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Redwood Creek, Marin County
2010 Monitoring Study of a Salmonid Habitat Stream Restoration Project:
Seven-Year Post-Project Evaluation

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Abstract

Located within an 8.9-square mile watershed in Marin County, California, Redwood Creek flows from the peaks of Mt. Tamalpais to Muir Beach, where it empties into the Pacific Ocean. The watershed supports the southernmost population of federally listed Coho Salmon (*Oncorhynchus kisutch*), as well as Steelhead Trout *(Oncorhynchus mykiss*), a federally endangered species in California. A 2003 restoration project at the Banducci Site, a former agricultural area created in the channel's natural floodplain, sought to restore juvenile salmonid rearing habitat and re-establish floodplain connectivity. Restoration activities included a series of Eucalyptus large woody debris structures, excavation of a pre-existing artificial levee, and revegetation of native plant species along the riparian corridor. Seven years after implementation, our study characterizes the creeks geomorphic conditions through photodocumentation, historic aerial imagery, facies mapping, and longitudinal profile and cross section surveys along the study reach. Results show that installation of the logjams are significant to the success of deep pool formations and improved geomorphological complexity, increasing the overall habitat complexity within the reach. Native vegetation is thriving along gravel bars, stream banks and the restored floodplain. Logjams are holding their integrity in the stream, and structure 6-7-8 is doing particularly well at collecting large amounts of natural woody debris from upstream, ideal for coho rearing habitat. Despite the currently low populations of salmonids, the restoration of Redwood Creek promises quality habitat for future fish passage.

Introduction

Context

Located within an 8.9-square mile watershed in Marin County, California, Redwood Creek flows from the peaks of Mt. Tamalpais to Muir Beach, where it empties into the Pacific Ocean (Figure 1). Much of the creek flows through undeveloped public lands managed by the National Park Service, Marin Municipal Water District, and California Department of Parks and Recreation, as well as a few small areas of privately owned property.

Redwood Creek provides habitat to a vast diversity of wildlife, including the federally endangered coho salmon (*Oncorhynchus kisutch*), steelhead trout (*Oncorhynchus mykiss),* the California red-legged frog (*Rana draytonii*), and the northern spotted owl (*Strix occidentalis caurina*). The landscapes within this watershed and its characteristic flora and fauna serve as a major tourism and recreation destination, accounting for nearly three million visitors annually. As a means of balancing a healthy ecosystem with extensive human interest, the National Park Service has initiated restoration efforts in the last decade to enhance the ecosystem. Restoration efforts have primarily focused on the Banducci Site of Redwood Creek (Figure 3). By restoring the geomorphic complexity of this stream, salmonid populations can potentially be improved.

History

Approximately 1 km upstream from Muir Beach is a 69-hectare parcel known as the Banducci Site. Here, Redwood Creek and old agricultural fields run between Muir Woods Road and an access road for private properties (Figure 2). This area was settled by the Banducci family around 1850 and turned into an 11-hectare agricultural space used to cultivate cut flowers. Throughout their ownership, the family converted the original floodplain into agricultural fields by diverting the creek to the east of the valley and by building a levee in 1949 to prevent flooding of their crops. These alterations channelized the stream and reduced rearing habitat for aquatic species within Redwood Creek. The straightest area of Redwood Creek, a 3,800 linear foot long channel, lies within this stretch of the Banducci Site and has been nicknamed "The Bowling Alley" after its narrow, fast flowing waters and homogeneous form (Figure 4).

In 1980, the National Park Service acquired this property from the Banducci Family with an agreement that the family could continue farming until 1995. This area is currently owned by the National Park Service and managed by the Golden Gate National Recreation Area (GGRNA); and is still referred to as the Banducci Site. The landscapes within this watershed, and its characteristic flora and fauna, serve as a major tourism and recreation destination for nearly three million visitors per year. As a means of balancing a healthy ecosystem with extensive human use, the National Park Service has been actively restoring and managing the site for its natural resource values, initiating restoration projects to restore the creek bed, floodplain, vegetation, and endangered species. Restoration efforts have primarily focused on the stretches of Redwood Creek between Muir Beach and the Redwood Creek section within the Banducci Site.

However, periodic water diversion for irrigation, livestock, fire protection, recreational, commercial and domestic use occurs in the upper reaches of the stream. Such water removal has large consequences on fish by altering stream flow, impairing upstream migration, and by reducing juvenile fish habitat in months of low flow (Matz and Purcell 2004). In addition to water withdrawal issues, other impacts on Redwood creek include degradation by sedimentation, channel modifications, removal of organic material, seepage of septic systems, agricultural and domestic runoff, and lagoon modification. Restoration projects have begun to improve water quality and habitat for salmonid populations and other local aquatic species. Such efforts have focused on enhancing the geomorphic complexity and amount of woody debris within the stream environment.

Restoration Project Background

The goal of the Banducci Site restoration project was to restore floodplain connectivity, increase channel complexity, and create rearing pools for juvenile salmonids. Restoration efforts at the Banducci Site have occurred in phases. In 2003, the first restoration efforts by the National Park Service were completed using the design of Phillips Williams and Associates (PWA). Within the "bowling alley" section (Figure 5), a series of engineered Eucalyptus logjams were placed roughly 200 feet apart to encourage pool formation on the downstream side of the structures. The levee containing the channel was breached to restore the functions of the agricultural fields as a natural floodplain zone. Project initiatives also included the removal of invasive plant species, and the revegetation of the riparian area with native plants. Because ecosystem processes and salmonid habitat were successfully achieved during the initial phase in 2003, a grant was approved for another phase through the California Department of Fish and Game Fisheries Restoration Grant Program to the Parks Conservancy. In the summer and fall of 2007, remaining areas along the levee were excavated, reconnecting a portion of the creek with the floodplain.

In addition to restoration efforts at the Banducci Site, Redwood Creek has most recently undergone a restoration project at Muir Beach. The phases and project areas along Redwood Creek in recent years have been a major attempt in diversifying habitat types and natural channel function. Throughout these projects, there have been many parties involved in the restoration effort including the National Park Service, Golden Gate Parks Conservancy, Stillwater Sciences, Philip Williams and Associates, and the California Department of Fish and Game.

Monitoring Background

Monitoring along Redwood Creek has been one of consistent research and has a particularly good compendium of data through technical reports, pre-project and as-built surveys, and monitoring of biological resources including salmonids, making all changes created through restoration easily recorded and compared (Purcell and Matz, 2004).

In 2004, Mike Matz and Alison Purcell, students from UC Berkeley in the Stream and River Restoration class developed facies mapping and photodocumentation points on a 432-foot reach of the Bowling Alley. Their research characterized changes in channel features and concluded that one year after implementation, the installation of the logjams were successful in creating pools and increasing the overall habitat complexity within the reach.

Additional monitoring data (Minear, unpublished data) along the Banducci Site occurred in 2005, 2006, and 2007, looking at channel morphology characteristics. A report studying 2003-2005 reveals a trend of aggradations of 1.5 to 2.0 feet at a point bar at the inside bends at the upstream end of the restoration project (upstream of our study reach), and measurements of 1.5 to 2.5 feet of scour downstream from log jam structures (Minear 2007). In 2006, significant rainfall events produced the opposite trend, causing degradation of up to 1.5 feet upstream of the point bar and 1.5 to 3.0 feet aggradations in the pools downstream of log jams (Minear 2007). These data results show that the logjam structures are performing as predicted, yet stochastic events alter periodic sediment filling and scouring within pools adjacent to the woody debris structures.

In summary, much of the data reflects the success of restoration elements in restoring ecosystem processes while enhancing both summer rearing and winter refugia habitat (National Park Service U.S. Department of the Interior 2007). The floodplain reconnection is proving successful based on regular inundation of channel overflows and sediment deposition (National Park Service U.S. Department of the Interior 2007).

Problem Statement

A paper published in 2008 (MacFarlane et al. 2008) ranks Redwood Creek at 100% decline of returning coho Salmon from 2007/2008 relative to the 2004/2005 returns. Coho salmon occur in a three-year cycle, and in recent years population surveys have been made to evaluate the strength of each.

Coho salmon and other dwindling salmonid species populations are a substantial driver of Redwood Creek restoration projects. Looking at previous monitoring studies and analyzing our data, the goal of this study is to evaluate the geomorphic and habitat conditions at the Banducci Site restoration project. Using photodocumentation, aerial imagery analysis, facies mapping, longitudinal profiles and cross sections, we evaluate the channel response to restoration actions, and critique how the restoration and monitoring processes might be bettered in future years. We compared our data to prior monitoring information to observe changes over the seven years since construction, focusing our evaluation on the degree to which restoration actions have increased complexity, connectivity, and variability.

Methods

Our group built upon the framework of Purcell and Matz's 2004 study to monitor geomorphic characteristics within the Redwood Creek study reach (Figure 3). Purcell and Matz characterized geomorphic features using facies maps and photodocumentation of 2004 post-project channel features within the study reach, about 430 feet along the Bowling Alley reach. In addition to replicating the facies mapping and photodocumentation, we analyzed channel response using a time series of aerial photography, and surveyed the longitudinal profile and six cross sections within the study reach. Restoration activities in this reach were constructed in 2003, and included placement of large woody debris structures, excavation of a levee to restore floodplain connectivity, and revegetating with native riparian species (Phillip Williams & Associates construction drawings, Figure 5).

We surveyed the longitudinal profile and cross sections by tape and level, using previously established benchmarks to tie our data to previous studies. The surveying benchmark we tied into was an orange plastic stake marking PC3, the downstream monitoring cross section at logjam structure 6-7-8. This point was set by PWA in 2003, at elevation 28.63 feet, North American Vertical Datum, 1988 (NAVD88), and all elevations shown herein reference that datum.

Repeating the procedure from previous studies, we strung 432 feet of tape from the downstream limit of the study reach, about 90 feet below logjam 6-7-8, to the upstream limit of the study reach above logjam 4. Due to dense overbank vegetation and limited field time, we kept our cross section surveys to within about 20 feet of the active channel banks.

To conduct a photo-documentation record of the fall 2010 conditions, we took photos of each woody debris structure, active channel features, bank erosion sites, and points of interest including a significant debris jam at logjam 6-7-8, and a series of about a dozen dead and dying mature red alder trees near the upstream end of the study reach. We juxtaposed these photos to previous studies to look for changes (Appendix B).

We developed detailed facies maps of the active channel over the study reach (Appendix E). We strung tapes along the bank and across the channel to mark our locations relative to the 2004 survey, and mapped channel features by walking the study reach, drawing geomorphic elements to scale. We specified the type of channel material such as gravel, cobble and sand, and the location and depth of pools, and noted local bank erosion sites. This 2010 mapping effort allows us to examine fluvial changes and responses since the 2004 study.

Results and Discussion

Monitoring of post-project conditions through photomonitoring, cross sections, and profiles has allowed us to observe the channel response to restoration over the last seven years since construction. While digital information and raw data was readily abundant, we found that basic monitoring technologies would greatly improve the accuracy of monitoring in future years. As an example, the project's monitor markings were often either hard to find, unlabeled, or semi-permanent objects.

The Banducci Site restoration contributed to the geomorphic complexity within the project reach, which currently provides rearing habitat within the channel pools. The significant large pools within this reach improve habitat by keeping the water temperature cool and the woody debris refuge is ideal for rearing juvenile salmonids.

1. Photomonitoring:

1.A. Large Woody Debris Structures

The large woody debris structures (also referred to as logjams) have had a clear impact on channel geometry. At most locations in the study reach, the woody debris structures have collected sediment on their upstream side and generated scour on the downstream side, creating large deep pools, ideal rearing habitat for juvenile salmonids. While adding to the complexity of stream morphology, the structures also encourage future channel meandering, divert flows away from the bank to reduce erosion, promote bar formation through induced sediment deposition, and increase in-stream cover and refugia. Large woody debris (LWD) plays a crucial role in salmonid habitat creation, shaping pools and bars, providing cover, reducing stream temperatures, and acting as substrate for microorganisms and invertebrates on which the fish feed (Cederholm et al., 1997; Giannico, 2000; Myers, 2000). Before the restoration, large woody debris was scarce in Redwood Creek, limiting the complexity of the stream LWD. Lack of natural woody debris in the watershed is largely the result of removal by humans. For example, despite a heavy storm event in the watershed in 1998, very little wood was added to the stream, resulting in a general loss in pool depth along the creek (Smith 1998).

1.B. Vegetation

Native riparian plants have flourished since their planting in phase one, serving as a very thick visual and physical barrier to human access. Riparian zones with native vegetation regulate in-stream primary production through shading, reduced light and water temperature, while contributing leaf litter and woody debris, adding nitrogen and debris to the stream (Noble 2010). Native vegetation along the riparian zone of Redwood Creek at the Banducci Site is dominated by red alder (*Alnus rubra*) and arroyo willow (*Salix lasiolepis*) (National Park Service U.S. Department of the Interior 2007). Other tree species occurring along the creek include buckeye (*Aesculus californica*), bay laurel (*Umbellularia californica*), and coast live oaks (*Quercus agrifolia*).

Within the bowling alley reach, we recorded very large woody debris accumulation at logjam 6-7-8. We tried to observe where the large amounts of debris were coming from and why they had stacked up so high at this woody debris structure, and not any of the others. About 150-200 feet upstream of logjam 6-7-8, we observed a collection of about a dozen large, dead, leafless alder trees, and about half consisted of only 10-foot-high tree trunks and their upper portions toppled (Figure 16).

