Title

Post-restoration changes in bed material and channel features, Redwood Creek, Marin County

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Post-restoration Changes in Bed Material and Channel Features, Redwood Creek, Marin County

by

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Abstract

Stream alterations and human disturbances over time have reduced salmonid fish populations in Redwood Creek (Marin County, California). A restoration project in fall 2003 sought to increase the number of juvenile fish rearing pools along an 1800-foot reach of Redwood Creek. To evaluate the success of this project, we characterized changes in channel morphology through feature and facies mapping and photo-documentation in a 432-foot sub-reach of the restoration site. Our post-project evaluation found that the installation of large woody debris weir structures was successful in creating pools and increasing the overall habitat complexity of this sub-reach. Our detailed survey map provides a basis for future monitoring at the Redwood Creek restoration site or other sites in need of evaluation.

I. **Introduction**

A. *Problem Statement*

Land development and other human-caused disturbances have altered stream systems and led to an overall decline in salmonid populations throughout the western United States (California Department of Fish and Game, 1998). Redwood Creek is a fairly undisturbed third order stream that flows from the peaks of Mt. Tamalpais through Muir Woods and empties into the Pacific Ocean at Muir Beach (Marin County, California) (Figure 1). Habitat destruction from road construction, agriculture and other development in the Redwood Creek watershed has reduced numbers of coho salmon (*Oncorhynchus kisutch*) and steelhead trout (*Oncorhynchus mykiss*), two species listed as threatened under the federal Endangered Species Act (Redwood Creek Watershed Vision Team, 2002).

In the fall of 2003, Philip Williams and Associates (PWA) conducted a restoration project on an 1800-meter reach of Redwood Creek, installing several weir structures into the banks to improve juvenile salmonid rearing habitat. PWA constructed the weir structures with large woody debris (LWD) jams. Our study evaluated the success of this restoration project in creating salmonid rearing pools after the 2003 winter flows. Our primary objective was to characterize changes in channel morphology through post-project feature and facies mapping and photo-documentation. Facies maps illustrate areas of varying sediment size classes throughout the study reach. We compared pre- and post-project maps of the restoration site to evaluate if project goals were met.

B. *Background on Redwood Creek*

The 8.9-square mile Redwood Creek watershed (Figure 2 and Appendix A, Photo 1 and 2) is primarily publicly owned. Managing agencies include the National Parks Service (Golden Gate National Recreation Area and Muir Woods National Monument), Marin Municipal Water District, and California Department of Parks and Recreation (Mt. Tamalpais State Park). A popular destination for tourism and recreation, this scenic watershed receives more than three million visitors each year.

The Redwood Creek watershed is located in a maritime climate with mild, wet winters and cool, foggy summers. Fog is significant and can contribute up to 10 inches of precipitation annually (Redwood Creek Watershed Vision Team, 2002). Seasonal flow patterns in Redwood Creek are typified by low flows in the summer and fall, low-to-moderate winter baseflows and sharp, short-duration winter storm peaks. Storm peaks typically occur between mid-October and mid-April (PWA, 2000). Water is diverted periodically from Redwood Creek and its tributaries for irrigation, stock watering, fire protection, recreation and domestic use.

The Redwood Creek watershed also encompasses a complex and fragile ecosystem. Vegetation communities include: redwood-Douglas fir forest, chaparral and grassland, riparian woodland, and seasonal wetland (Redwood Creek Watershed Vision Team, 2002). In addition to coho salmon and steelhead trout, other threatened species found in the Redwood Creek watershed include the California red-legged frog (*Rana aurora draytonii*), and the northern spotted owl (*Strix accidentalis caurina*) (PWA, 2000).

