old cars on the banks, concrete slabs, I-beam and chain link fence, and old board fence protecting banks just downstream of Crane Creek on the right bank. At river mile 7.0, eight large boulders have been placed in a triangle formation in the center of a cobble-gravel flatwater. The cascade under Lambert Bridge is made up of bedrock, boulders, and chunks of concrete, with an approximate 2’ drop. An 8’-high eroding streambank is exposed along outer bend of at river mile 6.4.

Figure 34: (upper left) Failed I-beam and chainlink fence stabilization efforts, (upper right) car bodies in the banks, (lower left) erosion along an outside bend, (lower right) a triangular boulder cluster in Dry Creek.

Habitat Classification

Reach 7 contains 35% pool habitat, 39% flatwater, 23% riffle, and 3% cascade (under Lambert Bridge) by relative frequency (Figure 35). Riffles represent only 10% of the 1.3 miles of main channel on a length basis. There are a few side channels and alcoves, one cascade and seven riffles ranging in length from 50 to 60 ft.

Figure 35: Proportion of Habitat Types by Relative Frequency in Reach 7



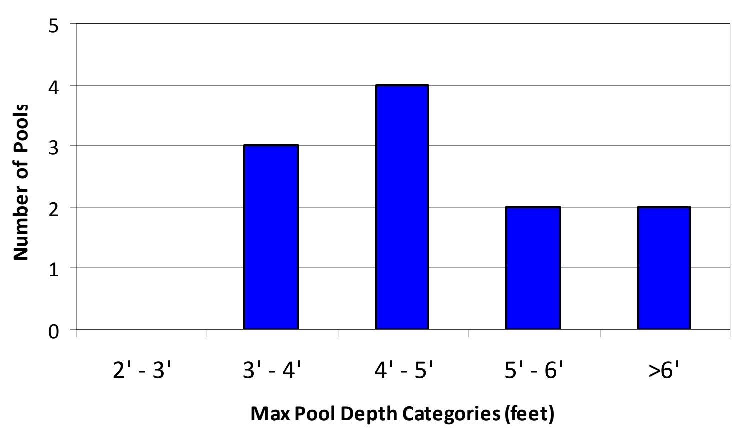
The average wetted width during the survey was 48 ft and the active channel and flood prone widths are 58.5 and 81 ft respectively. The average active channel depth was 2.5 ft. Adjacent terraces are about 10 ft above the channel bed.

Reach 7 is an F-type channel, due to its entrenched floodplain and a moderate-to-high width:depth ratio. However, in some segments of Reach 7, erosion, avulsion, and deposition are evidenced by a number of high quality alcoves, side-channels, and gravel bars and by creative bank stabilization efforts using I-beams, old cars, and boulder riprap.

Pools

The average maximum mainstem pool depth in Reach 7 was 5.4 feet (st.dev. 1.3), and the average maximum scour pool depth was 4.1 feet (st.dev. 0.4). Within Reach 7, a number of deep scour pools are associated with woody debris. All 11 pools are greater than 3 feet deep (Figure 36). Several of the pools include flatwaters shorter than a wetted channel width. In some areas, the water pools in the bedrock. The average residual pool depth was 3.5 ft., and the average pool crest depth was 1.4 ft. Ocular estimates of substrate identified gravel with sand covering the streambed in pools.

Figure 36: Maximum Pool Depths in Reach 7.

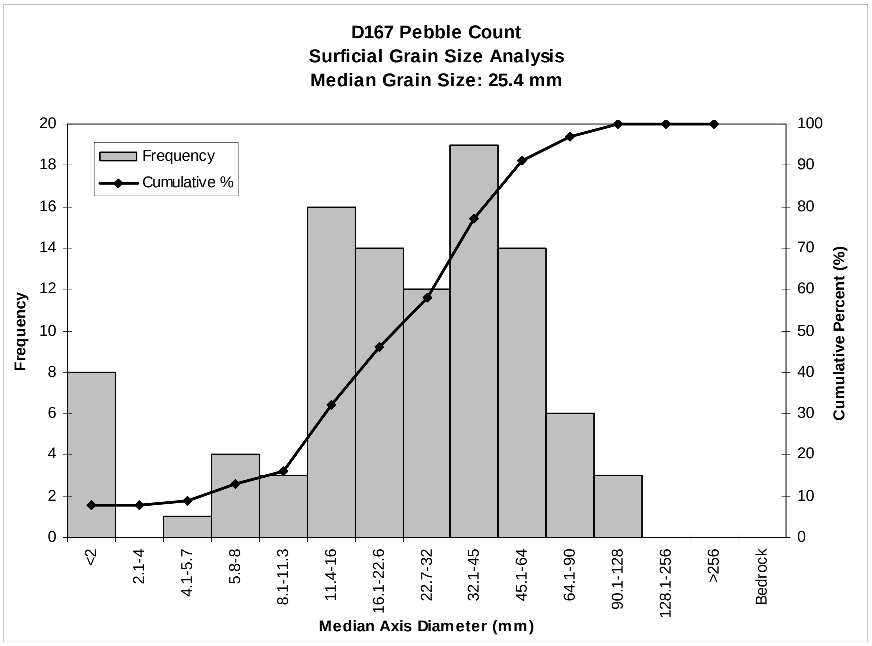


Riffles, Flatwaters & Cascade

The average depth is 1.0 feet for riffles, and 1.4 feet for flatwaters. The bed material through reach 7 is primarily gravel with some sand in the flatwaters and pools and small cobbles in the riffles. Riffles are primarily composed of coarse to very coarse gravels with material ranging from sand to small cobbles. Bedrock composed most of the bed material in the cascade and was identified in a few other locations through the reach. The single cascade under Lambert Bridge was bedrock-based, with boulders.

Pebble counts were conducted in four riffles in Reach 7, as well as in the mouths of Grape Creek and Crane Creek. The median grain size of four sampled riffles ranged from 16 to 30 mm (Figure 37). Most samples were medium gravels through very coarse gravels. 80% of all samples were within desirable coho/steelhead spawning sediment sizes, and 36% was within juvenile rearing size classes. 5% of the samples were fine sediments or sand (<2mm). A thick biomat of algae was observed to cover the gravel-sand substrate in several flatwaters.

Figure 37: Grain size distribution for four riffles between Grape Creek and Crane Creek.



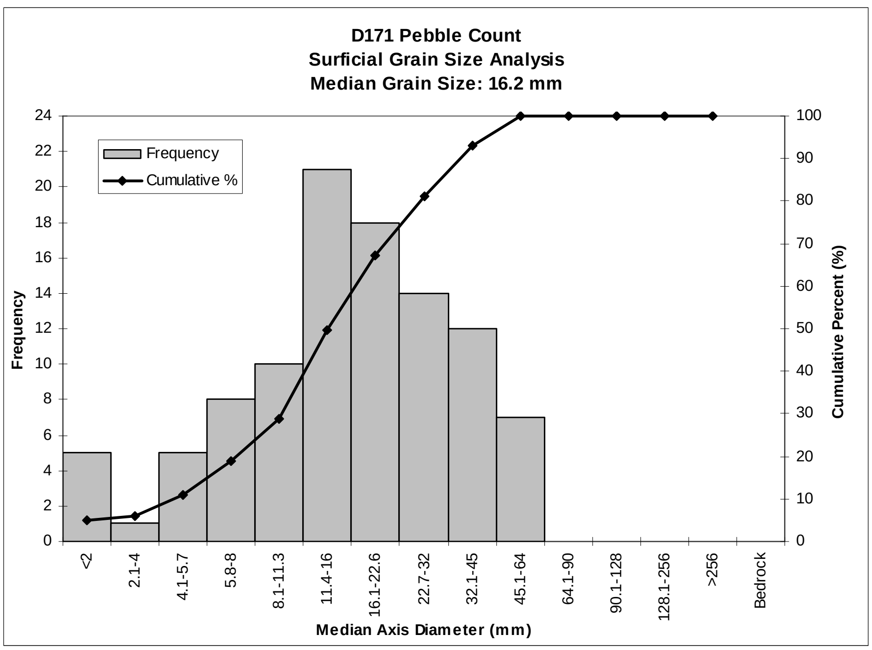
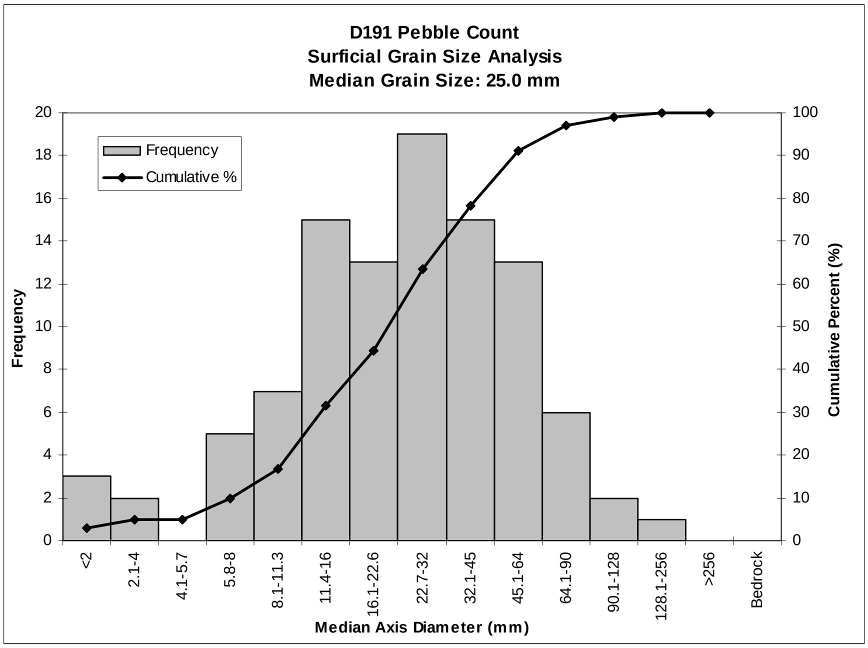
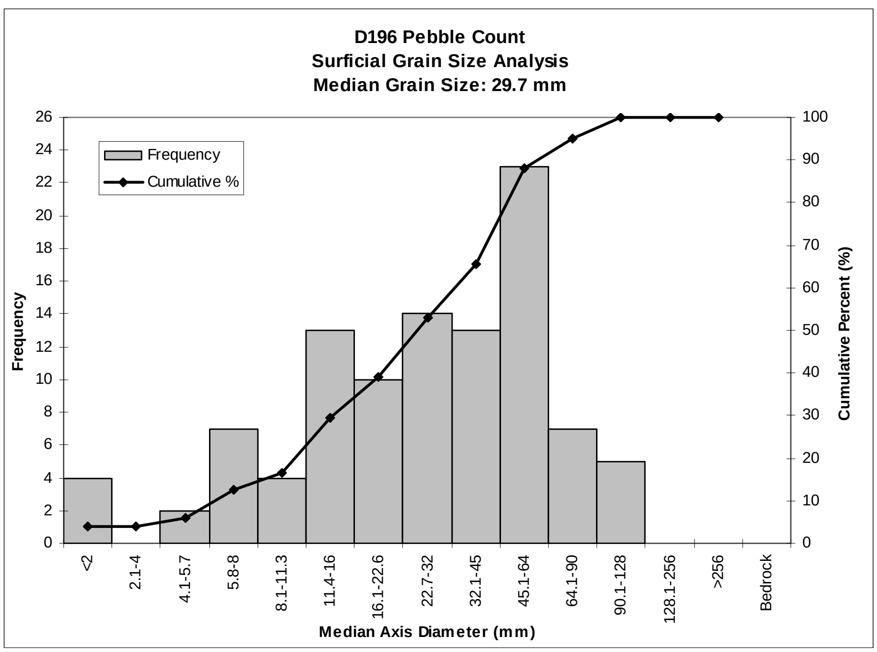


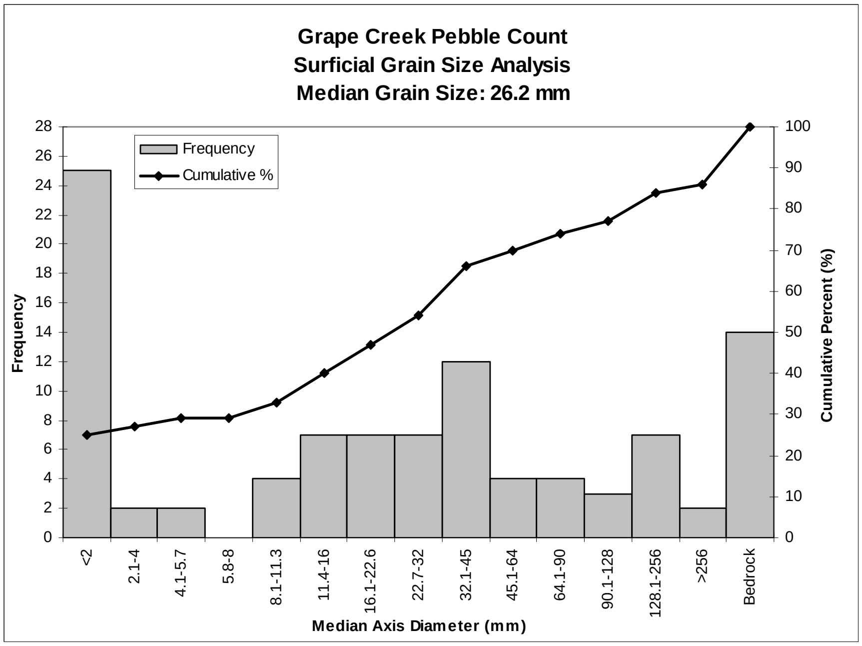
Figure 37, continued: Grain size distribution for four riffles between Grape Creek and Crane Creek.

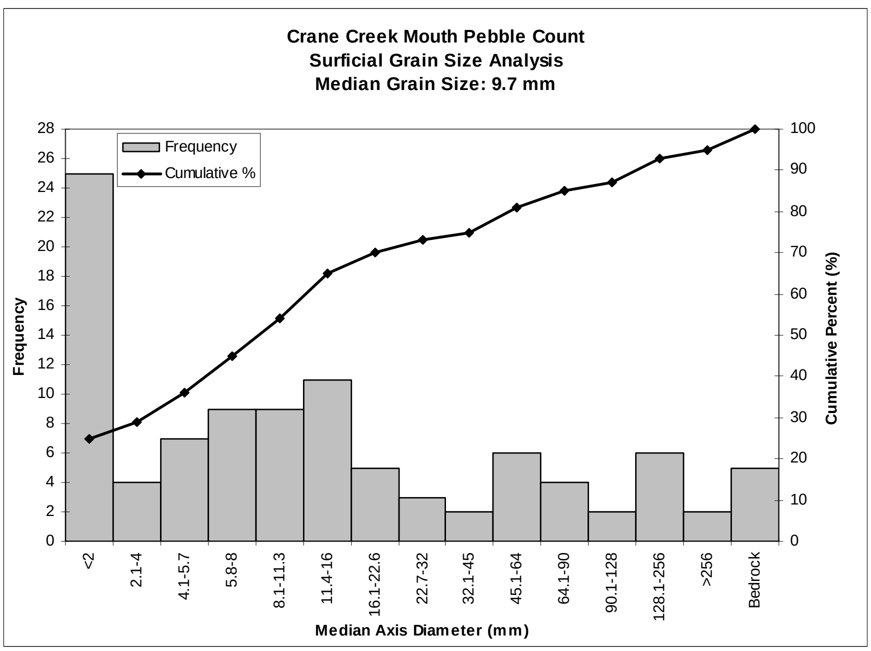




The bed material in Grape Creek is variable, ranging from sand to small boulders and bedrock. Though the median grain size is coarse gravel (26 mm), 25% of the material is sand and 14% is bedrock. The bed material in Crane Creek is similar to that in Grape Creek with 25% being sand and no other size class composing more than 9% of the material. The median grain size of Crane Creek is medium gravel (10 mm) (Figure 38).

Figure 38: Grain size distribution for the channel beds of Grape Creek and Crane Creek near their confluences with Dry Creek.





Side-Channels

Of the three side-channels in Reach 7, two were flatwater dominated and the third was riffle-dominated. The average side-channel depth was 0.8 feet. One of the flatwater-dominated side channels was 530 feet long (Figure 39), and 20 feet wide. This side-channel contained pools and riffles, as well as longer flatwater sections, with gravel with small cobble substrate. The other two side channels were shorter (30 feet and 70 feet long), with bedrock and gravel substrate with sand. The area where Grape Creek enters was very complex, with a long alcove along the left valley wall that serves as a side channel in higher flows.

Figure 39: (left) wood associated with a scour pool, (right) side channel D183.

Alcoves

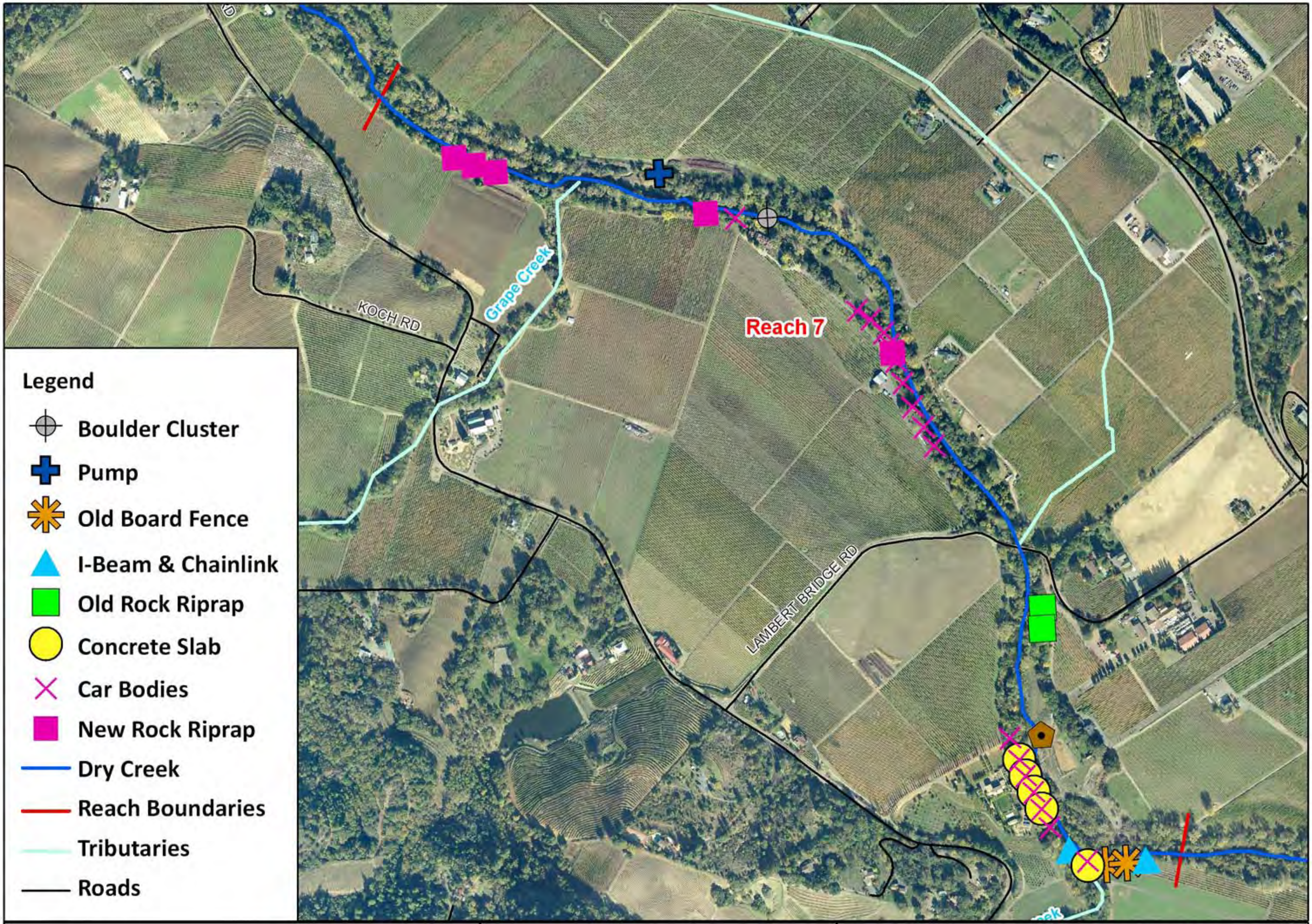
There are eight alcoves in Reach 7. The average maximum depth was 2.0 feet (st.dev. 1.0). Just downstream of Grape Creek, a long 400 foot alcove/canal was dug out and cleaned on the left bank, with an irrigation pump up on the left bank terrace. Substrate in the alcoves was gravel with sand, small cobble, and fine sediments. An additional 25'-long alcove, which was about 5' wide, was observed on the left bank of a scour pool at the head of the reach, but was deemed too small to count as a habitat unit.

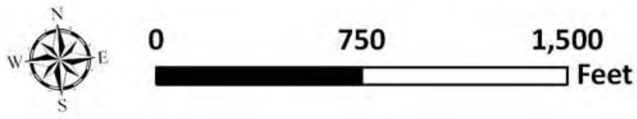
Instream Cover & Woody Debris

There are a total of 287 pieces of wood in Reach 7, with 193 pieces per mile in the mainstem (Table 7). The highest densities of wood were found in pools and riffles, followed by flatwaters, then side-channels and alcoves. 5 out of the 8 large wood pieces (>20" diameter) were found in pools. Cover was provided by overhanging vegetation, terrestrial vegetation growing in the water, and small woody debris, and also by boulders, bedrock, and root masses. Edge habitat was present in 44% of the habitat units.

Table 7: Instream woody debris, cover, and edge habitat frequency for Reach 7.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	162.5	47.9	3.4	213.8	41%	117	50%
Scour Pools	165.6	44.9	10.4	220.9	22%	67	40%
Riffles	129.3	38.0	15.2	182.6	22%	49	29%
Flatwaters	103.0	21.3	0.0	124.4	17%	41	33%
Cascades	0.0	0.0	0.0	0.0	95%	285	100%
Side-Channels	120.9	24.2	0.0	145.1	40%	80	33%
Alcoves	126.7	10.6	5.3	142.6	39%	87	75%
	mainstem pieces/mile			190.5			





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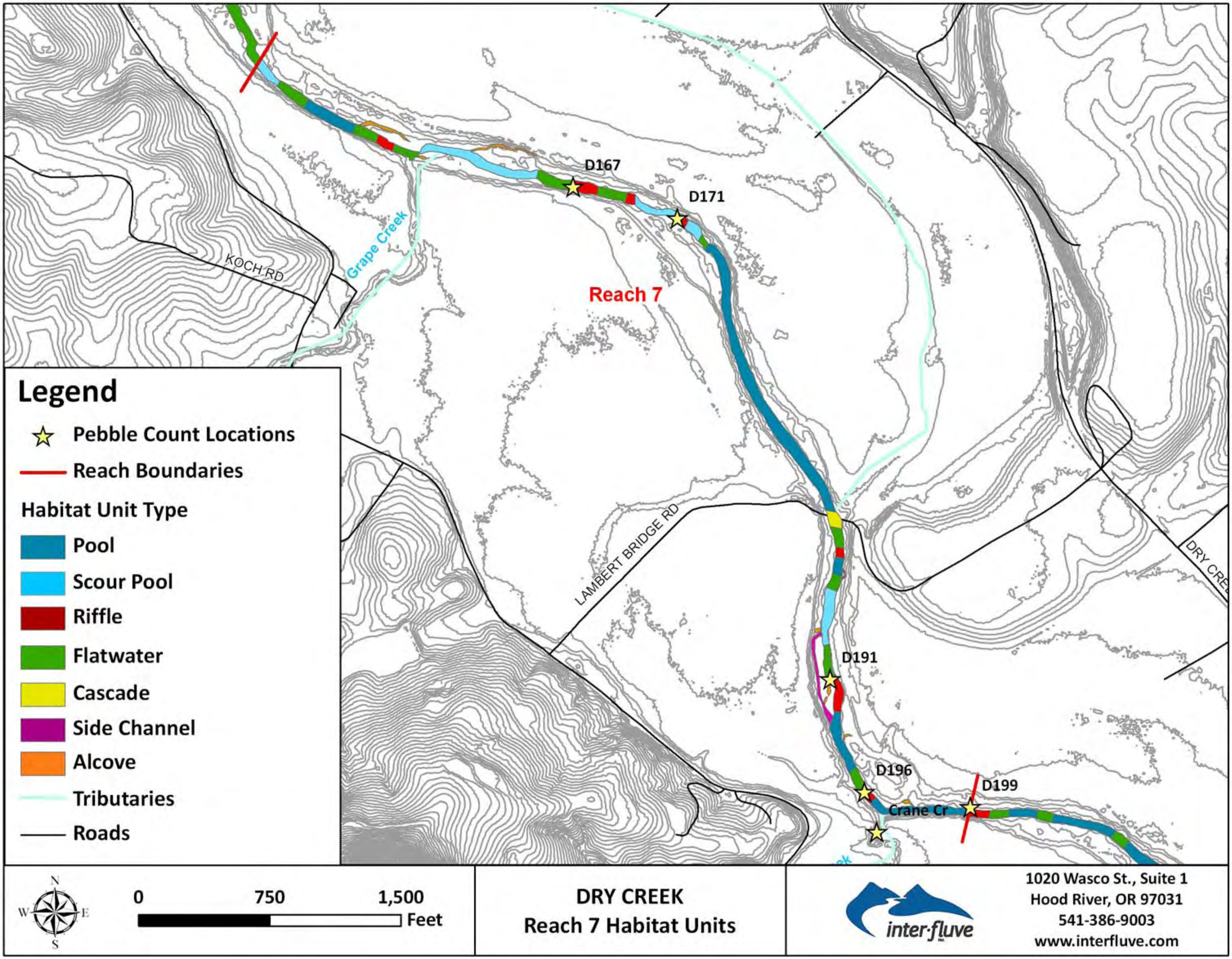

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N W E S

0 600 1,200 Feet

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Reach 7 - Channel Position Map

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REACH 8 (RM 7.5 to RM 9.0) **Moderately Confined with Bank Stabilization Features**

Nearly all of the various types of bank stabilization techniques applied in Dry Creek are present throughout Reach 8 (Figure 40). Approximately 2500 feet of banks are armored with large boulder riprap, some of it including car parts intermingled with the boulders and riprap. An old truckbed is used to stabilize one streambank at river mile 8.8, and a mix of metal pipes, logs, and rocks have been used to shore up another bank at river mile 7.9. Board fence lined 750 feet of the right[5] bank at river mile 8.5. A dry, unnamed tributary enters on the left bank at river mile 8.9.

Reach 8 is a single-thread channel extending 1.5 miles upstream from Grape Creek to river mile 9. The upstream reach boundary location is about 1700 ft downstream from the alignment of the lineament and the channel planform. The channel has incised and narrowed since the 1940s, but the general planform and channel location has remained similar for about half of the reach. Near the upstream reach boundary and the unnamed tributary, as well as between the downstream reach boundary and river mile 8.2, there has been moderate channel migration and changes in planform since the 1940s. Since the dam was built, however, the planform and location of the channel have remained relatively stable. The areas with different channel locations prior to the dam construction have a slightly wider riparian area and the old channels may provide opportunities for habitat enhancement.

Figure 40: Bank stabilization features. (upper left) Board Fence, (upper right) boulder riprap with car parts, (lower left) a truck bed, (lower right) metal poles with logs and rocks.

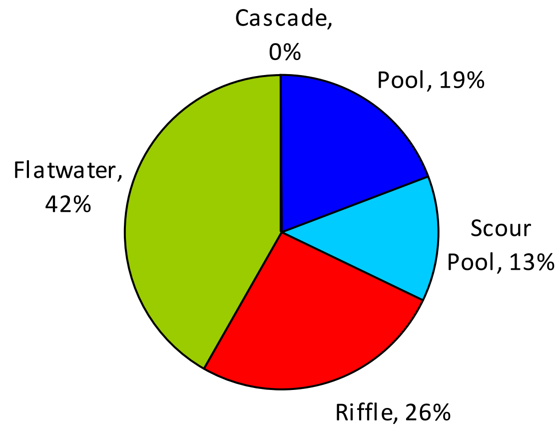
[5] In the individual reach summaries, right and left bank designation defined as looking downstream.

Habitat Classification

The channel in this reach is composed of pools (32%), and flatwaters (42%) and also contains 26% riffles on a frequency basis(Figure 41). The 8 riffles range in length from 50 to 100 ft and account for 11% of mainstem reach on a length basis. The average channel widths are similar to reach 7: The wetted width was 46 ft, the active channel width is 58.5 ft and the flood prone width is 70.5 ft. The average active channel depth in the riffles was 2.4 ft. The adjacent terraces are up to 15 ft above the channel bed.

The total length of Reach 8 was 1.5 miles. Reach 8 resembled an F4-type channel due to its low entrenchment ratio (1.2) and high active channel width:depth ratio (24).

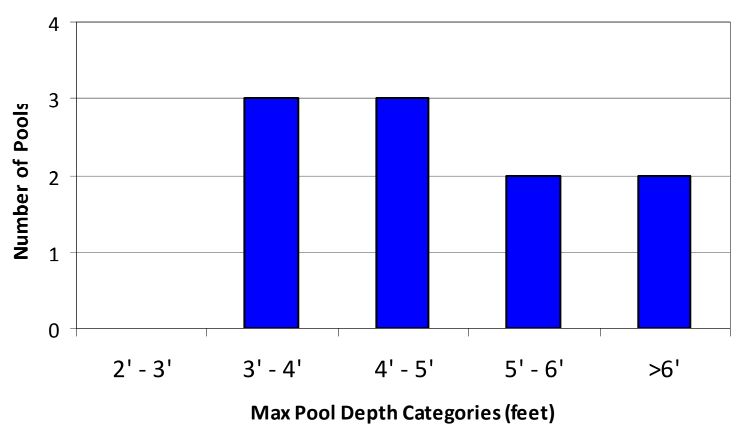
Figure 41: Proportion of Habitat Types by Relative Frequency in Reach 8



Pools

There were ten pools in Reach 8, four of which were identified as scour pools. All ten pools had maximum depths greater than 3 feet, with an average maximum pool depth of 4.7 feet (Figure 42). The average residual pool depth was 3.4 ft, and the average pool crest depth was 1.4 ft. Most substrate in pools was gravel with sand and small cobble, with several pools dominated by sand, and one with boulder substrate due to boulder riprap dropped into the channel.

Figure 42: Maximum Pool Depths in Reach 8.

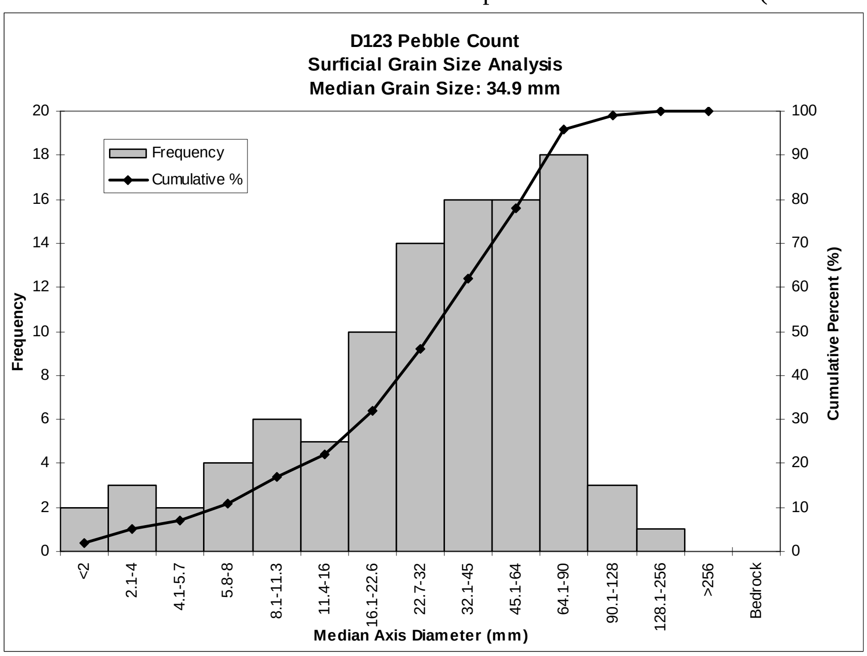


Riffles & Flatwaters

There were 8 riffles and 9 flatwaters in Reach 8. The average riffle depth was 1.0 feet and the average flatwater depth was 1.4 feet. The substrate in riffles was gravel with small cobble, and in flatwaters it was gravel with small cobble and sand. A pebble count was conducted in the in a riffle at the upstream extent of the reach (Figure 43). Bed material ranges from sand to large cobbles but is primarily composed of coarse to very coarse gravel. The median grain size of this riffle was 35 mm or coarse gravel (Figure 44). 82% of the sediment sampled was with the ideal coho/steelhead spawning sizes (11.4mm to 128mm), and 52% was within coho rearing sediment sizes (32mm to 128mm). 2% of the sediments were fine or sand (<2 mm).

Figure 43: (left) conducting a pebble count in a riffle, (right) pool habitat in Reach 8.

Figure 44: Grain size distribution for the riffle at the upstream extent of reach 8 (habitat unit #123).



Side-Channels

No side channels were observed in Reach 8.

Alcoves

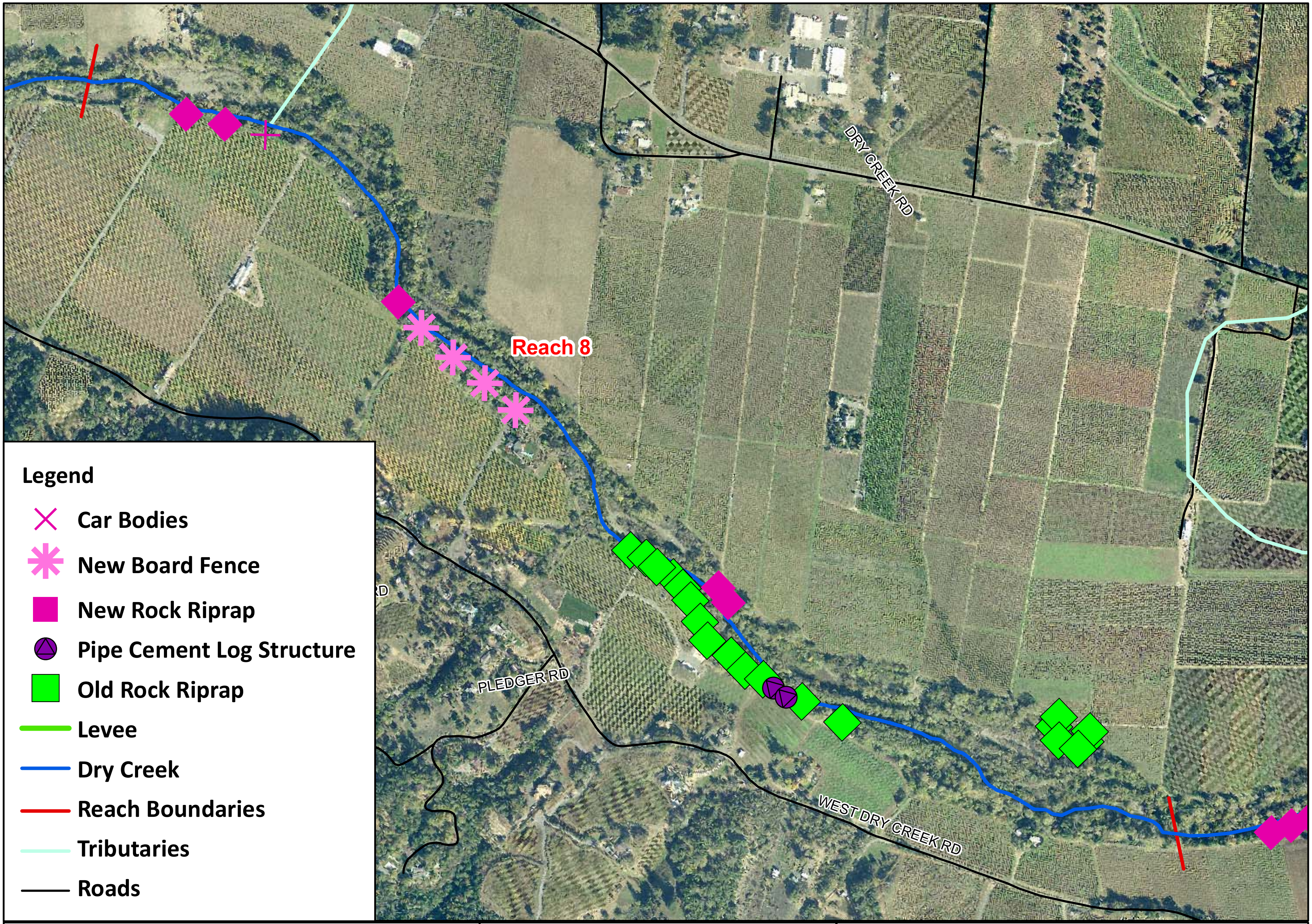
One alcove was measured in Reach 8. It was 15 feet wide, 110 feet long, with a maximum depth of 2 feet. Substrate in the alcove was gravel with fine sediment.

Instream Cover & Woody Debris

194 pieces of wood per mile were counted in Reach 8. Six out of the 8 pieces of large wood (>20" diameter) were found in pools, the other two were in a riffle. The highest densities of wood were in pools and the alcove, most of the wood falling into the small (6 to 12" diameter) category. The lowest cover and complexity was found in flatwaters, with only 13% cover and a complexity rating of 30. In Reach 8, the majority of instream cover was provided by terrestrial vegetation and small woody debris, with root masses providing limited cover in riffles and flatwaters. Boulders provided some additional cover in several pools, where bank stabilization boulders had tumbled into the channel. In addition, only a third of flatwaters contained edge habitat, whereas edge habitat was identified in most mainstem pools and in the alcove.