It is apparent at the Banducci Site, especially within this 432-foot reach that the leafless mature red alder trees along both sides of the bank are dying or dead. There are many downed trees along the bank and in the channel that are insect infested. In fact, in the three weeks that passed between our site visits, a tree that was upright had fallen into the stream. What looks to be a swift increase of woody debris supply directly upstream of logjam 6-7-8 has added to the debris jam size increase, as it appears from our observation that it is red alder logs that have piled up on the logjam. The reason for the mass death of these trees could be a number of factors. At Redwood Creek's Pacific Way site, downstream from the Banducci Site near Muir Beach, the NPS states in the EIR for that project that alders dying at that site is likely to be a result of the increased water table elevation caused by sedimentation in the creek channel. At the Banducci Site, tree age may also be a factor. Red alder is a short-lived tree with an average life span of approximately 40 to 60 years (Tree Book, n.d.). It is possible that these trees were planted in 1949 when the levees for the flower farm where constructed meaning their lifespan is up, but tree ring coring would identify their age. A combination of these factors could be contributing to their declining health, but diagnosing their health decline is outside the scope of our study.

The lack of tall shade trees in this reach could cause an issue to the salmonid habitat that has been restored at the Banducci Site. However, the large mount of large wood debris entering the channel could cause more debris jams like the one at logjam 6-7-8. This large supply of wood entering the channel could be helpful in creating habitat for salmonids. It might be helpful for NPS to get an expert to the site and determine if it is better to cut down the dead and dying trees and remove them or if they can be left. The health of mature shade trees should be considered during the design and construction phases of restoration projects. Additionally, a plan to replace the canopy vegetation in this reach of Redwood creek would be helpful to creating good riparian habitat.

2. Aerial Image Time Sequence Analysis

In recent years, aerial imagery has become more readily available through online sources like Google Earth. With its ease of accessibility and increasing frequency of photography, aerial image time sequence analysis is an increasingly valuable tool to conduct post-project monitoring. With the aide of aerial imagery, we were able to track the progression of the mature red alder trees within our study reach, examine revegetation growth rates, and observe construction disturbances. Our fieldwork hypothesized that logjam 6-7-8 had backed up with large woody debris from upstream where about a dozen alder trees are collapsing into the creek and washing downstream. With aerial imagery, we were able to observe the progression of vegetation cover of Redwood Creek between 1998 and 2010. Despite seasonal difference, dead red alder branches and trunks become progressively pronounced in photos after phase one of the restoration project. We recommend that an arborist look into potential causes of the tree health decline, including construction disturbances, increased post-project inundation, and disease.

3. Facies Mapping

Figure 37 compares the 2004 facies mapping effort with our 2010 effort. The purpose of the facies mapping is to identify changes in the channel over the last six years and what these changes can tell us about how the channel is responding to the restoration interventions. We acknowledge the constraints with comparing these two mapping efforts that were done by two different groups of people six years apart and we also understand the limits of the information a facies map can tell us. That said, there are some things that can be learned from the facies map comparison.

In general, the channel has became more complex over the last 6 six years. Reorganization of materials has been significant. Most pools have been maintained and there are more fine sediments in the channel than there was in 2004. A number of logs and other wood debris that was in the middle of the channel or across it in 2004 are now gone. Today most large woody debris is found along the banks and behind logjam structures. In reach one (Figure 38), there has been a significant reorganizing of materials and erosion of the right bank. This has exposed tree roots and created pools along that bank. But, the scale of the right bank erosion should be a considered significant since in 2004 it was shown to only be eroding in a small area and now it is much of the reach. The pools have migrated but have been maintained. Also in reach one we can see that the channel bottom is more complex than in 2004. In reach two, logjam #4 has expanded the size of the pool downstream and accumulated some large wood debris upstream. There are more fine sediments in the reach than there were six years ago. In reach three, logjam #5 has maintained the large pool downstream. We recorded the beginnings of bank erosion just downstream of the logjam on the right bank and some on the left bank as well. There is also a more complex material being deposited downstream of the logjam were it was mostly just cobble before. In reach four and five, the mapping comparison also shows the significant growth that logjam 6-7-8 has undergone as debris has piled up at the debris structure. Upstream from the three logjam complex there have been major changes to the stream as local hydraulic flow path has become more dynamic. In 2004, there was a significant cobble bar with riffles on both sides. At the time of our study, a deep pool exists behind the debris jam. Downstream of the logjam 6-7-8 debris jam the changes are somewhat less pronounced, riffles still remain and so does the large gravel bar on the left bank.

4. Longitudinal Profile Survey

The pre-project channel profile (Figure 29) had a constant slope, with no variability. The distinguishing characteristic of the 2010 profile is the 2 to 4 feet deep pools near the large woody debris structures. Toby Minear, UC Berkeley graduate student, generously provided us with cross section and profile data from 2003 (immediately following placement of woody debris structures), 2005, and 2006. Each pool's depth, length, and relative location to the large woody debris structures has varied from year to year, but in each post-construction survey, the pools trend towards both deeper and longer with increased distance downstream. One potential reason for this is that the woody debris structures and thickening vegetation could be recruiting sediment towards the upstream reach, creating hungrier water and causing increasing pool scour with increasing distance downstream.

It would be interesting to observe how this profile trend might change in the future, particularly if the debris jam remains in tack. We hypothesize that the debris jam will have a backwater affect, slowing water velocities in the reach upstream.

5. Cross Section Surveys

Each as-built cross section (Figures 30 - 35) shares the same generally flat-bedded trapezoidal channel shape, with the high downstream left bank, and reconnected floodplain on the right overbank. The active channel showed a constant, continuous canal-like section. Since the first year after construction, the active channel has formed pools and depositional areas, visible on the cross section plots. The 4 to 5 foot scour pools are each located in the immediate vicinity of the woody debris, with depositional areas focused downstream of each pool. General year-to-year trends are difficult to parse out, but the study reach's downstream sections experienced deeper scour than the upstream sections. Cross sections downstream of each woody debris structure (PC3, 5, and 7) show various stages of pool formation, while sections upstream of each woody debris structure (PC4, 6, and 8) each indicate signs of accretion, and deposition. One interesting exception is at PC4, just upstream of the debris jam, where three feet of scour is shown on the downstream left toe of bank. As shown in the design plans, this section cuts through a longitudinally placed large woody debris log along this left toe of bank, with its rootwad facing upstream. This has caused local scour under the log downstream of the rootwad. This location shows the typical local complex flow patterns and bed variability caused by the large woody debris. The cross sections we surveyed indicate the continued effectiveness of the large woody debris in contributing to channel complexity, and sustained pool habitat seven years after placement.

Upstream of the woody debris structures, deposition is causing a smaller flow area with the development of gravel bars. This is creating a terracing effect (PC8) that adds to the lateral connectivity and floodplain inundation frequency and provides increased variability for near water vegetation. From year to year, significant changes in active channel form are pronounced. As the channel recovers from its past straightening and confinement, it will be interesting to see how the active channel migrates over time. The levee removal and woody debris placement appears to have set the stage for passive restoration of a more natural plan form.

It's difficult to isolate the cause of geomorphic features on the profile and cross section with the variety of parameters contributing to channel scour and sediment transport. For example, upstream channel changes can have significant impact on sediment transport in the restoration reach. One parameter we can examine is the recent hydrology (Figure 28). The highest Redwood Creek flow event since 2003 construction was the 2006 New Years storm, which was about a 10-year event. We don't have data that closely brackets this event, but one feature that appears after this event was the left bank toe scour at section PC4 mentioned above.

Conclusion

Through our photodocumentation, aerial image time sequencing, facies mapping, longitudinal profile and cross section surveys, our study indicates continued increase in channel complexity, variability, and connectivity seven years after construction. We built upon the framework of previous studies, expanded the scope of monitoring by combining a larger suite of metrics, and set comprehensive repeatable approach for future monitoring studies.

Restoring floodplain connectivity by levee removal has widened the riparian zone. With the help of the increased lateral connectivity, the increasingly inundated floodplain revegetation is taking hold. Levee removal has also reduced the concentration of flow, depth of flow, and shear stress in the active channel. This has contributed towards a more natural sediment transport regime in the restoration reach, with increasing deposition at bars and the beginning of a plan view migrating channel within the straightened Bowling Alley reach. The reduction in shear stress within the previously confined channel appears to be allowing for more vegetation success within the active channel. This increased roughness, together with more natural sediment transport regime will continue to add to the floodplain connectivity and restore more natural geomorphic processes. It will be interesting to see how the channel migrates after both a larger storm event, and over a longer period of time.

Placing woody debris is a low cost, low disturbance, simple to place method that this study proves to be effective in restoring channel complexity and improving habitat conditions. Our study concludes that seven years after placement the woody debris structures are succeeding in recruiting other woody debris and sustaining deep pools and contributing to channel complexity. Despite the currently low populations of salmonids, the restoration of Redwood Creek promises quality habitat for future fish passage.

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Figure Captions

Appendix A: Site Context and Maps

Appendix B: Photomonitoring

Appendix C: Aerial Imagery

Appendix D: Cross Section Surveys and Longitudinal Profiling

Appendix E: Facies Mapping

Appendix A
Restoration Context and Maps

Figure 1
Regional context and watershed map

Figure 2
Local context map, the Banducci Site

Figure 3
Site context map, restoration reach of Redwood Creek called "The Bowling Alley"

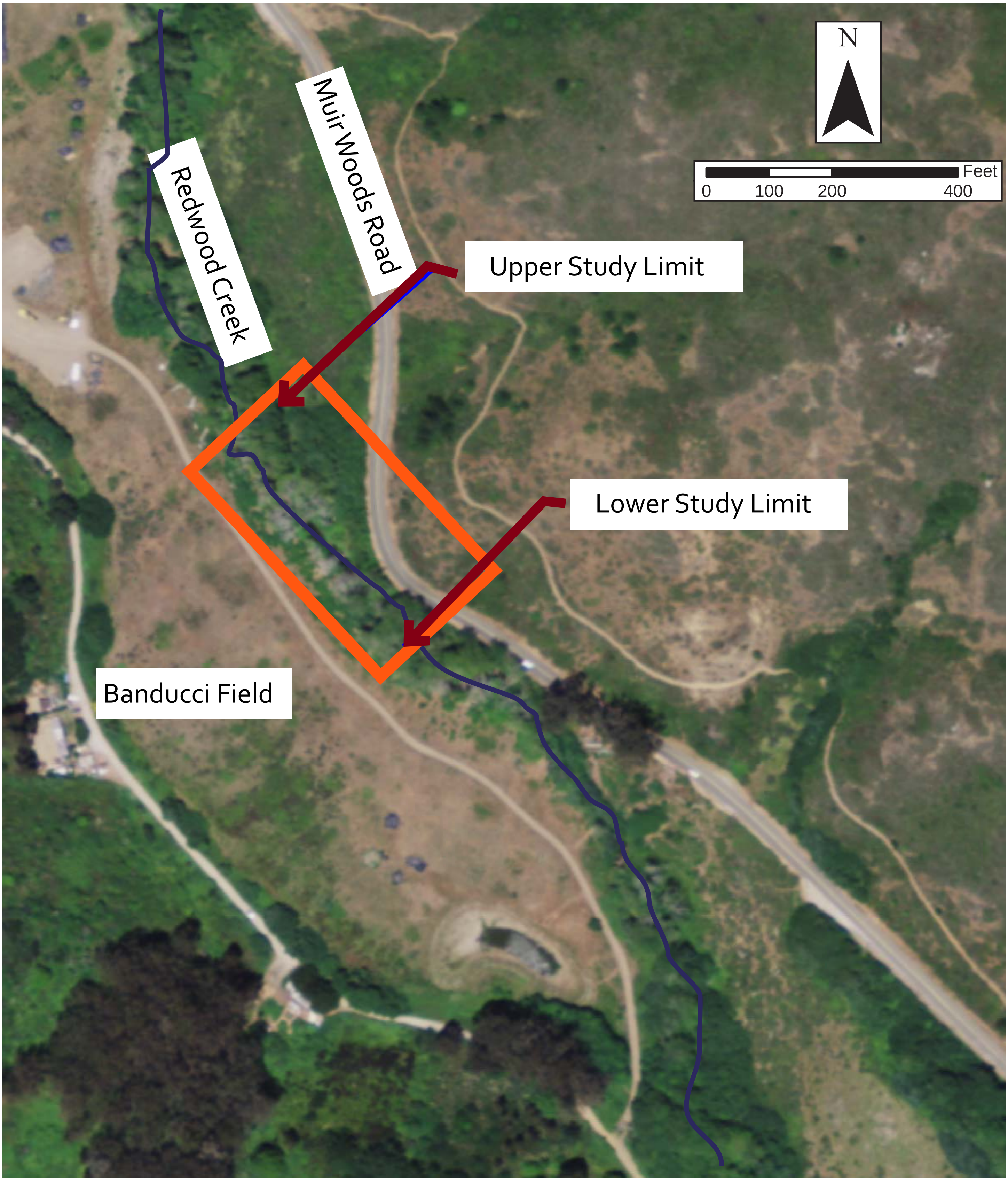


Figure 4
Redwood Creek coho salmon spawner survey results for 1998-1999 through 2007-2008
Source: 2007-2008 Coho and Steelhead Spawner Survey Summary, NPS, San Francisco Bay Area Network, Inventory and Monitoring Program.