C. *Salmonid Habitat Requirements and Importance of Large Woody Debris (LWD)*

Alteration of the stream channel and riparian corridor has impacted the habitat of coho salmon and steelhead trout in Redwood Creek (Jennifer Vick, National Parks Service, personal communication, March 2004). These fish species have an anadromous life cycle; the young rear in freshwater streams for the first one to three years of their life and then migrate to the ocean as adults (Moyle, 2002). To complete their life cycle, these species require adequate spawning gravels with little to no fine sediment, and cool, deep rearing pools in the freshwater environment (Moyle, 2002). An evaluation of coho and steelhead populations in Redwood Creek found a distinct lack of rearing pools (Snider, 1984).

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). LWD can also create slack water areas of reduced velocity (Cherry and Beschta, 1989), which can provide valuable salmonid spawning and rearing habitats and refuge during high and low flows (Kimball, 2002). Over the past 50 years, removal of LWD from Redwood Creek has reduced the number of rearing pools and overall habitat complexity in Redwood Creek (PWA, 2000).

D. *Banducci Site Restoration Project*

In the fall of 2003, PWA conducted a restoration project on an 1800-meter reach of Redwood Creek—a reach identified as a crucial location for improving salmonid rearing habitat (Snider, 1984). The goals of the restoration project were to:

- Create juvenile rearing pools by installing LWD jams made of Eucalyptus trees (Appendix A, Photos 3 and 4);
- Re-establish a functioning floodplain by breaching the levees and regrading the upland area adjacent to the creek;

- Remove invasive non-native vegetation and revegetate with native plants in the riparian corridor (Appendix A, Photo 5); and
- Install erosion control mats to stabilize banks while new vegetation establishes (Appendix A, Photos 6).

The restoration site, named the Banducci site for its former owners, is located along a 170-acre parcel of land adjacent to Redwood Creek (Figure 3). Levees were built along the creek in 1948-49 to prevent flooding of the agricultural fields (PWA, 2000). By breaching the levees and regrading the banks, the restoration project in 2003 changed the floodplain inundation frequency from once every 52 years to approximately once every one and a half to two years (PWA, 2000). This flood frequency is more representative of the natural, pre-disturbance condition.

Our study reach on the Banducci site is part of a straight creek segment known as the “bowling alley” (Figure 3). The bowling alley contains three installed LWD weir structures, identified as structures 4, 5, and 6-7-8 in PWA’s design sheets. The restoration project graded sections of the right bank to re-establish an active floodplain.

II. Methods

During a site visit on March 26, 2004, we created a post-project Facies Map of a 432-foot reach of the “bowling alley” section of Redwood Creek (Appendix B). We first selected easily identifiable start and end points for our map (Figure 4). The upstream start point was a post at the top of the right bank that marked the beginning of “Grade Area 3”—a region delineated on a project plan sheet created by PWA just prior to the restoration project. The downstream endpoint was a fallen log (resting on the top of both banks) 432 feet from the upstream start point. We ran a measuring tape from the start point stake to the endpoint fallen log along the top of the right bank roughly parallel to the stream channel, and firmly secured the tapes for the duration of our mapping exercise (Appendix A, Photo 7).

We mapped features of the creek on graph paper, labeling the x-axis as the longitudinal distance downstream from the upstream start point and the y-axis as the cross-sectional distance from the right bank. We defined a scale for our measurements (1 inch = 8 feet), so each page fit an 80-foot creek reach. Due to the generally linear form of the "bowling alley" reach, we assumed that slight bends in the channel did not contribute significantly to the measured longitudinal distance.

We started mapping the 432-foot reach at the upstream start point. As we walked downstream, we identified landmark features such as an alder tree or the end of a gravel bar, measured the length and width of these features, and plotted these measurements on our pre-labeled graph paper. Using these measurements as size guides, we delineated and labeled regions of the channel by particle size class (i.e., cobble, gravel, sand, silt) and outlined their extent and shape on graph paper. We used labels listing two size classes (e.g., "gravel/cobble") to describe patches with two particle sizes (Appendix B). For such double labels, the first word (in this case, gravel) denoted the dominant feature. We shaded all non-wetted channel portions on our map and left wetted portions unshaded. We also took photographs of many of the mapped features (Appendix A). We numbered these features on a map key (first page of Appendix A) to identify locations of features in specific photographs.