Table 8: Instream woody debris, cover, and edge habitat frequency for Reach 8.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	158.5	36.7	7.7	203.0	22%	66	67%
Scour Pools	212.9	61.3	6.5	280.6	17%	50	50%
Riffles	134.0			134.0	18%	46	38%
Flatwaters	113.9	27.9	4.3	146.1	16%	40	38%
Alcove	480.0	192.0		672.0	30%	90	100%
	mainstem pieces/mile			193.6			



0 700 1,400 Feet

DRY CREEK
Reach 8 Features

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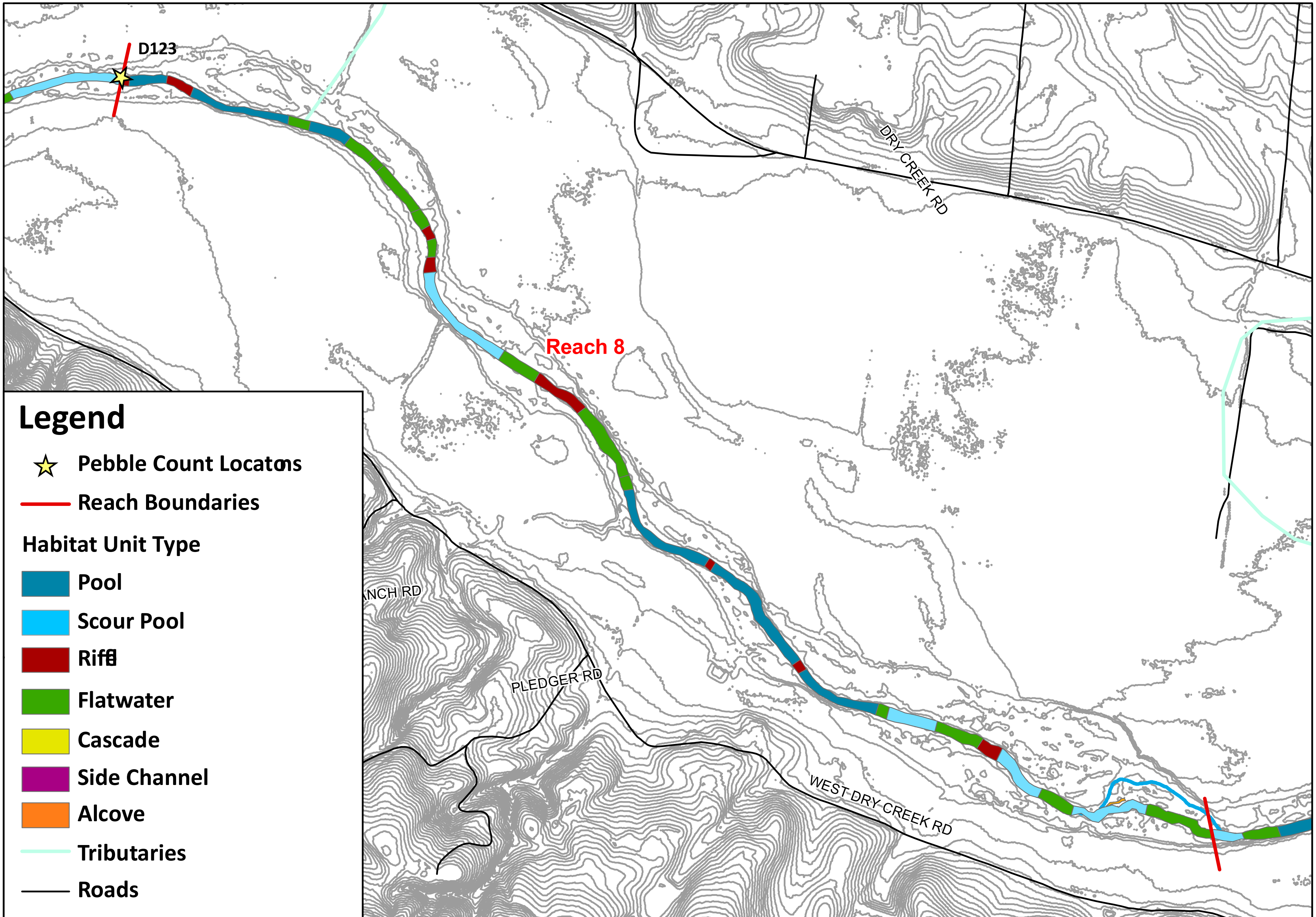

N E S W

0 700 1,400 Feet

DRY CREEK
Reach 8 Habitat Units

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Feet

DRY CREEK
Reach 8 - Channel Positon Map

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Appendix A:

Reprint of Individual Study Sub-Reach summaries from current conditions report

REACH 9 (RM 9.0 to RM 9.8) **Confined along a fault lineament, elevated former channels**

Reach 9 is a single-thread channel extending upstream to the lower extent of a long stretch of new rock riprap bank stabilization on the right[6] bank. The upper reach boundary is also about 800 feet downstream of where the west lineament diverges from the channel. The Dry Creek channel flows along, or close to, this lineament for about half of the length of Reach 9. There is little sinuosity in this reach and there has been little channel change since the 1940s, other than channel narrowing resulting from channel incision. In some areas, the older and wider channel bed provides opportunities for habitat enhancement. These older channel beds are elevated a few feet above the current channel bed and are often separated from the current channel by alder ‘fences’ (Figure 45), but habitat could be created with some excavation.

Notable features include a pipe that runs under the creek at river mile 9.4, where the first bedrock was observed as part of the active streambank. A culvert appears to drain directly to the creek at river mile 9.75. Otter scat was also observed in this reach full of crawdad exoskeletons. A former channel ran along the left bank for more than 500 feet. It was protected by a well-vegetated straight berm. The former channel is a long, mostly dry side-channel with one wet alcove. It is filled with alluvial gravel substrate and includes an old rope swing hanging above the dry former channel. Trees grow along the berm in a very straight line. Lastly, a thick layer of algae was observed growing on the substrate of several of the flatwaters and pool tail-outs (e.g. river mile 9.6, in a flatwater).

[6] In the individual reach summaries, right and left bank designation defined as looking downstream.

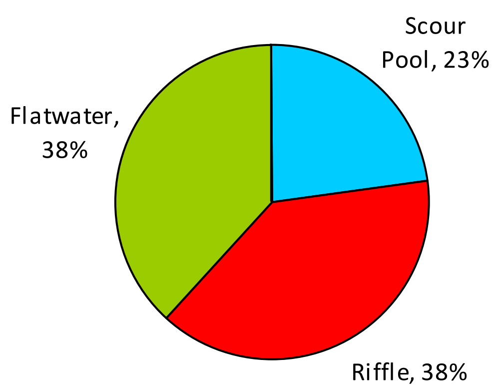
Figure 45: (upper row) pool habitat with riprap bank protection, (lower left) alcove habitat, (lower right) former channel along left bank, protected by a long, straight berm vegetated by even-aged alders.

Habitat Classification

Reach 9 is comprised of 23% pool habitat, 38% flatwater habitat, and 38% riffle habitat by relative frequency (Figure 46). Of the 1.0 mile long reach, there are four riffles that are 65 to 200 ft long representing 15% of the reach on a length basis. The average wetted channel width was 46.0 (st.dev. 9.4).

The average active channel width was 54.0 feet, the active channel depth was 2.6 feet, and the average floodprone width was 93.0 feet. The reach resembled an F4 channel type, with an entrenchment ratio of 1.7 and a active channel width:depth ratio of 22.

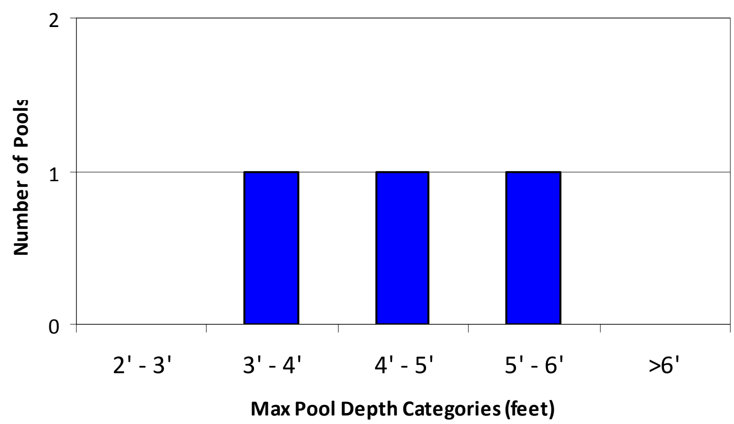
Figure 46: Proportion of Habitat Types by Relative Frequency in Reach 9



Pools

There were three scour pools in Reach 9, one of which contained two very short riffles and a small flatwater section that were shorter than the average wetted width of the channel, and were therefore not classified as separate units. The average maximum pool depth was 4.2 feet, average residual depth of 3 feet, with all of the pools greater than 3 feet deep (Figure 47). Substrate in pools was sand with gravel.

Figure 47: Maximum Pool Depths in Reach 9

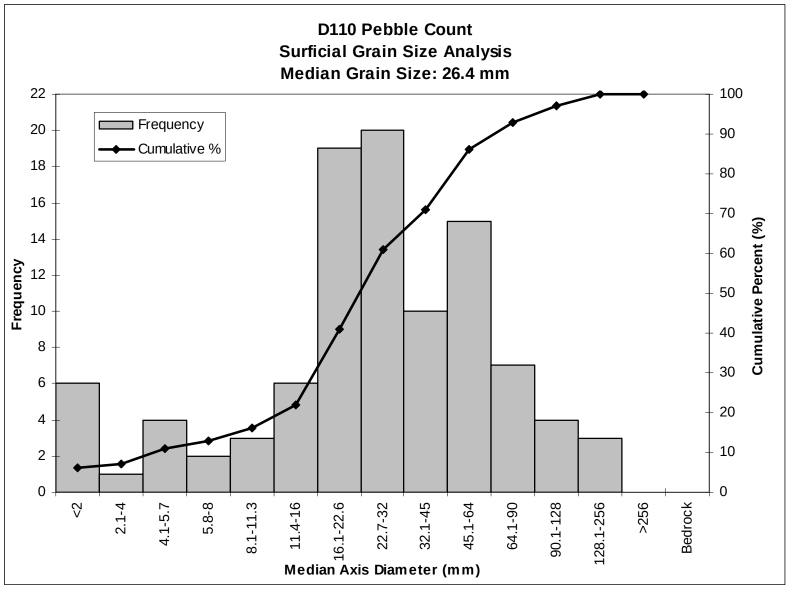


Riffles & Flatwaters

There were five riffles and five flatwaters in Reach 9. The average riffle depth was 0.9 feet, and the average flatwater depth was 1.5 feet. Substrate in riffles was gravel and small cobble, and in flatwaters it was gravel with small cobble and sand. One pebble count was conducted in a riffle near the upstream end of the reach.

The bed material in the riffle near the upstream extent of the reach ranges from sand to large cobbles but is primarily composed of coarse to very coarse gravel with a median grain size of 26 mm (Figure 48). The majority of the sediment fell within the coarse to very coarse gravel category. 81% of the sediment sampled was within desirable size classes for coho spawning (11.4 to 128mm), and 36% was within the desirable size classes for juvenile rearing (32 to 128 mm). 6% of the samples were fine sediments or sand.

Figure 48: Grain size distribution for a riffle near the upstream extent of reach 9 (habitat unit #110).



Side-Channels

No side channels were observed in Reach 9.

Alcoves

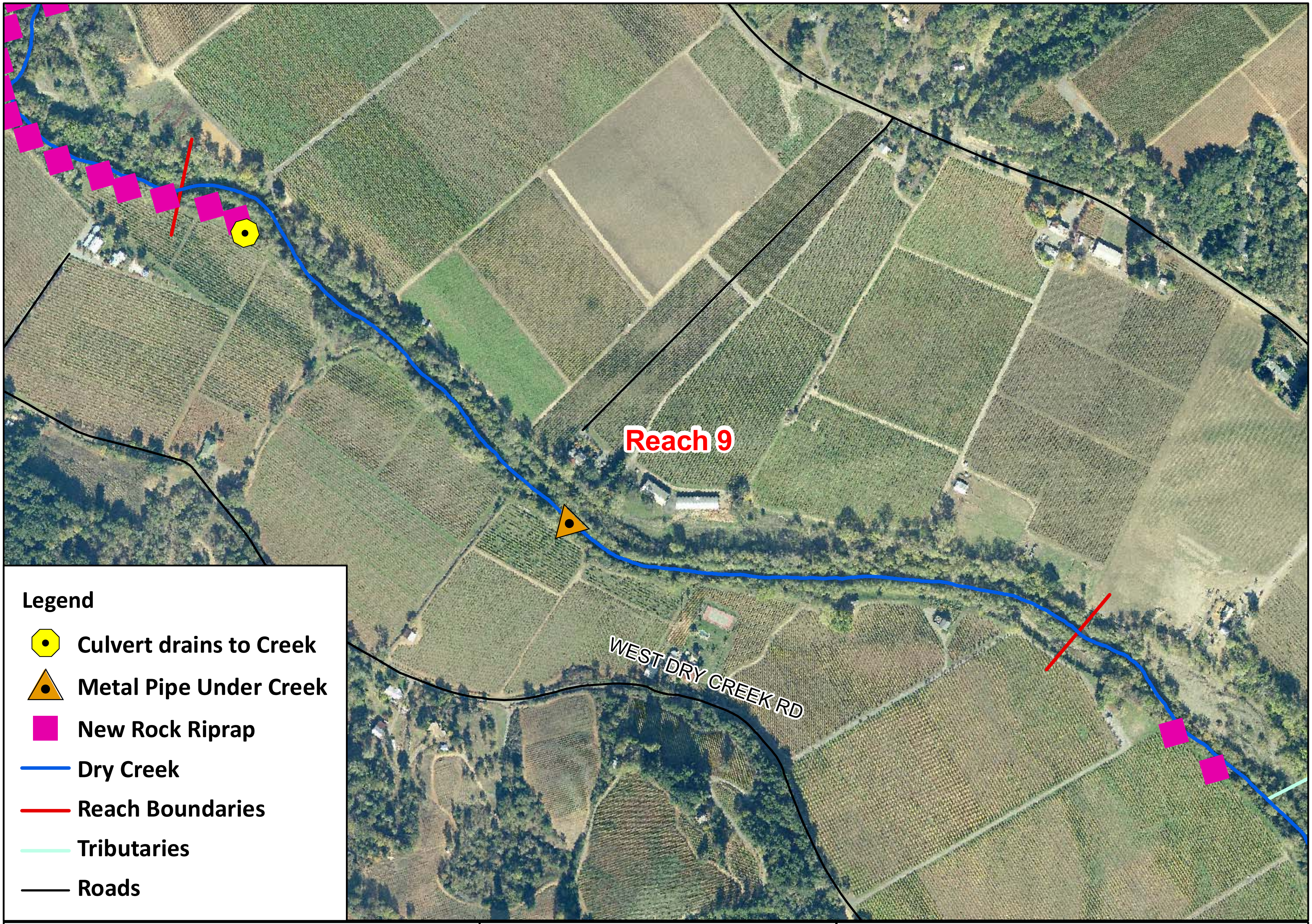
One alcove was measured in Reach 9. It was 53 feet long, 12 feet wide, with a maximum depth of 1.5 feet. Substrate was fine sediment with sand.

Instream Cover & Woody Debris

There were 193 pieces of wood per mile counted in Reach 9 (Table 9). A total of 155 pieces were counted. Of the 9 pieces of large wood (>20" diameter), 8 were counted in pools. The highest density of instream wood was in the mainstem pool, followed by scour pools and riffles. Although cover was provided by terrestrial vegetation and small woody debris in all habitat types, with some additional cover provided by root masses in riffles and flatwaters, and by riprap boulders in one pool. Only the alcove had abundant aquatic vegetation and high percent cover and shelter ratings. Edge habitat was only present in 4 out of a total of 13 habitat units.

Table 9: Instream woody debris, cover, and edge habitat frequency for Reach 9.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Scour Pools	159.8	33.5	12.9	206.3	28%	85	33%
Riffles	161.5	34.0	8.5	204.1	18%	55	20%
Flatwaters	143.3	17.1	10.2	170.5	16%	47	40%
Alcove	99.6	0.0	0.0	99.6	90%	270	0%
	mainstem pieces/mile			192.8			



N E S W

0 500 1,000 Feet

DRY CREEK
Reach 9 Features

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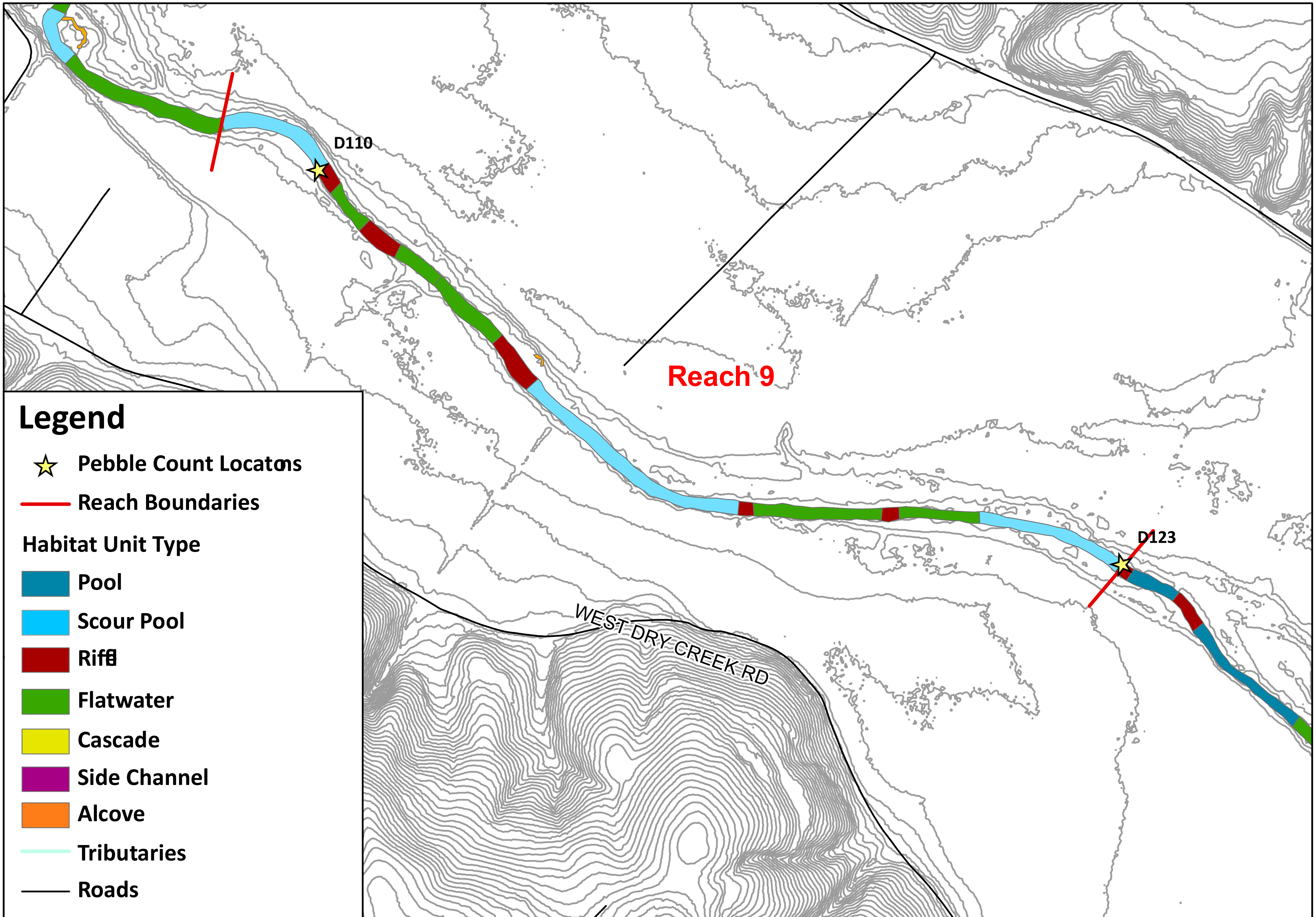

N E S W

0 500 1,000
Feet

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N E S W

0 500 1,000 Feet

DRY CREEK
Reach 9 - Channel Positon Map

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REACH 10 (RM 9.8 to RM 10.3) **Bank stabilization structures, with native sourced boulders**

This reach contains significant length of stabilized streambank. From the start of Reach 10 at river mile 9.8, boulder riprap lines the right[7] bank for 0.3 miles upstream. At river mile 10.1, the tall, eroding left bank is covered with dead grapevines (Figure 49). The right bank at this site has a wide floodplain. Last, at river mile 10.3, I-beam and chainlink fence stabilization structures have been built along the left bank for 250 feet.

Reach 10 is a single-thread channel that extends upstream to where the east lineament intersects Dry Creek about 150 ft downstream of the inflow from an unnamed tributary. This reach is short but contains one large meander bend. Since the dam was built, the channel has narrowed substantially and the meander bend has migrated or avulsed to the opposite side of the riparian corridor. Despite channel modifications that have been built to try to stop bank erosion, the meander bend has continued to migrate southward in the last 25 years.

Figure 49: (upper row) vegetated islands in the middle of a riffle, recruiting small woody debris and creating a small scour pool, (lower left) native green boulder, (lower right) dead grapevine dump to stabilize the bank.

The channel change that has occurred has resulted in a large elevated bar on the right bank that is about 400 ft wide and 500 ft long as well as off-channel pools and backwater channels. The off-channel pools and backwater channels are fed by hyporheic flows and

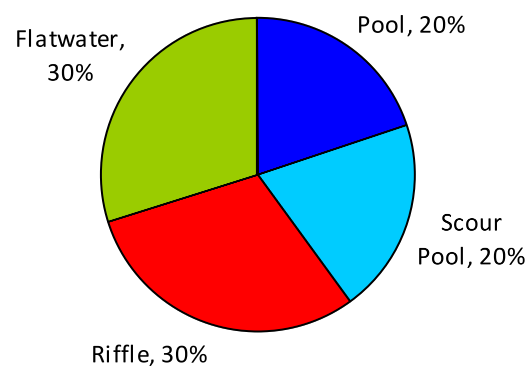
[7] In the individual reach summaries, right and left bank designation defined as looking downstream.

contain numerous salmonids. These areas may provide good analogs for enhancing habitat elsewhere. The large bar provides significant space for enhancing habitat, though this may require a large amount of excavation as the old channels are 6 to 7 ft above the bed.

Also in Reach 10, large, possibly native sourced boulders were observed in the stream, lime-green rocks w/white veins, 3'x3' boulders in substrate at river mile 10.2.

Habitat Classification

Figure 50: Proportion of Habitat Types by Relative Frequency in Reach 10



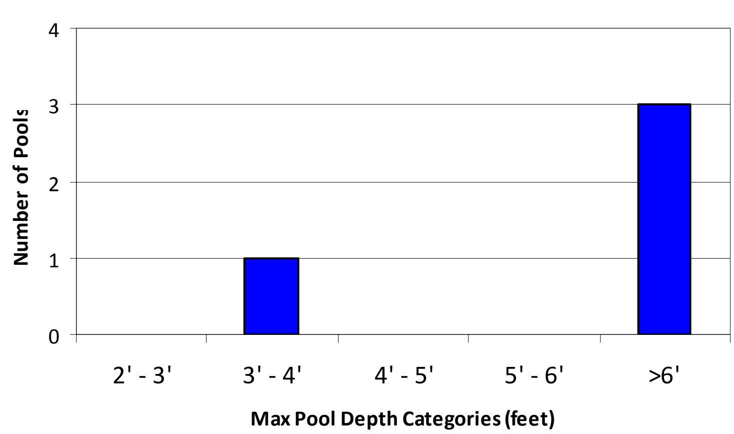
The channel in this reach was composed of 30% flatwaters, 20% pools, 20% scour pools, and 30% riffles by relative frequency (Figure 50). There were three riffles in the reach ranging from 70 to 150 ft in length representing only 12% of the reach on a length basis. The average wetted width during the survey was similar to reach 9 (48 ft), but the active channel was wider (78 ft) and the flood prone width was narrower (87 ft). The average active channel depth was 2.4 ft. The total mainstem length of Reach 10 is 0.6 miles.

With a low entrenchment ratio (1.1) and a high active channel width:depth ratio (32), the reach resembles an F4-type channel, plane-bed reach with ample flatwater habitat and deep pools.

Pools

There are four pools in Reach 10, two of which are scour pools. All of the pools have a maximum depth of greater than 3 feet, with average maximum depth of 6.3 feet and average residual depth of 5 feet (Figure 51). Substrate in pools is gravel with sand, and some small cobble.

Figure 51: Maximum Pool Depths in Reach 10.



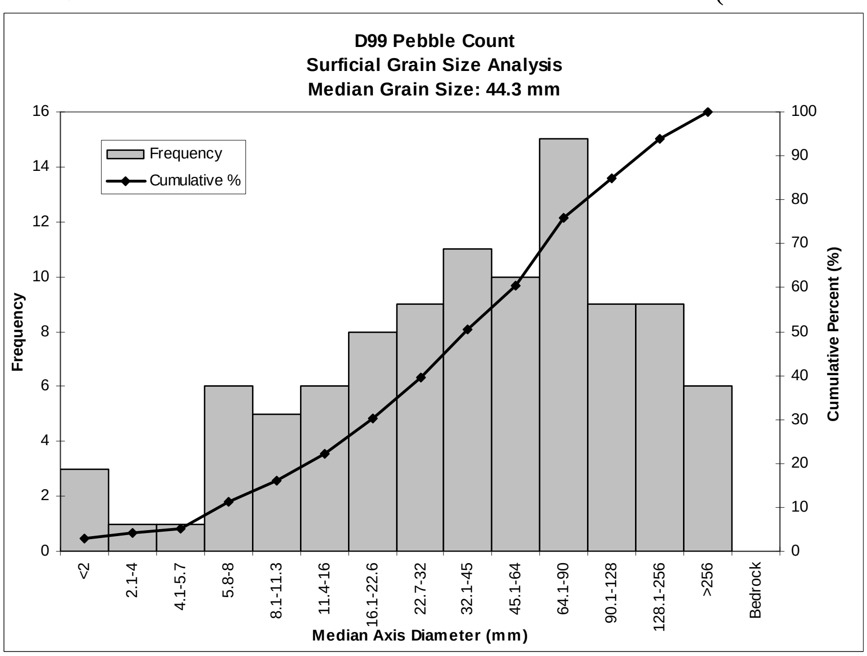
Riffles & Flatwaters

Three riffles and three flatwaters were in Reach 10. The average riffle depth was 1.1, while the average flatwater depth was 1.9 feet. Substrate in riffles was small cobble, with gravel and some large cobble. In flatwaters substrate was gravel with small cobble and sand. Algal mats grow on the substrate in some flatwaters.

The bed material in a riffle in the middle of the reach ranges from sand to small boulders but is primarily composed of very coarse gravel and small cobble. In this riffle, there were two mid-channel bar/islands with living willows and alders that have recruited a small woody debris jam. One island has formed a 15’x20’ scour pool within the riffle. The median grain size for this riffle is very coarse gravel at 44 mm (Figure 52). 69% of the sediments were within ideal spawning sizes, and 45% were within ideal juvenile rearing sizes. 3% were fine sediment or sand. This riffle had a higher proportion of large cobbles and small boulders than any other.

Bed material may not be transported through this reach as easily as further downstream. The bed material in this reach is generally larger than downstream and there is evidence of aggradation: the bases of alders near the channel are buried by gravels and cobbles. The ability of the reach to transport bed material will need to be determined before attempting habitat enhancement.

Figure 52: Grain size distribution for a riffle in the middle of reach 10 (habitat unit #99).



Side-Channels

One riffle-dominated side channel in Reach 10 was measured, with a length of 70 feet, a width of 7 feet, and an average depth of 0.3 feet (Figure 53). Substrate was gravel, with small cobble.

Figure 53: (left) side channel, (right) alcove habitat.

Alcoves

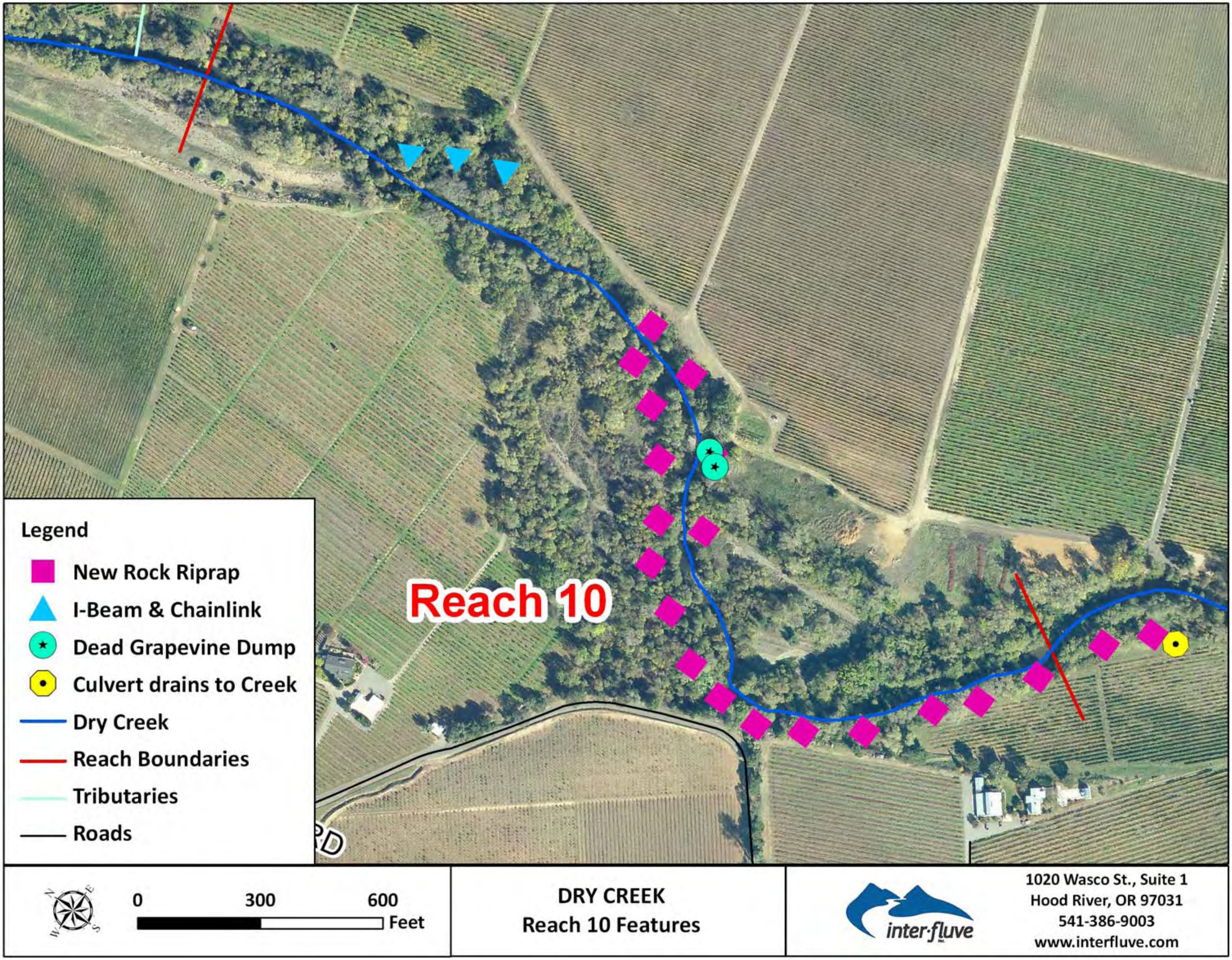
Three alcoves were observed in Reach 10. Water temperature measured in one alcove was 60° F, while Dry Creek water was 56° F. Several juvenile salmonids were seen in this alcove. Another alcove was 350 feet long, and resembled a side channel with no outlet. The water temperature in this series of small pools was also 60° F. Many small fish, frogs, and lizards were observed. This long alcove may serve as a template for enhancement or construction of additional alcoves. The average maximum depth of the alcoves was 2.6 feet, with substrate consisting of sand, gravels, fine sediment, and some small cobble.

Instream Cover & Woody Debris

In Reach 10, there were 362 pieces of wood per mile. A total of 235 pieces of wood were counted, 209 of these in the mainstem (Table 10). The highest wood densities by length were in scour pools, riffles, alcoves, and pools. Out of nine large wood pieces (>20" diameter), 7 were in pools. Only side channels and alcoves had significant percent cover and shelter rating (>40% and >100, respectively). Cover was primarily provided by small woody debris and terrestrial vegetation, and by aquatic vegetation in alcoves. There were few units with edge habitat present in Reach 10, with only two out of the two mainstem habitat pools, and all of the three alcoves providing edge habitat.

Table 10: Instream woody debris, cover, and edge habitat frequency for Reach 10.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	229.0	60.6	13.5	303.1	28%	83	100%
Scour Pools	355.7	125.5	34.9	516.1	33%	98	0%
Riffles	402.7	119.3	14.9	536.9	20%	60	0%
Flatwaters	201.1	41.1	4.6	246.9	22%	65	0%
Side-Channels				0.0	50%	100	0%
Alcoves	188.6	138.3		326.9	86%	258	100%
	mainstem pieces/mile			361.8			



DRY CREEK
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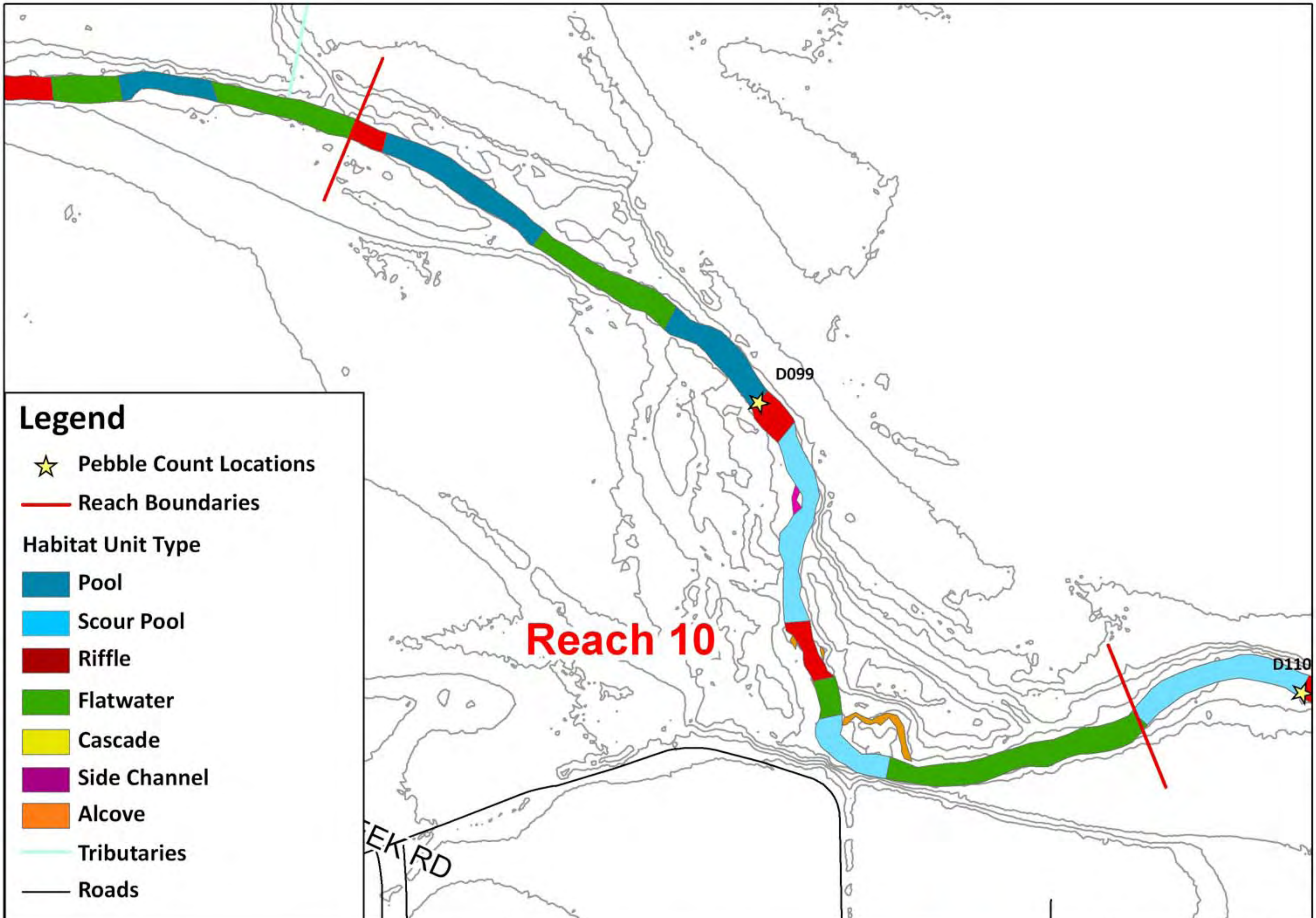

0 300 600 Feet

DRY CREEK
Reach 10 Habitat Units

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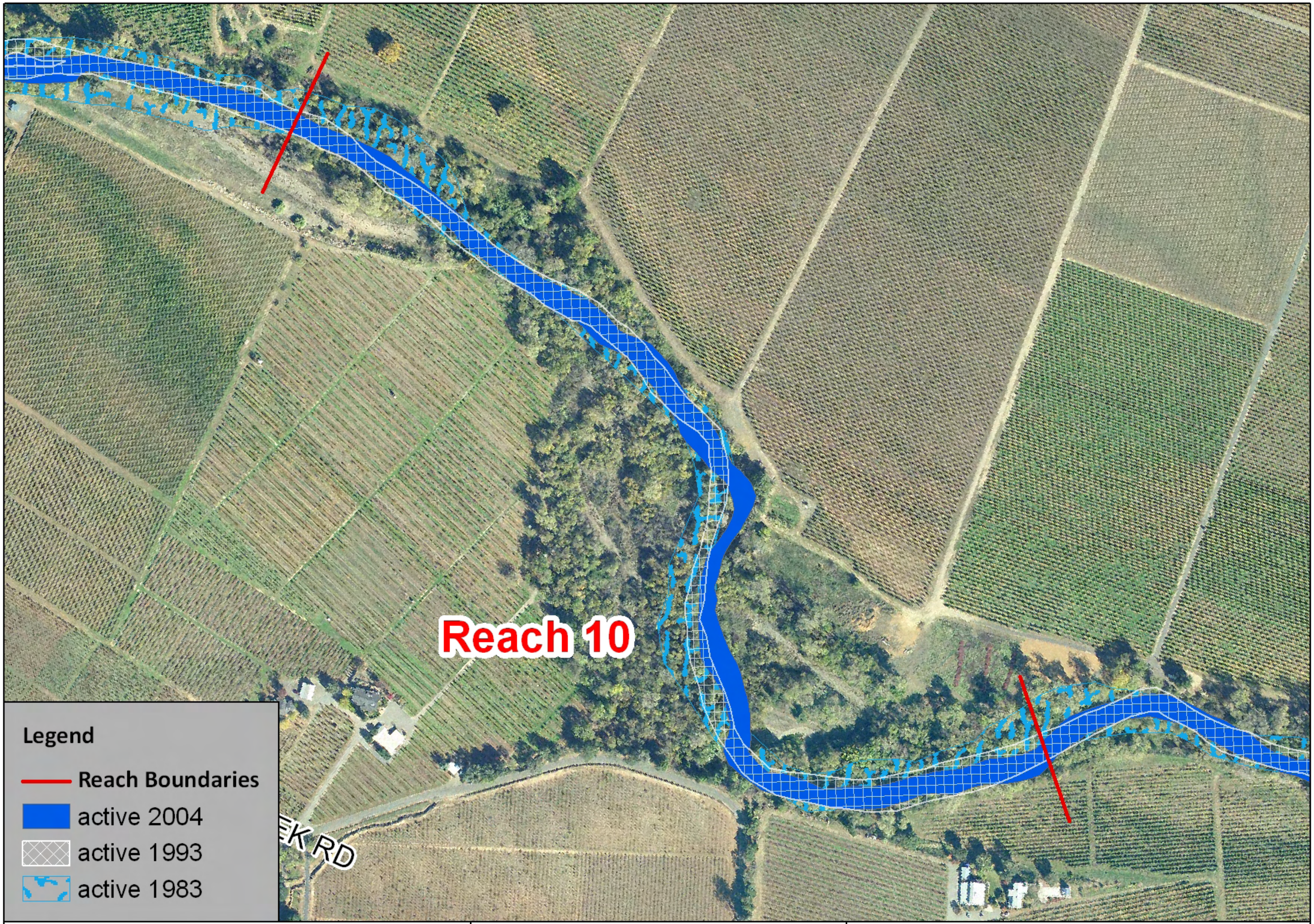

0 300 600 Feet

DRY CREEK
Reach 10 - Channel Position Map

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REACH 11 (RM 10.3 to RM 11.0) **Yoakim Bridge to Pena Creek**

Reach 11 contains several notable features (Figure 54). First, the upper boundary of Reach 11 is the confluence of Pena Creek with Dry Creek. The mouth of Pena Creek remains watered in the summertime, as serves as a 100 foot by 25 foot-wide alcove. The Pena Creek inlet was also hopping with hundreds of small frogs at the time of the survey. The Pena Creek watershed is the largest of the tributaries in the study area (22.3 mi^2) and contributes substantial quantities of flow and sediment to Dry Creek.