Redwood Creek coho salmon spawner survey results for 1998-1999 through 2007-2008

Year	# of Surveys	AUC Range 100% OE RT 8-17 days	AUC Range 50% OE RT 8-17 days	PLD Index	Total Redds
2007-2008	7	-	-	0	0
2004-2005	7	169-359	338-718	171	74
2001-2002	5	116-247	233-494	105	29
1998-1999	11	39-83	78-167	39	55

2007-2008 Coho and Steelhead Spawner Survey Summary,
NPS, San Francisco Bay Area Network, Inventory and Monitoring Program

Figure 5
Restoration design of the Bowling Alley reach
Designed by PWA, 2003.

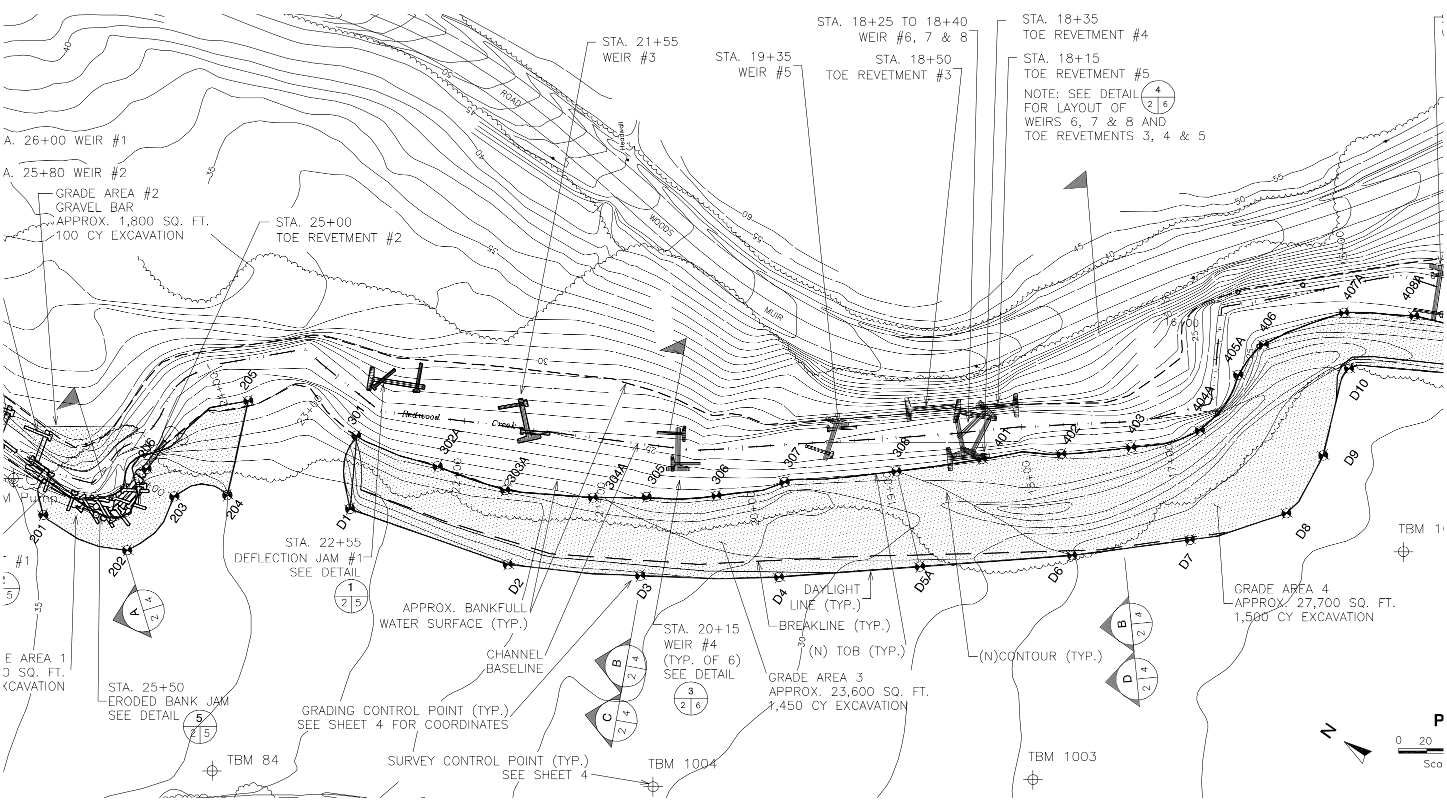


Figure 6
Pre-project geomorphic survey map (PWA, 2000)
Note: This map shows the entire restoration site. The arrows indicate the start and end points of our 432- foot study reach.

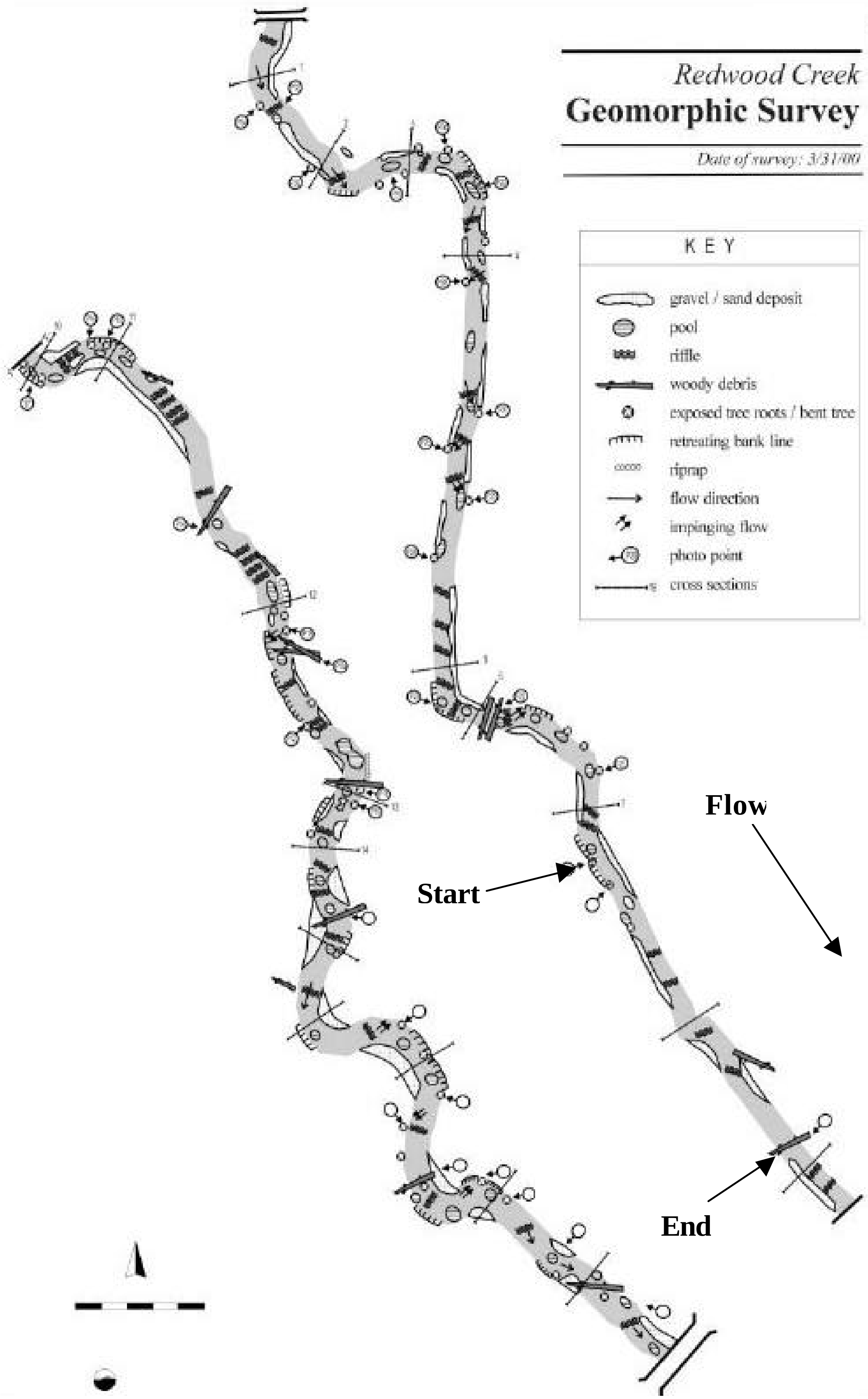


Figure 7
Channel morphology before (2002) and after restoration (2004)
Source: National Park Service

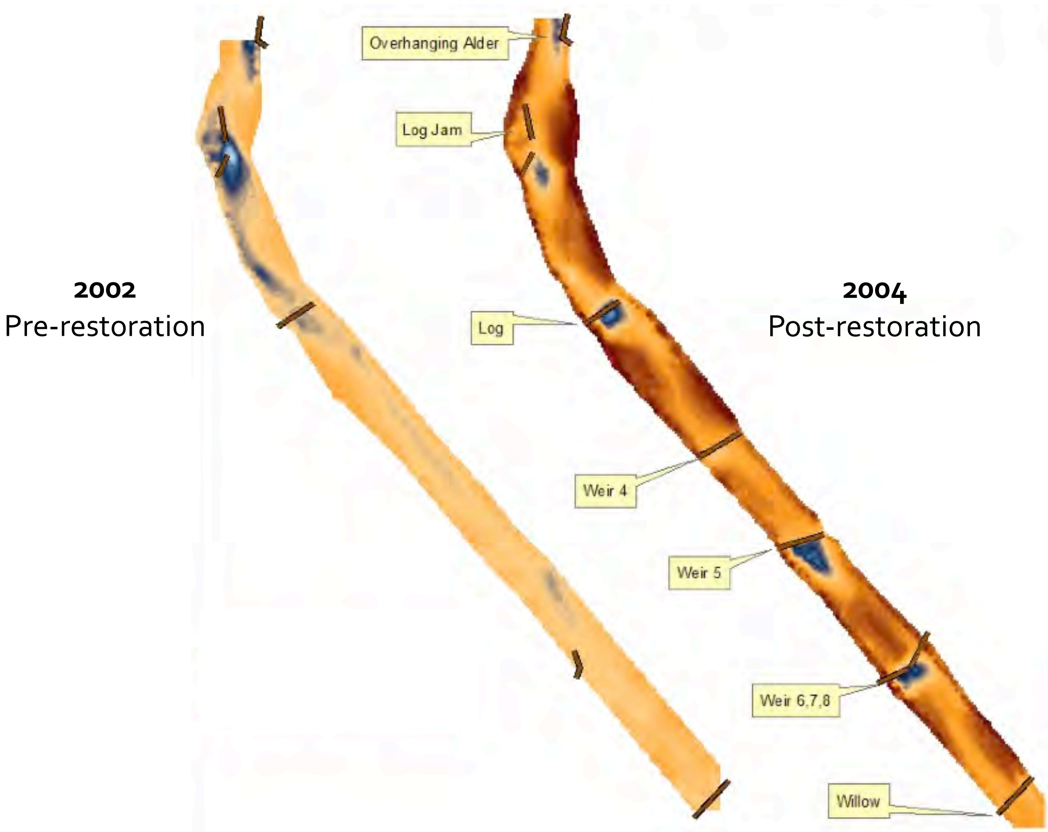


Figure 8
Photo of logjam 6-7-8 in 2006, post-restoration
Source: Mark Thompkins

Appendix B
Photomonitoring

Photodocumentation
Looking downstream at logjam 6-7-8

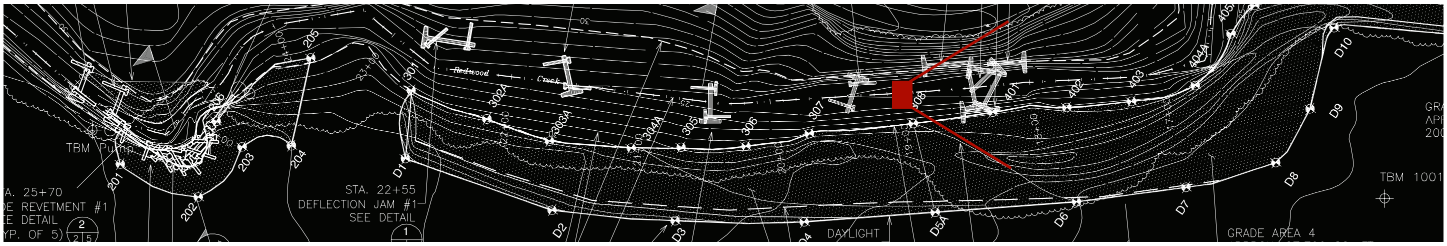


Figure 9A
Photo Location

Figure 9B
2004
Source: Matz and Purcell 2004

Figure 9C
2010
Willow and other native vegetation types have colonized along the gravel bars. From this view, entire large tree trunks have added to debris jam 6-7-8, creating a solid woody debris structure above the water, ideal for coho rearing habitat.