Next, we evaluated the channel for other features, including pools, riffles, retreating bank lines (steep, eroding bank areas), naturally occurring large woody debris, installed weir structures, trees (in channel or on banks), exposed tree roots, flow direction, and backwater areas. We outlined and labeled these features on the graph paper, noting their extent and shape.

We then walked along the channel again for quality control. We double-checked that we included all appropriate features, and that we marked features at the correct locations along the x-axis of our graph. We also used a tape measure to check sizes of features.

Our completed post-project Facies Map (Appendix B) includes all features documented in the field. This map was considerably more detailed than the pre-project Geomorphic Survey Map (Figure 4), completed as part of the PWA restoration feasibility report in March 31, 2000. Therefore, we used our post-project Facies Map to create a post-project Geomorphic Survey Map (GSM) comparable in detail to the pre-project GSM. We adjusted the pre-project and post-project GSMs to the same scale. Figure 5 shows both pre-project and post-project GSMs side-by-side at the same scale.

III. Results

A. *Comparison of Pre-Project and Post-Project Geomorphic Survey Map (GSM) Features*

This section compares features in the pre-project GSM with features in the post-project GSM. The two maps are shown side-by-side in Figure 5.

1. <u>Pools.</u> While the pre-project GSM showed one small pool in our 432-foot reach, our post-project GSM indicated nine pools. New pools formed downstream of all three installed weir structures. In particular, an approximately 600-square-foot pool was located downstream of weir structure 5 (Appendix A, Photo 9).

2. Bars. The pre-project GSM contained five bars, while the post-project GSM indicated nine bars. New bars formed upstream of all three weir structures. An especially striking example was the nearly 500-square-foot bar in the center of the channel immediately upstream of weir structure 6-7-8 (Appendix A, Photo 10). The locations of the bars are dramatically different in the pre- and post-project GSMs.

3. Riffles. The pre-project GSM had four riffles while the post-project GSM contained five riffles, all of which were in new locations. New riffles formed immediately upstream of weir structure 4 (Appendix A, Photo 11), and upstream (Appendix A, Photo 12) and downstream of weir structure 6-7-8 (Appendix A, Photo 13). We did not compare sizes of pre- and post-project riffles because it was difficult to gauge the size of the riffles on the pre-project GSM.

4. Exposed roots. There were three exposed root areas in the pre-project GSM and seven exposed root areas in the post-project GSM. The most dramatic change was the four new exposed root areas upstream of weir structure 6-7-8. (Appendix A, Photo 14 shows one of these areas.)

5. Split channel. The entire pre-project reach was a single channel. In the post-project GSM, bars upstream and downstream of weir structure 6-7-8 split the channel into two (Appendix A, Photo 10). Elsewhere, the post-project reach was a single channel.

6. Retreating bank lines. The pre-project GSM showed a single retreating bank line along a portion of the right bank at the upstream end of the reach. The post-project GSM had three

retreating bank line areas in new locations, including one just downstream and one upstream (Appendix A, Photo 12) of weir structure 6-7-8.

7. Flow direction: The pre-project GSM did not indicate any unique flow direction features. On the post-project GSM, weir structures 4 and 6-7-8 re-directed the flow (see Appendix A, Photo 15; Appendix B, longitudinal range 320-344 feet).

Table 1 summarizes the results of our comparison of the pre- and post-project GSMs.