Reach 11 flows under Yoakim Bridge at river mile 10.7. A flow gage that operated in the past is located on Yoakim Bridge. Concrete and concrete chunks 200 feet downstream of the bridge along the left[8] bank and across the channel cause a small cascade in the mainstem. At river mile 10.45, an intermittent stream enters on the left bank of Dry Creek. A car body is partially buried in the left bank of this tributary, and vegetation has been cleared from all of the banks.

Figure 54: (upper left) A large gravel bar in Pena Creek 100 feet upstream from its confluence with Dry Creek, (upper right) an invasive grass (*Arundo donax*) grows on the right bank just downstream from Pena Creek, (lower left) small, intermittent stream with cleared banks, (lower right) Pebble count being conducted in a riffle in Reach 11.

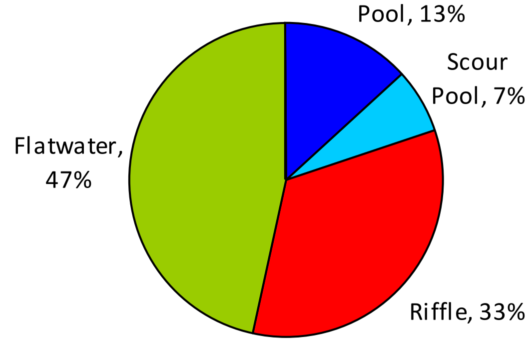
[8] In the individual reach summaries, right and left bank designation defined as looking downstream.

The channel in reach 11 is single-thread with little sinuosity. Although the channel has narrowed, there has been little channel change since the 1940s except in the middle of the reach around Yoakim Bridge.

Habitat Classification

The channel in reach 11 is primarily composed of flatwaters (47%) and riffles (33%) but also contains a few pools and scour pools (20% combined), on a relative frequency basis (Figure 55). The five riffles in this reach ranging from 50 to 330 ft in length comprise 21% of the reach on a length basis. The channel geometry is similar to reach 10; the average wetted width during the survey was 47 ft. The average active channel depth in the riffles was 2.6 ft. The active channel and flood prone widths are narrower than in Reach 10 at 57 and 78 ft respectively. The total length of this reach is 0.7 miles.

Figure 55: Proportion of Habitat Types by Relative Frequency in Reach 11

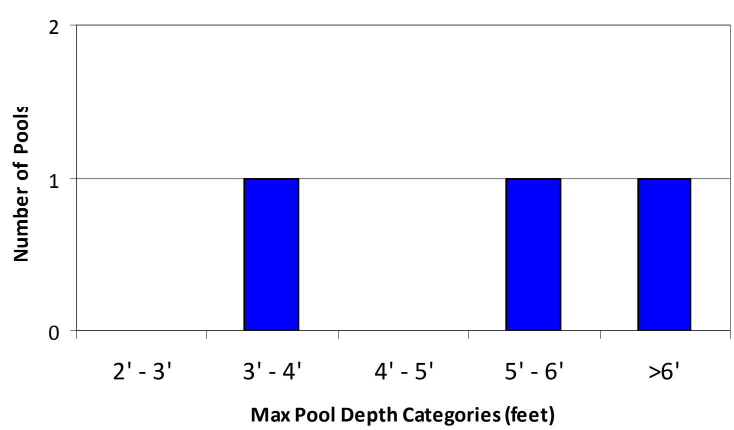


The high active channel width:depth ratio of 22 and the low entrenchment ratio of 1.4 cause this channel to resemble an F4 channel type. The abundant flatwaters and deep pools resemble a plane-bed channel morphology.

Pools

There were three pools in Reach 11, one of which was a scour pool. All of the pools had a maximum depth of greater than 3 feet, with an average maximum depth of 5.1 feet (Figure 56). The average residual pool depth was 4.3 ft, and the average pool crest depth was 1.6 ft. Substrate in pools was gravel with sand, and some small cobble.

Figure 56: Maximum Pool Depths in Reach 11.

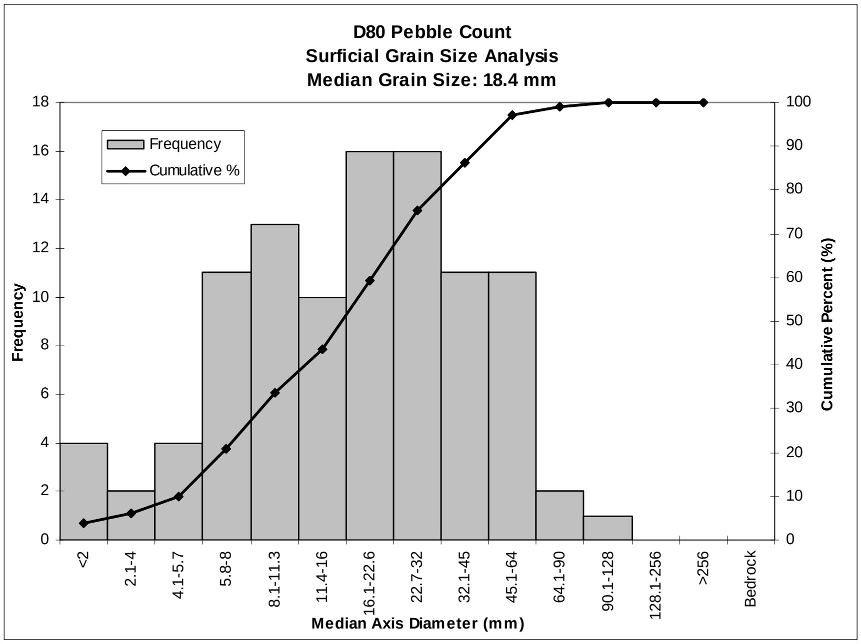


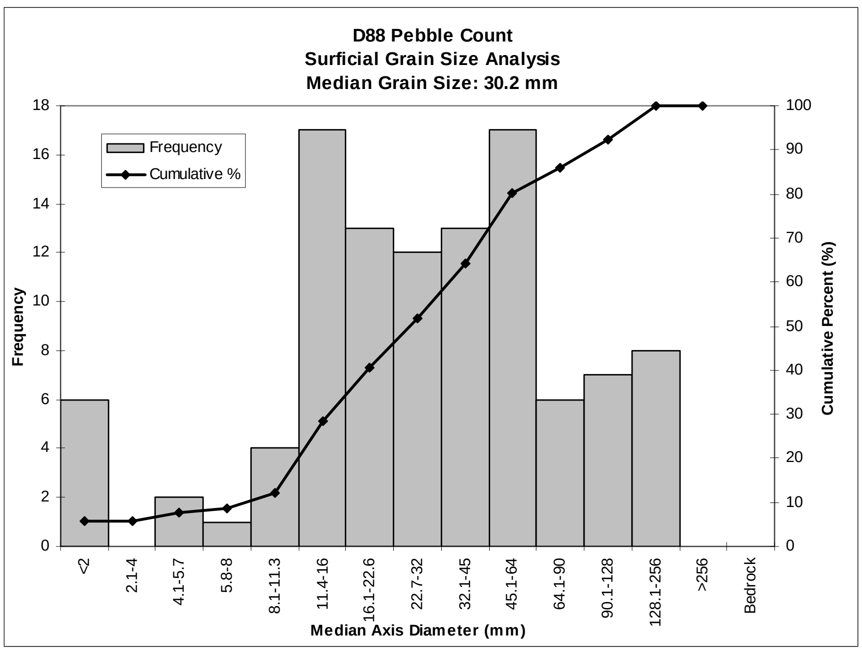
Riffles & Flatwaters

There were five riffles and six flatwaters in Reach 11. The flatwaters were extremely long, with two over 600 feet long, and another over 300 feet long. The average riffle depth was 1.0, and the average flatwater depth was 1.8 feet. Substrate in both riffles and flatwaters was predominantly gravel with small cobble.

The bed material in riffles downstream from Pena Creek and downstream from Yoakim Bridge ranges from sand to large cobbles but is primarily composed of coarse to very coarse gravel with median grain sizes of 18 and 30 mm respectively (Figure 57). 73% was within ideal spawning gravel sizes, 33% within ideal fry rearing size classes, and 5% of the samples were fine sediment or sand.

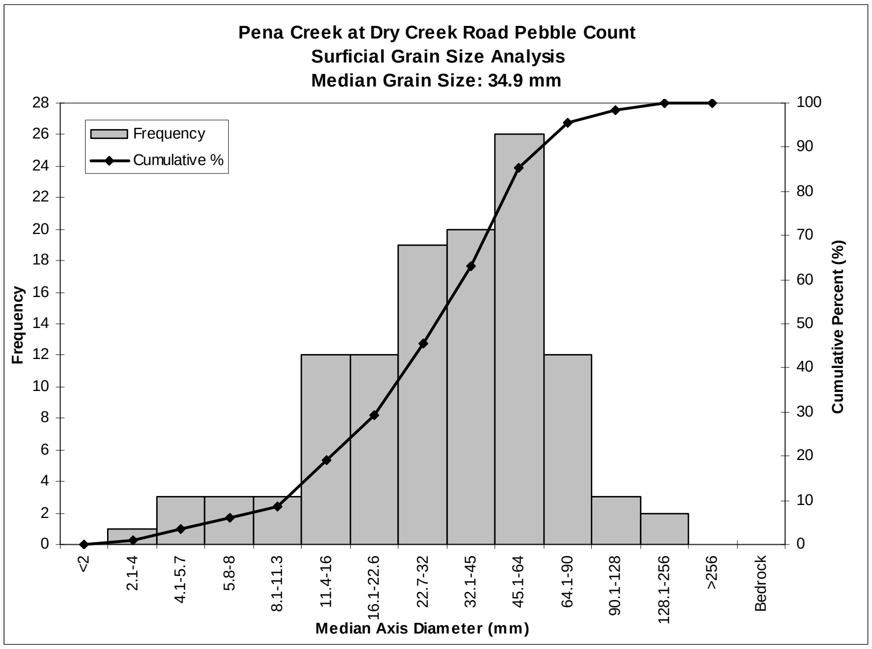
Figure 57: Grain size distribution for riffles downstream from Pena Creek (habitat unit #80) and downstream from Yoakim Bridge (habitat unit #88).

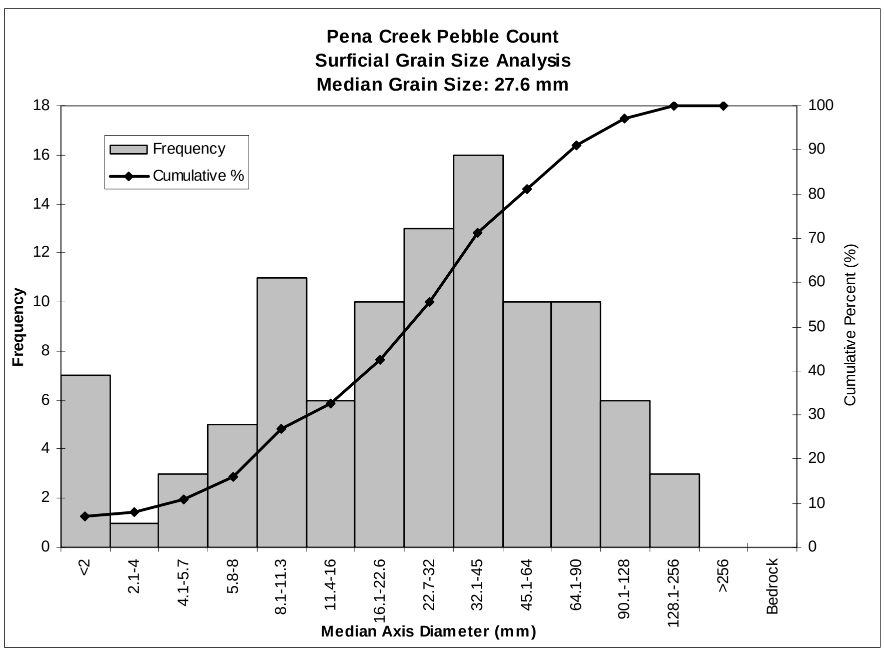




The bed material of Pena Creek was analyzed at the mouth and near the Dry Creek Road bridge about 1 mile upstream from the confluence with Dry Creek. At both locations, the Pena Creek bed material is primarily coarse to very coarse gravel. The median grain size decreases from 35 mm at the bridge to 28 mm near the mouth (Figure 58). This bed material is similar to the Dry Creek bed material downstream of Pena Creek.

Figure 58: Grain size distribution for Pena Creek at the Dry Creek Road bridge and near the confluence with Dry Creek.





Side-Channels

One, 100 foot long side channel was located on the left bank upstream from Yoakim Bridge. It was 25 feet wide, with an average depth of 1 foot. Substrate was gravel with small cobble.

Alcoves

The primary alcove in Reach 11 was the inlet at the mouth of Pena Creek. The maximum depth of this alcove was 2.3 feet. Substrate was gravel with fine sediment. Just downstream of Pena Creek, there were two very small alcoves that were less than a channel-width long. One was on the left bank in the flatwater, and another 10’ long alcove was located on the right bank of the first riffle.

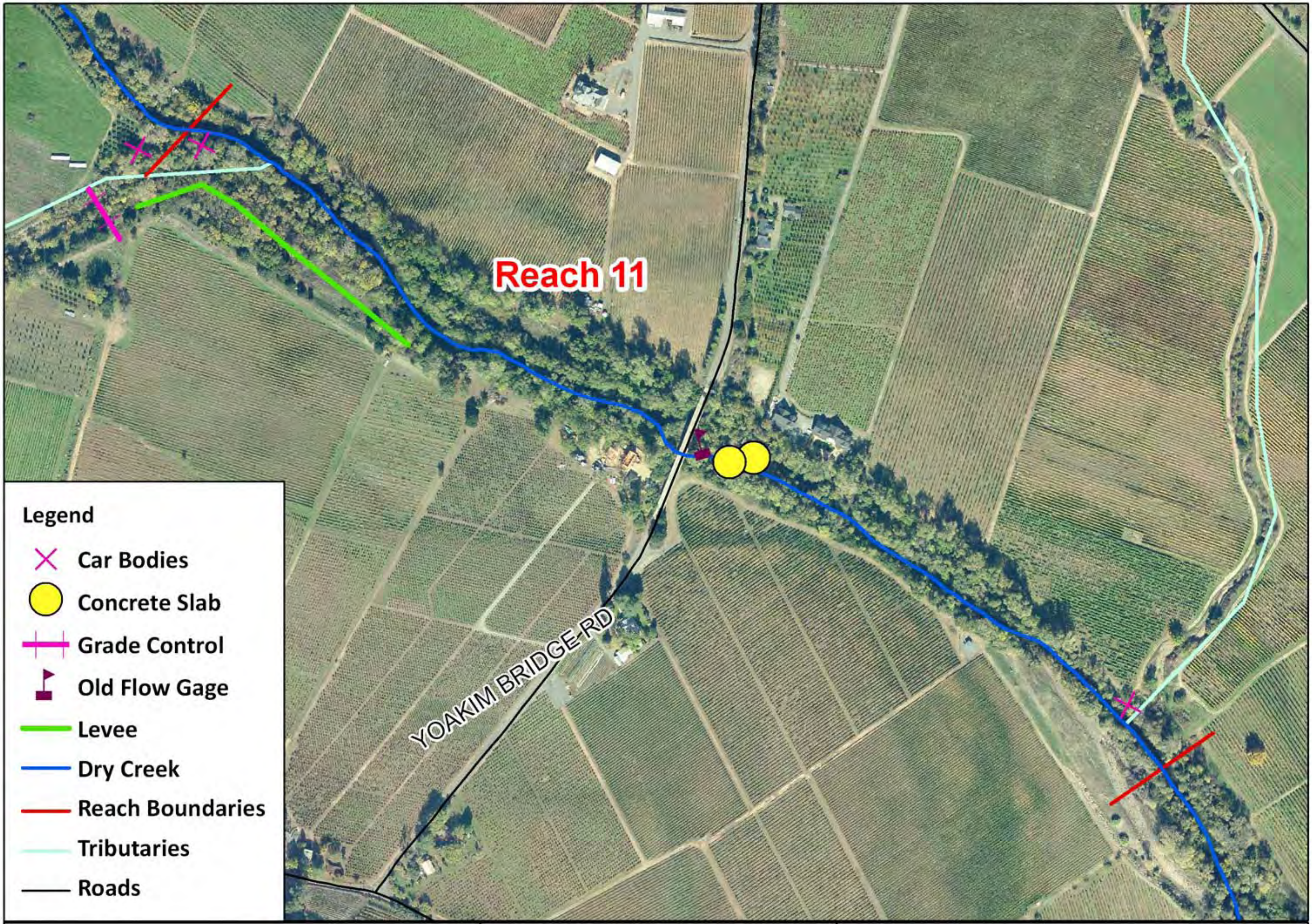
Figure 59: (left) glide habitat in Reach 11, (right) a deep pool with overhanging willows.

Instream Cover & Woody Debris

In Reach 11, there were 269 pieces of wood per mile. A total of 196 pieces of wood were counted, 47% of them in pools (Table 11). However, this number is likely an underestimate for these deeper pools, because woody debris could have been hidden under profuse willow thickets overhanging deeper, dark waters. Regardless, the highest density of wood was recorded in pools, although 6 out of the 12 large wood pieces (>20” diameter) were recorded in flatwaters. The highest levels of instream cover were also found in pools. Most of the cover was provided by woody debris and terrestrial vegetation, with some root masses. There was very little edge habitat in Reach 11, most of it associated with scour pools, and some present at the inlet of Pena Creek.

Table 11: Instream woody debris, cover, and edge habitat frequency for Reach 11.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	302.0	201.4	22.4	525.8	38%	113	0%
Scour Pools	330.0	132.0	0.0	462.0	20%	60	100%
Riffles	79.0	52.7	19.8	151.4	10%	29	0%
Flatwaters	183.7	52.5	15.3	251.4	19%	58	0%
Side-Channels	105.6			105.6	5%	15	0%
Alcoves	105.6			105.6	10%	20	100%
	mainstem pieces/mile			269.0			



N E S W

0 400 800 Feet

DRY CREEK
Reach 11 Features

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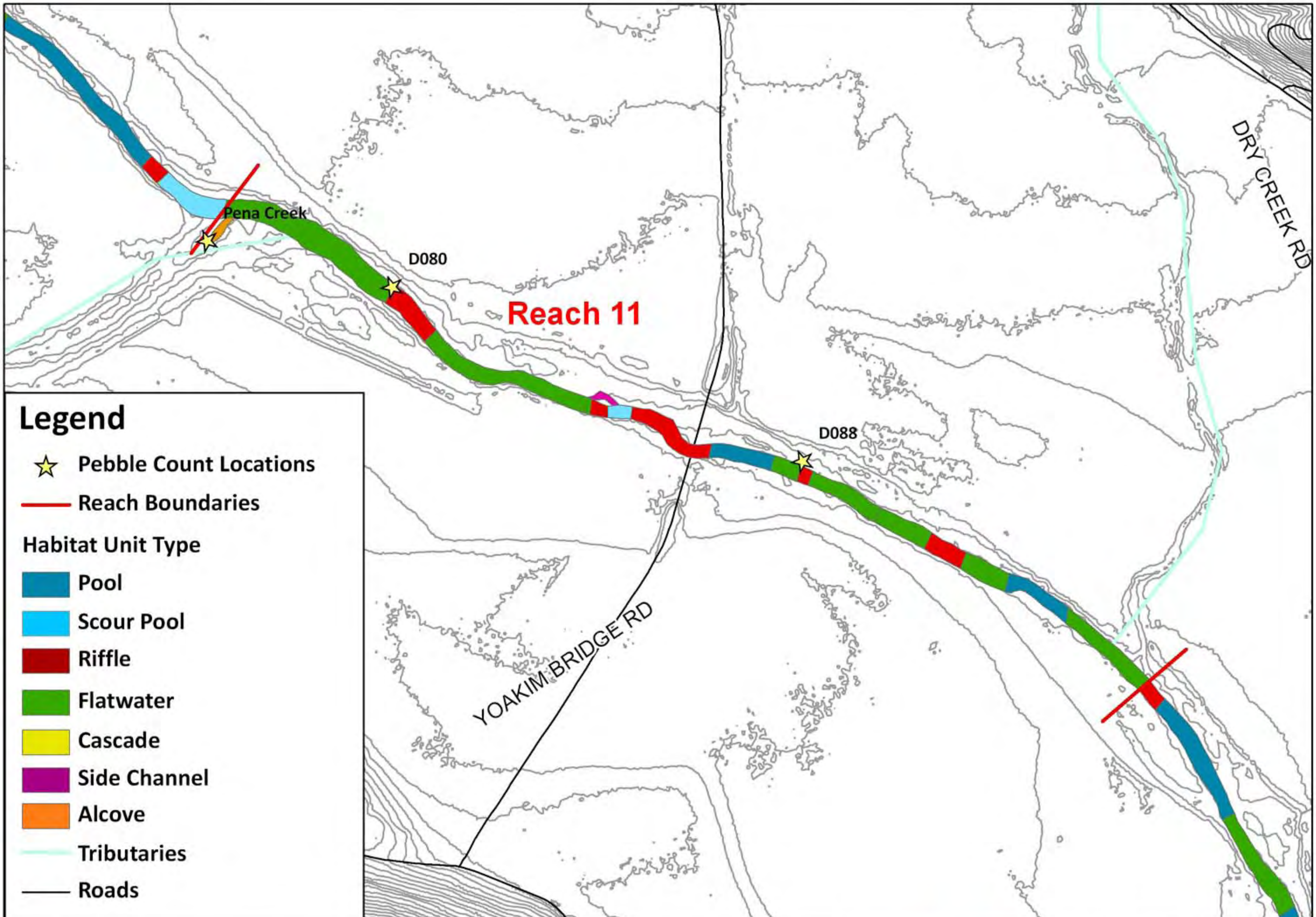

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Reach 11 Habitat Units

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DRY CREEK
Reach 11 - Channel Position Map

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REACH 12 (RM 11.0 to RM 11.7) **Pena Creek to Dutcher Creek**

Reach 12 is a single-thread channel extending from the Pena Creek confluence upstream to below the Dutcher Creek confluence. In addition to Dutcher and Pena creeks, an unnamed tributary flows into Dry Creek on the left[9] bank about half way through the reach at river mile 11.6. The active channel has narrowed substantially through the photo record, but there has been little lateral channel change since the dam was built, except for slight migrations immediately downstream from the unnamed tributary.

Figure 60: (upper left) pump in Dry Creek at river mile 11.75, (upper right) tributary at river mile 11.6, (lower left) straight bermed streambank along left bank, (lower right) gravel bar at river mile 11.75.

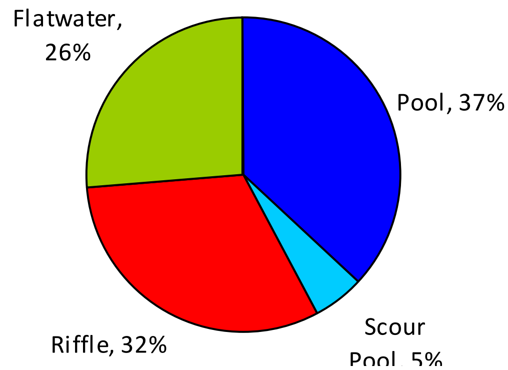
At river mile 11.65, a gravel bar forms along the left bank. Riprap bank stabilization covers the streambanks for about 800 feet throughout Reach 12. Riprap boulders have tumbled into the creek from these bank protection measures and provide some cover. A fault lineament runs along the left bank for the lower half of Reach 12.

[9] In the individual reach summaries, right and left bank designation defined as looking downstream.

Habitat Classification

By relative frequency, Reach 12 is primarily composed of pools (42%) but also contains riffles (32%) and flatwaters (26%, Figure 61). Side channels and alcoves represent 8% of the wetted channel area. There are six riffles that range in length from 50 to 230 ft and represent 19% of the mainstem on a length basis. The two riffles near the upstream reach boundary appear to have significant riprap materials as part of the substrate.

Figure 61: Proportion of Habitat Types by Relative Frequency in Reach 12

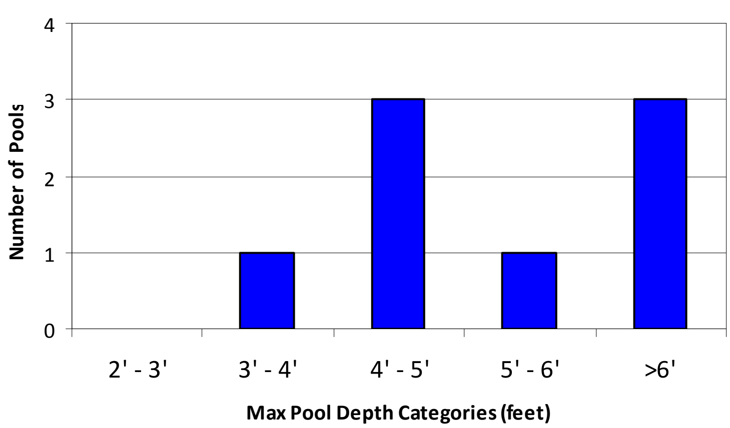


The average wetted channel width in Reach 12 was 46.0 feet, similar to Reach 11. The average active channel width was 54.0 feet, with an active channel depth of 2.6 feet, and a floodprone width of 93.0 feet. The entrenchment ratio was 1.7, and the active channel width:depth ratio was 21.

Pools

There were 8 pools in Reach 12, one of which was a scour pool. All of the pools had a maximum depth greater than 3 feet (Figure 62). Two pools had a maximum depth over 7 feet. The average maximum pool depth was 5.5 feet (stdev=2.0). The average residual depth was 3.9 ft., and the average pool crest depth was 1.5 ft. Substrate in pools was gravel with small cobble and sand, with a few boulders derived from riprap bank protection.

Figure 62: Maximum Pool Depths in Reach 12.

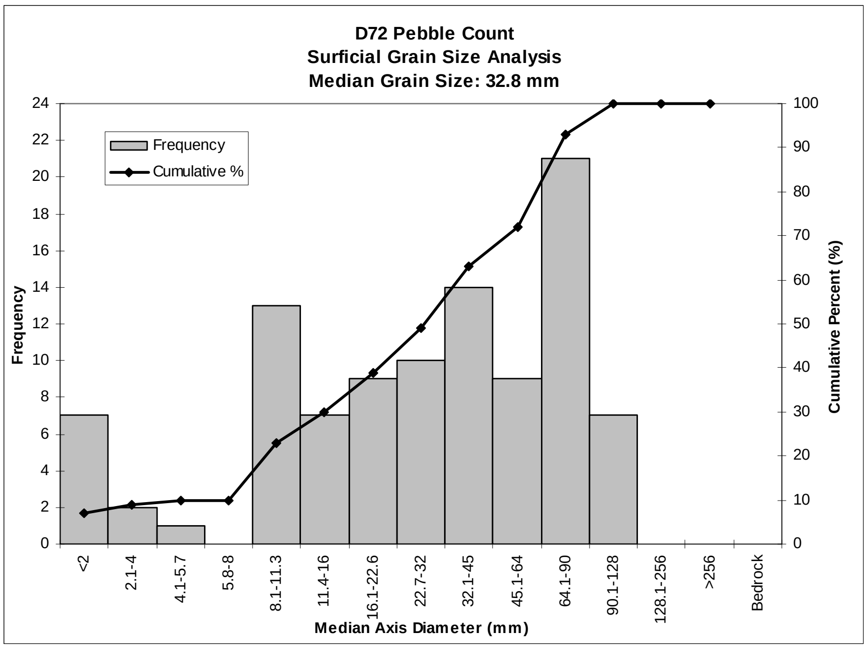


Riffles & Flatwaters

There were 6 riffles and 5 flatwaters in Reach 12. The average riffle depth was 1.4 feet, and the average flatwater depth was 2.0 feet. Substrate in riffles and flatwaters was gravel with small cobble, and some boulders associated with riprap banks.

The material in the riffle in the middle of the reach below the unnamed tributary ranges from sand to small cobbles with fairly even percentages of medium, coarse and very coarse gravel and small cobbles. The median grain size is coarse gravel at 33 mm. 77% were within ideal sizes for coho spawning (11.4 to 128mm), and 51% were within ideal sizes for juvenile rearing (32 to 128mm). 7% of the samples were fine sediments or sand.

Figure 63: Grain size distribution for a riffle in the middle of reach 12 downstream of an unnamed tributary (habitat unit #72).



Side-Channels

There were three side channels in Reach 12, two were pool dominated, and one was comprised of a single riffle. The side channel pools were 90 and 120 feet long, 12 and 32 feet wide, and 2.1 and 3.2 feet deep. Substrate in the pools was gravel with sand. The longer side channel pool resembled a straight canal, similar to the long alcove unit in this reach. The side channel riffle was 140 feet long, by 15 feet wide, with an average depth of 1.1 feet. Substrate in the side channel riffle was gravel with small cobble.

Alcoves

There was one alcove in Reach 12. It was 300 feet long, 25 feet wide, and had a maximum depth of 2.5 feet. Substrate was gravel with fine sediment. In addition, two small off-channel pools were observed on the left bank gravel bar that forms river mile 11.75. Each pool was 10 feet by 10 feet in area.

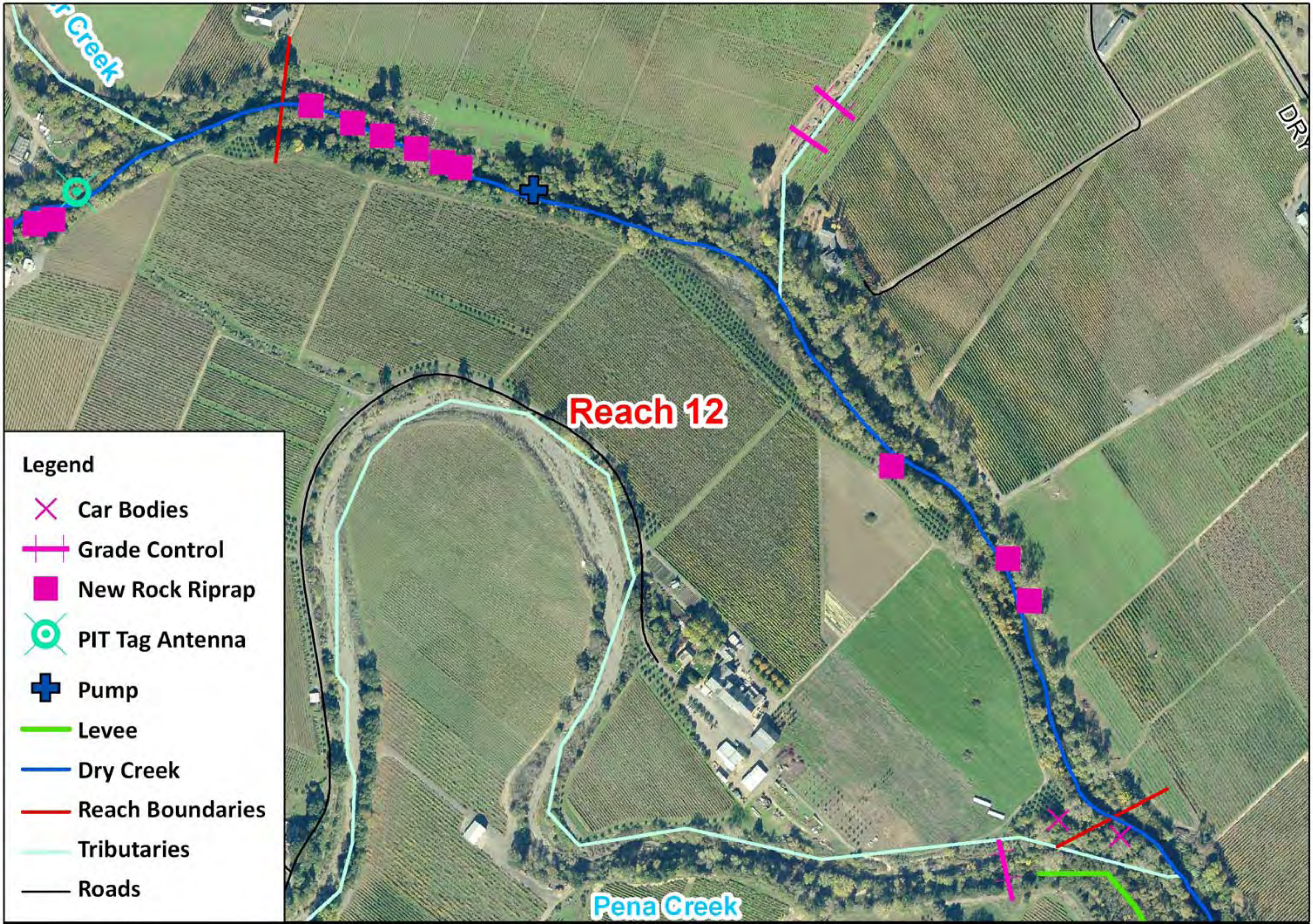
Instream Cover & Woody Debris

161 pieces of wood were categorized in Reach 12. Of these, 44% were in pools (Table 12). The highest densities of woody debris were found in side channels and in scour pools. Only three large pieces of wood were observed in Reach 12, one of which was in a side channel. Overall, cover was provided by overhanging vegetation and woody debris (Figure 64). Some cover was provided by boulders associated with bank stabilization measures, and boulders in riffles, root masses provided some limited instream cover. Edge habitat was associated with four out of the eight pools in Reach 12, and with a side channel and an alcove.

Figure 64: (left) green tunnel of riparian vegetation, (right) vegetation providing instream cover.

Table 12: Instream woody debris, cover, and edge habitat frequency for Reach 12.