Photodocumentation
Looking towards the right bank at logjam 6-7-8

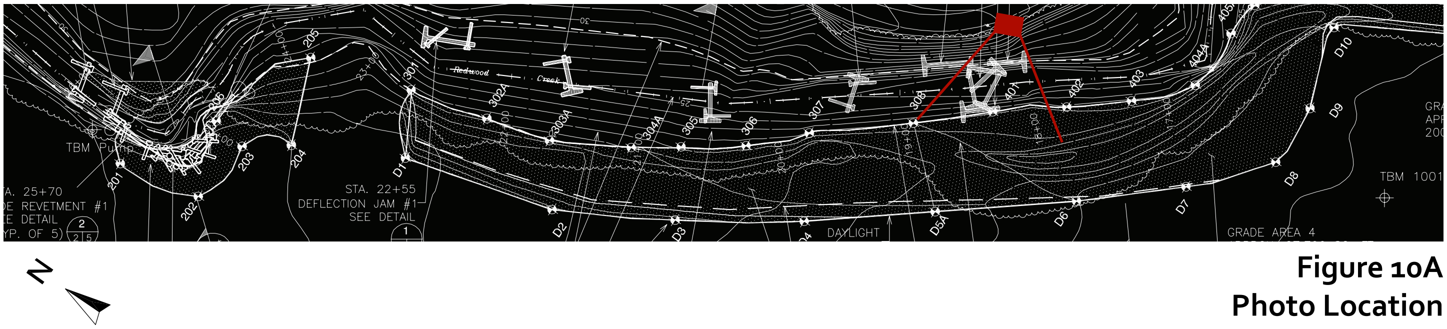
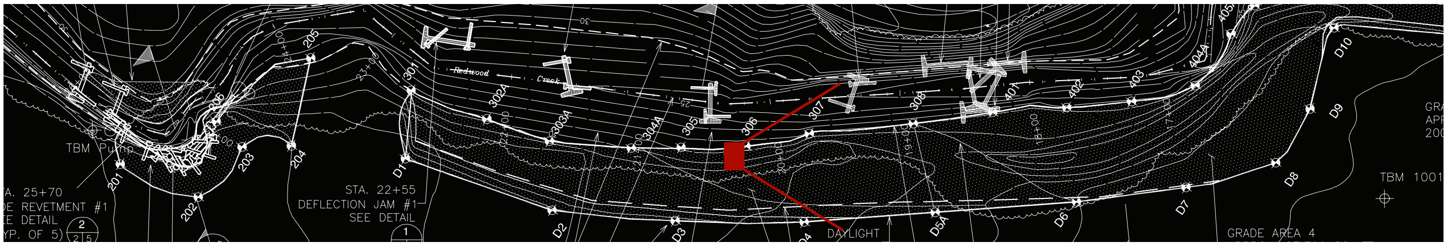


Figure 10A
Photo Location

Figure 10B
2004
Source: Matz and Purcell 2004

Figure 10C
2010
Logjam 6-7-8 has grown nearly 4' above the surface of the water , consisting mostly of the dead red alder branches washing down from upstream of the restoration project.

Photodocumentation
Revegetation along the right bank of Redwood Creek



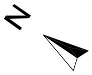


Figure 11A
Photo Location

Figure 11B
2004
Source: Matz and Purcell 2004

Figure 11C
2010
Revegetation in mats and individual species planted along the stream banks and along the edge of the floodplain have grown nearly 20 ft tall is some areas, creating a dense and native riparian plant palette.

Photodocumentation
Study endpoint, looking upstream at logjam 6-7-8

Figure 12A
Photo Location

Figure 12B
2004
Source: Matz and Purcell 2004

Figure 12C
2010
From this view, vegetation growth along the creek edges and gravel bars has grown tall and thick. This section of the reach shows areas of riffle after logjam 6-7-8.

Photodocumentation
Pool downstream of structure 6-7-8

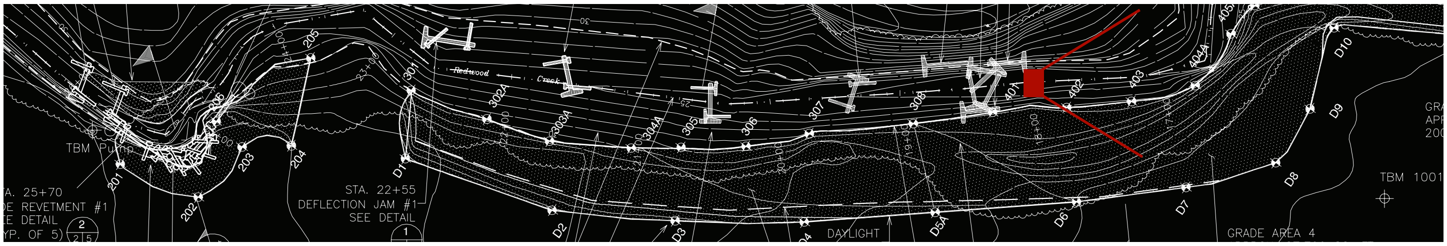


Figure 13A
Photo Location

Figure 13B
2004
Source: Matz and Purcell 2004

Figure 13C
2010
Vegetated gravel bars have directed channel movement, creating fast flowing waters with riffles between pools formed downstream of each logjam.

Photodocumentation
Pool immediately downstream of structure 6-7-8

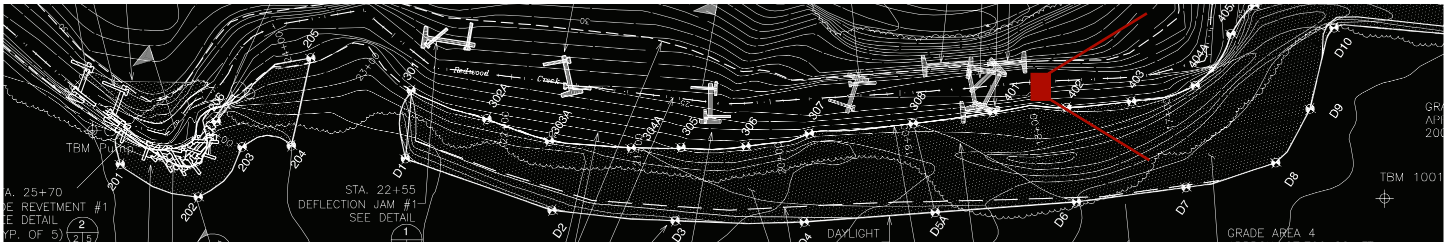


Figure 14A
Photo Location

Figure 14B
2004
Source: Matz and Purcell 2004

Figure 14C
2010
Vegetation growth along gravel bars and creek edges has filled in successfully providing habitat, nutrients and cover to keep the stream cool.

Photodocumentation

Pool immediately downstream of logjam 5 (view from far right bank)

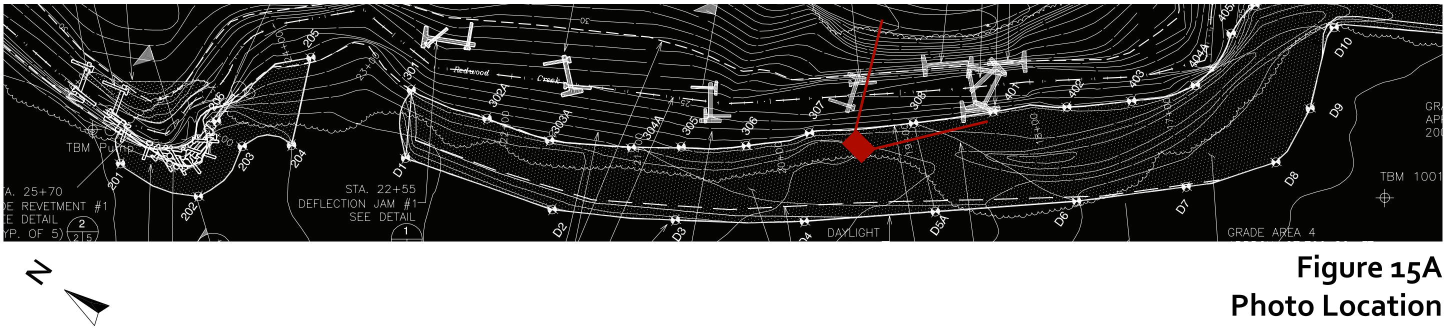


Figure 15A
Photo Location

Figure 15B
2004
Source: Matz and Purcell 2004

Figure 15C
2010
Seven years after restoration, the logjam structures have held their integrity. While the design of structure 6-7-8 has been the most successful in collecting additional woody debris, the other log-jams, such as number 5 have not natually accumulated additional woody debris collection as well.

Figure 16
Additional site photos: Redwood Creek riparian alder tree canopy

Photo 1
Dead alder tree canopy just upstream from the 432-foot bowling alley reach.

Photo 2
Alder trunks falling into Redwood Creek showing signs of interior decay.

Photo 3
Woody debris added to the creek.

Photo 4
Alder branches and trunks providing woody debris growth at logjams downstream.

Photo 5
Alder tree canopy breakage.

Appendix C
Aerial Imagery

Figure 17
Aerial Imagery June 11, 1993. Pre-restoration, the historic floodplain of Redwood creek is farmed by the Banducci family and maintained through adjacent levee.
Source: Google Earth

Figure 18
Aerial Imagery August 24, 1993. Pre-restoration, Banducci fields being farmed and Redwood Creek corridor contained by levee.
Source: Google Earth

Figure 19
Aerial Imagery June 8, 2002. Post-farming of Banducci fields, pre-restoration construction, riparian vegetation appears healthy.
Source: Google Earth

Figure 20
Aerial Imagery October 6, 2002. Pre-restoration construction, riparian vegetation appears healthy.
Source: Google Earth

Figure 21
Aerial Imagery October 30, 2002. Pre-restoration construction, staging of materials such as woody logjam structures visible. Riparian vegetation appearing healthy.
Source: Google Earth

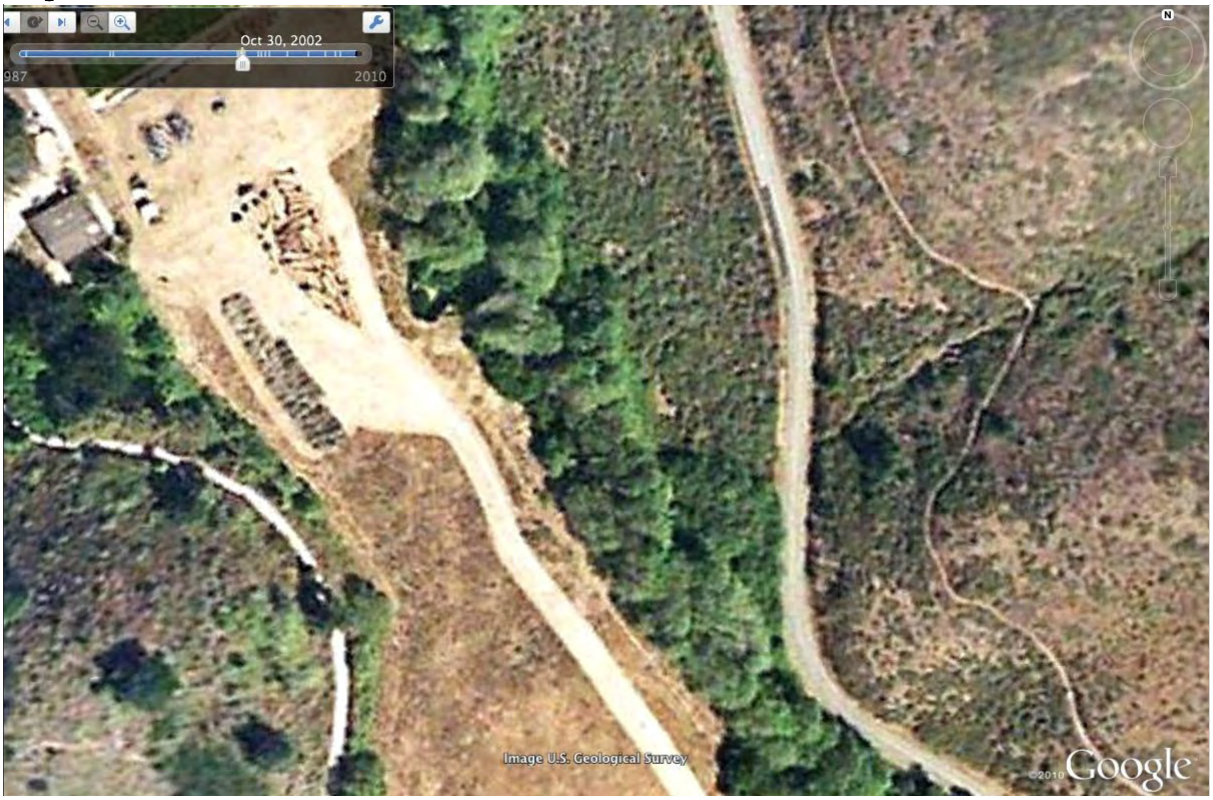


Figure 22
Aerial Imagery December 30, 2003. Restoration work of revegetation, levee removal, and logjam structures visibe. Decline in riparian tree canopy health visible.
Source: Google Earth

Figure 23
Aerial Imagery February 28, 2004. Restoration construction of 2003 completed. Riparian canopy health continues to decline.
Source: Google Earth

Figure 24
Aerial Imagery October 3, 2004. One year post-restoration.
Source: Google Earth

Figure 25

Aerial Imagery January 29, 2007. Coninued visibility in decline of riparian tree canopy health. Success of revegetation along levee removed areas and logjam bank revetment successful.

Source: Google Earth

Figure 26

Aerial Imagery September 29, 2008. Five years post-project construction. Phase 2 of revegetation and levee removal visible. Riparian tree canopy health continually declining.