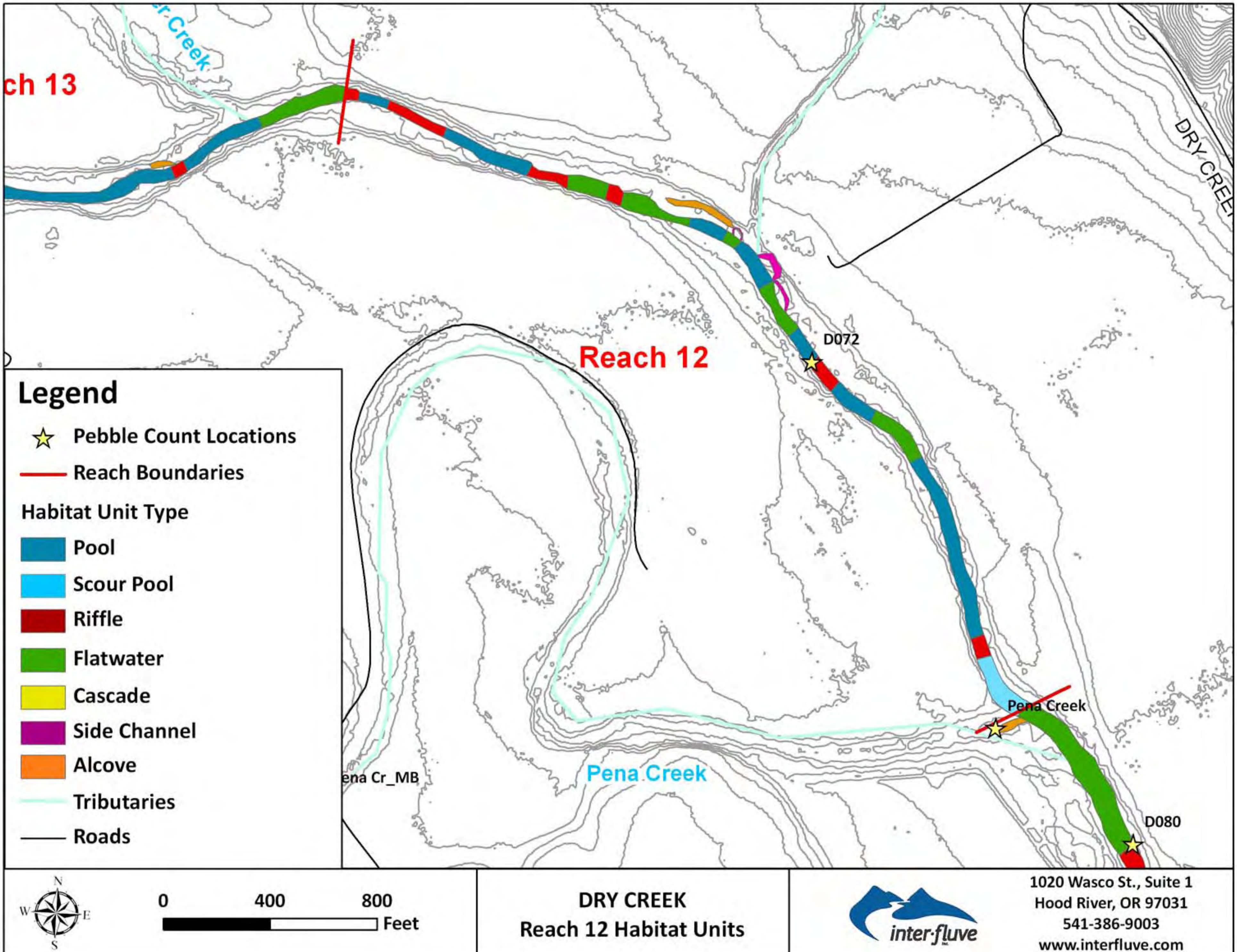
	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	110.6	34.9	0.0	145.5	25%	68	57%
Scour Pools	142.2	121.8	0.0	264.0	25%	75	0%
Riffles	142.9	30.1	7.5	180.5	20%	53	0%
Flatwaters	170.1	34.0	5.7	209.8	28%	83	0%
Side-Channels	301.7	105.6	15.1	422.4	20%	60	33%
Alcoves	140.8	17.6	0.0	158.4	95%	285	100%
	mainstem pieces/mile			176.6			



0 400 800 Feet

DRY CREEK
Reach 12 Features

inter·fluve
1020 Wasco St., Suite 1
Hood River, OR 97031
541-386-9003
www.interfluve.com



DRY CREEK
Reach 12 Habitat Units

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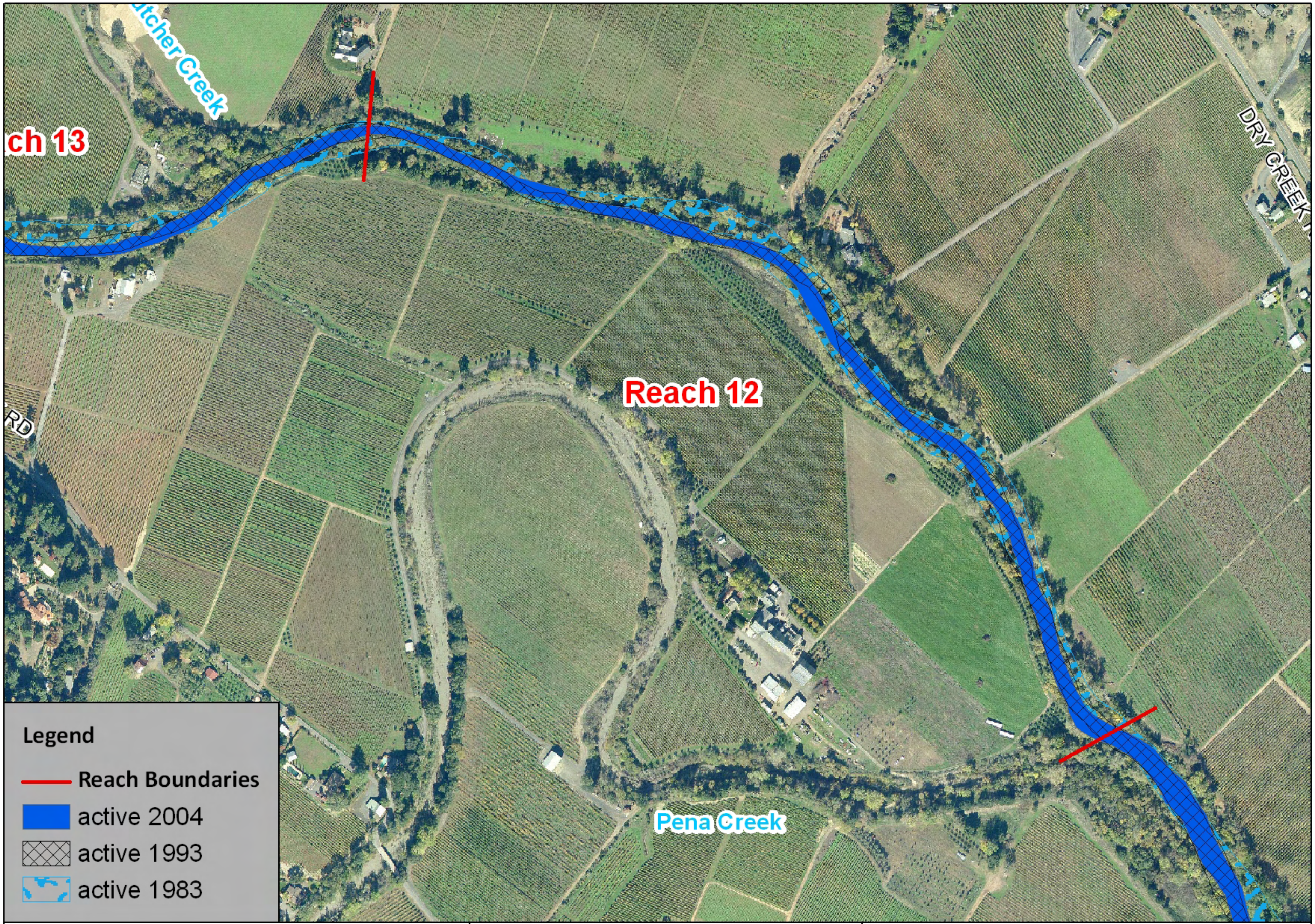

N S E W

0 400 800 Feet

DRY CREEK
Reach 12 - Channel Position Map

inter-fluve
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REACH 13 (RM 11.7 to RM 12.6**) Dutcher Creek to above Fall Creek**

Reach 13 extends from 0.05 miles below the Dutcher Creek tributary junction upstream to approximately river mile 12.6. Dutcher Creek enters Dry Creek on the left[10] bank at river mile 12, and Fall Creek flows into Dry Creek on the right bank at river mile 12.4. Upstream of Fall Creek, the channel planform and location has remained relatively stable since the dam was built. Downstream from Fall Creek slight channel migration since the dam was built has occurred. At the upstream extent of the reach, trees near previous channel boundaries are about 26 years old, the approximate date of dam construction. Trees close to the current channel are about 14 years old, indicating that narrowing and vegetation encroachment along the active channel margins has occurred.

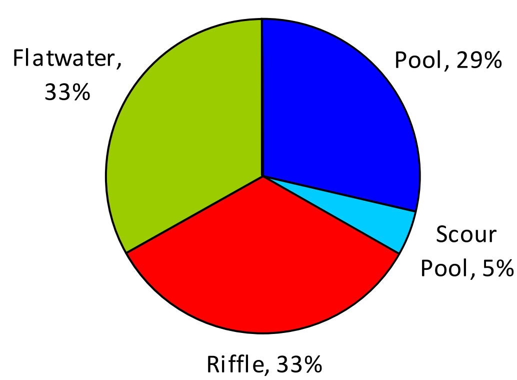
A pit tag recording station at river mile 12.05 creates a short riffle. A pump was observed on the left bank at river mile 12.1, with boulder riprap on the opposite bank along the pool unit. A short section of riprap armored the left bank at the top of the reach.

Figure 65: (left) Pump in Dry Creek, (right) Pit-tag antennae spans Dry Creek.

Habitat Classification

The channel in reach 13 alternates primarily between pools (34%) and flatwaters (33%) on a relative frequency basis (Figure 66). Seven riffles make up 33% of the reach by relative frequency, 21% of the channel on a length basis, and range from 40 to 400 ft in length. The channel banks are steep, so the average wetted and active channel widths are similar at slightly more than 40 ft wide. The flood prone width is 62 ft. The average active channel depth in the riffles is 2.3 ft. Terraces in reach 13 are approximately 10 ft above the channel bed.

Figure 66: Proportion of Habitat Types by Relative Frequency in Reach 13



Reach 13 resembles an F4 Rosgen channel type

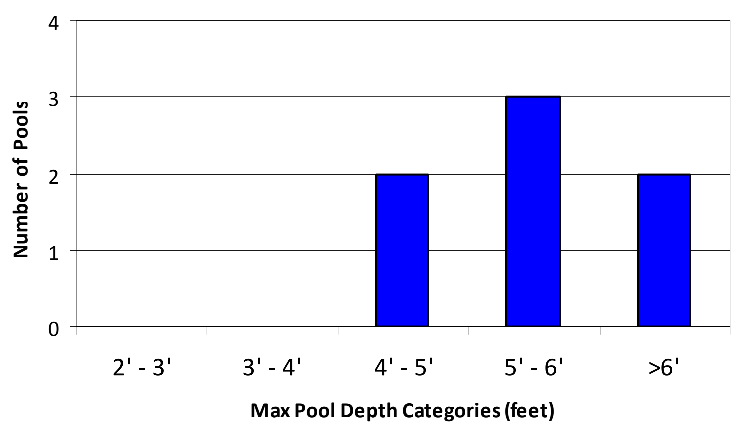
[10] In the individual reach summaries, right and left bank designation defined as looking downstream.

with an entrenchment ratio of 1.5 and a active channel width:depth ratio of 17.6. This reach has a plan-bed channel verging on pool-riffle morphology.

Pools

All of the eight pools measured in Reach 13 were greater than three feet deep (Figure 67). The average pool depth was 5.7 feet (stdev1.5). The average residual pool depth was 3.8 ft, and the average pool crest depth was 2.0 ft. Substrate in pools was gravel with cobbles and some sand.

Figure 67: Maximum Pool Depths in Reach 13.

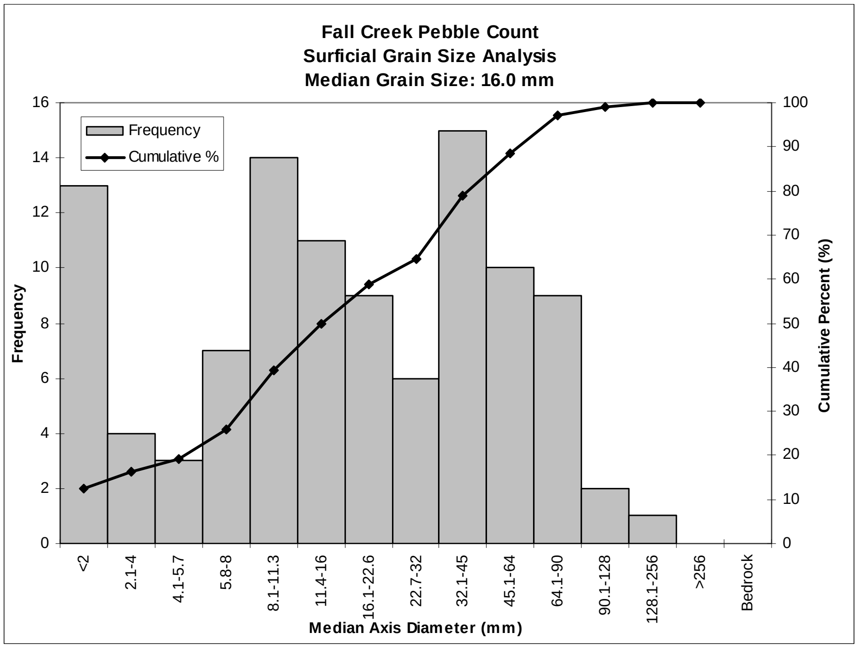


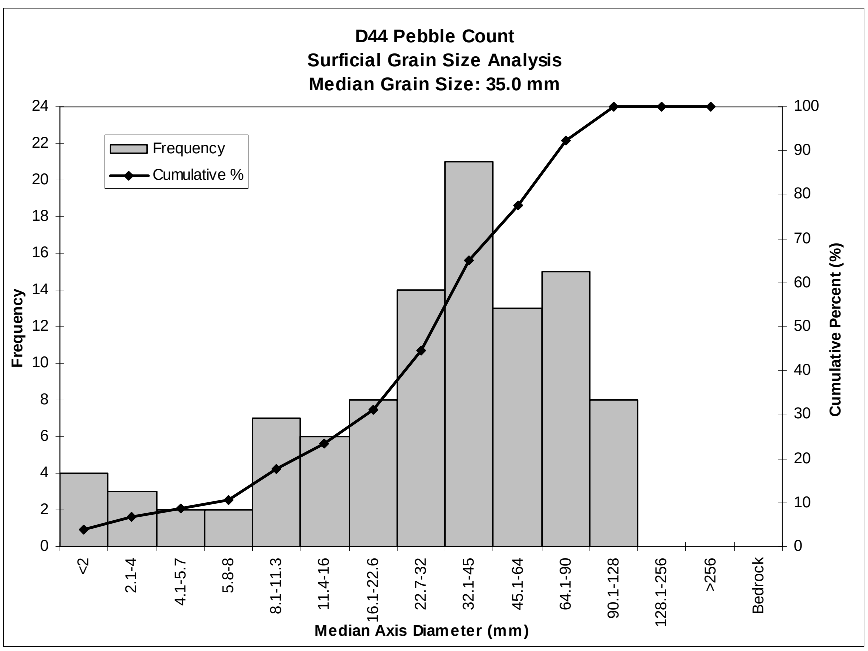
Riffles

Water depths in the riffles and flatwaters were 1.2 ft and 2.2 ft respectively during the survey. The bed material in reach 13 is primarily gravel with some small and large cobbles throughout the reach. Material in the riffle immediately downstream from the Fall Creek confluence ranges from sand to small cobbles but is primarily composed of coarse gravel to small cobble. The median grain size for this riffle is 35 mm (Figure 68). 83% of the sediments are within ideal spawning sizes, and 55% are within ideal fry rearing sizes. 4% of the samples were fine sediments or sand.

The bed material of Fall Creek is smaller (median grain size of 16 mm) than that found in Dry Creek.

Figure 68: Grain size distribution for the channel bed of Fall Creek and for a riffle on Dry Creek downstream of the Fall Creek inflow (habitat unit #44).





Side-Channels
No side channels were observed in Reach 13.

Alcoves
Three alcoves in Reach 13 measured 60, 80, and 90 feet long, 10, 18, and 12 feet wide, with maximum depths of 2.4, 2.5, and 1.6 feet. Substrate in the alcoves was fine sediment, sand, and gravel.

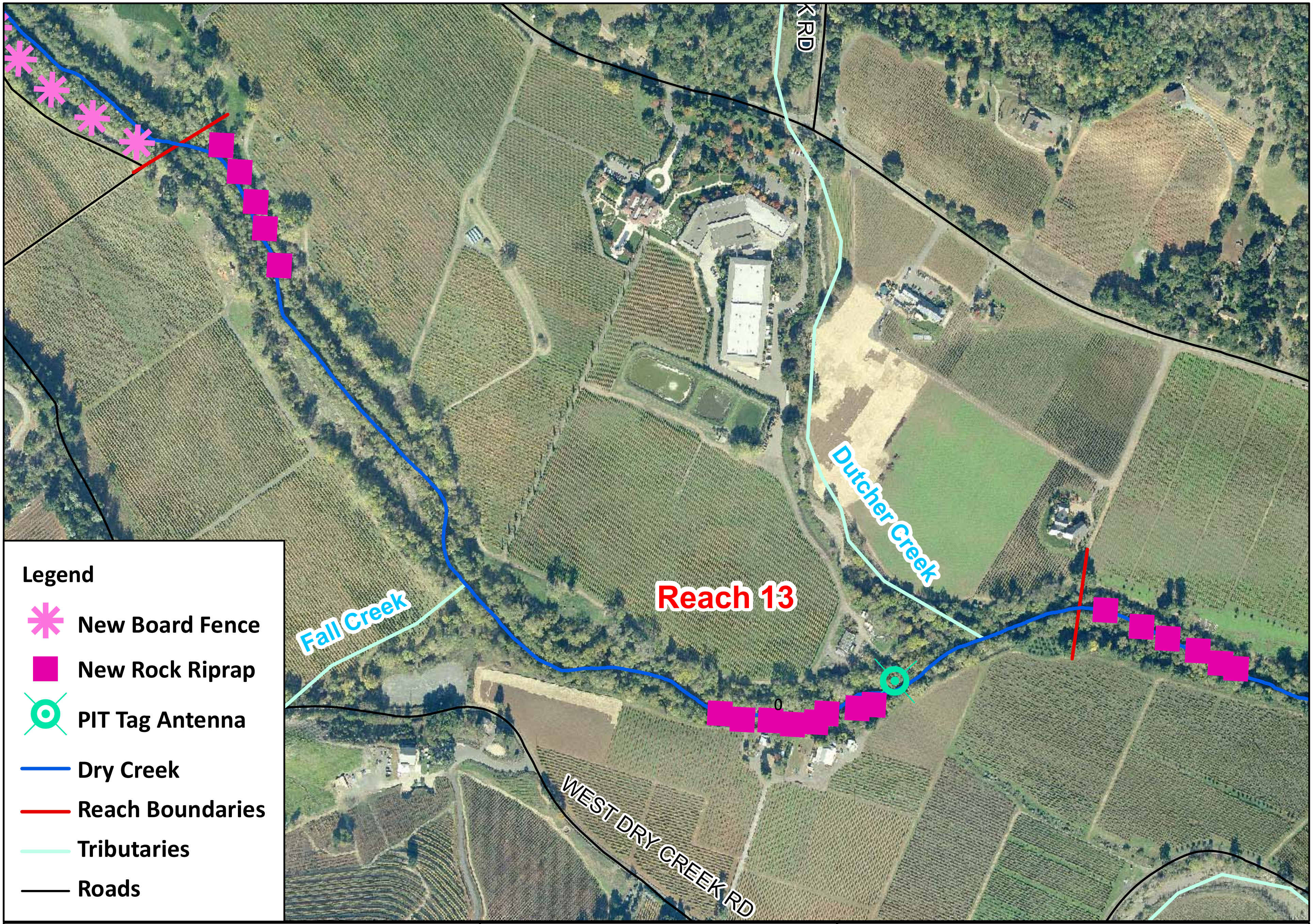
Instream Cover & Woody Debris

Overall, wood density in this reach of Dry Creek was 160 pieces per mile. A total of 141 pieces were counted, with 86 counted in pools. The highest densities of wood were in pools and alcoves. Of the six large pieces >20” diameter, three were located in pools. Instream cover was mainly provided by terrestrial vegetation and small woody debris, with some root mass cover provided in riffles. Aquatic vegetation with small woody debris provided abundant cover in alcoves (Figure 69). Edge habitat was observed in four pools, a riffle, a flatwater, and two alcoves.

Figure 69: Alcoves in Reach 13 with abundant cover provided by aquatic vegetation.

Table 13: Instream woody debris, cover, and edge habitat frequency for Reach 13.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	124.7	41.6	5.9	172.2	26%	78	50%
Scour Pools	303.0	86.6	21.6	411.1	35%	105	100%
Riffles	88.1	11.7	0.0	99.8	8%	17	14%
Flatwaters	91.7	40.4	7.3	139.4	22%	60	14%
Alcoves	91.8	91.8	23.0	206.6	87%	260	67%
	mainstem pieces/mile			159.9			



N W E S

0 500 1,000 Feet

DRY CREEK
Reach 13 Features

inter·fluve
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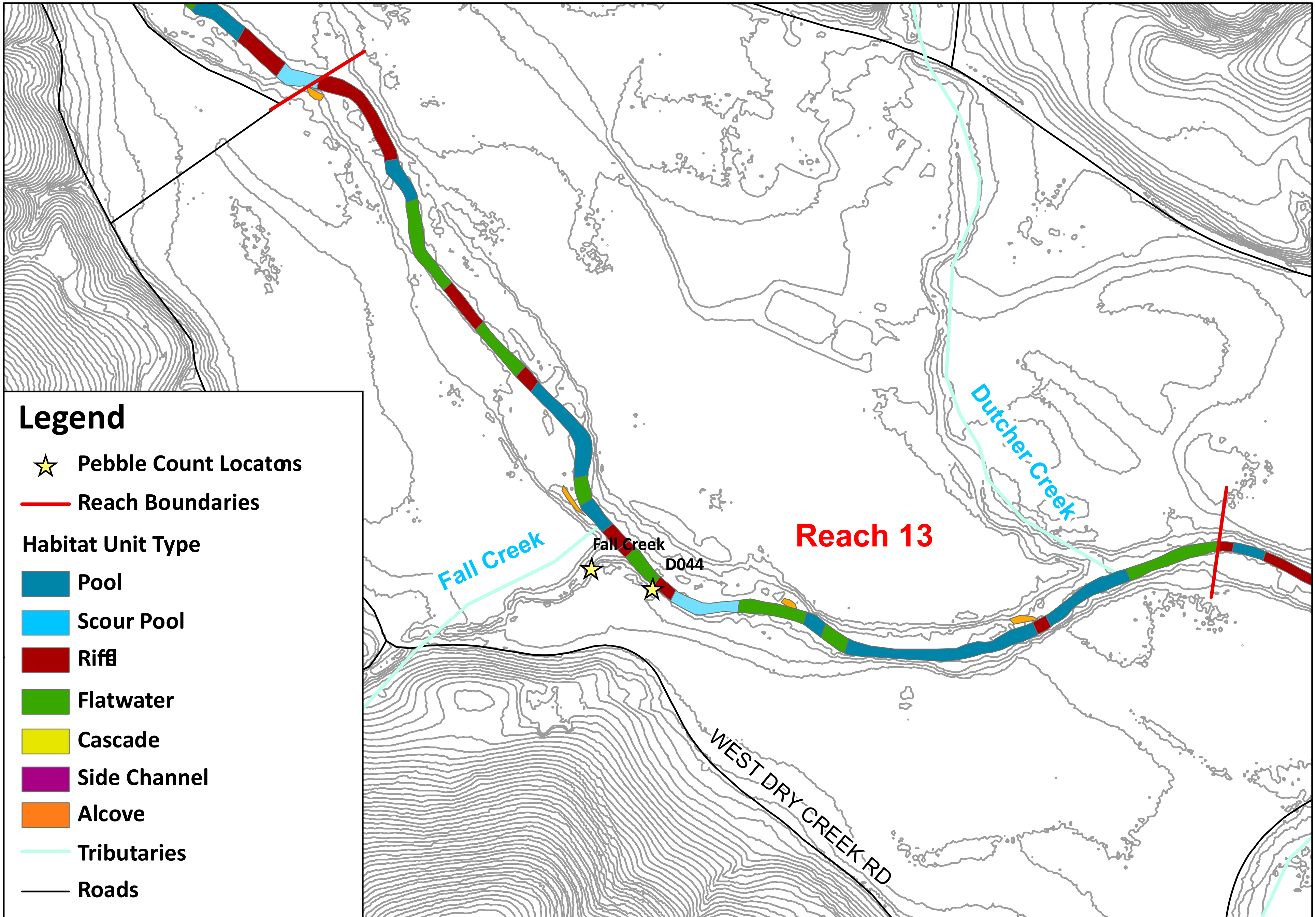

N W E S

0 400 800 Feet

DRY CREEK
Reach 13 Habitat Units

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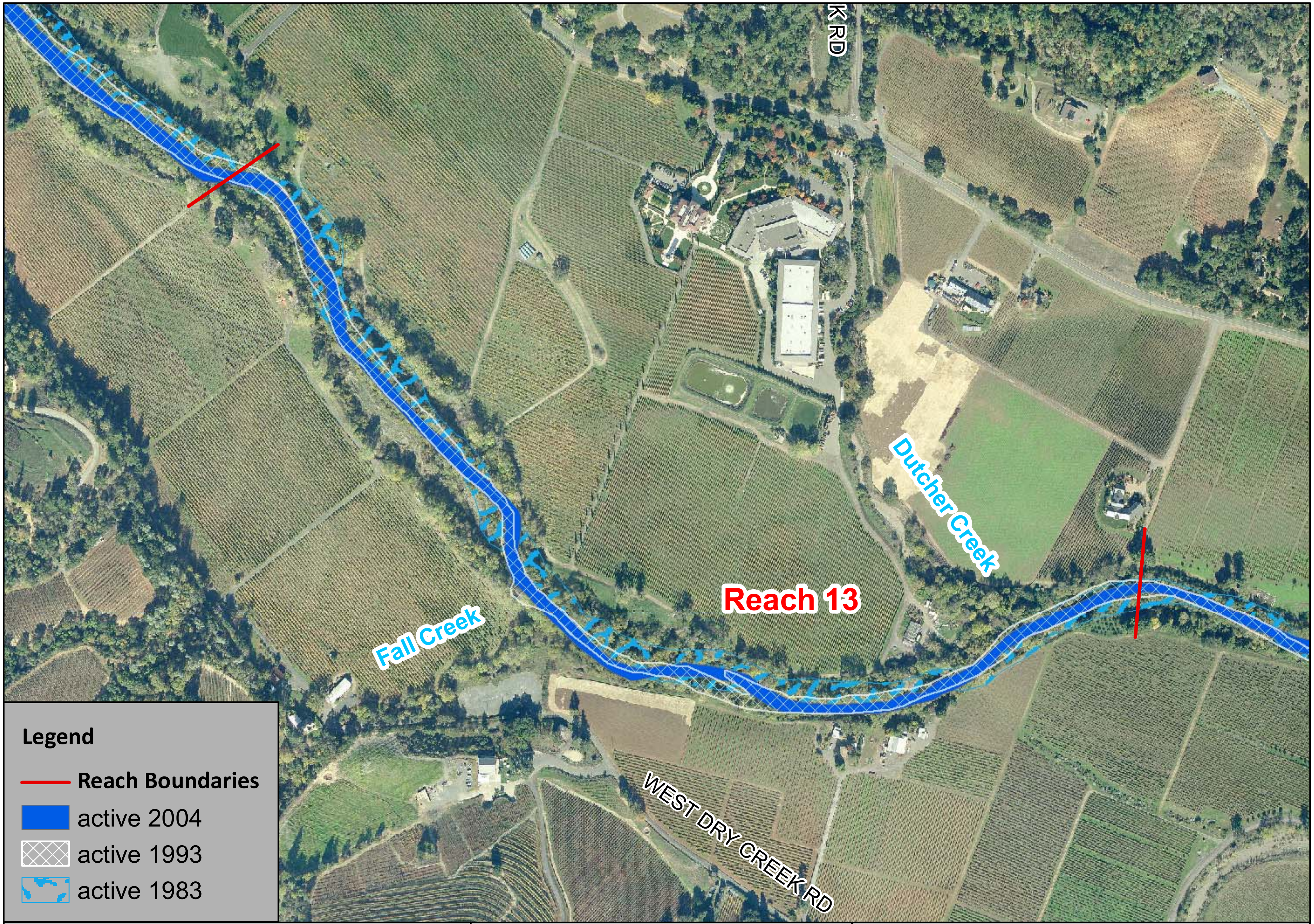

N
W E
S

0 400 800
Feet

DRY CREEK
Reach 13 - Channel Positon Map

inter-fluve

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REACH 14 (RM 12.6 to RM 13.3) **Schoolhouse Creek**

Reach 14 is a single-thread channel extending upstream to the Schoolhouse Creek confluence. The channel is slightly less entrenched than reach 13 and has migrated laterally slightly prior to, and since, dam construction. The air photo record suggests that the channel has generally narrowed over time as incision occurred.

Board fence bank protection was constructed along the lower 500 feet of the right[11] bank of Reach 14. Riprap boulder bank armor was installed along the banks near the upstream end of the reach for about 1,200 feet. Some litter was observed in Reach 14, including a ¾" black pipe on the left bank that disappears into the floodplain forest at river mile 12.9, and tires in the center of a flatwater at river mile 13.3 at the top of the reach.

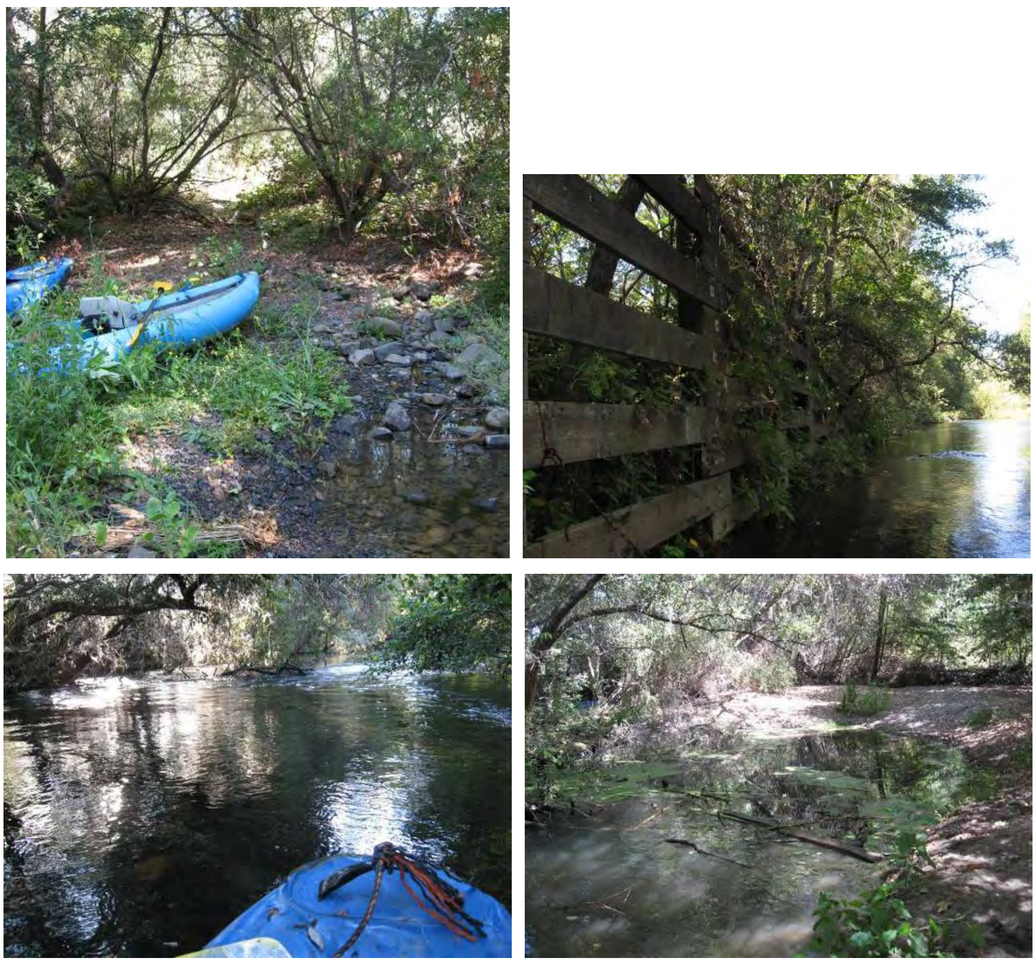


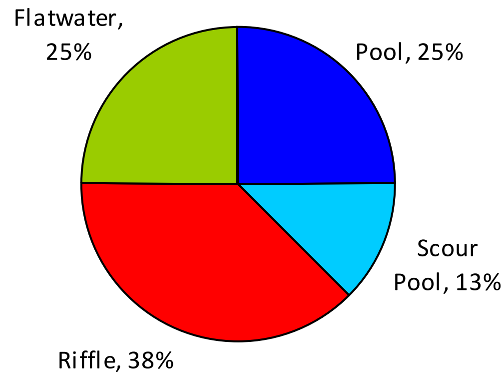
Figure 70: (upper left) mouth of Schoolhouse Creek, (upper right) board fence along the right bank, (lower left) deep pools with interacting live tree cover, (lower right) alcove habitat with aquatic vegetation.

[11] In the individual reach summaries, right and left bank designation defined as looking downstream.

Habitat Classification

The channel in reach 14 alternates between pools (38%), riffles (38%) and flatwaters (25%) on a relative frequency basis (Figure 71). There are nine riffles throughout the reach ranging in length from 50 to 300 ft making up 32% of the total reach on a length basis. The channel is wider than in the more confined reach 13, with an average wetted width of 48 ft during the survey and active channel and flood prone widths of 65 and 139 ft respectively. The average active channel depth of the riffles was 2.6 ft.

Figure 71: Proportion of Habitat Types by Relative Frequency in Reach 14

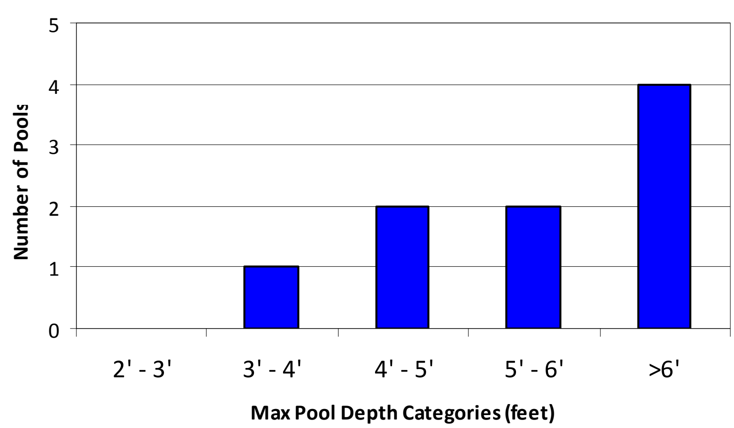


This portion of channel resembles an F4 Rosgen channel type, with a active channel width:depth ratio of 25 and an entrenchment ratio of 2.1. The reach has characteristics of both plane-bed and pool riffle morphology.

Pools

There were 9 pools in Reach 14, 3 of these were scour pools. All of the pools had a maximum depth greater than 3 feet, eith average maximum pool depth of 5.7 feet (Figure 72). The average residual pool depth was 4.4 feet, and the average pool crest depth was 1.4 ft. Substrate in the pools consisted of gravel with sand, with some small cobble.

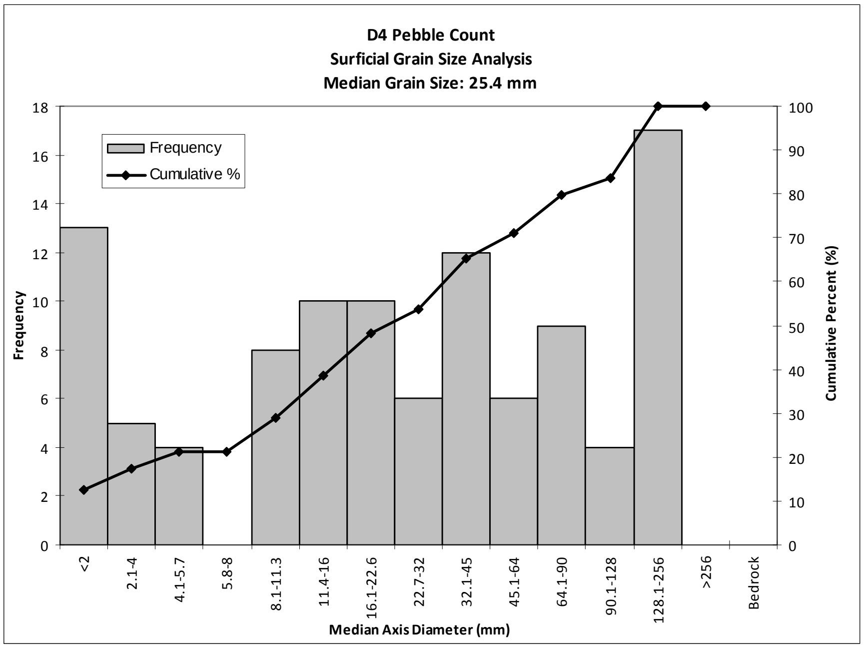
Figure 72: Maximum Pools Depths in Reach 14.

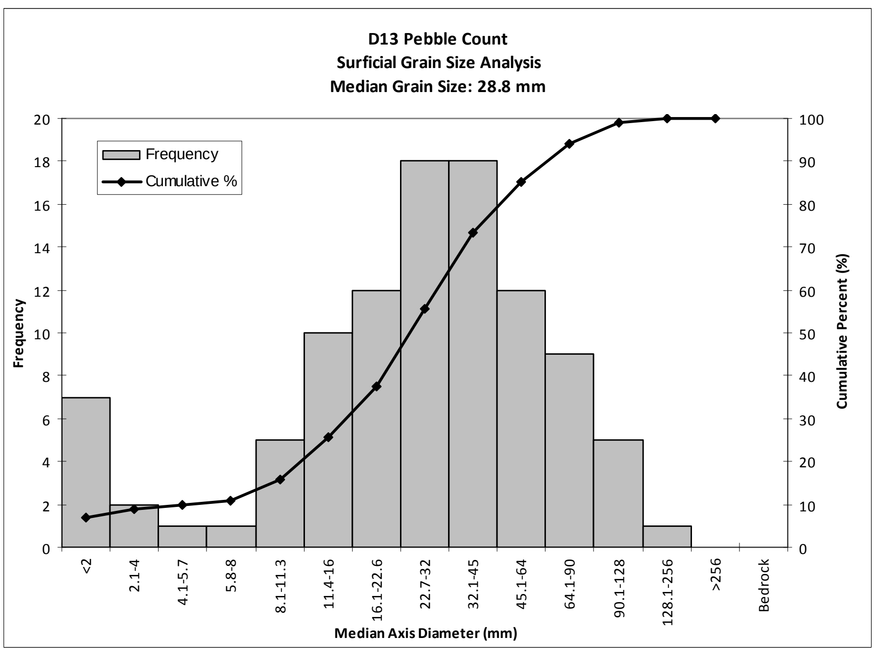


Riffles & Flatwaters

There were 9 riffles and 6 flatwaters in Reach 14. The average riffle depth was 1.1 feet, and the average flatwater depth was 2.3 feet. Substrate in riffles and flatwaters was gravel and small cobble. The bed material of two riffles were sampled, one at the upstream extent of the reach and the second approximately 0.25 miles downstream. The upstream riffle was primarily composed of medium to very coarse gravel with a median grain size of 25 mm. The downstream riffle was primarily composed of coarse to very coarse gravel with a median grain size of 29 mm.

Figure 73: Grain size distribution for two riffles in reach 14 (habitat units #4 and #13).





Side-Channels

One side channel, dominated by flatwater habitat, was observed in Reach 14. Dimensions were 118 feet long, by 15 feet wide, and an average of 1.1 feet deep. Substrate was gravel with sand.

Alcoves

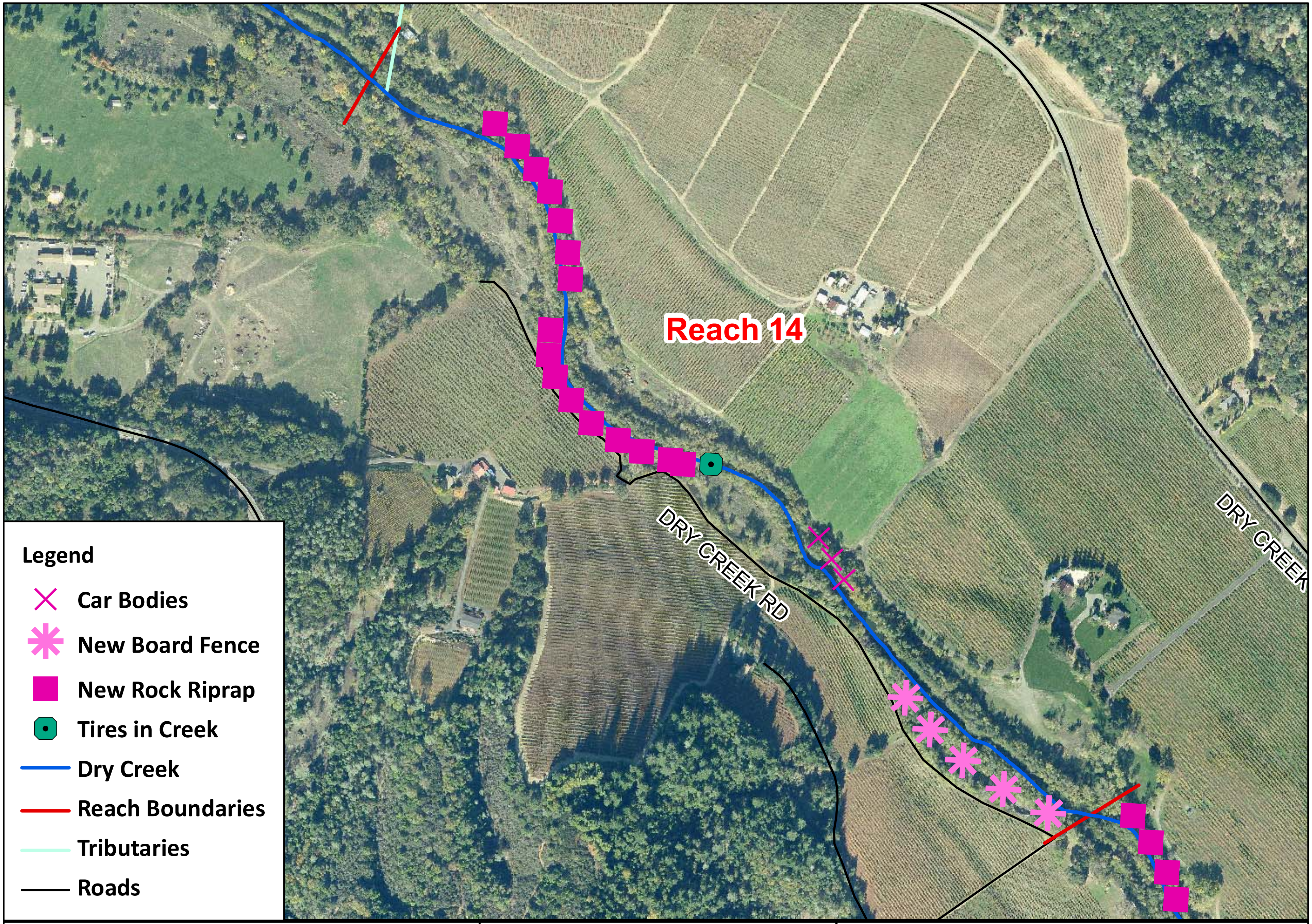
Three alcoves were measured in Reach 14. The alcoves were 58 and 38 feet long, 20 and 25 feet wide, with maximum depths of 1.5 and 5.4 feet. Substrate in the alcoves was fine sediment, with gravel and sand.

Instream Cover & Woody Debris

121 pieces of wood per mile were counted in Reach 14, with a total of 93 pieces counted in the reach (Table 14). There were no large pieces of wood observed, and 53 of the pieces were counted in pools. The highest densities of wood were found in pools and alcoves. Very low instream cover was present in Reach 14, provided by terrestrial vegetation and small woody debris, and less so by root masses and aquatic vegetation. Edge habitat was observed in one pool, three flatwaters, and the side channel.

Table 14: Instream woody debris, cover, and edge habitat frequency for Reach 14.

	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pools	135.7	72.4		208.1	23%	66	17%
Scour Pools	57.4	23.0		80.3	20%	47	0%
Riffles	62.8	16.7		79.6	20%	50	0%
Flatwaters	54.1	27.0		81.1	18%	50	50%
Side-Channels					30%	90	100%
Alcoves	110.0	55.0		165.0	28%	69	0%
	mainstem pieces/mile			117.0			



DRY CREEK
Reach 13 Features

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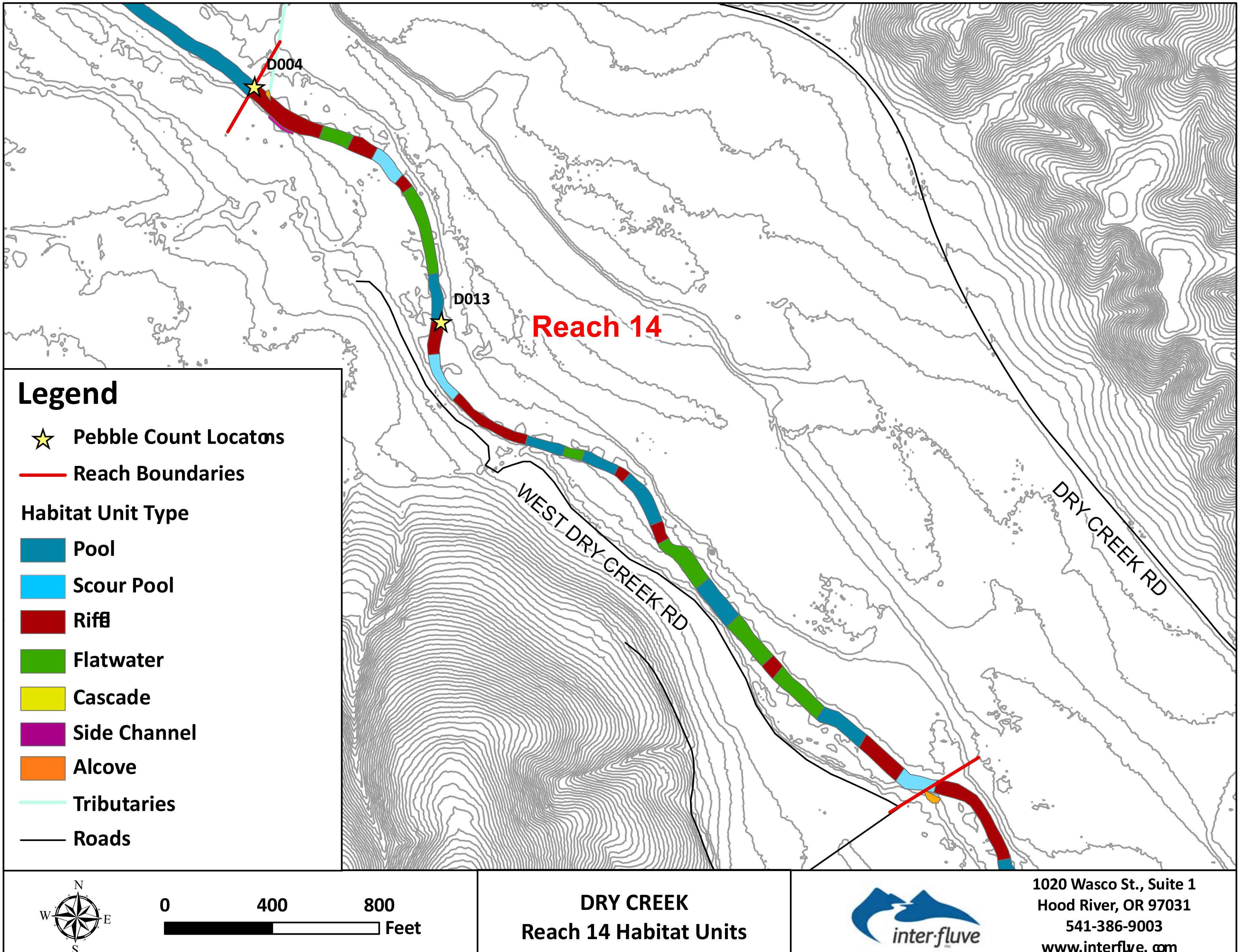

DRY CREEK
Reach 14 Habitat Units

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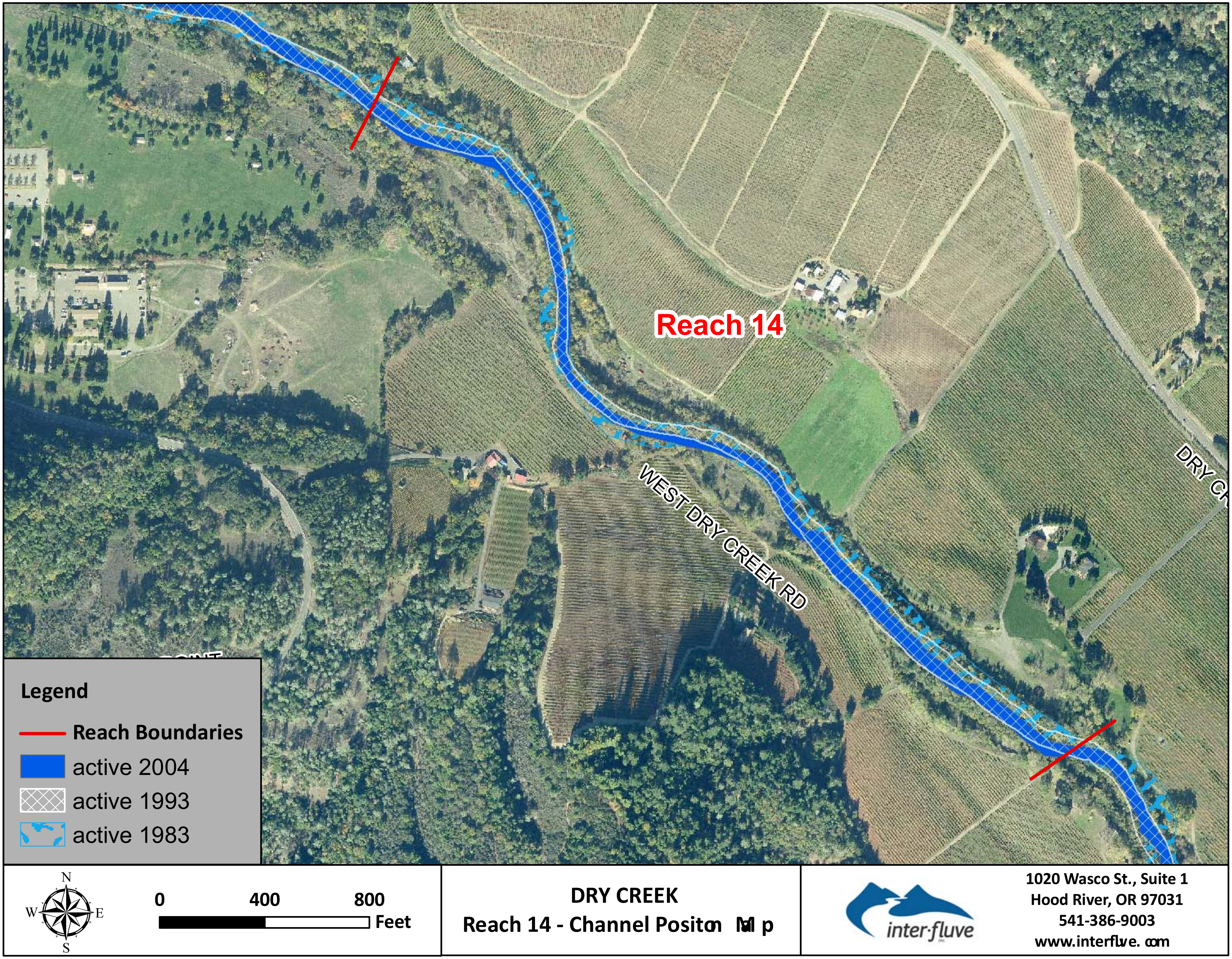

DRY CREEK
Reach 14 - Channel Positon Map

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REACH 15 (RM 13.3 to RM 13.6) **Schoolhouse Creek to Bord Bridge**

Reach 15 is a single-thread channel extending upstream from Schoolhouse Creek to the Bord Bridge. The channel here has a very low sinuosity and has experienced little channel change within the air photo record except for narrowing over time. The riparian corridor is narrow.

At the Bord Bridge, a boulder revetment associated with the bridge armors the right[12] bank. Higher on this bank, there is evidence of an older wood revetment. The high canopy cover in this reach is provided by California bay, willow, alder, and cottonwood. Himalayan blackberries and other exotics were present on both banks, but overstory vegetation dominates. An old board fence with metal mesh and cable covers part of the right bank along a pool unit. In general the banks were steeper on the right, and with a more gradual floodplain on the left bank.

Figure 74: (upper left) the riffle under Bord Bridge, (upper right) canopy cover, (lower left) deep, slow pool unit downstream, , (lower right) the long pool.

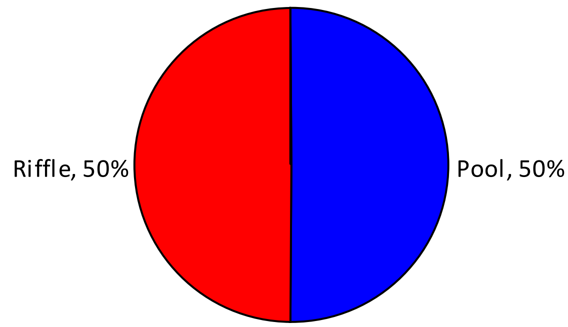
[12] In the individual reach summaries, right and left bank designation defined as looking downstream.

Habitat Classification

Reach 15 consists of a 48 foot long riffle and an extremely long, 1630 foot pool (Figure 75). This is the first stream channel habitat downstream of the dam outlet influence. The wetted channel width of the riffle was 23.0 feet, and the wetted width of the long pool was 55.0 feet.

Channel dimensions were measured at the riffle under the Bord Bridge. The active channel width was 45.0 feet, the average active channel depth was 2.9 feet, and the floodprone width with 126.0 feet. This riffle resembles a C4 channel type due to its moderate entrenchment ratio of 2.8 and its moderate width:depth ratio of 15.

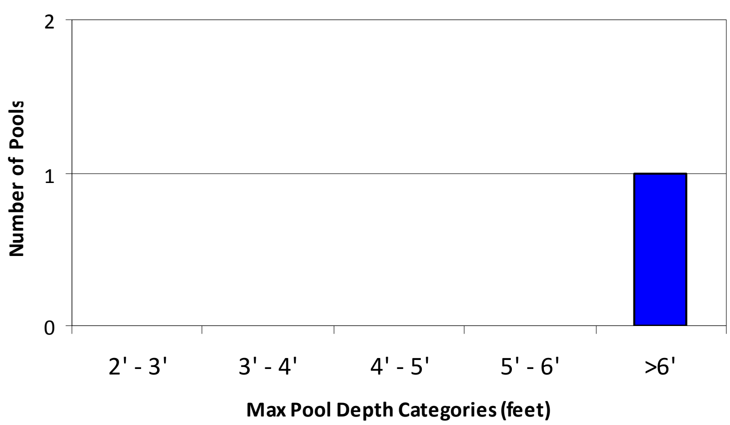
Figure 75: Proportion of Habitat Types by Relative Frequency in Reach 15



Pool

The single, very long pool in Reach 15 had a maximum depth of 7.0 feet. The residual depth was 4.5 feet, with a pool crest depth of 2.5 feet. Substrate in this pool was gravel with small cobble.

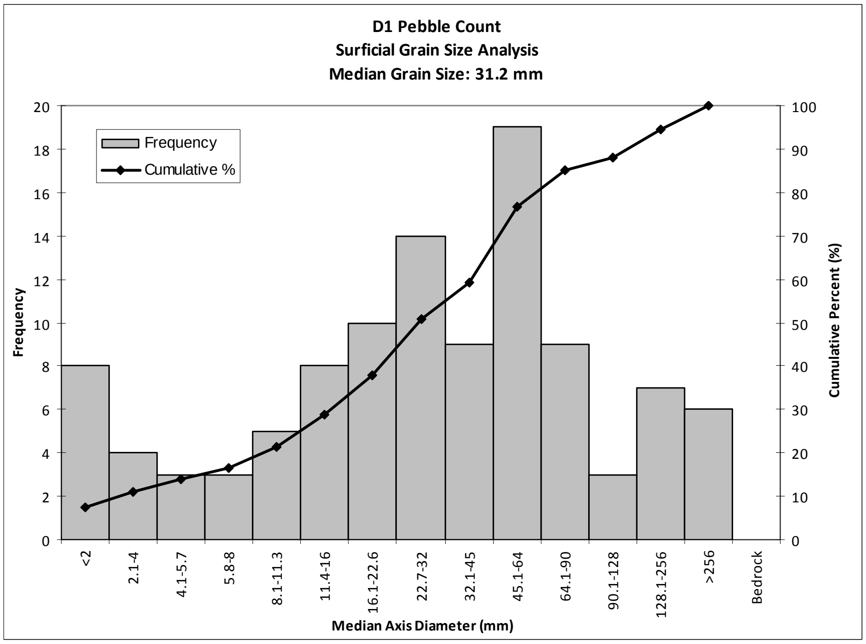
Figure 76: Maximum Pool Depth in Reach 15.



Riffle

The short, 48 foot long riffle had an average depth of 1.0 foot. The bed material is primarily gravel with some small cobbles. The material in the riffle is primarily coarse to very coarse gravel but ranges from sand to small boulders. The median grain size for this riffle is 31 mm (Figure 77). 67% was within ideal spawning sizes for coho and steelhead (11.4 to 128mm), and 37% was within ideal juvenile rearing sediment sizes (32mm to 128mm). 7% of the samples were sand or fine sediments.

Figure 77: Grain size distribution for the riffle below Bord Bridge in reach 15 (habitat unit #1).



Side-Channels

No side channels were observed in Reach 15.

Alcoves

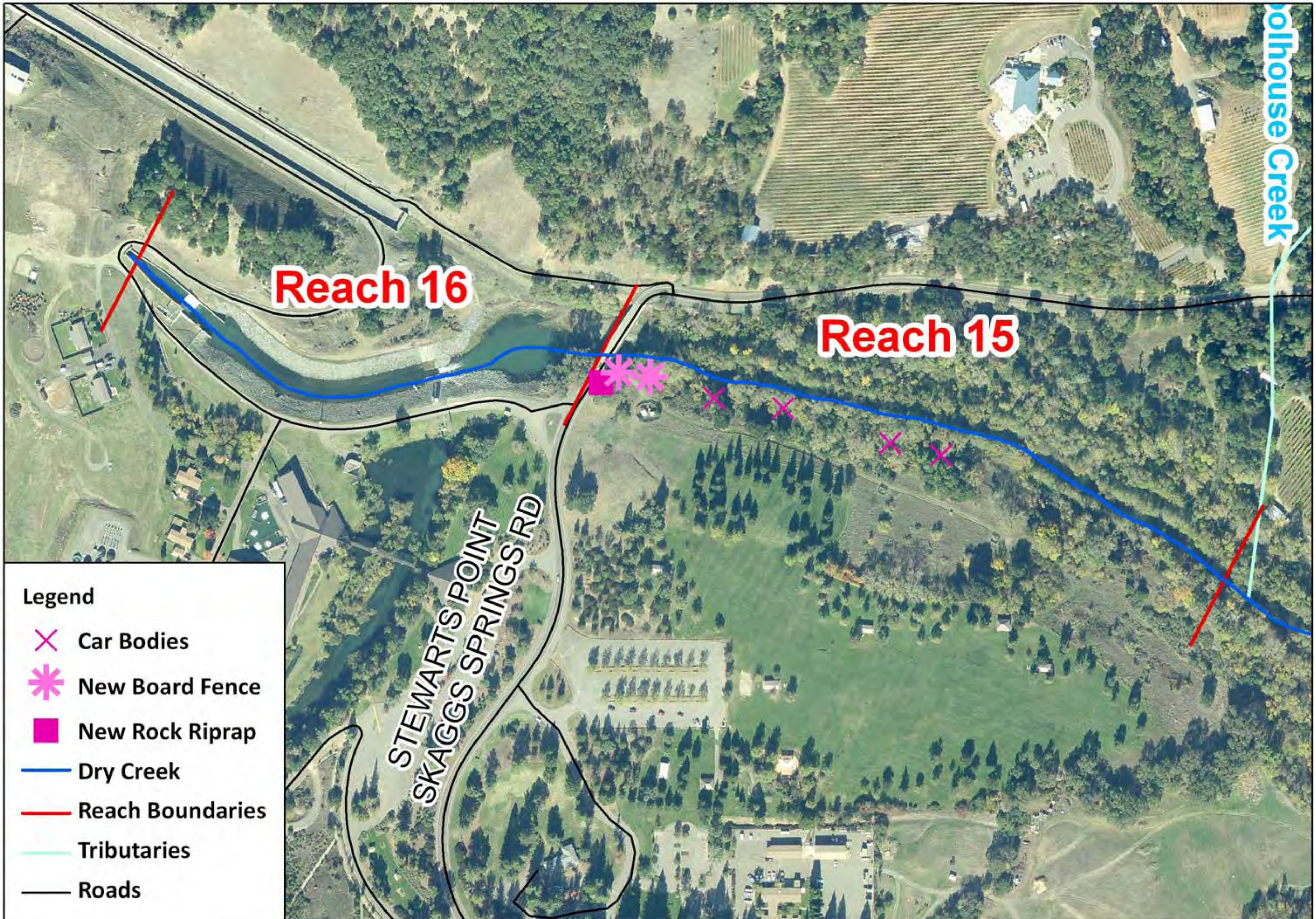
One alcove was observed in Reach 15. It was 45 feet long and 27 feet wide, with a maximum depth of 3.0 feet. Substrate in the alcove was fine sediment with sand.

Instream Cover & Woody Debris

There were 63 pieces of wood per mile in Reach 15. A total of 20 pieces of wood were counted, with no large pieces of wood observed (Table 15). 19 of the 20 pieces were found in the long pool, but the density of wood pieces in the riffle was much higher. Cover was provided in the pool by terrestrial vegetation, with additional cover provided by aquatic vegetation. In the riffle, a modicum of cover was provided by terrestrial vegetation and boulders associated with the bridge riprap bank armoring. In the alcove, cover was provided by aquatic vegetation with some overhanging vegetation. Edge habitat was observed only along the margins of the riffle in Reach 15.

Table 15: Instream woody debris, cover, and edge habitat frequency for Reach 15.

	wood pieces/mile				instream cover		
	small 6" - 12"	med 12" - 20"	large >20"	total	% cover	shelter rating	% units with edge habitat
Pool	38.9	22.7	0.0	61.5	30%	90	0%
Riffle	110.0	0	0	110.0	7%	7	100%
Alcove	0	0	0	0	80%	240	0%
	mainstem pieces/mile			62.9			



DRY CREEK
Reach 15 Features

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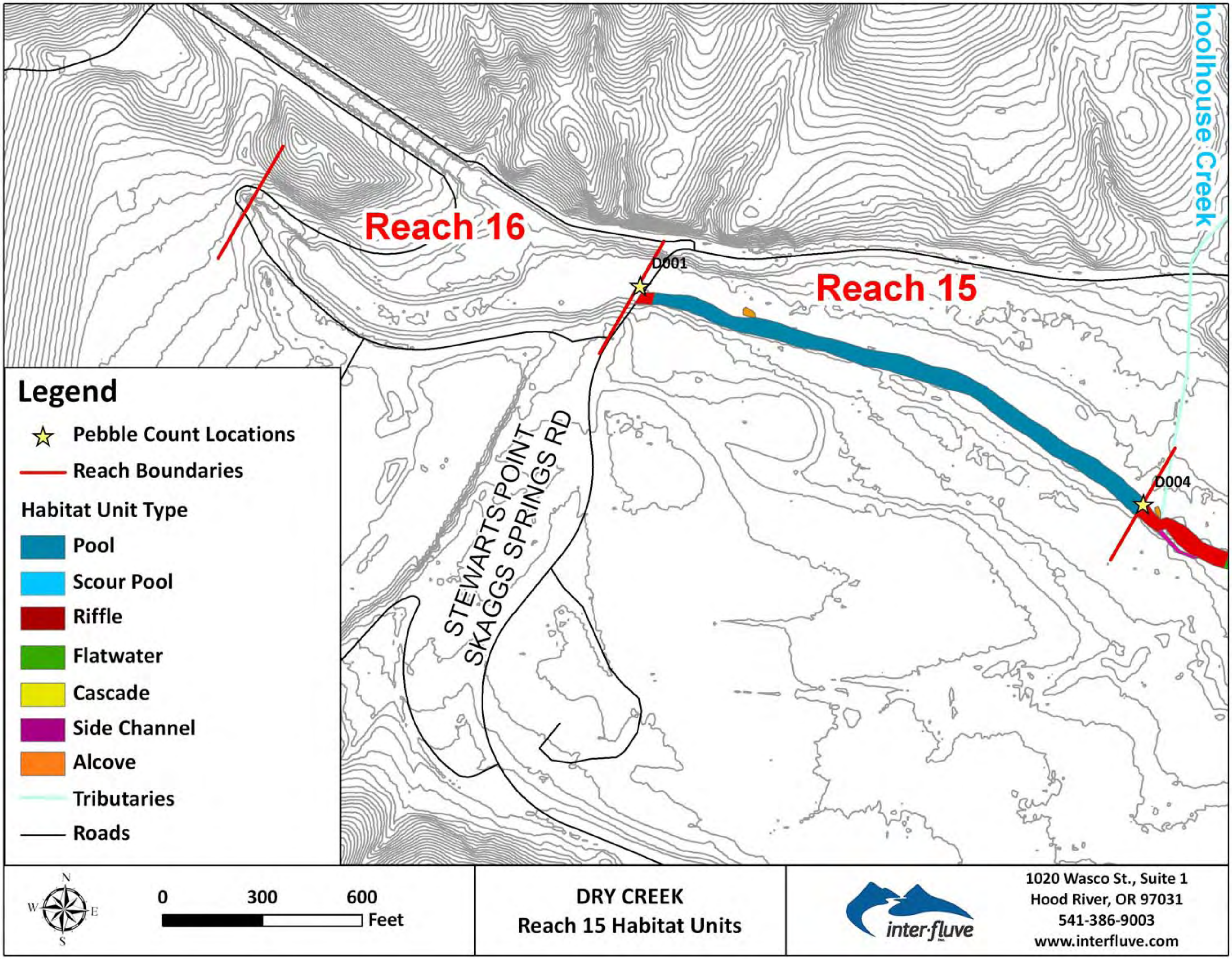

DRY CREEK
Reach 15 Habitat Units

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DRY CREEK
Reach 15 - Channel Position Map

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REACH 16 (RM 13.6 to RM 13.9) **Bord Bridge to dam spillway pool**

Reach 16 extends upstream from Bord Bridge to a flow measuring flume immediately below Warm Springs Dam. From the outlet of the dam, water flows through a constructed channel and over two drop structures before spilling into a deep pool (>12 feet deep) immediately upstream of the Bord bridge. Boulder revetments cover both banks within this constructed channel.

Figure 78: (left) looking upstream at the deep pool downstream of the measuring flume structure, (right) preparing to launch from the measuring flume structure.

Appendix B:

Substrate sampling data sheets from 2010 supplemental substrate sampling program

Dry Creek BLK - 1

Sediment Grain Size Analysis

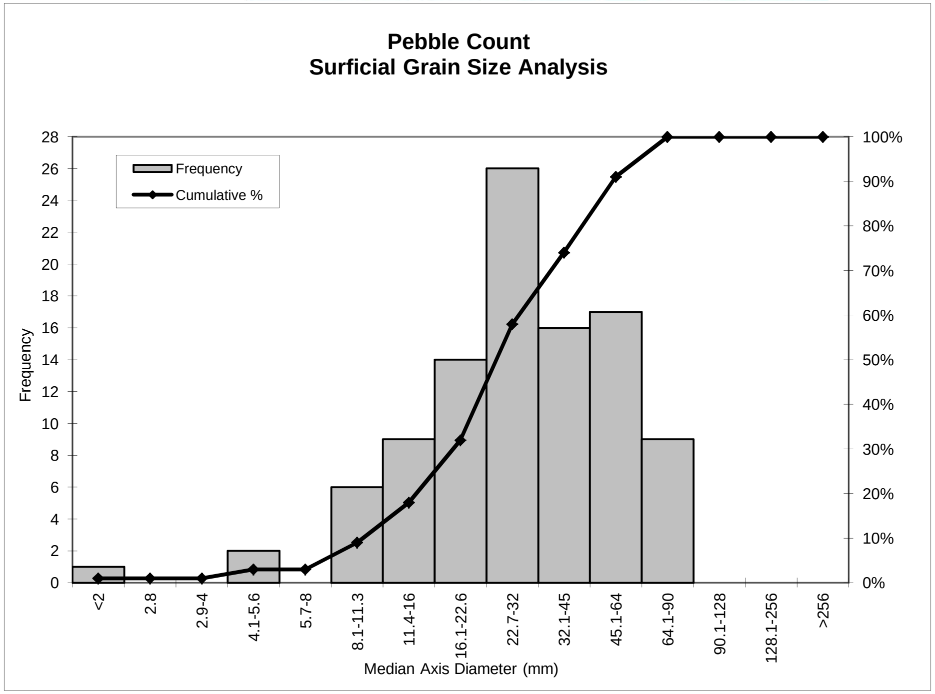
riffle	Identifier
11/8/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	1	1.0%
Sand	2.8	0	1.0%
Very Fine Gravel	2.9-4	0	1.0%
Fine Gravel	4.1-5.6	2	3.0%
Fine Gravel	5.7-8	0	3.0%
Medium Gravel	8.1-11.3	6	9.0%
Medium Gravel	11.4-16	9	18.0%
Coarse Gravel	16.1-22.6	14	32.0%
Coarse Gravel	22.7-32	26	58.0%
Very Course Gravel	32.1-45	16	74.0%
Very Course Gravel	45.1-64	17	91.0%
Small Cobble	64.1-90	9	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



Dry Creek BLK - 1

Bulk Sediment Grain Size Analysis

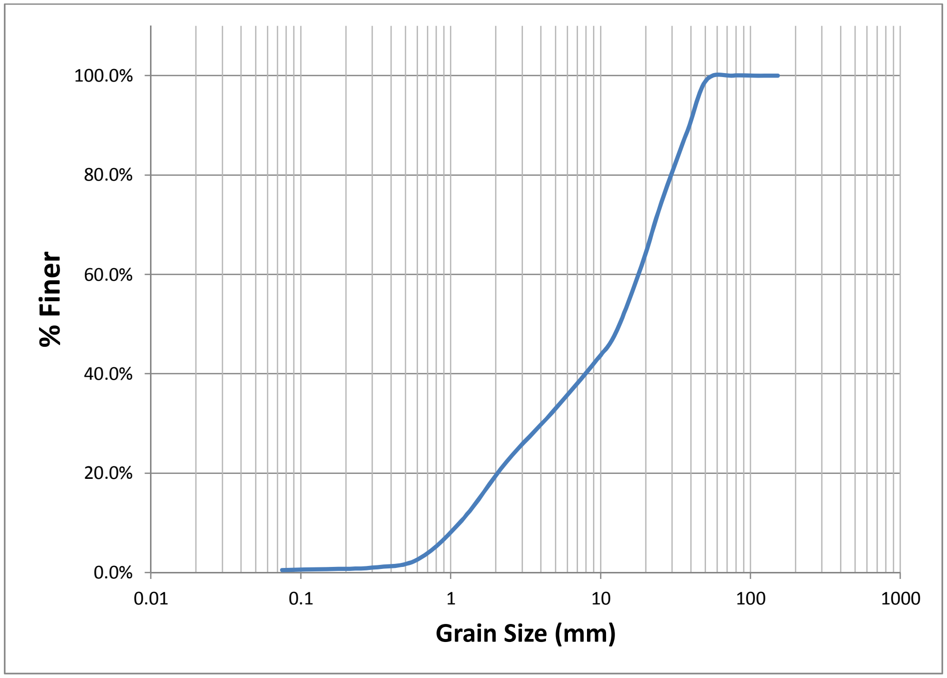
riffle	Identifier
11/8/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Fines	<2	18.7%
Fine Sand	2.8	24.1%
Medium Sand	2.9-4	29.1%
Coarse Saned	4.1-5.6	34.1%
Fine Gravel	5.7-8	39.5%
Medium Gravel	8.1-11.3	46.0%
Medium Gravel	11.4-16	55.6%
Coarse Gravel	16.1-22.6	69.1%
Coarse Gravel	22.7-32	82.0%
Very Course Gravel	32.1-45	94.5%
Very Course Gravel	45.1-64	99.6%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%
		100.0%



Dry Creek BLK - 2

Sediment Grain Size Analysis

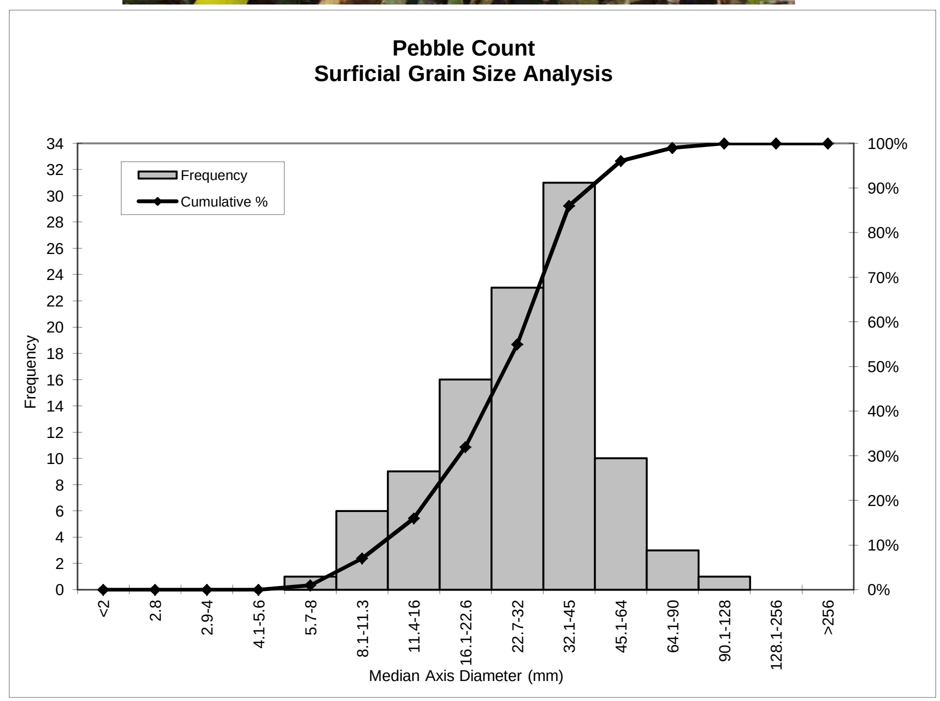
riffle	Identifier
11/8/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	0	.0%
Fine Gravel	4.1-5.6	0	.0%
Fine Gravel	5.7-8	1	1.0%
Medium Gravel	8.1-11.3	6	7.0%
Medium Gravel	11.4-16	9	16.0%
Coarse Gravel	16.1-22.6	16	32.0%
Coarse Gravel	22.7-32	23	55.0%
Very Course Gravel	32.1-45	31	86.0%
Very Course Gravel	45.1-64	10	96.0%
Small Cobble	64.1-90	3	99.0%
Small Cobble	90.1-128	1	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



Dry Creek BLK - 2

Bulk Sediment Grain Size Analysis

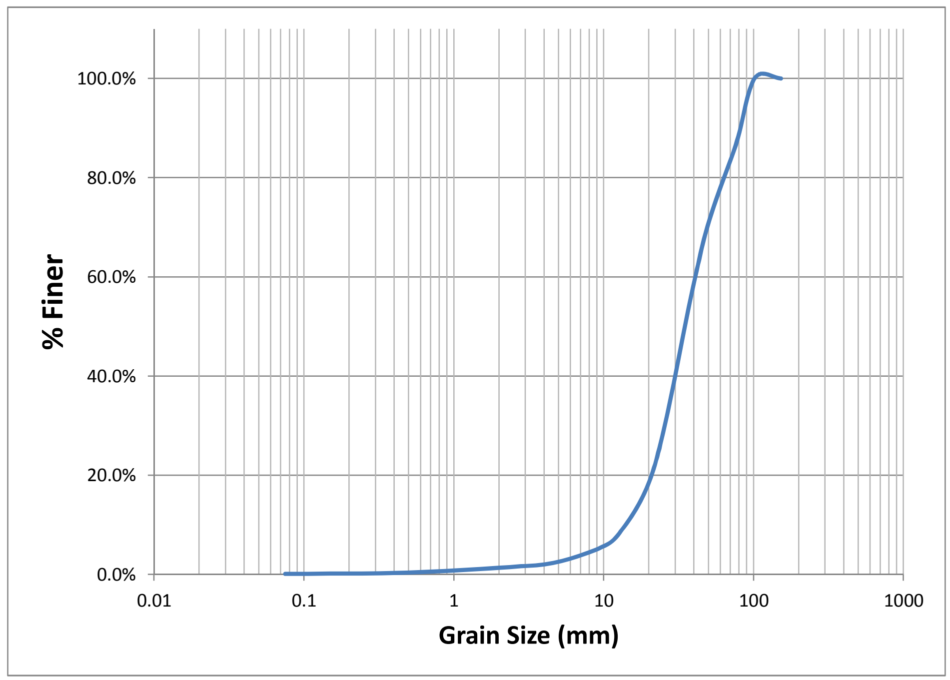
riffle	Identifier
11/8/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

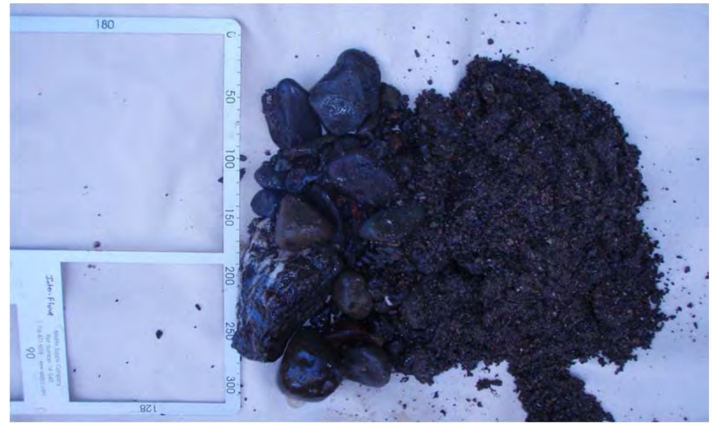
Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	1.3%
Sand	2.8	1.7%
Very Fine Gravel	2.9-4	2.1%
Fine Gravel	4.1-5.6	2.9%
Fine Gravel	5.7-8	4.5%
Medium Gravel	8.1-11.3	7.0%
Medium Gravel	11.4-16	12.8%
Coarse Gravel	16.1-22.6	24.0%
Coarse Gravel	22.7-32	43.2%
Very Course Gravel	32.1-45	64.3%
Very Course Gravel	45.1-64	100.0%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