Source: Google Earth

Figure 27

Aerial Imagery October 24, 2009. Six years post-project construction, riparian tree canopy health continually declining. Banducci Site responding well to restoration as a revegetated floodplain of Redwood Creek.
Source: Google Earth

Appendix D

Cross Section Surveys and Longitudinal Profiling

Figure 28
Redwood Creek hydrology, peak annual discharge

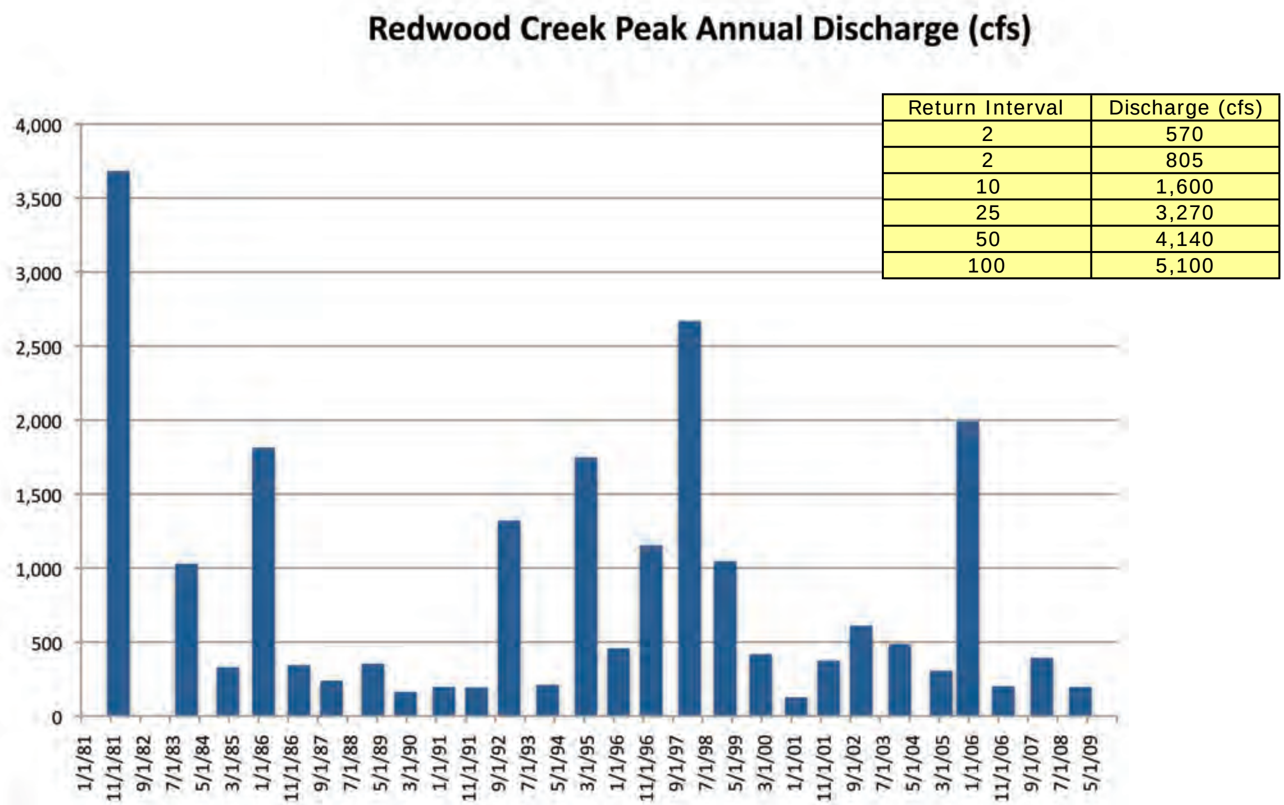


Figure 29
Map of cross section monitoring points throughout the 432-foot Bowling Alley reach

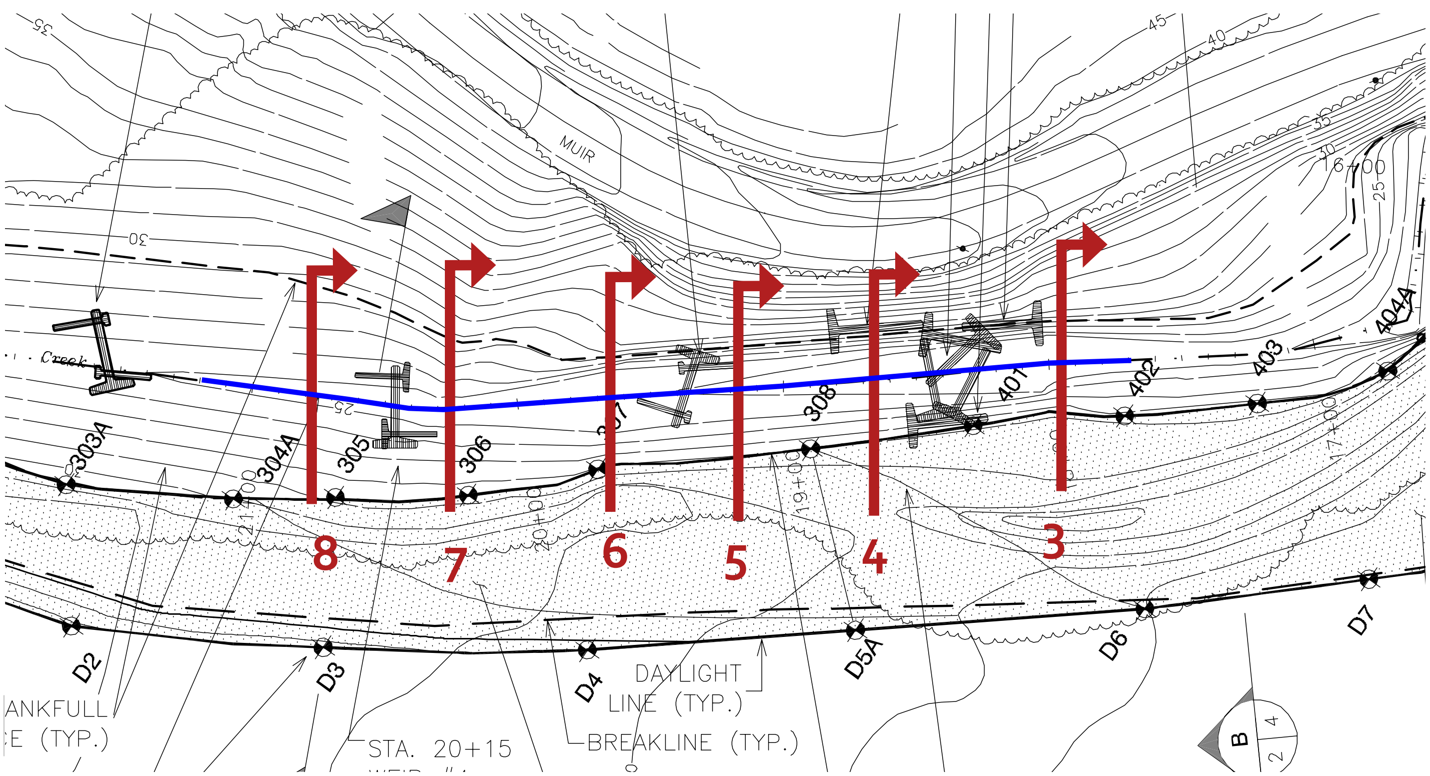


Figure 30
Redwood Creek Cross Section Survey XS PC 3

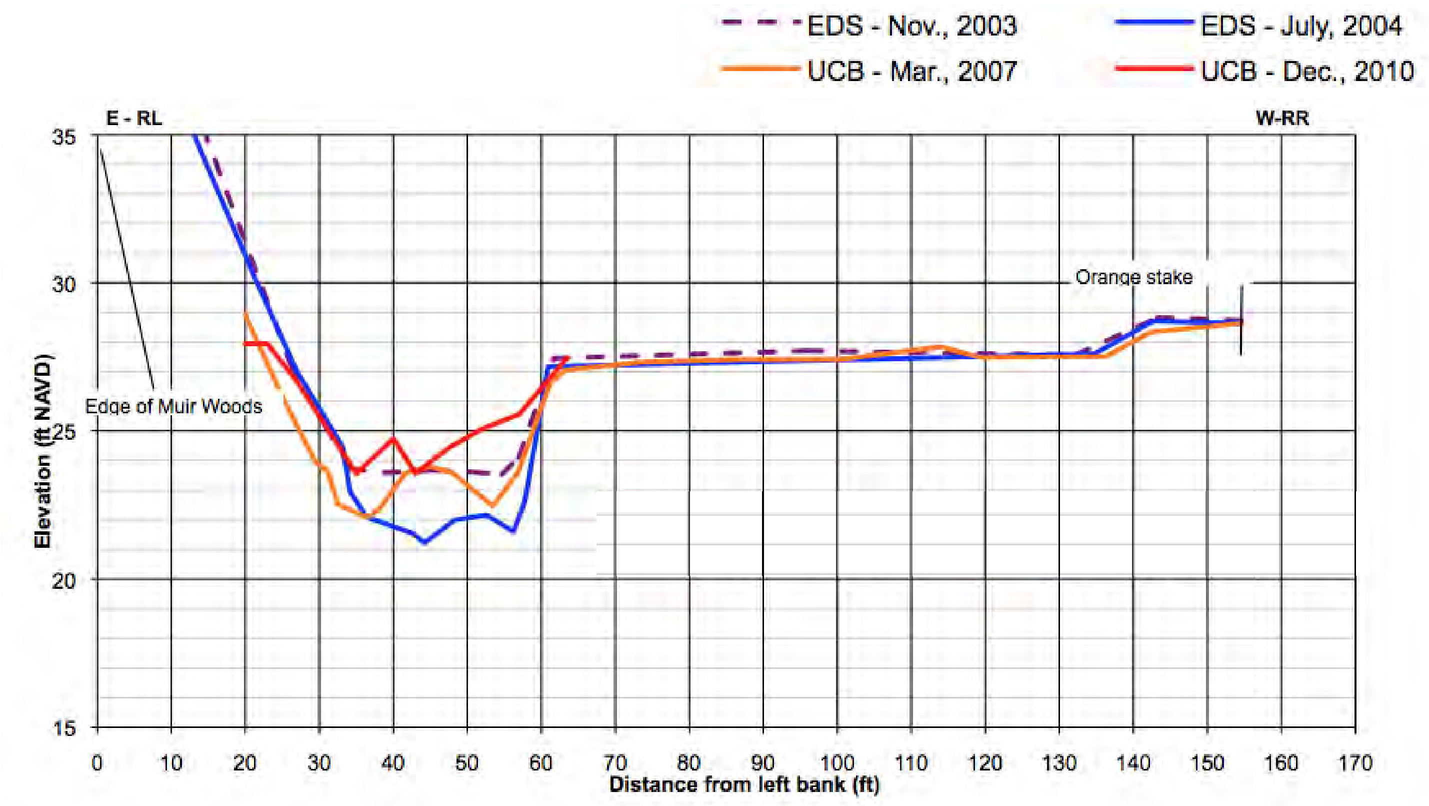


Figure 31
Redwood Creek Cross Section Survey XS PC 4

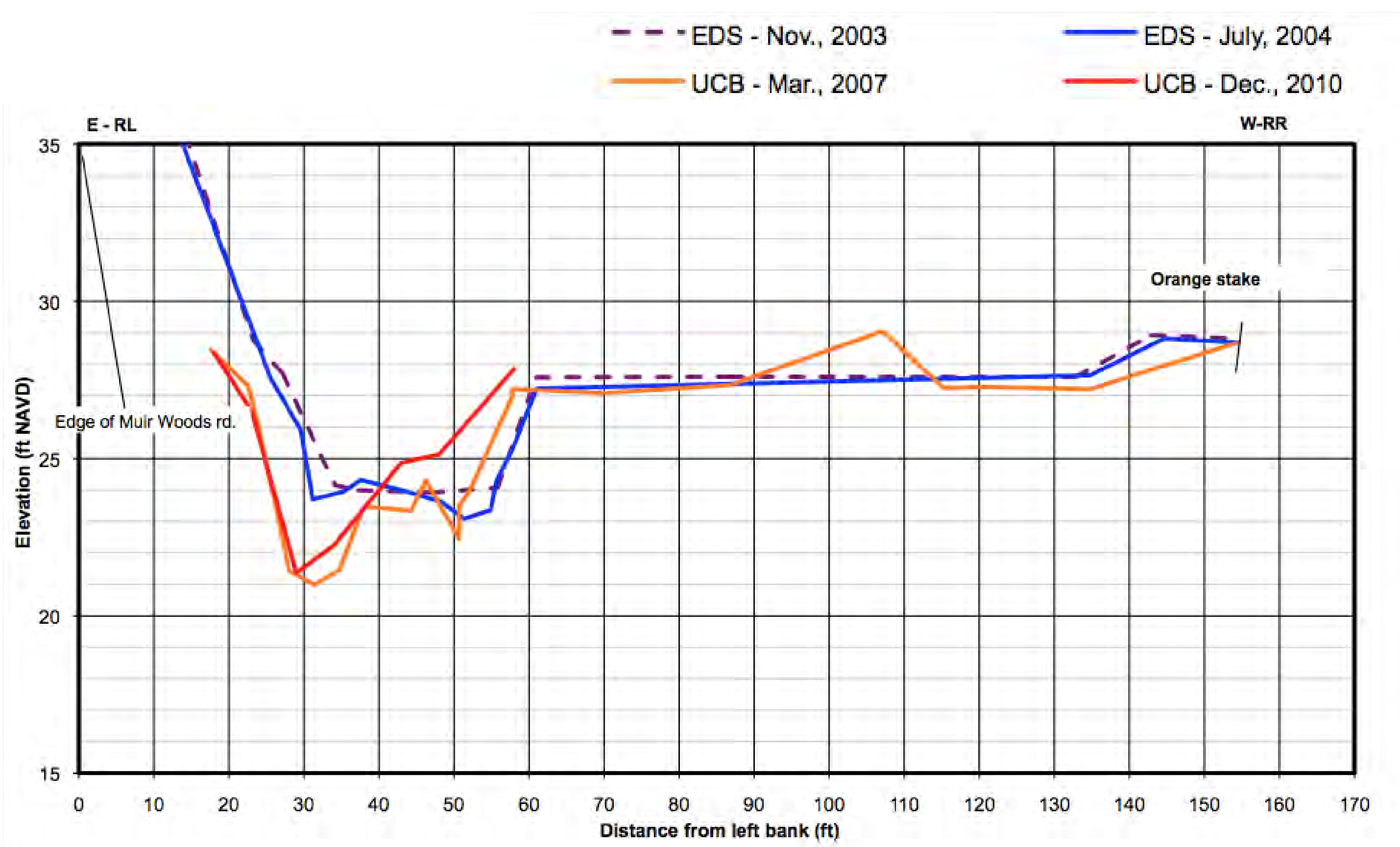


Figure 32

Redwood Creek Cross Section Survey XS PC 5

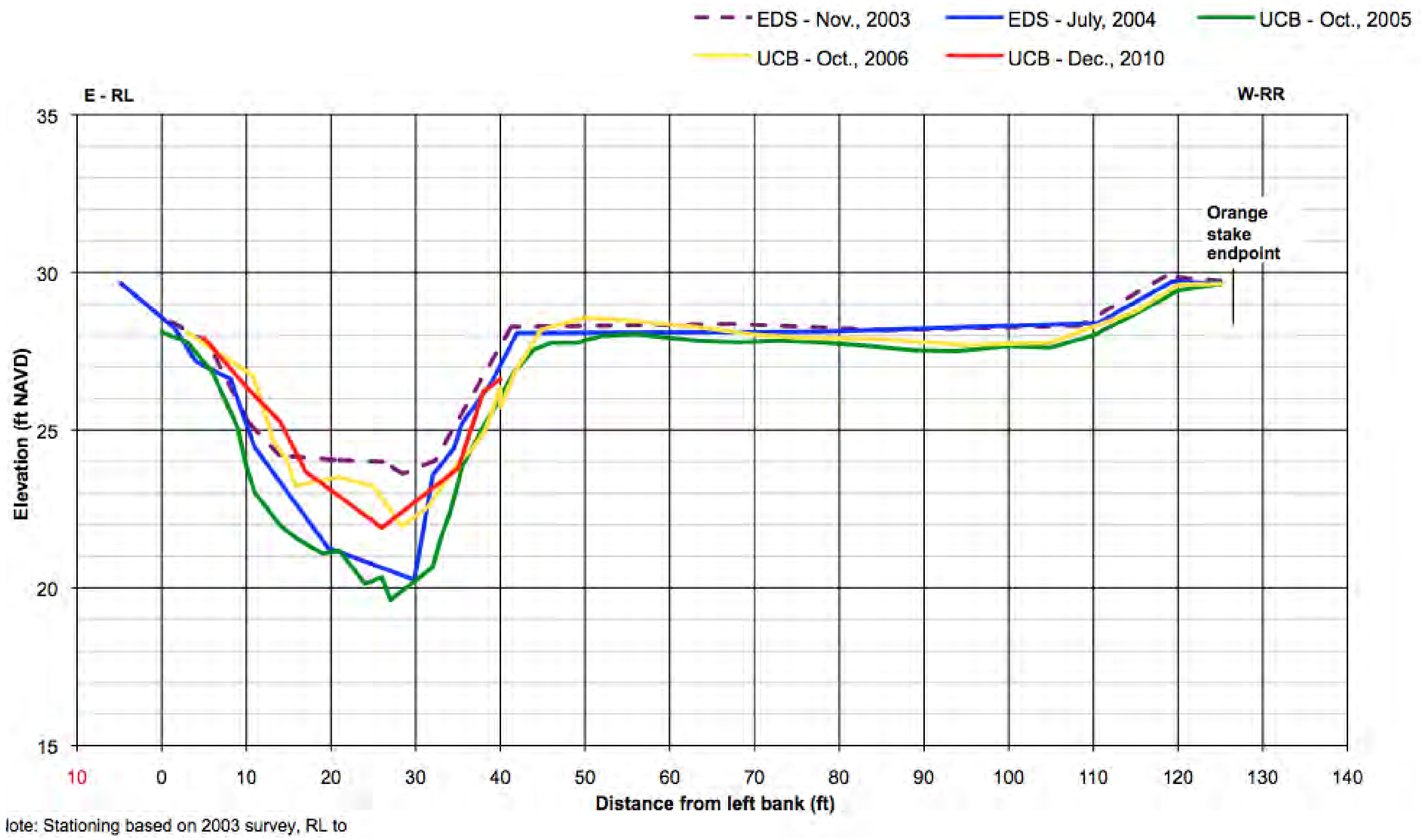


Figure 33

Redwood Creek Cross Section Survey XS PC 6

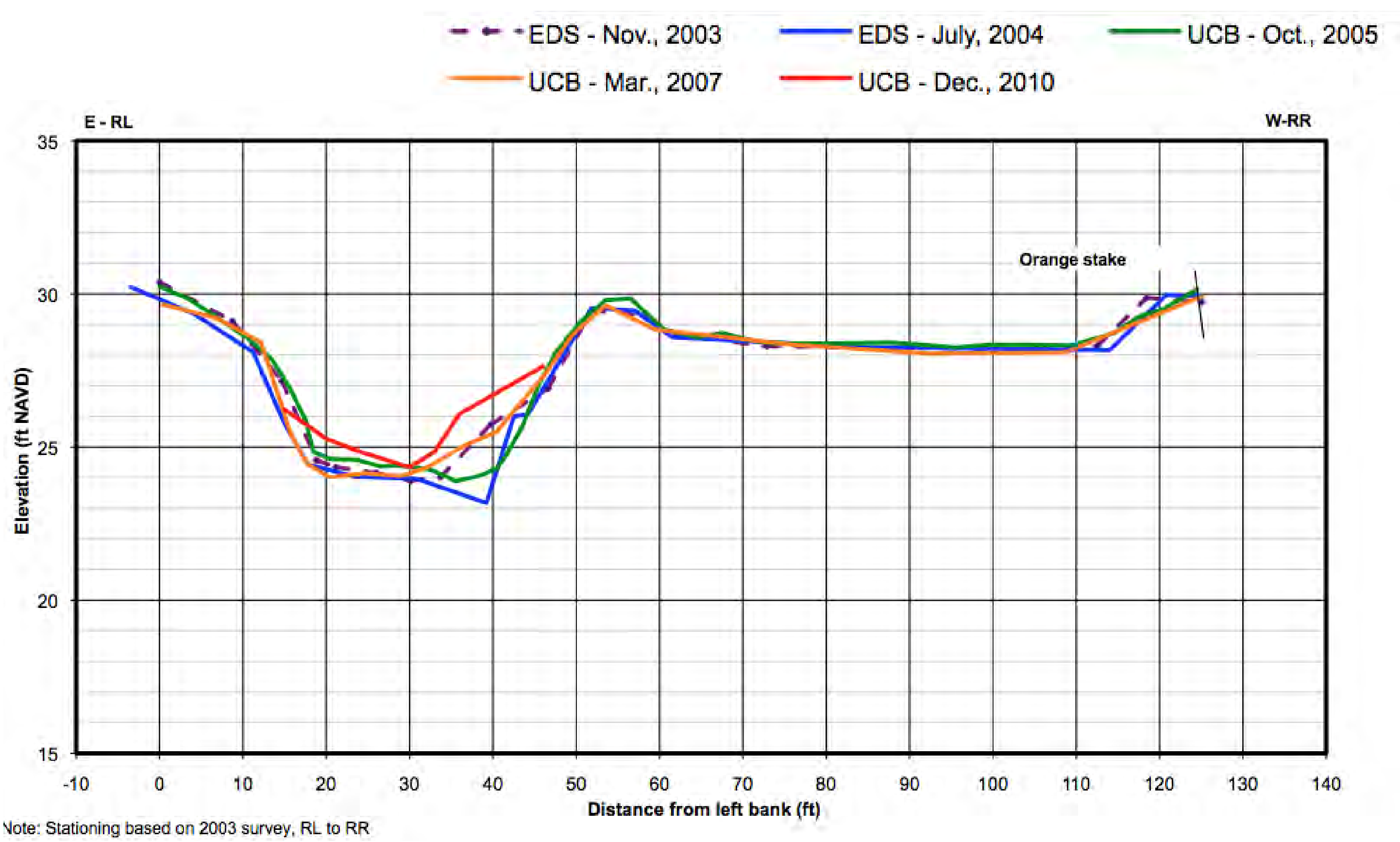