Dry Creek BLK - 3

Sediment Grain Size Analysis

riffle	Identifier
11/8/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

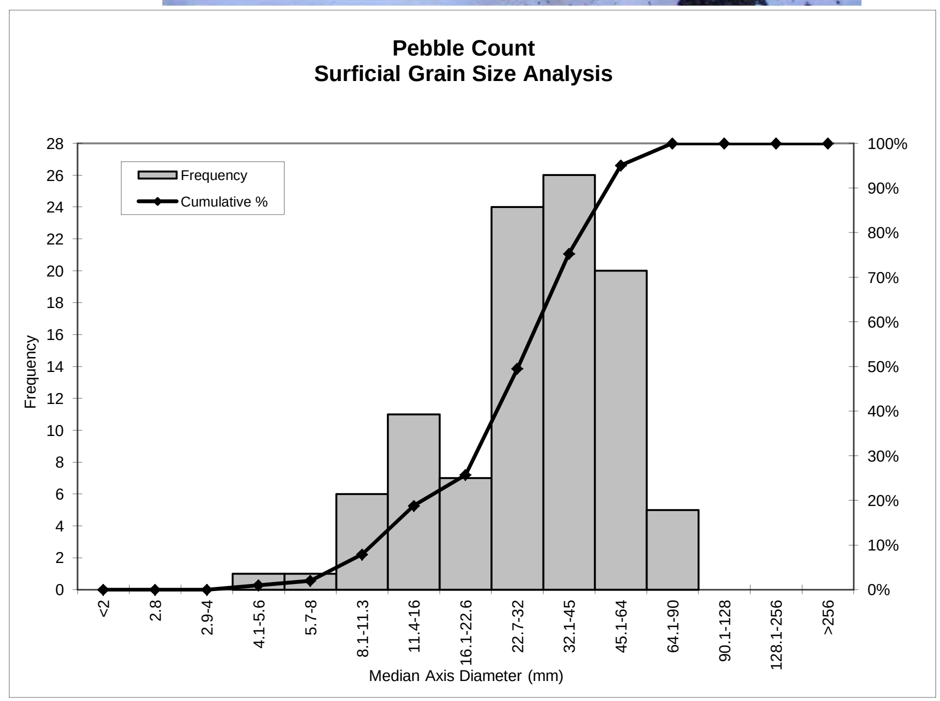


Notes:

View
Looking
upstream

Pebble Count Data

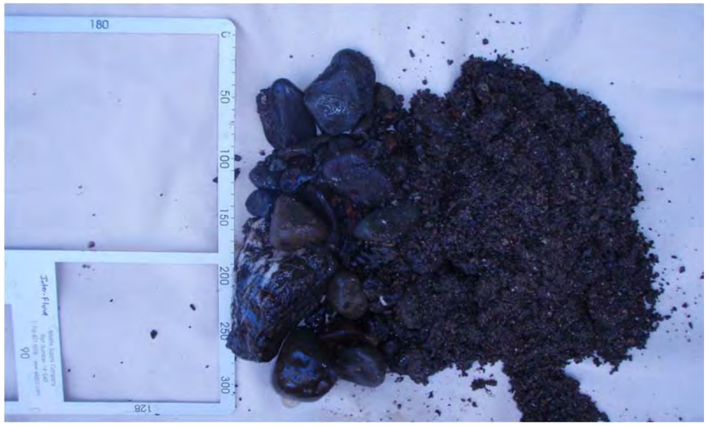
Class (Wentworth)	Size Class mm	Frequency	Cumulative %
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	0	.0%
Fine Gravel	4.1-5.6	1	1.0%
Fine Gravel	5.7-8	1	2.0%
Medium Gravel	8.1-11.3	6	7.9%
Medium Gravel	11.4-16	11	18.8%
Coarse Gravel	16.1-22.6	7	25.7%
Coarse Gravel	22.7-32	24	49.5%
Very Course Gravel	32.1-45	26	75.2%
Very Course Gravel	45.1-64	20	95.0%
Small Cobble	64.1-90	5	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	101	



Dry Creek BLK - 3

Bulk Sediment Grain Size Analysis

riffle	Identifier
11/8/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

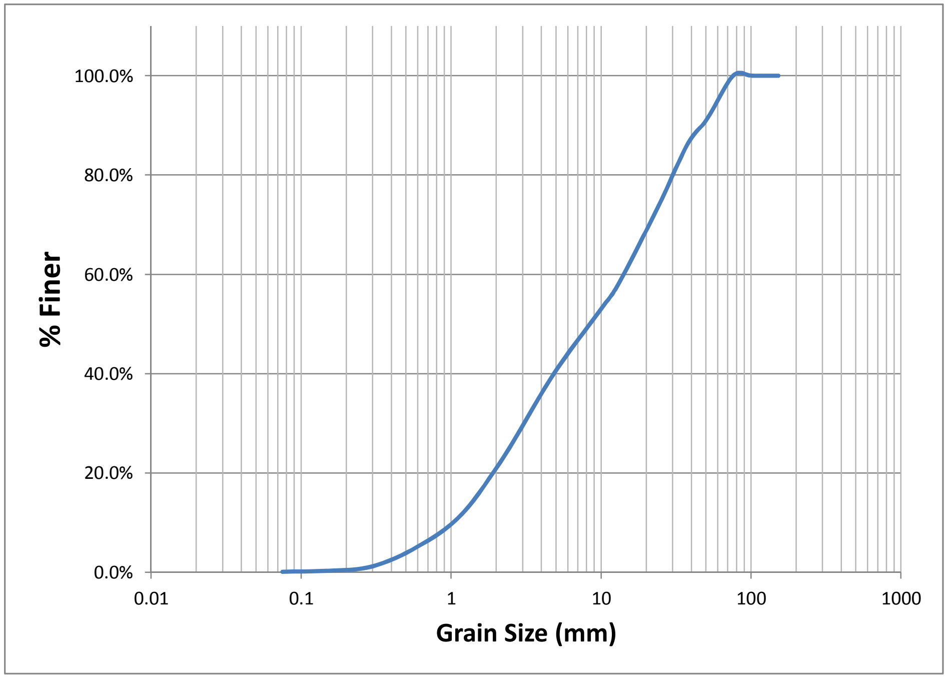


Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	20.5%
Sand	2.8	27.1%
Very Fine Gravel	2.9-4	34.8%
Fine Gravel	4.1-5.6	41.8%
Fine Gravel	5.7-8	48.2%
Medium Gravel	8.1-11.3	55.1%
Medium Gravel	11.4-16	62.7%
Coarse Gravel	16.1-22.6	71.8%
Coarse Gravel	22.7-32	81.0%
Very Course Gravel	32.1-45	89.0%
Very Course Gravel	45.1-64	96.2%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



Dry Creek BLK - 4

Sediment Grain Size Analysis

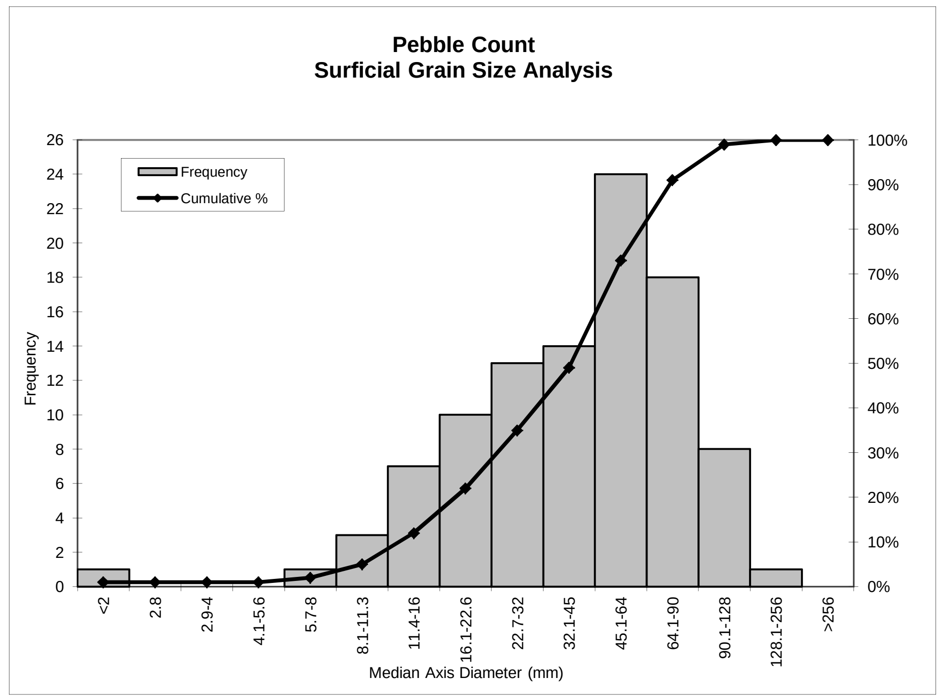
riffle	Identifier
11/8/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

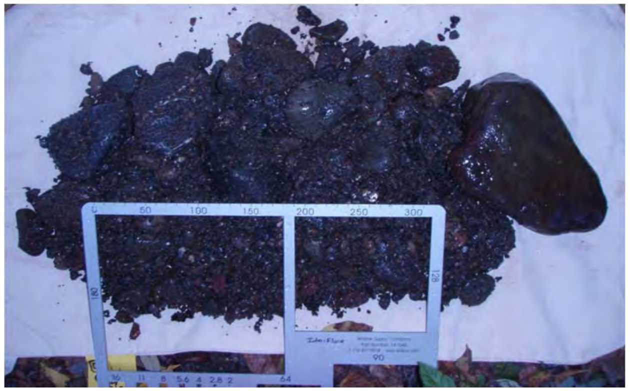
Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	1	1.0%
Sand	2.8	0	1.0%
Very Fine Gravel	2.9-4	0	1.0%
Fine Gravel	4.1-5.6	0	1.0%
Fine Gravel	5.7-8	1	2.0%
Medium Gravel	8.1-11.3	3	5.0%
Medium Gravel	11.4-16	7	12.0%
Coarse Gravel	16.1-22.6	10	22.0%
Coarse Gravel	22.7-32	13	35.0%
Very Course Gravel	32.1-45	14	49.0%
Very Course Gravel	45.1-64	24	73.0%
Small Cobble	64.1-90	18	91.0%
Small Cobble	90.1-128	8	99.0%
Large Cobble	128.1-256	1	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



Dry Creek BLK - 4

Bulk Sediment Grain Size Analysis

riffle	Identifier
11/8/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

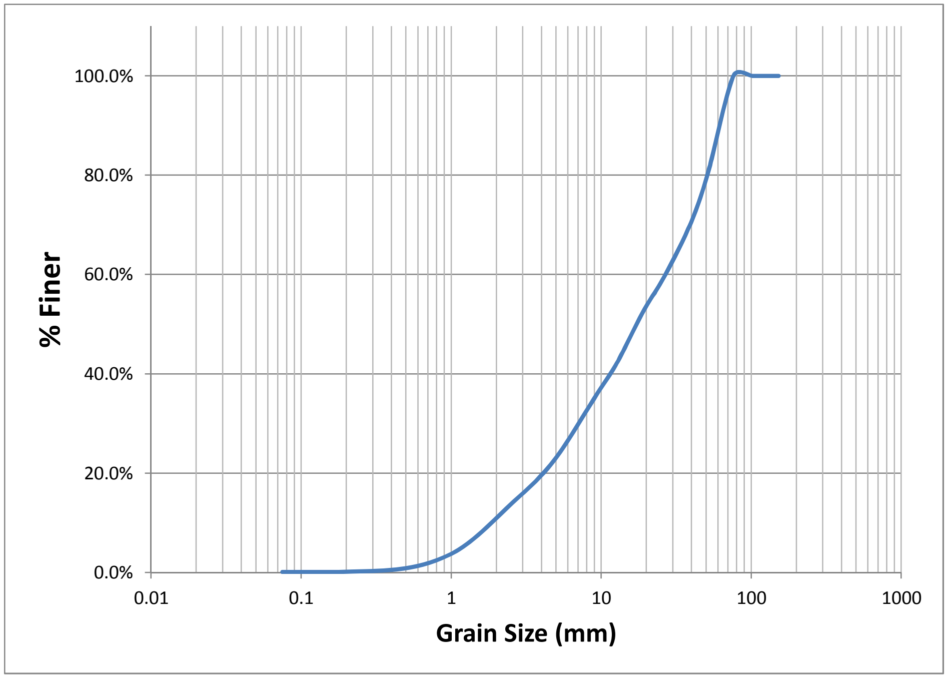


Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	10.6%
Sand	2.8	14.7%
Very Fine Gravel	2.9-4	19.3%
Fine Gravel	4.1-5.6	24.7%
Fine Gravel	5.7-8	31.8%
Medium Gravel	8.1-11.3	39.5%
Medium Gravel	11.4-16	47.5%
Coarse Gravel	16.1-22.6	56.0%
Coarse Gravel	22.7-32	64.2%
Very Course Gravel	32.1-45	75.0%
Very Course Gravel	45.1-64	90.8%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



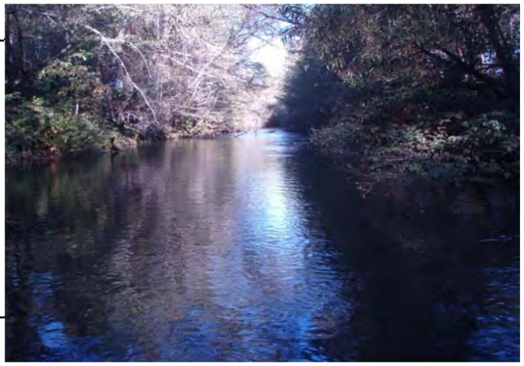
Dry Creek BLK - 5

Sediment Grain Size Analysis

riffle	Identifier
11/9/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

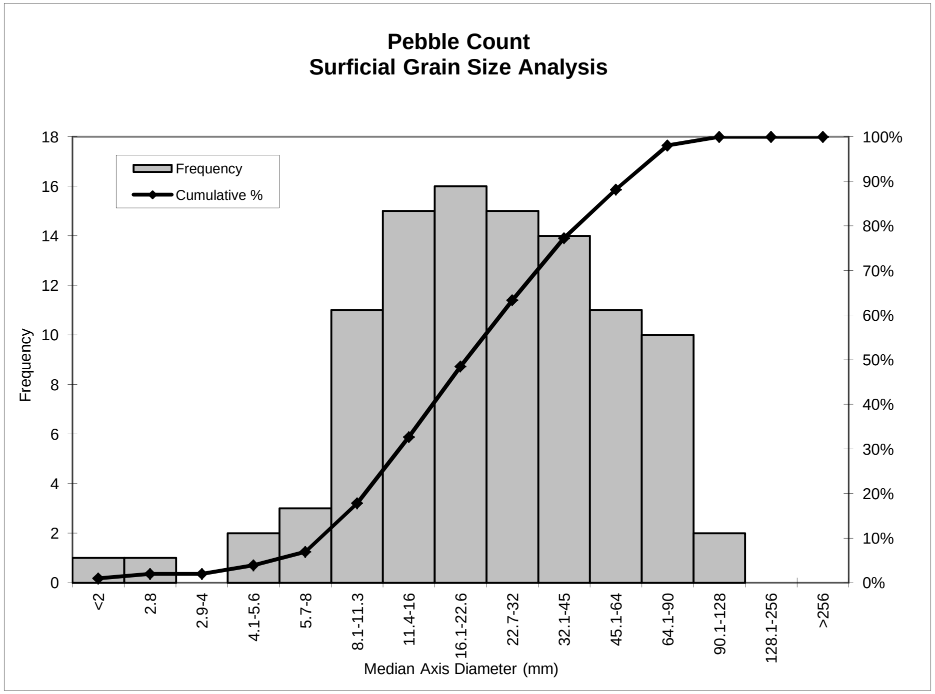
Notes:

View Looking upstream



Pebble Count Data

Class (Wentworth)	Size Class mm	Frequency	Cumulative %
Sand	<2	1	1.0%
Sand	2.8	1	2.0%
Very Fine Gravel	2.9-4	0	2.0%
Fine Gravel	4.1-5.6	2	4.0%
Fine Gravel	5.7-8	3	6.9%
Medium Gravel	8.1-11.3	11	17.8%
Medium Gravel	11.4-16	15	32.7%
Coarse Gravel	16.1-22.6	16	48.5%
Coarse Gravel	22.7-32	15	63.4%
Very Course Gravel	32.1-45	14	77.2%
Very Course Gravel	45.1-64	11	88.1%
Small Cobble	64.1-90	10	98.0%
Small Cobble	90.1-128	2	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	101	



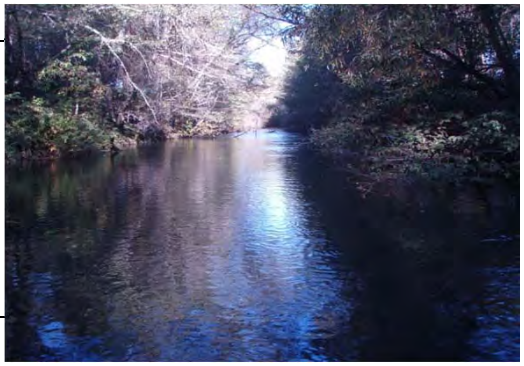
Dry Creek BLK - 5

Bulk Sediment Grain Size Analysis

riffle	Identifier
11/9/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

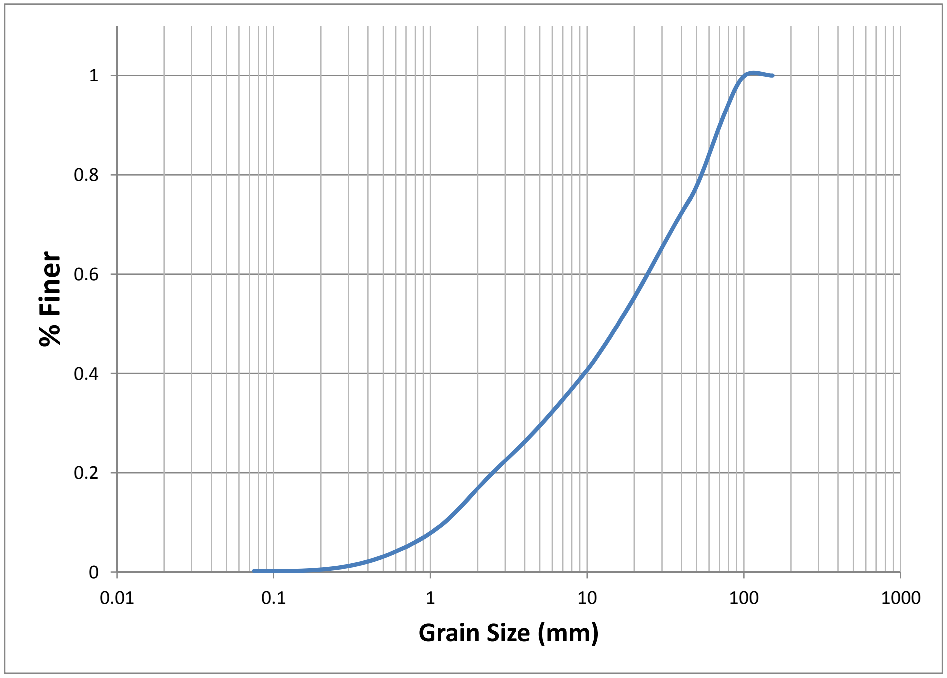
Notes:

View Looking upstream



Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2		16.2%
Sand	2.8		20.9%
Very Fine Gravel	2.9-4		25.7%
Fine Gravel	4.1-5.6		30.7%
Fine Gravel	5.7-8		36.3%
Medium Gravel	8.1-11.3		42.9%
Medium Gravel	11.4-16		49.9%
Coarse Gravel	16.1-22.6		58.0%
Coarse Gravel	22.7-32		66.3%
Very Course Gravel	32.1-45		75.0%
Very Course Gravel	45.1-64		85.5%
Small Cobble	64.1-90		96.7%
Small Cobble	90.1-128		100.0%
Large Cobble	128.1-256		100.0%
Small Boulders	>256		100.0%
			100.0%



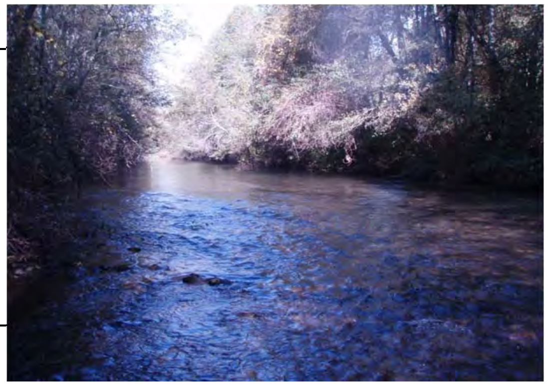
Dry Creek BLK - 6

Sediment Grain Size Analysis

riffle	Identifier
11/9/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

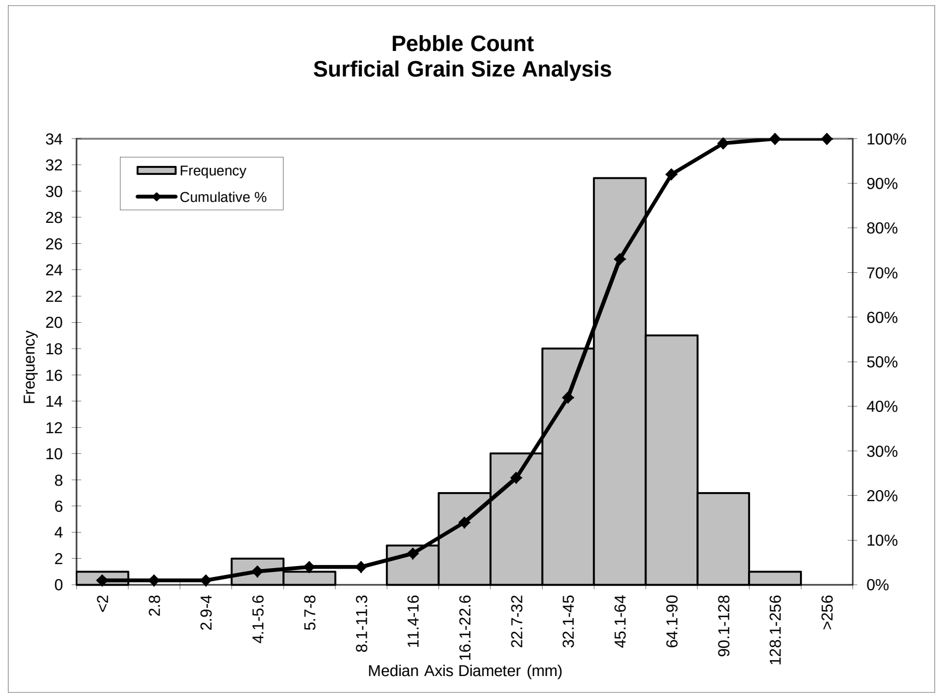
Notes:

View
Looking
upstream



Pebble Count Data

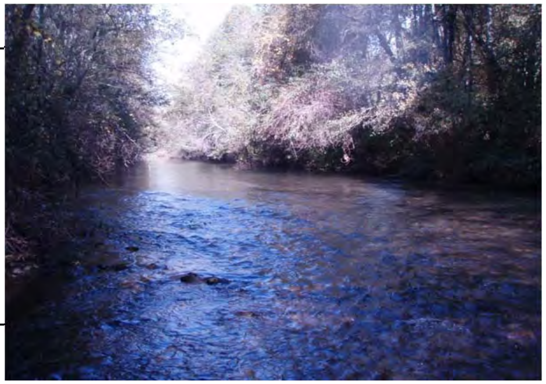
Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	1	1.0%
Sand	2.8	0	1.0%
Very Fine Gravel	2.9-4	0	1.0%
Fine Gravel	4.1-5.6	2	3.0%
Fine Gravel	5.7-8	1	4.0%
Medium Gravel	8.1-11.3	0	4.0%
Medium Gravel	11.4-16	3	7.0%
Coarse Gravel	16.1-22.6	7	14.0%
Coarse Gravel	22.7-32	10	24.0%
Very Course Gravel	32.1-45	18	42.0%
Very Course Gravel	45.1-64	31	73.0%
Small Cobble	64.1-90	19	92.0%
Small Cobble	90.1-128	7	99.0%
Large Cobble	128.1-256	1	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



Dry Creek BLK - 6

Bulk Sediment Grain Size Analysis

riffle	Identifier
11/9/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

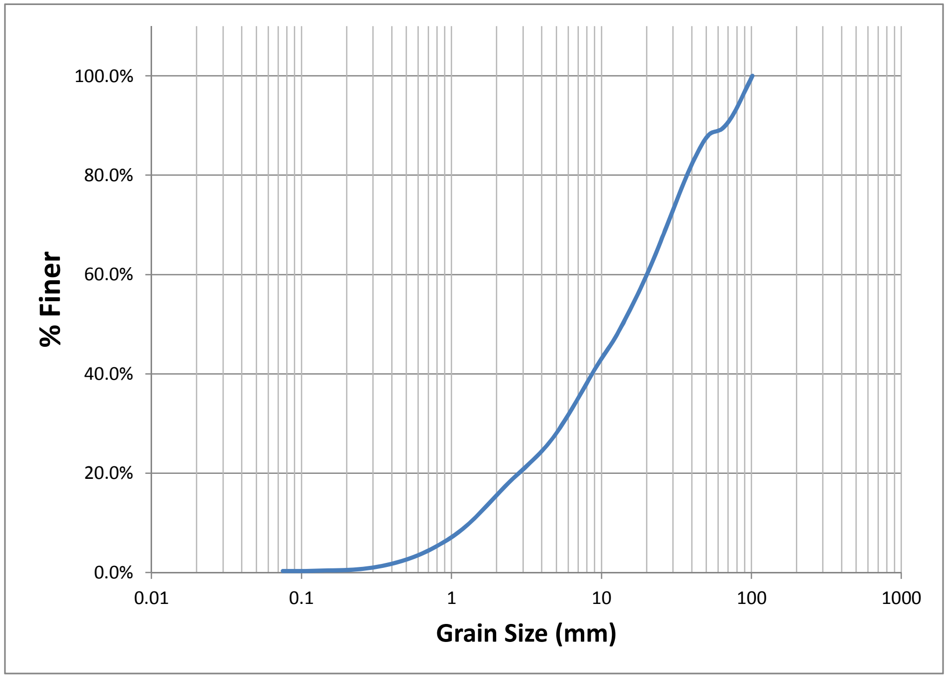


Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	15.0%
Sand	2.8	19.5%
Very Fine Gravel	2.9-4	24.2%
Fine Gravel	4.1-5.6	29.8%
Fine Gravel	5.7-8	37.3%
Medium Gravel	8.1-11.3	45.3%
Medium Gravel	11.4-16	53.4%
Coarse Gravel	16.1-22.6	63.4%
Coarse Gravel	22.7-32	74.3%
Very Course Gravel	32.1-45	84.6%
Very Course Gravel	45.1-64	89.4%
Small Cobble	64.1-90	96.5%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



Dry Creek BLK - 7

Sediment Grain Size Analysis

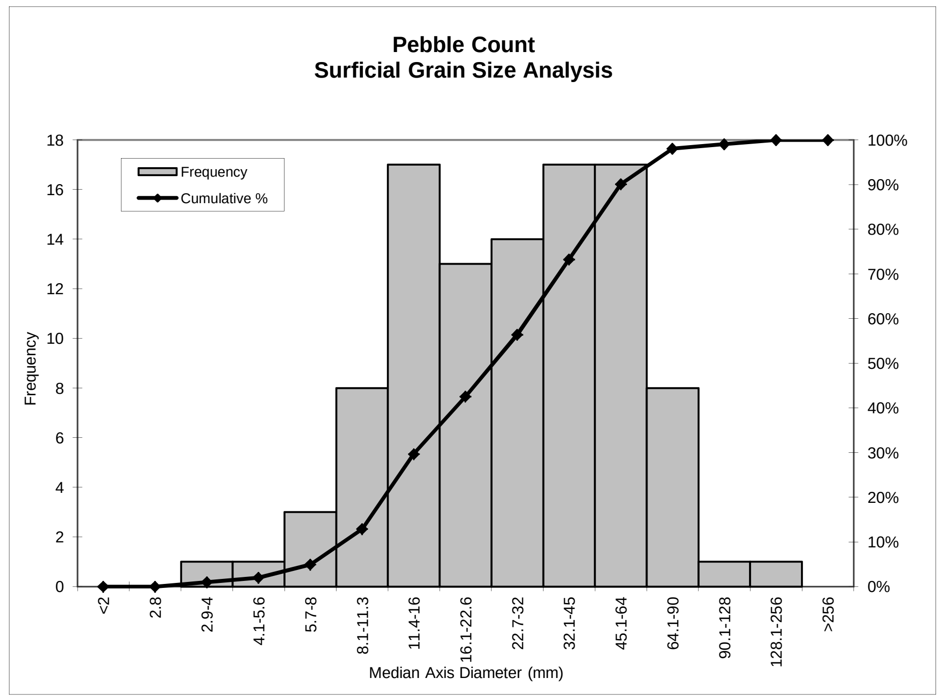
riffle	Identifier
11/9/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	1	1.0%
Fine Gravel	4.1-5.6	1	2.0%
Fine Gravel	5.7-8	3	5.0%
Medium Gravel	8.1-11.3	8	12.9%
Medium Gravel	11.4-16	17	29.7%
Coarse Gravel	16.1-22.6	13	42.6%
Coarse Gravel	22.7-32	14	56.4%
Very Course Gravel	32.1-45	17	73.3%
Very Course Gravel	45.1-64	17	90.1%
Small Cobble	64.1-90	8	98.0%
Small Cobble	90.1-128	1	99.0%
Large Cobble	128.1-256	1	100.0%
Small Boulders	>256	0	100.0%
	Total	101	



Dry Creek BLK - 7

Bulk Sediment Grain Size Analysis

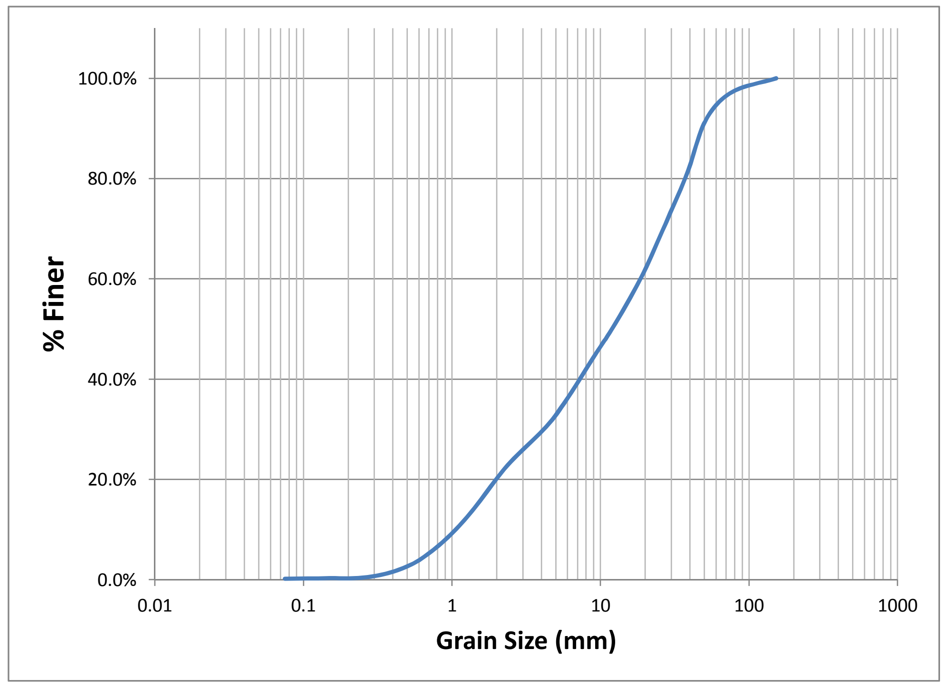
riffle	Identifier
11/9/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

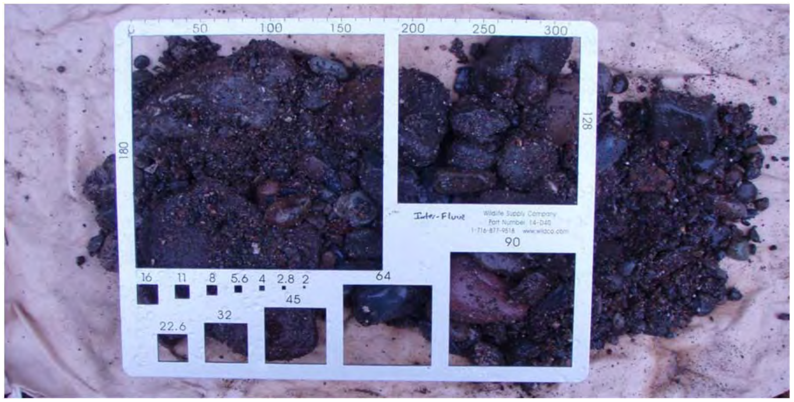
Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	19.4%
Sand	2.8	24.5%
Very Fine Gravel	2.9-4	29.1%
Fine Gravel	4.1-5.6	34.4%
Fine Gravel	5.7-8	41.2%
Medium Gravel	8.1-11.3	48.8%
Medium Gravel	11.4-16	56.1%
Coarse Gravel	16.1-22.6	65.2%
Coarse Gravel	22.7-32	75.1%
Very Course Gravel	32.1-45	86.7%
Very Course Gravel	45.1-64	97.3%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



Dry Creek BLK - 8

Sediment Grain Size Analysis

riffle	Identifier
11/9/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

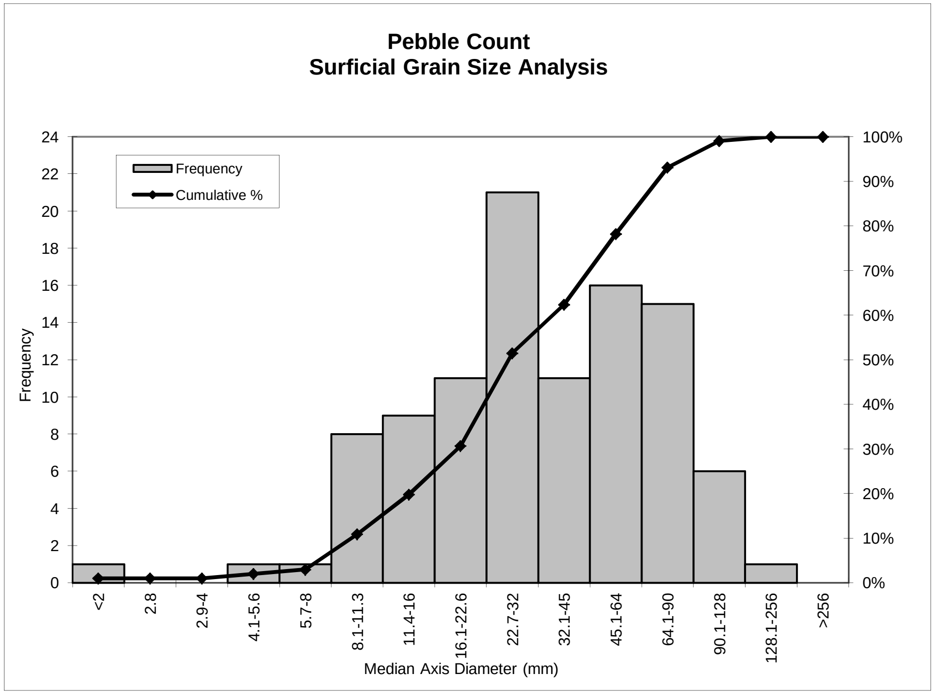


Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	1	1.0%
Sand	2.8	0	1.0%
Very Fine Gravel	2.9-4	0	1.0%
Fine Gravel	4.1-5.6	1	2.0%
Fine Gravel	5.7-8	1	3.0%
Medium Gravel	8.1-11.3	8	10.9%
Medium Gravel	11.4-16	9	19.8%
Coarse Gravel	16.1-22.6	11	30.7%
Coarse Gravel	22.7-32	21	51.5%
Very Course Gravel	32.1-45	11	62.4%
Very Course Gravel	45.1-64	16	78.2%
Small Cobble	64.1-90	15	93.1%
Small Cobble	90.1-128	6	99.0%
Large Cobble	128.1-256	1	100.0%
Small Boulders	>256	0	100.0%
	Total	101	



Dry Creek BLK - 8

Bulk Sediment Grain Size Analysis

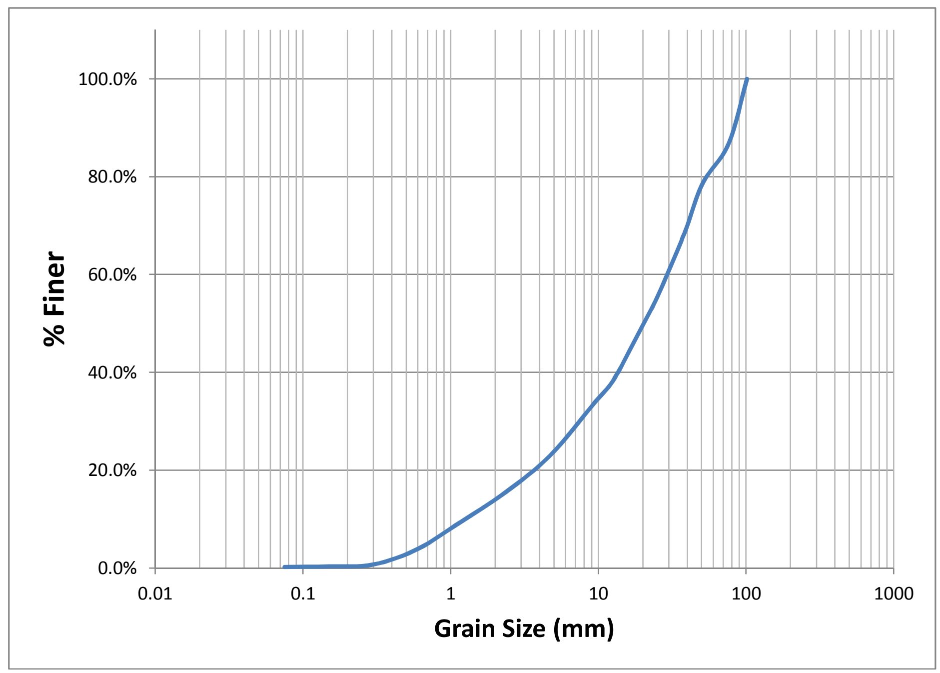
riffle	Identifier
11/9/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	13.7%
Sand	2.8	16.9%
Very Fine Gravel	2.9-4	20.7%
Fine Gravel	4.1-5.6	25.0%
Fine Gravel	5.7-8	30.5%
Medium Gravel	8.1-11.3	36.5%
Medium Gravel	11.4-16	43.7%
Coarse Gravel	16.1-22.6	52.6%
Coarse Gravel	22.7-32	62.3%
Very Course Gravel	32.1-45	73.9%
Very Course Gravel	45.1-64	82.8%
Small Cobble	64.1-90	93.9%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



Dry Creek BLK - 9

Sediment Grain Size Analysis

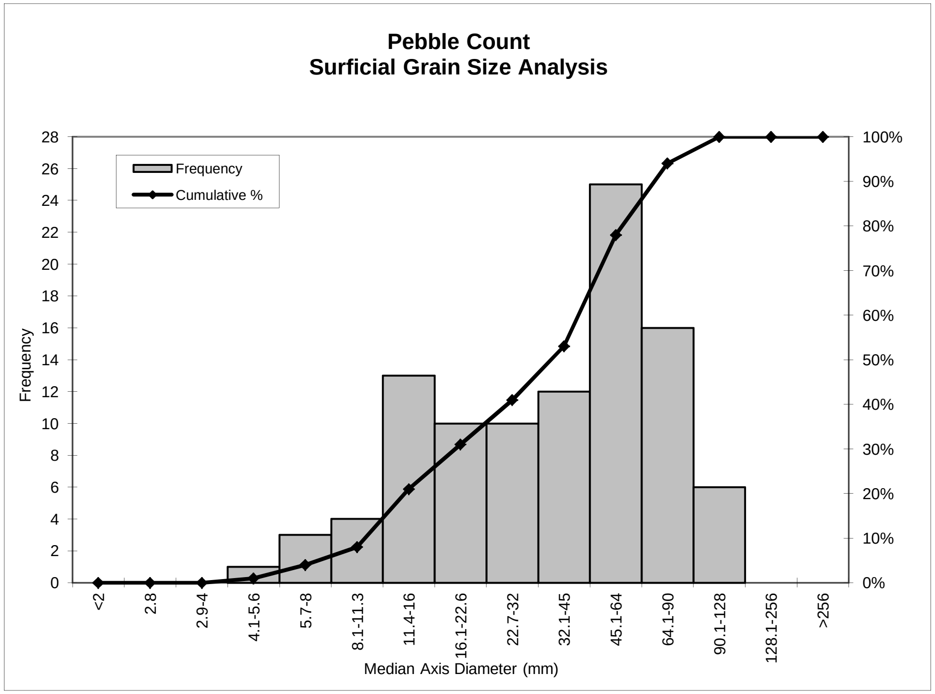
riffle	Identifier
11/10/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

Notes:

View Looking upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	0	.0%
Fine Gravel	4.1-5.6	1	1.0%
Fine Gravel	5.7-8	3	4.0%
Medium Gravel	8.1-11.3	4	8.0%
Medium Gravel	11.4-16	13	21.0%
Coarse Gravel	16.1-22.6	10	31.0%
Coarse Gravel	22.7-32	10	41.0%
Very Course Gravel	32.1-45	12	53.0%
Very Course Gravel	45.1-64	25	78.0%
Small Cobble	64.1-90	16	94.0%
Small Cobble	90.1-128	6	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



Dry Creek BLK - 9

Bulk Sediment Grain Size Analysis

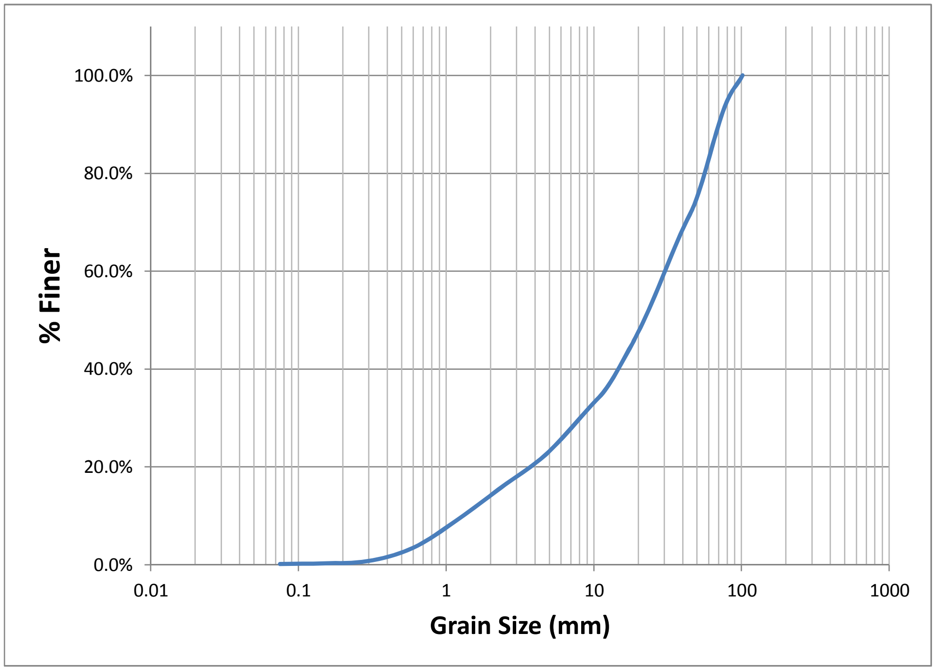
riffle	Identifier
11/10/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

Notes:

View Looking upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	13.8%
Sand	2.8	17.1%
Very Fine Gravel	2.9-4	20.5%
Fine Gravel	4.1-5.6	24.4%
Fine Gravel	5.7-8	29.3%
Medium Gravel	8.1-11.3	34.9%
Medium Gravel	11.4-16	41.8%
Coarse Gravel	16.1-22.6	50.8%
Coarse Gravel	22.7-32	61.1%
Very Course Gravel	32.1-45	71.8%
Very Course Gravel	45.1-64	84.8%
Small Cobble	64.1-90	96.9%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



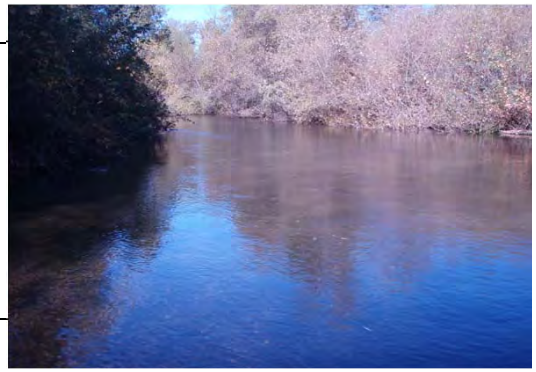
Dry Creek BLK - 10

Sediment Grain Size Analysis

riffle	Identifier
11/10/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

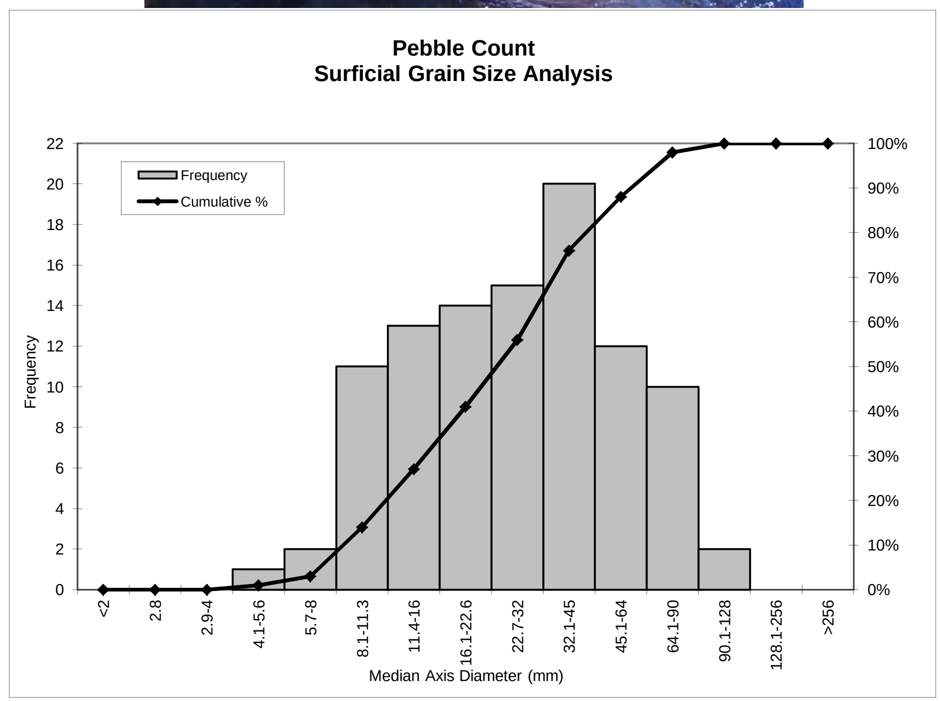
Notes:

View
Looking
upstream



Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	0	.0%
Fine Gravel	4.1-5.6	1	1.0%
Fine Gravel	5.7-8	2	3.0%
Medium Gravel	8.1-11.3	11	14.0%
Medium Gravel	11.4-16	13	27.0%
Coarse Gravel	16.1-22.6	14	41.0%
Coarse Gravel	22.7-32	15	56.0%
Very Course Gravel	32.1-45	20	76.0%
Very Course Gravel	45.1-64	12	88.0%
Small Cobble	64.1-90	10	98.0%
Small Cobble	90.1-128	2	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



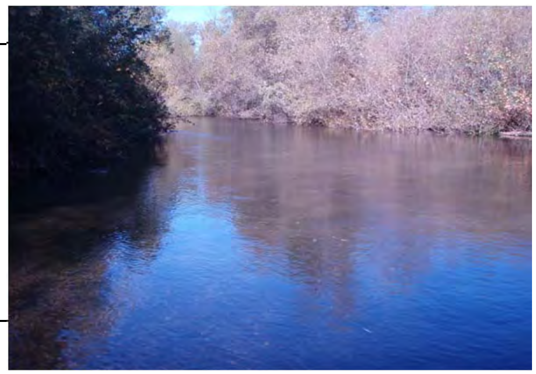
Dry Creek BLK - 10

Bulk Sediment Grain Size Analysis

riffle	Identifier
11/10/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

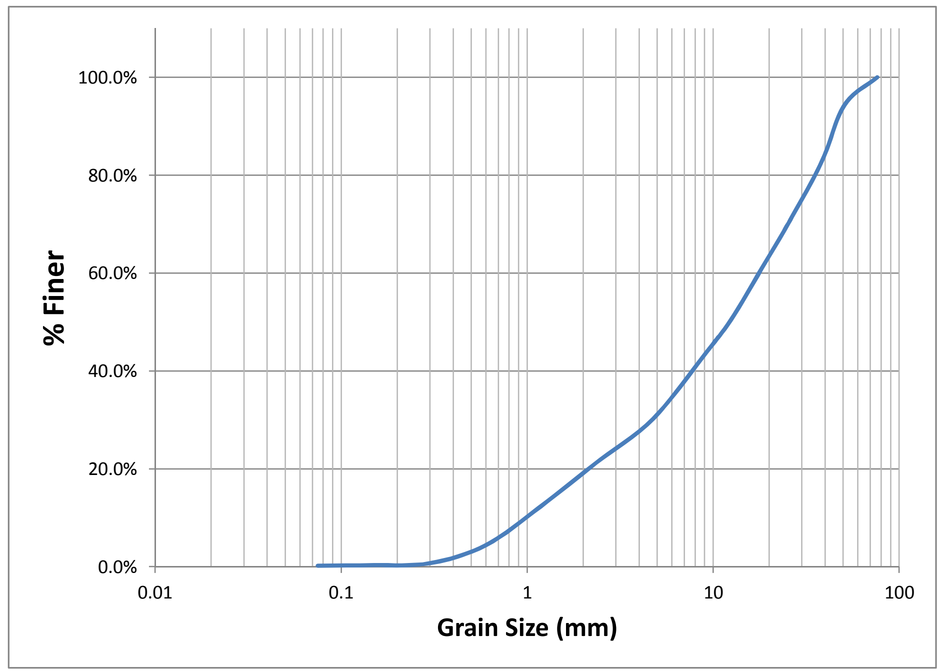
Notes:

View Looking upstream



Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	18.6%
Sand	2.8	22.9%
Very Fine Gravel	2.9-4	27.4%
Fine Gravel	4.1-5.6	32.8%
Fine Gravel	5.7-8	40.0%
Medium Gravel	8.1-11.3	48.1%
Medium Gravel	11.4-16	56.7%
Coarse Gravel	16.1-22.6	66.6%
Coarse Gravel	22.7-32	76.6%
Very Course Gravel	32.1-45	88.9%
Very Course Gravel	45.1-64	97.3%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



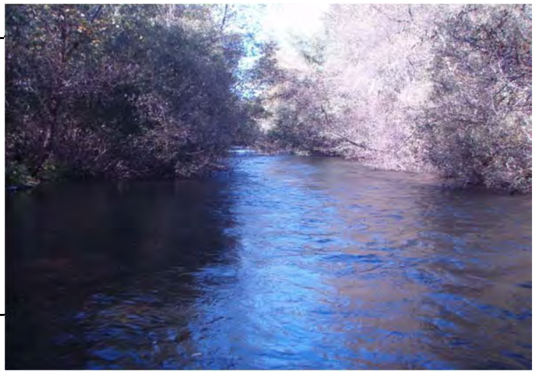
Dry Creek BLK - 11

Sediment Grain Size Analysis

riffle	Identifier
11/10/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

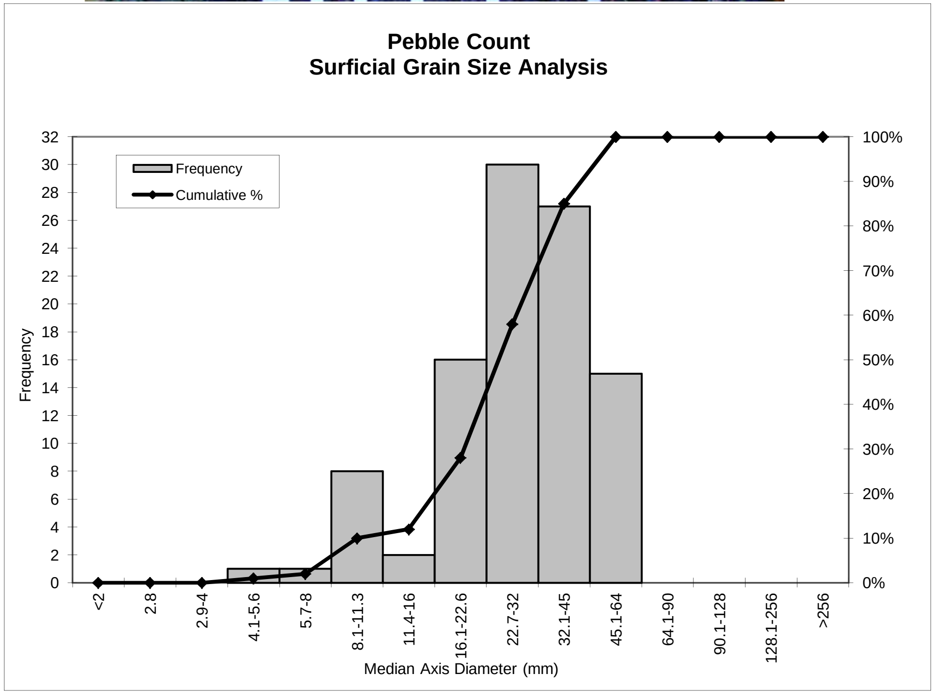
Notes:

View Looking upstream



Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	0	.0%
Fine Gravel	4.1-5.6	1	1.0%
Fine Gravel	5.7-8	1	2.0%
Medium Gravel	8.1-11.3	8	10.0%
Medium Gravel	11.4-16	2	12.0%
Coarse Gravel	16.1-22.6	16	28.0%
Coarse Gravel	22.7-32	30	58.0%
Very Course Gravel	32.1-45	27	85.0%
Very Course Gravel	45.1-64	15	100.0%
Small Cobble	64.1-90	0	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



Dry Creek BLK - 11

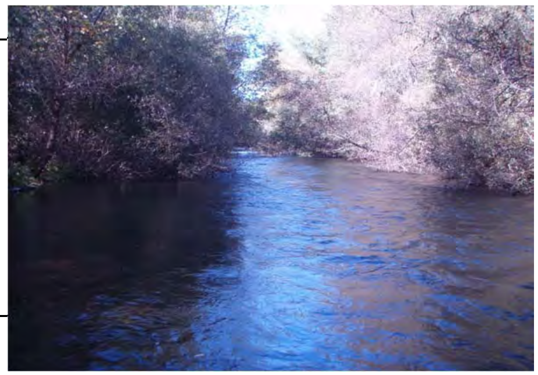
inter-fluve, inc.

Bulk Sediment Grain Size Analysis

riffle	Identifier
11/10/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

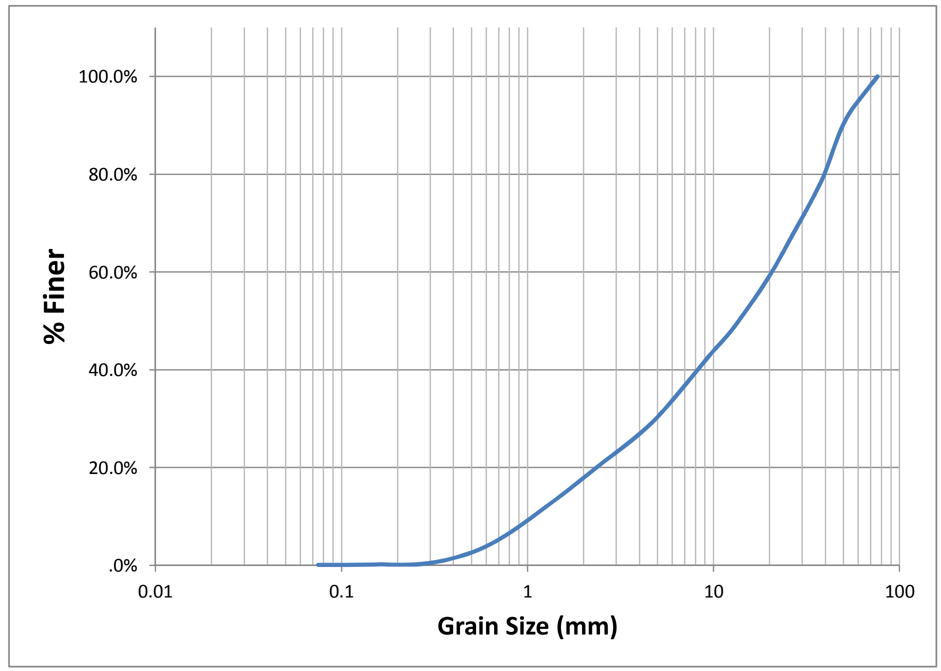
Notes:

View
Looking
upstream



Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	17.4%
Sand	2.8	21.8%
Very Fine Gravel	2.9-4	26.6%
Fine Gravel	4.1-5.6	31.9%
Fine Gravel	5.7-8	38.7%
Medium Gravel	8.1-11.3	46.0%
Medium Gravel	11.4-16	53.4%
Coarse Gravel	16.1-22.6	62.6%
Coarse Gravel	22.7-32	72.7%
Very Course Gravel	32.1-45	85.3%
Very Course Gravel	45.1-64	95.6%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



Dry Creek BLK - 12

inter-fluve, inc.

Sediment Grain Size Analysis

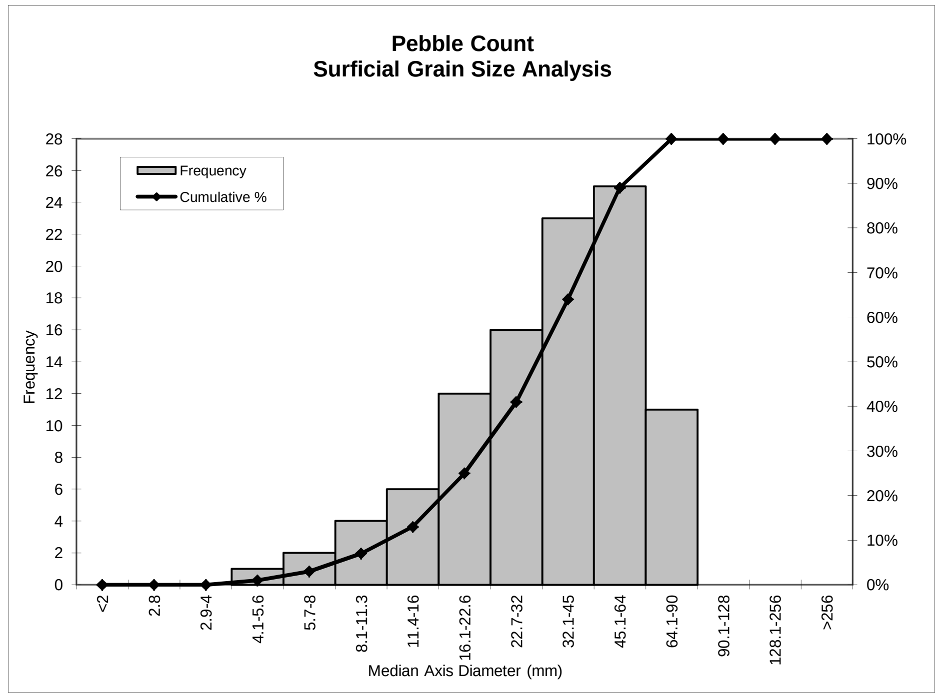
riffle	Identifier
11/10/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	0	.0%
Fine Gravel	4.1-5.6	1	1.0%
Fine Gravel	5.7-8	2	3.0%
Medium Gravel	8.1-11.3	4	7.0%
Medium Gravel	11.4-16	6	13.0%
Coarse Gravel	16.1-22.6	12	25.0%
Coarse Gravel	22.7-32	16	41.0%
Very Course Gravel	32.1-45	23	64.0%
Very Course Gravel	45.1-64	25	89.0%
Small Cobble	64.1-90	11	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



Dry Creek BLK - 12

Bulk Sediment Grain Size Analysis

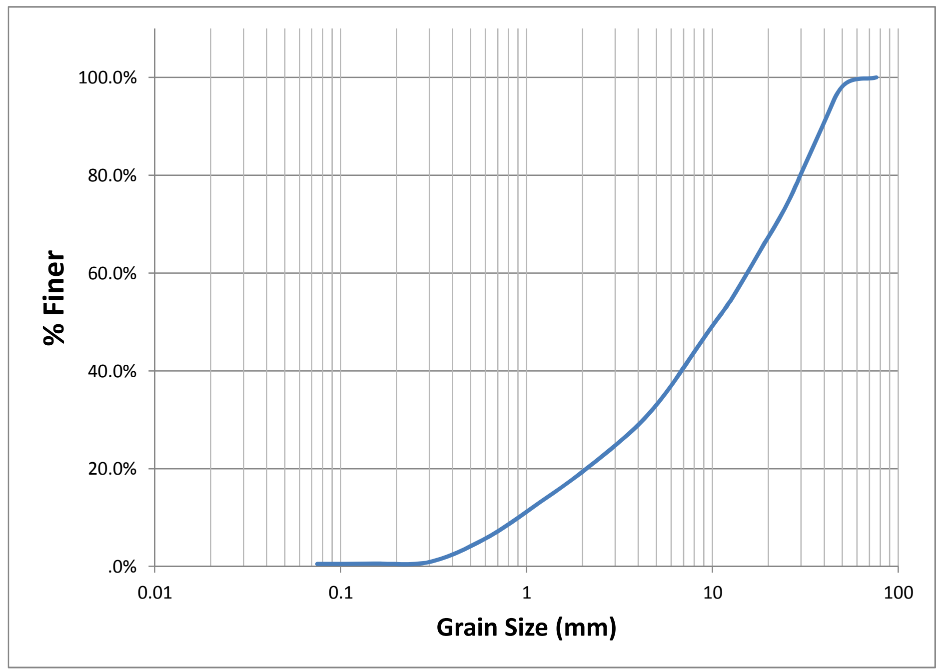
riffle	Identifier
11/10/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

Notes:

View
Looking
upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	18.9%
Sand	2.8	23.4%
Very Fine Gravel	2.9-4	28.7%
Fine Gravel	4.1-5.6	34.9%
Fine Gravel	5.7-8	42.9%
Medium Gravel	8.1-11.3	51.8%
Medium Gravel	11.4-16	60.6%
Coarse Gravel	16.1-22.6	70.7%
Coarse Gravel	22.7-32	81.9%
Very Course Gravel	32.1-45	94.1%
Very Course Gravel	45.1-64	99.2%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



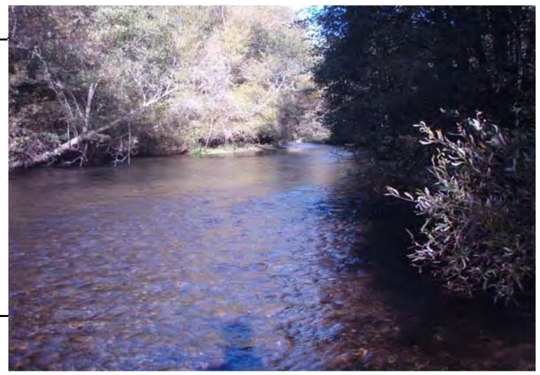
Dry Creek BLK - 13

Sediment Grain Size Analysis

riffle	Identifier
11/11/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

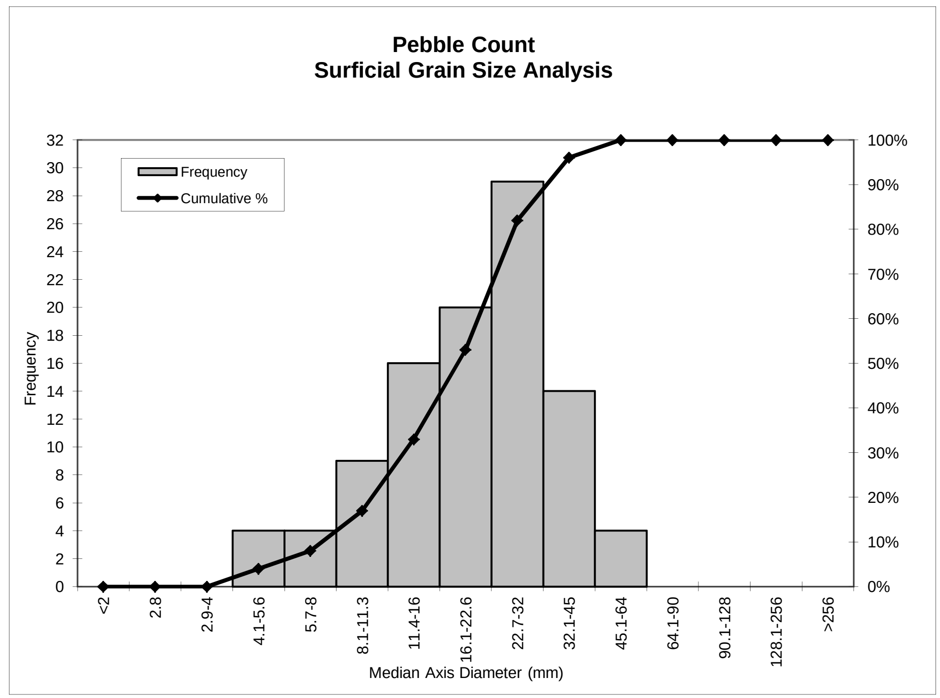
Notes:

View Looking upstream



Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	0	.0%
Fine Gravel	4.1-5.6	4	4.0%
Fine Gravel	5.7-8	4	8.0%
Medium Gravel	8.1-11.3	9	17.0%
Medium Gravel	11.4-16	16	33.0%
Coarse Gravel	16.1-22.6	20	53.0%
Coarse Gravel	22.7-32	29	82.0%
Very Course Gravel	32.1-45	14	96.0%
Very Course Gravel	45.1-64	4	100.0%
Small Cobble	64.1-90	0	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	100	



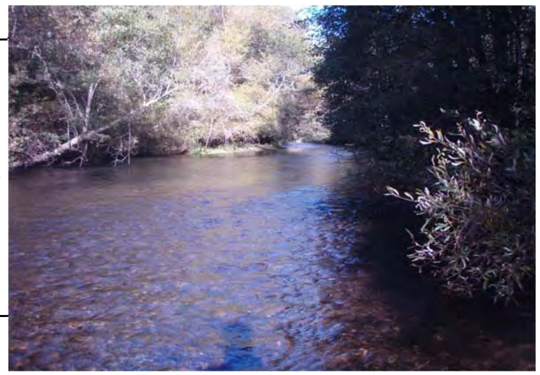
Dry Creek BLK - 13

Bulk Sediment Grain Size Analysis

riffle	Identifier
11/11/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

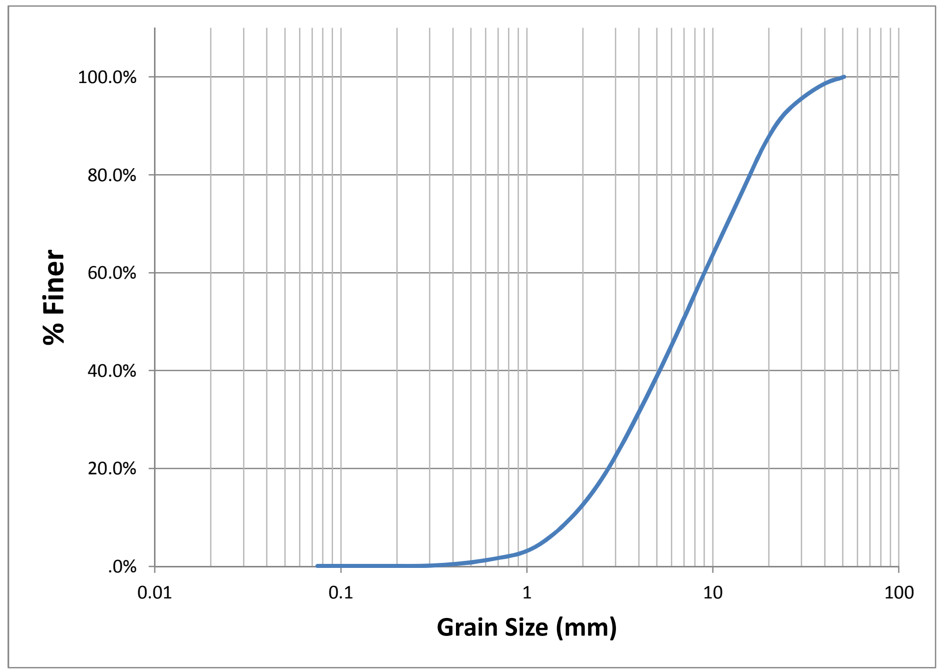
Notes:

View
Looking
upstream



Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	12.7%
Sand	2.8	20.0%
Very Fine Gravel	2.9-4	30.5%
Fine Gravel	4.1-5.6	41.5%
Fine Gravel	5.7-8	54.1%
Medium Gravel	8.1-11.3	67.6%
Medium Gravel	11.4-16	79.5%
Coarse Gravel	16.1-22.6	90.2%
Coarse Gravel	22.7-32	95.8%
Very Course Gravel	32.1-45	99.2%
Very Course Gravel	45.1-64	100.0%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



Dry Creek BLK - 14

Sediment Grain Size Analysis

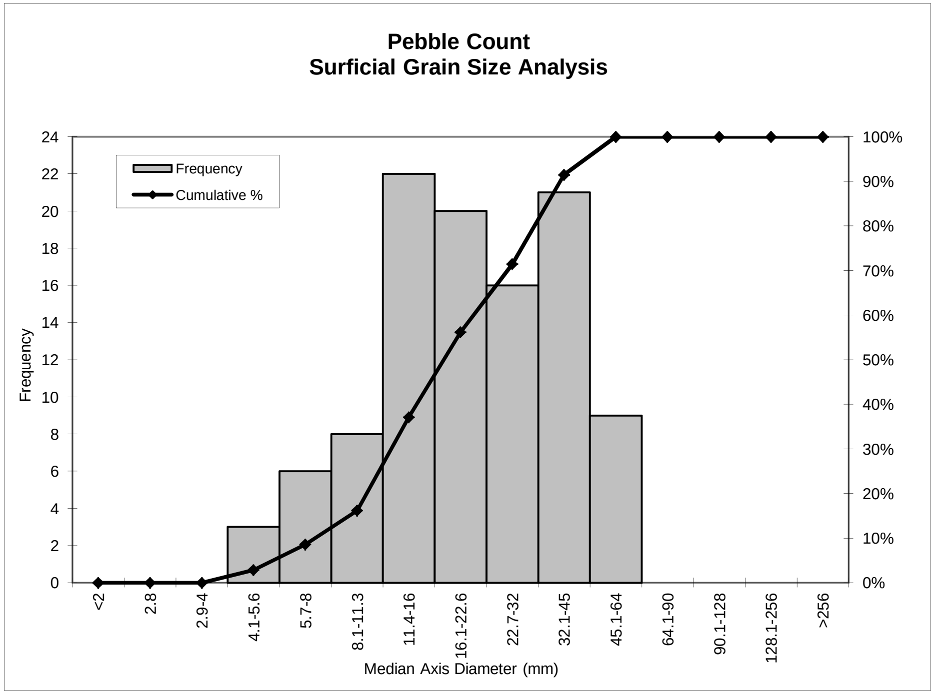
riffle	Identifier
11/11/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
surficial material	Sample Type: Armor Layer or Subarmor

Notes:

View Looking upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Frequency*	*Cumulative %*
Sand	<2	0	.0%
Sand	2.8	0	.0%
Very Fine Gravel	2.9-4	0	.0%
Fine Gravel	4.1-5.6	3	2.9%
Fine Gravel	5.7-8	6	8.6%
Medium Gravel	8.1-11.3	8	16.2%
Medium Gravel	11.4-16	22	37.1%
Coarse Gravel	16.1-22.6	20	56.2%
Coarse Gravel	22.7-32	16	71.4%
Very Course Gravel	32.1-45	21	91.4%
Very Course Gravel	45.1-64	9	100.0%
Small Cobble	64.1-90	0	100.0%
Small Cobble	90.1-128	0	100.0%
Large Cobble	128.1-256	0	100.0%
Small Boulders	>256	0	100.0%
	Total	105	



Dry Creek BLK - 14

Bulk Sediment Grain Size Analysis

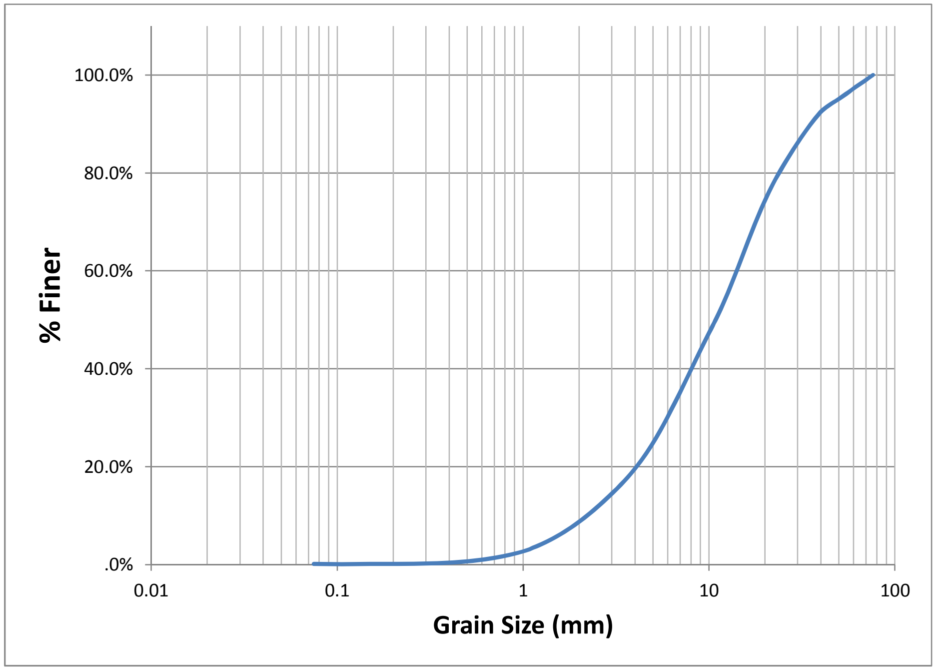
riffle	Identifier
11/11/10	Date
JE, NN	Personnel
Dry Creek	Stream
n/a	Approximate Depth of Flow at Thalweg (ft)
stream bed substrate	Longitudinal Description (Pool, Riffle, Bend, Crossing)
Bulk Sediment	Sample Type: Armor Layer or Subarmor

Notes:

View Looking upstream

Pebble Count Data

Class (Wentworth)	*Size Class mm*	*Cumulative %*
Sand	<2	8.7%
Sand	2.8	13.2%
Very Fine Gravel	2.9-4	19.5%
Fine Gravel	4.1-5.6	27.5%
Fine Gravel	5.7-8	38.6%
Medium Gravel	8.1-11.3	51.3%
Medium Gravel	11.4-16	64.5%
Coarse Gravel	16.1-22.6	77.8%
Coarse Gravel	22.7-32	86.9%
Very Course Gravel	32.1-45	93.6%
Very Course Gravel	45.1-64	97.7%
Small Cobble	64.1-90	100.0%
Small Cobble	90.1-128	100.0%
Large Cobble	128.1-256	100.0%
Small Boulders	>256	100.0%



Appendix C:

Draft summary memo from subsurface exploration

MEMORANDUM

TO: Michael Burke – Inter-Fluve, Inc.

FROM: Darren A. Mack, G. E.

DATE: December 1, 2010

RE: Interim Technical Memorandum
Dry Creek Habitat Enhancement Projects – Phase 2
Station 673+00 to 697+00
Sonoma County, California
Project No. 07-082.01

Sanders & Associates Geostructural Engineering, Inc. (SAGE) is pleased to submit this interim technical memorandum summarizing the preliminary results of our field investigation for the proposed habitat enhancements in Dry Creek, a major tributary to the Russian River in Sonoma County, California. Specifically, this investigation was focused on the Phase 2 Feasibility Study enhancements in the upper reaches of Dry Creek (see Figure 1), between station 673+00 and station 697+00. A full geotechnical report will be submitted once feasibility level designs for the habitat enhancements have been selected.

For the purposes of this memo, we are assuming that the Phase 2 enhancements are similar to the Phase 3 enhancements for the Demonstration Reach. Therefore, the purpose of the proposed habitat enhancements is as described in our previous report titled *Draft Geotechnical Investigation Report, Dry Creek Habitat Enhancement Demonstration Projects, Station 325+00 to 383+00*, dated October 29, 2010. Similarly, the geologic conditions and seismicity are similar to the information presented in our previous report, with the exception of the bedrock type. Volcanic rocks associated with the Coast Range ophiolite are mapped by Blake, Graymer, and Stamski (2002) on the slopes west of the Phase 2 reach.

SUBSURFACE INVESTIGATION

For this investigation, we explored the subsurface conditions by excavating five (5) test pits at the proposed restoration site on USACE property, referred to as DCP 4 (Figure 2). The test pits were excavated by Luce Backhoe Excavation of Santa Rosa, California. The test pits were excavated on October 21, 2010 using a CAT 315L track-mounted excavator equipped with a 42-inch bucket. Prior to the start of drilling, all test pits were cleared by a private utility locator. During excavation of the test pits, our geologist logged the materials encountered and obtained representative samples for visual classification and laboratory testing. The materials encountered were classified in general accordance with the Unified Soil Classification System (USCS) as summarized on Figure A-1. Logs of the test pits are presented on Figure A-2.