Figure 34
Redwood Creek Cross Section Survey XS PC 7

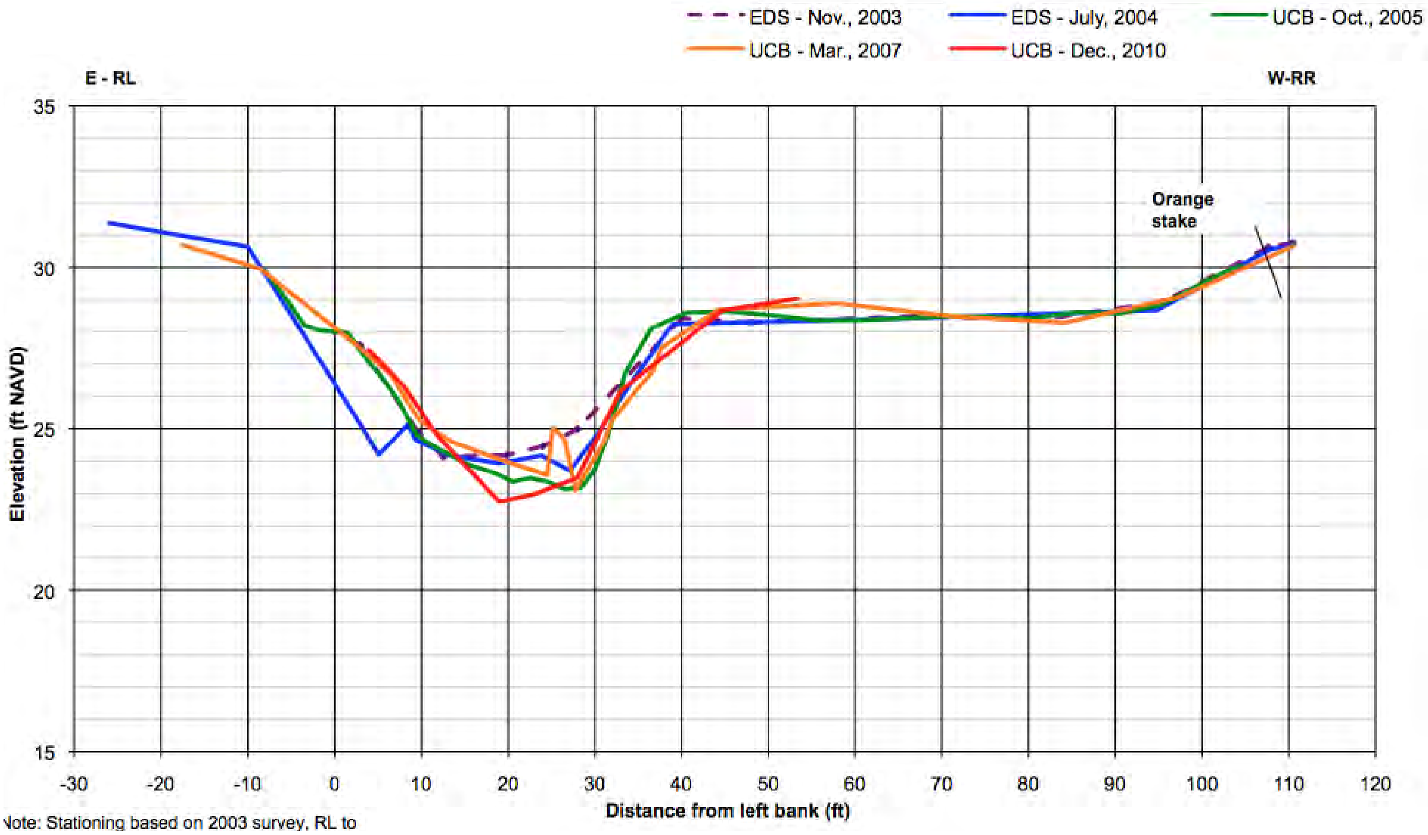


Figure 35
Redwood Creek Cross Section Survey XS PC 8

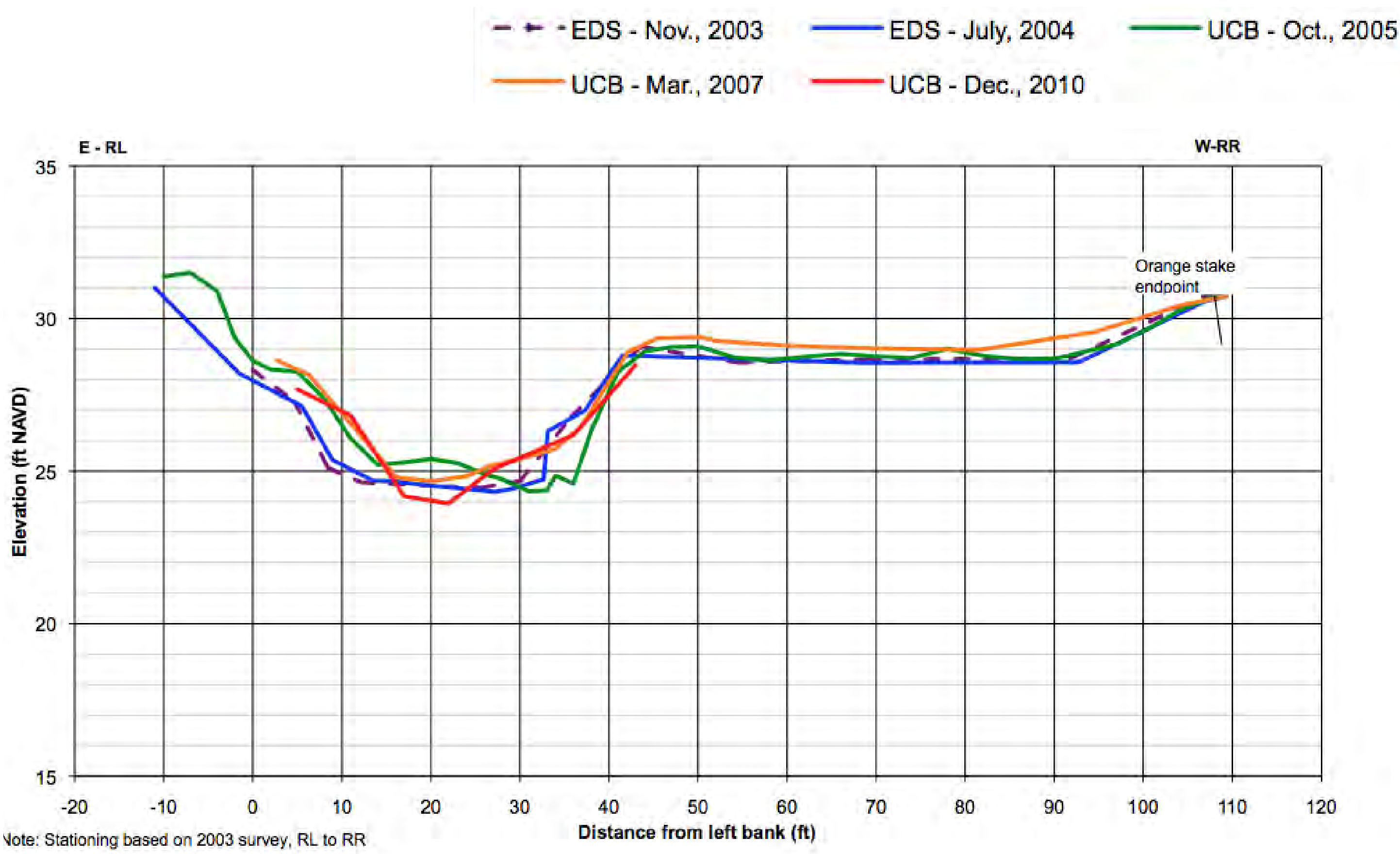
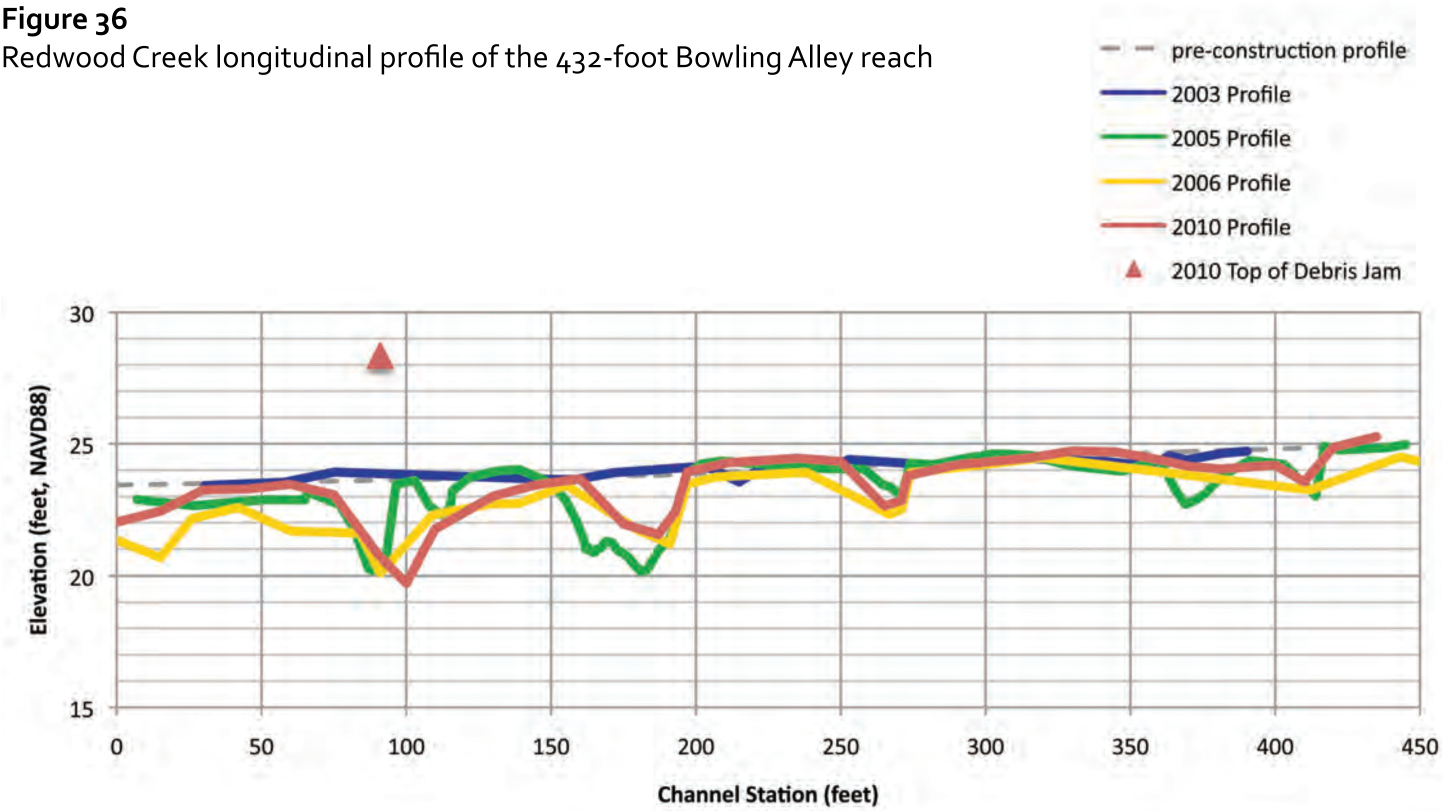


Figure 36
Redwood Creek longitudinal profile of the 432-foot Bowling Alley reach



Appendix E

Facies Mapping

Figure 37
Facies mapping overview of 432-foot reach comparing 2004 study with 2010 study

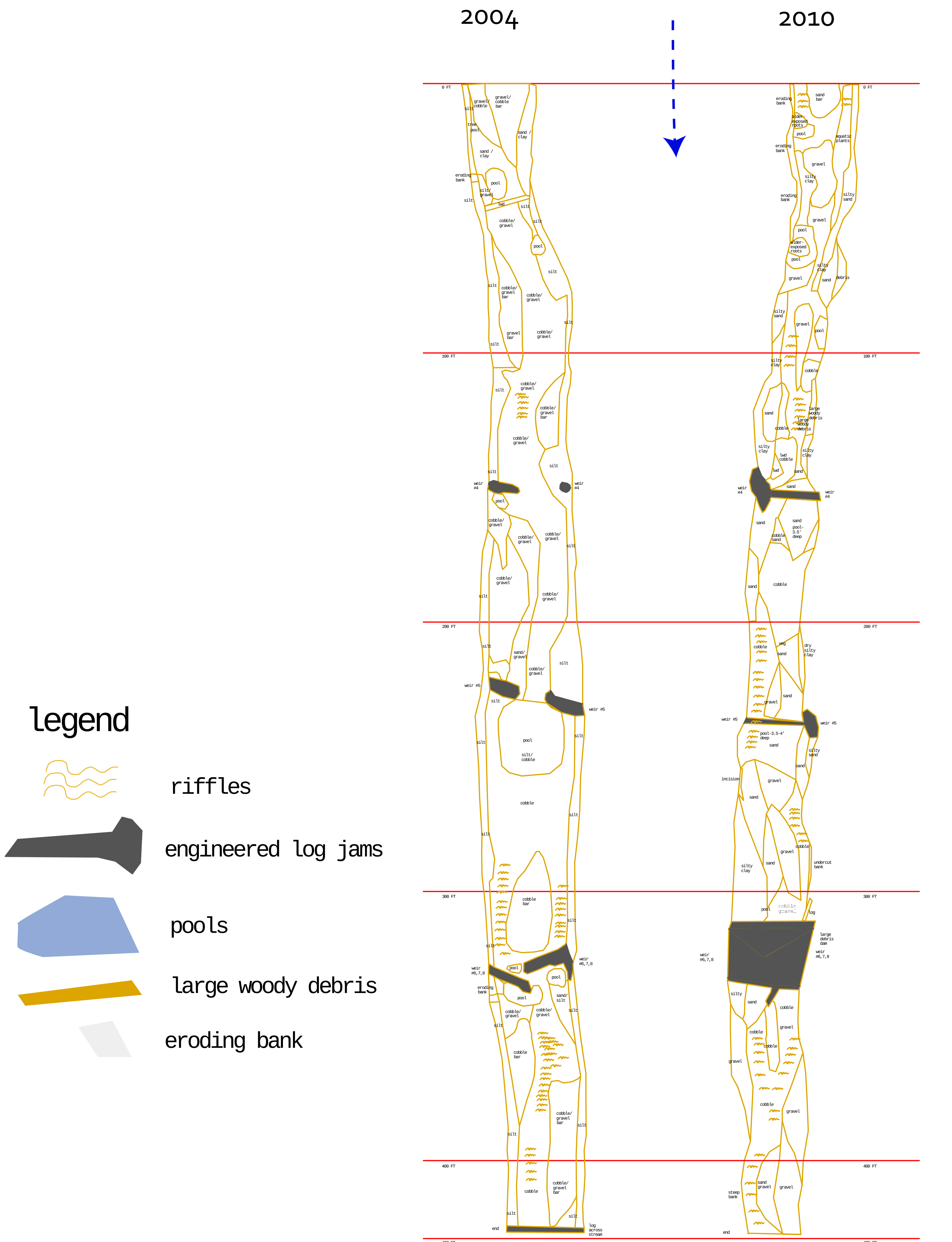


Figure 38
Facies mapping comparison at reach 1

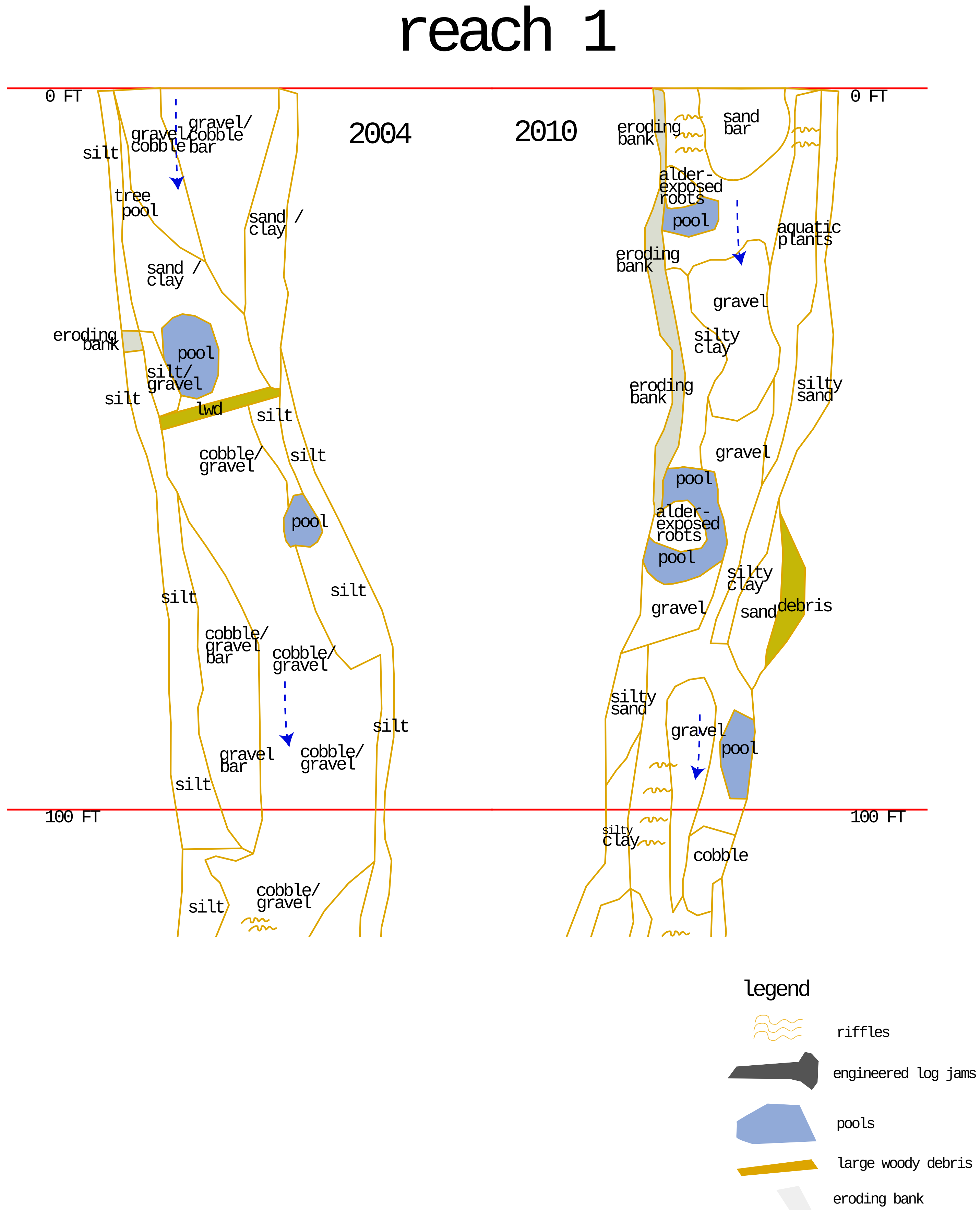


Figure 39
Facies mapping comparison at reach 2

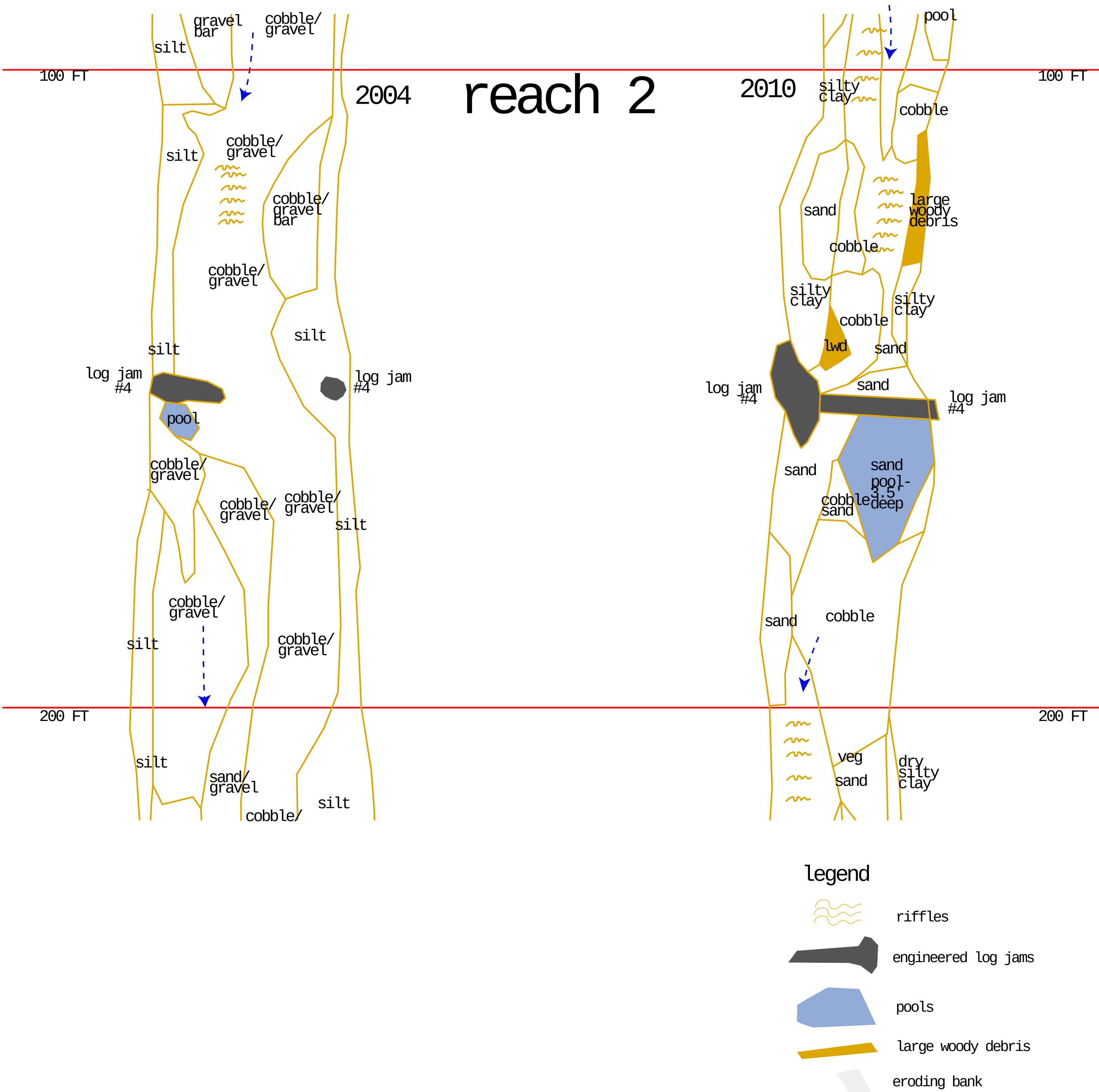


Figure 40

Facies mapping comparison at reach 3

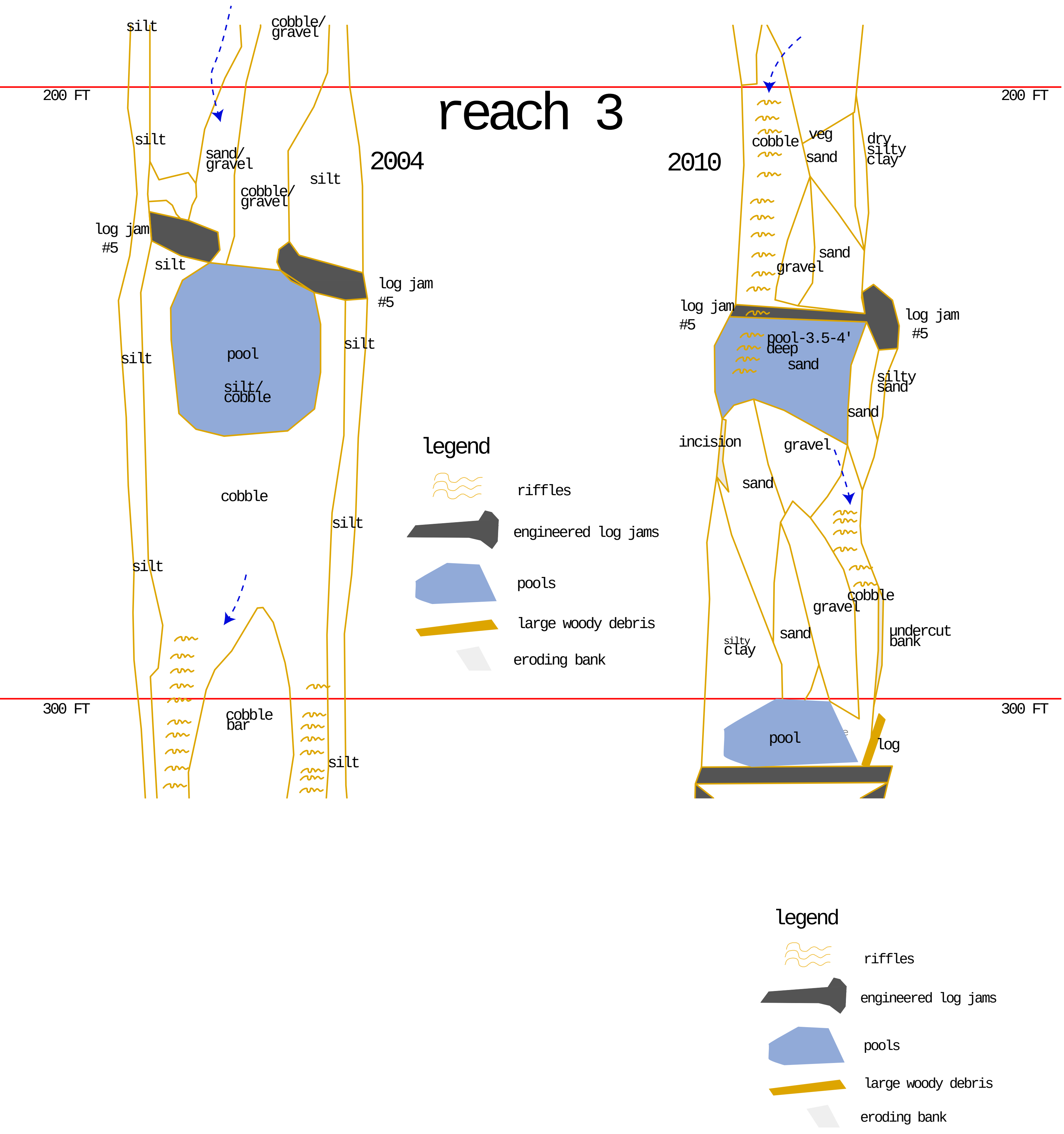


Figure 41
Facies mapping comparison at reach 4

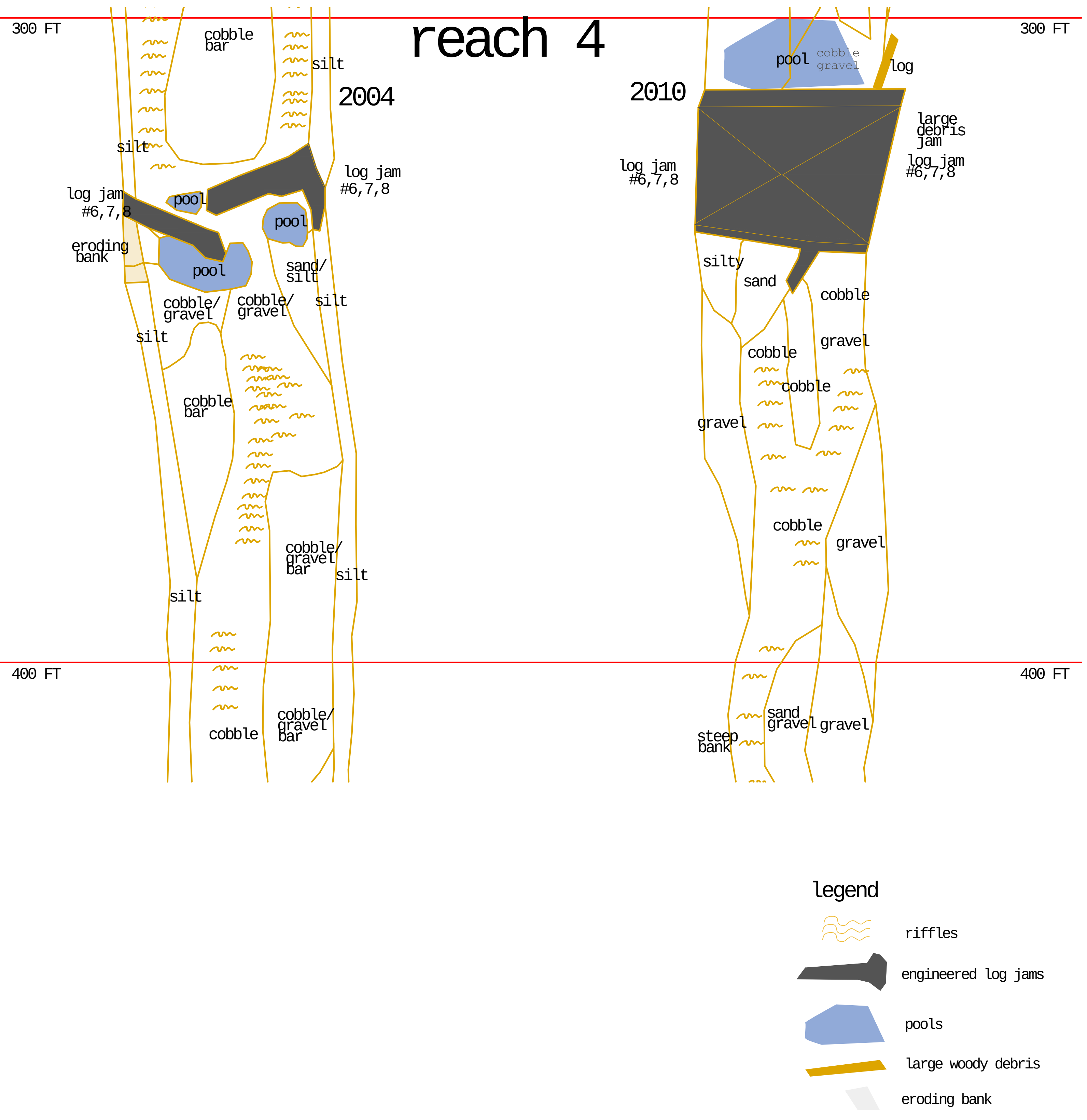


Figure 42

Facies mapping comparison at reach 5