In addition, NORCAL Geophysical Consultants (NORCAL) performed a geophysical survey at the proposed restoration site on the Weinstock property, referred to as DCP 6, which could not be accessed by conventional mechanized equipment. The geophysical survey was performed on October 20, 2010 and included two seismic refraction lines at the locations shown on Figure 2. The NORCAL report is attached.

SUBSURFACE CONDITIONS

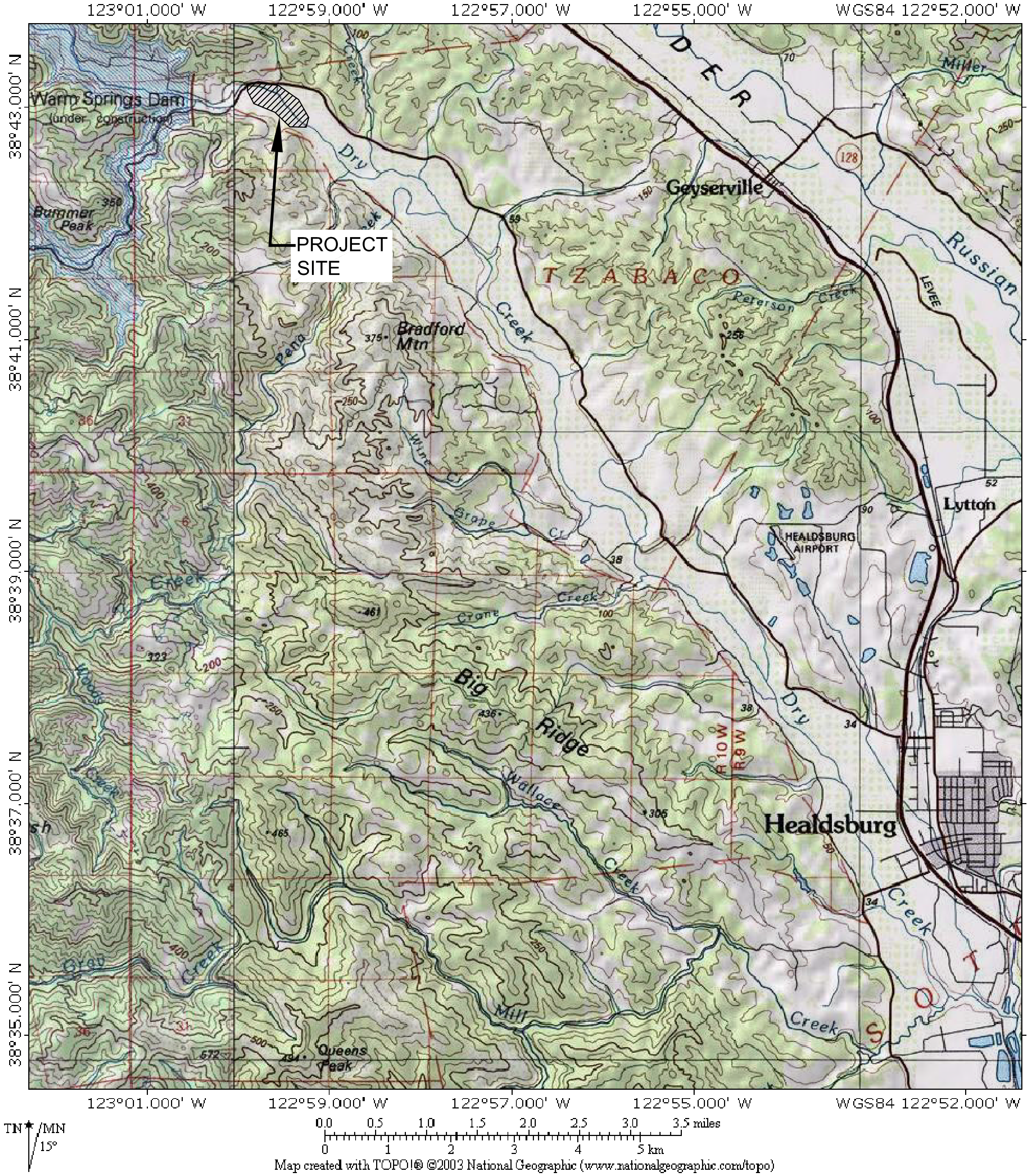
The materials encountered in the test pits were generally coarse grained sands and gravels ranging in classification from sandy gravel to sand. The materials were loose at the excavation surface and increased to a maximum density of medium dense at the bottom of the excavations. Similarly, the materials were dry at the surface and increased in moisture with depth. The material was very easy to excavate until caving limited the excavation depth. Test pit depths varied from 9 to 13 feet below ground surface.

Fines contents were less than five percent aside from a localized layer of sandy clay encountered in TP1. Trace cobbles up to 9 inches in diameter were also encountered. Abundant to trace amounts of roots were encountered in TP2 through TP5.

For each test pit, the side slopes were marginally stable in dry to moist conditions. However, rapid caving or sloughing generally occurred below the water table, particularly where active seepage was encountered, which limited the depth of the test pits. Groundwater was encountered between El. 187.9 and 188.2 feet.

Although volcanic bedrock of the Coast Range ophiolite is visible a drainage channel on the Weinstock property just upstream of DCP6, bedrock was not encountered in the test pits.

Results from the geophysical survey at DCP6 suggest that bedrock is between 10 and 19 feet below the existing ground surface. Therefore, it does not appear that riffles in the existing channel are bedrock controlled. Furthermore, it is likely that bedrock will not be encountered during construction.



SANDERS & ASSOCIATES GEOSTRUCTURAL ENGINEERING
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4180 Douglas Blvd., Ste. 100
Granite Bay, CA 95746
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F (916) 729-7706

DRY CREEK HABITAT ENHANCEMENT PROJECTS - PHASE 2

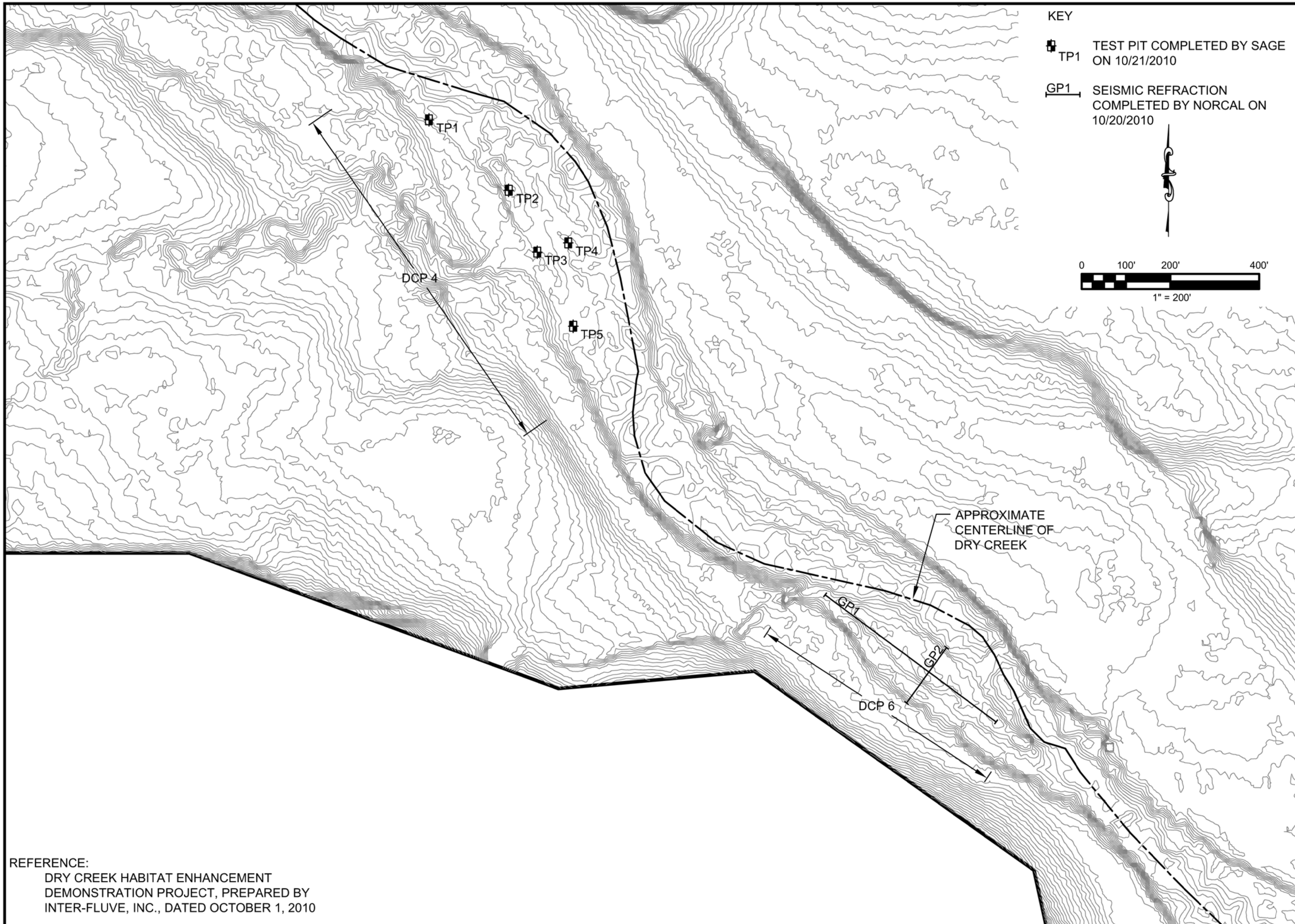
SONOMA COUNTY | SITE LOCATION MAP | CALIFORNIA

FIG 1

1 OF 2

DATE: 12/01/10	FILE: 07-082.01	SCALE: NONE	JOB NO.: 07-082.01

F:\1-PROJECTS\2007\07-082 Dry Creek Habitat Restoration\3 - Feasibility Study Geotechnical Invest. (Phase 2 - Task 4.20)\DRAWINGS\DRY CREEK - PHASE 2.dwg, FIG 1, 2010-12-01 5:22:33 PM, RAbernathy, Adobe PDF, Letter, 1:1



REFERENCE:
DRY CREEK HABITAT ENHANCEMENT DEMONSTRATION PROJECT, PREPARED BY INTER-FLUVE, INC., DATED OCTOBER 1, 2010

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SUBSURFACE EXPLORATION MAP

DRY CREEK HABITAT ENHANCEMENT PROJECTS - PHASE 2

COUNTY OF SONOMA CALIFORNIA

REV	BY	DATE	DESCRIPTION
0	-	-	-

DATE: 12/01/10
SCALE: 1" = 200'
DESIGNED BY: RMA
DRAFTED BY: RMA
CHECKED BY: DGK
JOB NO.: 07-082.01
FILE: 07-082.01

FIG 2

FIGURE 2 OF 2

UNIFIED SOIL CLASSIFICATION SYSTEM

Major Divisions		Symbols	Typical Names
Coarse-Grained Soils (more than holf of soil > No. 200 sieve size)	Gravels (More than half of coarse fraction > No. 4 sieve size)	GW	Well-graded gravels or gravel-sand mixtures, little or no fines
		GP	Poorly-graded gravels or gravel-sand mixtures, little or no fines
		GM	Silty gravels, gravel-sand-silt mixtures
		GC	Clayey gravels, gravel-sand-clay mixtures
	Sands (More than half of coarse fraction > No. 4 sieve size)	SW	Well-graded sands or gravelly sands, little or no fines
		SP	Poorly-graded sands or gravelly sands, little or no fines
		SM	Silty sands, sand-silt mixtures
		SC	Clayey sands, sand-clay mixtures
Fine-Grained Soils (more than holf of soil < No. 200 sieve size)	Silts and Clays LL = < 50	ML	Inorganic silts and clayey silts of low plasticity, sandy silts, gravelly silts
		CL	Inorganic clays of low to medium plasticity, gravelly clays, sandy clays, lean clays
		OL	Organic silts and organic silt-clays of low plasticity
	Silts and Clays LL = > 50	MH	Inorganic silts of high plasticity
		CH	Inorganic clays of high plasticity, fat clays
		OH	Organic silts and clays of high plasticity
Highly Organic Soils		PT	Peat and other highly organic soils

GRAIN SIZE CHART

Classification	Range of Grain Sizes	
	U.S. Standard Sieve Size	Grain Size in Millimeters
Boulders	Above 12"	Above 305
Cobbles	12" to 3"	305 to 76.2
Gravel coarse fine	3" to No.4 3" to 3/4" 3/4" to No. 4	76.2 to 4.76 76.2 to 19.1 19.1 to 4.76
Sand coarse medium fine	No. 4 to No. 200 No. 4 to No. 10 No. 10 to No. 40 No. 40 to No. 200	4.76 to 0.074 4.76 to 2.00 2.00 to 0.420 0.420 to 0.074
Silt and Clay	Below No. 200	Below 0.074

TYPES OF STRENGTH TESTS

PP	Pocket Penetrometer
TV	Field Torvane
LVS	Laboratory Vane Shear
UC	Unconfined Compression
TXUU	Triaxial, unconsolidated, undrained
DS	Direct Shear

▽ Unstabilized (initial) groundwater level

▼ Stabilized groundwater level

SAMPLER TYPE

C — Core barrel

O — Osterberg piston sampler using 3.0-inch outside diameter, thin-walled Shelby tube

PT — Pitcher tube sampler using 3.0-inch outside diameter, thin-walled Shelby tube

ST — Shelby tube (3.0-inch outside diameter, thin-walled tube) advanced with hydraulic pressure

BULK — Disturbed grab sample

CA — California split-barrel sampler with 2.5-inch outside diameter and 1.93-inch inside diameter

MCA — Modified California split-barrel sampler with 3.0-inch outside diameter and 2.5-inch inside diameter

SPT — Standard Penetration Test (SPT) split-barrel sampler with a 2.0-inch outside diameter and a 1.5-inch inside diameter

○ Sampling attempted without recovery

DRY CREEK HABITAT ENHANCEMENT PROJECTS - PHASE 2

Sonoma County California

SANDERS & ASSOCIATES GEOSTRUCTURAL ENGINEERING
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SOIL CLASSIFICATION CHART

Project No. 07-082.01

Date 12/01/10 Figure A-1

FIGURE A-2 - LOGS OF TEST PITS TP1 THROUGH TP5

Test Pit Number	Depth (feet)	Soil Classification	Soil Description
TP1 (El. 193.2')	0' – 3.2'	SANDY GRAVEL (GP)	brown, loose, dry to 2', moist below, fine gravel with medium to coarse grained sand, trace fines, trace coarse gravel below 2.5', 49.1% medium to coarse sand, 50.7% gravel (42.3% fine, 8.4% coarse), 0.2% fines
	3.2' – 4'	SANDY CLAY (CL)	gray, medium stiff, moist, fine grained sand, with organics, locally grades to silty and clayey sand, abundant iron oxide staining
	4' – 10'	SANDY GRAVEL (GP)	brown gray, loose to medium dense, moist, wet below 5', fine to coarse gravel, medium to coarse sand, trace fines (<5%), trace cobbles, cobbles up to 9" in max dimension, 54.6% gravel (33.4% fine, 21.2% coarse), 45.3% sand, 0.1% fines Groundwater encountered at El. 188.2'
TP2 (190.6')	0' – 1.8'	GRAVELLY SAND (SW)	brown, loose, dry, medium to coarse grained sand with fine to coarse gravel, trace fines, abundant roots, estimates for overall unit gradation: 70% medium to coarse sand, 20% gravel (fine to coarse), 10% fines
	1.8' – 3'	SAND (SP)	brown, medium dense, moist, wet below 2.5', medium to coarse grained, trace fine gravel
	3' – 9'	GRAVELLY SAND (SP)	brown gray, loose to medium dense, wet, fine to coarse gravel, medium to coarse sand, 47.5% gravel (32.9% fine, 14.6% coarse), 52.4% sand, 0.1% fines Groundwater encountered at El. 188.1'
TP3 (192.9')	0' – 11'	SANDY GRAVEL (GW)	brown gray, medium dense, dry, moist below 1.5', wet below 4.7', medium to coarse sand, fine to coarse gravel, with clay, trace roots, estimates for overall unit gradation: 66.9% gravel (36.9% fine, 30% coarse), 33% sand, 0.1% fines, thin (~3" – 4") clean gravel lenses, trace cobbles up to 6" in max dimension, less silt below 5' Groundwater encountered at El. 188.2'

TP4 (El. 191.1')	0' – 2'	SANDY GRAVEL (GW)	brown, loose to medium dense, dry, medium to coarse sand, fine to coarse gravel, trace fines, trace roots, fining upward sequence with clean gravel along base of unit, abrupt lower contact with silt and roots (former terrace surface), 75.3% gravel (8.6% coarse, 66.7% fine), 24.5% sand, 0.2% fines
	2' – 3.5'	SAND WITH GRAVEL (SP)	brown, loose to medium dense, moist, wet below 3.2', medium to coarse grained, with fine gravel, trace roots, estimate 85% sand, 15% gravel
	3.5' – 12'	SANDY GRAVEL (GW)	brown gray, medium dense, wet, fine to coarse gravel, medium to coarse sand, trace fines, gray clay lenses locally, discontinuous, 57.5% gravel (32.9% fine, 24.6% coarse), 42.5% sand, 0 fines Groundwater encountered at El. 187.9'
TP5 (El. 192. 0')	0' – 1.8'	SANDY GRAVEL (GP)	brown, loose to medium dense, dry, medium to coarse sand, fine to coarse gravel, trace fines, trace roots, abrupt lower contact with silt and roots (former terrace surface), estimates for overall unit gradation: 70% gravel (50% fine, 20% coarse), 25% sand, 5% fines
	1.8' – 3'	GRAVELLY SILTY SAND (SM)	brown, medium dense, moist, medium to coarse sand, fine to coarse gravel, with silt, abundant rootlets, estimates for overall unit gradation: 60% sand, 25% gravel (20% fine, 5% coarse), 15% silt
	3' – 4.7'	SAND WITH GRAVEL (SP)	brown, loose to medium dense, moist, wet below 3.9', medium to coarse grained, with fine gravel
	4.7' – 13'	SANDY GRAVEL (GW)	brown gray, medium dense, wet, fine to coarse gravel, medium to coarse sand, with cobbles, cobbles up to 8" in maximum dimension, trace fines, estimates for overall unit gradation: 50% gravel (30% fine, 20% coarse), 30% sand, 15% cobbles, 5% fines Groundwater encountered at El. 188.1'

NORCAL GEOPHYSICAL CONSULTANTS, INC.

November 22, 2010

Mr. Drew G. Kennedy
Sanders & Associates Geostructural Engineering
4180 Douglas Blvd., Ste. 100
Granite Bay, CA 95746

Subject: Seismic Refraction Survey
Dry Creek Habitat Enhancement Demonstration Project
Site DCP6, Feasibility Study Reach
Sonoma County, California
NORCAL Job # 10-916.04

Dear Mr. Kennedy:

This report presents the findings of a seismic refraction (SR) survey performed by NORCAL Geophysical Consultants, Inc. along Dry Creek in Sonoma County, CA. The survey was performed on October 20, 2010 by NORCAL Professional Geophysicists William E. Black and Donald J. Kirker, and geophysical technician David Spaulding. Logistical support was provided by Drew Kennedy of Sanders & Associates Geostructural Engineering (SAGE).

1.0 SITE DESCRIPTION AND PURPOSE

The geophysical survey was conducted at Site DCP6 of the Feasibility Study Reach of Dry Creek. It is located approximately 1 mile downstream of the Warm Springs Dam on the Weinstock Parcel. The site comprises a relatively flat river cut terrace that is generally open and covered with grass. The parcel is accessed by a gravel/dirt road from an adjacent vineyard south of the creek.

The seismic refraction survey was conducted along two lines, as shown on Plate 1. They are designated as Lines 3-1 and 3-2, and are located on the river cut terrace. Surface elevations in this area range from 184- to 192-ft above mean sea level (msl).

The local geology, as indicated by SAGE, consists of alluvium (interbedded clays, silt, sand, and gravel) over volcanic bedrock of the Coastal Range Ophiolite Sequence.

The purpose of the SR survey was to obtain seismic refraction data to aid in evaluating the thickness of overburden and the depth and excavation characteristics (rippability) of the bedrock. We understand that this information will be used in conjunction with other geotechnical investigations to plan for the construction of backwater ponds and channels associated with habitat enhancements along the creek.

2.0 METHODOLOGY

The SR method is used to determine the compressional velocity of subsurface materials. The seismic velocity of fill, sediments, and rock are dependent on physical properties such as compaction, density, hardness, and induration. However, other factors such as bedding, fracturing, and saturation also affect seismic velocity. Typically, low velocities are indicative of loose soil, poorly compacted fill material, poorly to semi-consolidated sediments, and deeply weathered and highly fractured rock. Moderate velocities are usually indicative of dense and highly compacted sediments and fill, and/or moderately weathered and moderately fractured rock. High velocities are indicative of slightly weathered to unweathered rock with little fracturing. It should be noted that apparent velocities can be affected by the orientation of bedding planes with respect to the direction of the seismic profile. Apparent velocities of rock are typically slower when measured along lines oriented perpendicular to bedding planes of steeply dipping rock, than those measured along lines oriented parallel. A more detailed description of the SR methodology is provided in Appendix A.

3.0 FIELD INVESTIGATIONS

SR data were obtained along two crossing transects distributed over a river terrace along the south bank of Dry Creek, as determined by SAGE. They are designated as Lines 3-1 and 3-2 on Plate 1 and are 420 and 275 feet long, respectively. Line 3-1 consisted of two overlapping geophone arrays (spreads) and Line 3-2 consisted of one spread. For this survey a spread consisted of 3-shot points and 24-geophones distributed in a collinear array. Along Line 3-1, the geophones were coupled to the ground surface at 10 foot intervals. Two of the shot points were located 10 feet beyond the end geophones of each spread, and the third shot point was positioned in the center of the spread. Along Line 3-2, the geophones were coupled to the ground surface at 7 foot intervals. Two of the shot points were located 7 feet beyond the end geophones of each spread. The third shot point was positioned in the center of the spread.

The SR data were recorded using a Geometrics ***Geode***, 24-bit digital seismic recording system and Oyo Geospace digital-grade geophones with a natural frequency of 10-Hz. We produced seismic energy at each shot point by striking an aluminum plate, placed on the ground surface, with a 16-pound sledge hammer. An accelerometer attached to the hammer transmitted a triggering pulse to the seismograph each time the plate was struck. The resulting travel time data were recorded on a seismograph and processed to generate seismic velocity cross-sections.

We used a Trimble global positioning system (GPS) with sub-meter accuracy to measure the geographical coordinates of the geophones along each line. These positions were differentially corrected and exported for data analysis. A more detailed description of data acquisition and analysis procedures are also provided in Appendix A.

4.0 RESULTS

The results of the SR survey are illustrated by the seismic velocity profiles shown on Plate 2. On each profile, the vertical axis represents elevation (above mean sea level) and the horizontal axis represents distance. The solid line along the top of the profile depicts the ground surface. The color contours represent seismic velocities according to the color scale shown at the bottom of the plate.

The SR velocity profiles on Plate 2 indicate average seismic velocities ranging from 1,000- to 7,000-ft/s to depths of approximately 50 feet. With each seismic line, the contours indicate a gradual increase in velocity with depth. Since ground truth from borings is not available for comparison to the detected seismic velocities shown along each line, our interpretation of these velocities is based on general geological information obtained from SAGE and on our experience from past seismic surveys in this area. Therefore, we interpret velocities ranging from 1,000 to about 3,000 ft/s (purple to dark blue) as representing surficial soils and unconsolidated sediments. Velocities ranging from 3,000 to 5,000 ft/s (green) are consistent with semi-consolidated sediments, saturated alluvium, and/or highly weathered/fractured bedrock. Velocities of over 5,000 ft/s represent moderately weathered and/or fractured rock. Both SR profiles on Plate 2 show that the interpreted bedrock is generally flat lying and ranges in depth from about 7-ft at the southwest end of Line 3-2 to about 18-ft at the southeast end of Line 3-1.

5.0 EXCAVATION CHARACTERISTICS (Rippability)

The interpreted bedrock exhibits velocities that range from 5,000- to 7,000-ft/s. Seismic velocity charts relating seismic velocity and excavation characteristics have been developed from field tests by others. These charts list the seismic velocity of various types of rock and their relative ease of excavation using different types of rippers. Caterpillar Tractor Company publishes a performance manual that lists ripper performance charts for the D8L, D9L, and D11L tractors. The following information in Table A was obtained from a performance chart for a D9L Ripper:

Table A: D9L Ripper Performance Chart

PERFORMANCE	ROCK TYPE	VELOCITY RANGE (ft/s)
Rippable	Sedimentary	< 6,400 to 7,800
	Igneous	< 6,700 to 7,600
	Metamorphic	< 7,200 to 7,300
Marginally Rippable	Sedimentary	6,400 to 9,700
	Igneous	6,700 to 8,600
	Metamorphic	7,200 to 9,200
Non-rippable	Sedimentary	> 8,600 to 9,700
	Igneous	> 8,000 to 8,700
	Metamorphic	> 9,000 to 9,200

According to the D9L Ripper Performance chart above, velocities of 5,000- to 7,000-ft/s are consistent with rock that is rippable to marginally rippable. This information should only be used as a general guide, however, as many other factors should also be considered. These factors include rock jointing and fracture patterns, the experience of the equipment operator, and the equipment and excavation methods selected. Also, the computed velocities measured along each profile are an average for each layer, and that the data analysis routine assumes that the velocity of subsurface materials increase with depth. Therefore, there may be localized zones within each layer where the velocities may be higher or lower than indicated. This is especially true in areas where bedrock is highly bedded and steeply dipping. Also, if a layer has velocities that are slower than those of the material above it, the slower layer will not be resolved. Since the accuracy of our findings is subject to these limitations, it should be noted that subsurface conditions may vary slightly from those depicted in the final results. A more detailed discussion of the limitations with regard to the seismic refraction method is presented in Appendix A.

6.0 STANDARD OF CARE

The scope of NORCAL's services for this project consisted of using geophysical methods to characterize the subsurface. The accuracy of our findings is subject to specific site conditions and limitations inherent to the techniques used. We performed our services in a manner consistent with the standard of care ordinarily exercised by members of the profession currently employing similar methods. No warranty, with respect to the performance of services or products delivered under this agreement, expressed or implied, is made by NORCAL.

We appreciate having the opportunity to provide you with this information.

Respectfully,

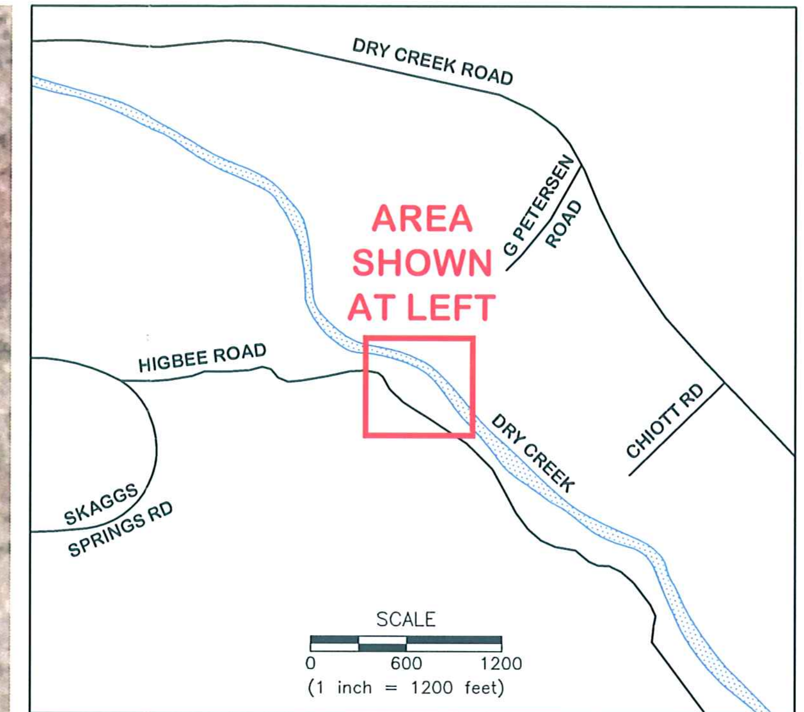
NORCAL Geophysical Consultants, Inc.

Donald J. Kirker

Donald J. Kirker
Professional Geophysicist, PGp-997

DJK/tt

Enclosures: Plates 1 and 2
Appendix A Seismic Refraction Survey



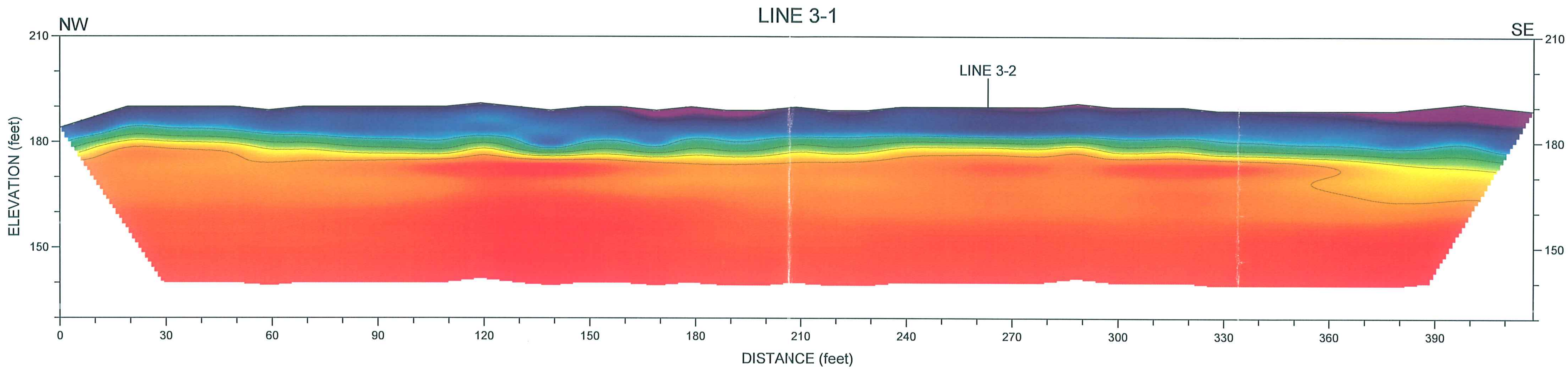
VICINITY MAP

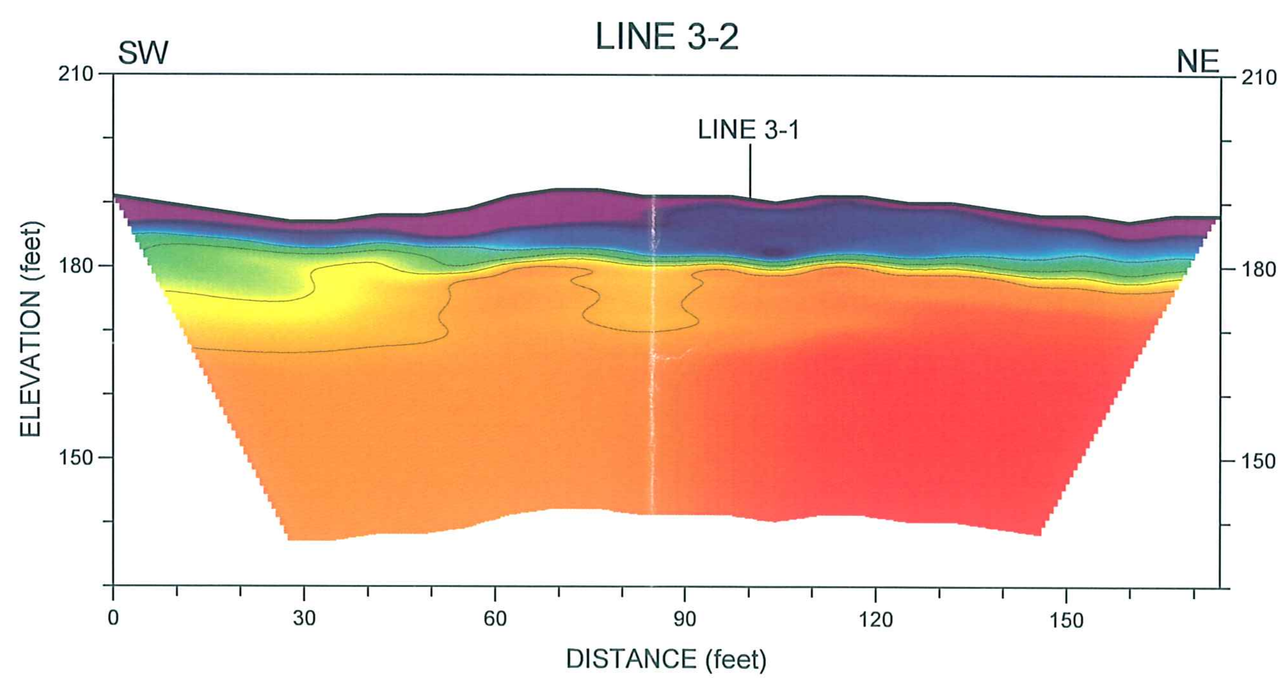
SCALE
0 30 60 120
(1 inch = 60 feet)

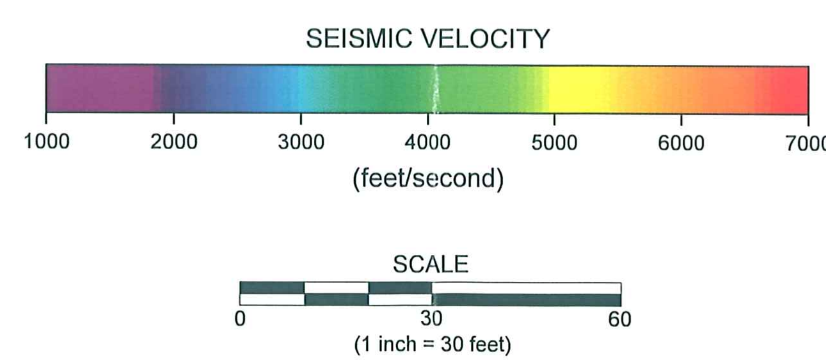
LEGEND

(red line)	SEISMIC REFRACTION PROFILE LOCATION

NORCAL	SITE LOCATION MAP – SITE 3 FEASIBILITY STUDY REACH WINESTOCK PARCEL	
	LOCATION: DRY CREEK, HEALDSBURG, CALIFORNIA	
	CLIENT: SAGE	PLATE 1
JOB #: 10-916.04	NORCAL GEOPHYSICAL CONSULTANTS INC.	
DATE: NOV. 2010	DRAWN BY: G.RANDALL	APPROVED BY: DJK







NORCAL

SEISMIC REFRACTION PROFILES
LINES 3-1 & 3-2
SITE 3 FEASIBILITY STUDY REACH
WEINSTOCK PARCEL

LOCATION: DRY CREEK, HEALDSBURG, CALIFORNIA		
CLIENT: SAGE		PLATE
JOB #: 10-916.04	NORCAL GEOPHYSICAL CONSULTANTS INC.	2
DATE: NOV. 2010	DRAWN BY: G.RANDALL	APPROVED BY: DJK

Appendix A

SEISMIC REFRACTION SURVEY

Appendix A

SEISMIC REFRACTION (SR)

Methodology

The seismic refraction method provides information regarding the seismic velocity structure of the subsurface. An impulsive (mechanical or explosive) source is used to produce compressional (P) wave seismic energy. The P-waves propagate into the earth and are refracted along interfaces caused by an increase in velocity. A portion of the P-wave energy is refracted back to the surface where it is detected by sensors (geophones) that are coupled to the ground surface in a collinear array (spread). The detected signals are recorded on a multi-channel seismograph and are analyzed to determine the shot point-to-geophone travel times. These data can be used along with the corresponding shot point-to-geophone distances to determine the depth, thickness, and velocity of subsurface seismic layers.

The seismic refraction technique is based on several assumptions. Paramount among these are:

1) that seismic velocity increases with depth, and,
2) that the velocity of each seismic layer is uniform over the length of the given spread.

In cases where these assumptions do not hold, the accuracy of the technique decreases. For example, if a low velocity layer occurs between two layers of higher velocity, the low velocity layer will not be detected and the depth to the underlying high velocity layer will be erroneously large. Also, if the velocity of a seismic layer varies laterally within a spread, those variations will be interpreted as fluctuations in the elevation of the underlying seismic layer.

Instrumentation

Data acquisition is initiated along each SR line by producing seismic energy using a mechanical source. Mechanical sources produce energy by impacting a metal strike plate on the ground surface with either a 12-16 pound sledge hammer or an elastic-band driven weight drop. The resulting seismic wave forms are recorded using a Geometrics 24-channel engineering seismograph and Mark Products geophones with a natural frequency of 10 Hz. The data are recorded on hard copy records (seismograms) as well as on computer disks for future processing. The seismograms display the amount of time it takes for a compression (P) wave to travel from a given shot point to each geophone in a spread.

Data Analysis

The seismic data are downloaded to a computer and processed using the program ***Seisimager*** by Geometrics, Inc. This is an interactive program that is used to determine the shot point to geophone travel times, and to compute a 2D model based on those times. Once the travel times for a given line are determined, the programs time-term algorithm is used to compute a preliminary 2D seismic model. This model is then used as input for the programs tomographic routine. Using this procedure, the program divides the starting model into a network of cells and assigns velocities to those cells based on the starting model. The program then traces the refracted seismic travel paths through those cells and computes the associated travel times. It then compares the computed travel times with the measured times and adjusts the velocities of the appropriate cells to improve the fit. The software is programmed to continue this procedure for twenty iterations. Typically, at the end of the twenty iterations the travel times associated with the computed model match the observed travel times to an accuracy of one milli-second (mS) or better. Once a satisfactory model is computed, the software contours the model velocities to produce seismic velocity vs. depth and distance cross-sections (profiles).

Limitations

In general, there are limitations unique to the SR method. These limitations are primarily based on assumptions that are made by the data analysis routine. First, the data analysis routine assumes that the velocities along the length of each spread are uniform. If there are localized zones within each layer where the velocities are higher or lower than indicated, the analysis routine will interpret these zones as changes in the surface topography of the underlying layer. A zone of higher velocity material would be interpreted as a low in the surface of the underlying layer. Zones of lower velocity material would be interpreted as a high in the underlying layer.

Second, the data analysis routine assumes that the velocity of subsurface materials increase with depth. Therefore, if a layer exhibits velocities that are slower than those of the material above it, the slower layer will not be resolved. Also, a velocity layer may simply be too thin to be detected. Due to these and other limitations inherent to the SR method, the results of the SR survey should be considered only as approximations of the subsurface conditions. The actual conditions may vary locally.