Table 1. Comparison of Features in Pre- and Post-Project GSMs

Feature	Pre-project GSM	Post-project GSM
Pools	• Total of one pool, about 200 ft^2	• Total of nine pools • Pools immediately downstream of installed weir structures • ~600 ft^2 pool downstream of weir structure 5
Bars	• Total of five bars	• Total of nine bars • New bars upstream of all three installed weir structures • Bars in different location than in pre-project GSM
Riffles	• Total of four riffles	• Total of five riffles • Three riffles upstream of installed weir structures • New riffles upstream of weir structure 4, and upstream and downstream of weir structure 6-7-8
Exposed tree roots	• Total of three exposed root areas	• Total of seven exposed root areas • Four new exposed root areas upstream from weir structure 6-7-8
Split channel	• Single channel throughout reach	• Channel split by bars upstream and downstream of weir structure 6-7-8
Retreating bank line	• One retreating bank line area	• Total of three retreating bank line areas, all in different locations from retreating bank areas in pre-project GSM • One retreating bank just downstream of weir structure 6-7-8
Flow direction	• No unique flow features indicated	• Weir structures 4 and 6-7-8 resulted in dramatic flow direction changes

B. *Facies Map*

Our post-project Facies Map (Appendix B) showed several additional significant features:

- The active channel was dominated by gravel and cobble. The only exception was a band of sand and gravel downstream of weir structure 4.

- The banks were primarily composed of silt and sand (for a typical silty bank, see Appendix A, Photo 16.). The one exception was a small cobble bar immediately upstream of weir structure 5.
- There was significant silt deposition upstream of weir structures 4 (Appendix A, Photo 17) and 5 (left bank). Cobble and gravel bars were immediately upstream of all three weir structures.
- Instream silt was generally associated with pools.
- There were three backwater areas (see Appendix B, longitudinal stations 108, 176, and 428 feet).

IV. Discussion

A. *Analysis of Results*

Analysis of our Facies Map, our post-project GSM, and PWA's pre-project GSM revealed significant changes in channel morphology after the restoration project. It is worth noting that we mapped the site at about the same time of year (end of March) as PWA's pre-project geomorphic survey.

No significant geomorphic changes occurred in this stream reach between spring 2000 (when the pre-project map was completed) and the restoration in fall 2003 (Carolyn Shoulders, National Parks Service, personal communication, March 2004). Prior to fall 2003, the bathometry of the creek bottom was fairly uniform throughout the bowling alley reach. In addition, there were no major topographic breaks upstream and downstream of the weir structures when they were first installed (Courtney Johnson, National Parks Service, personal communication, March 2004).

Grading the banks and breaching the levees on the right bank reconnected Redwood Creek with its floodplain during a flow of 1,110 cubic feet per second on December 29, 2003 (Darren Fong, National Parks Service, unpublished data, January 2004). After this high flow, the topography and bathometry of the streambed dramatically changed. No rating curves were available at the time of our analysis. Our post-project GSM shows topographic breaks immediately downstream of the weir structures—breaks that did not exist before the restoration project. These changes are a result of the weir structures, which trapped sediment in bars upstream and scoured out pools downstream during the winter.

In addition, the weir structures appear to have increased habitat complexity—more bars, pools, riffles, exposed roots, and split channels. Scour and undercutting associated with winter high flows may have caused the increased number of pools and exposed tree roots. The new pools can provide refuge for juvenile fish during high and low flows, and create areas of cooler temperatures needed to survive long, dry summers. Exposed tree roots also provide refuge for fish and create habitat for benthic macroinvertebrates--a major food source for juvenile fish.

Reconnection of the stream channel with the floodplain will create a more stable environment for aquatic organisms by reducing hydrograph flashiness and flow velocities—and by lowering the potential for supercritical flows that can wash migrating fish downstream.

The preponderance of silt in the bottoms of pools was likely a result of deposition during low flows. This explanation is based on the velocity reversal hypothesis, which holds that pools are areas of scour during high flows (due to high shear stress) and are depositional areas during low flows (Keller, 1974). The high proportion of fine sediment along the margins of the bed is due to deposition from lower-velocity flows near the banks.

B. *Lessons for Future Research*

Several lessons emerged from our experience with facies mapping. First, if a researcher's goal is to create a post-restoration project facies map for comparison with pre-project conditions, it is essential to have a detailed pre-project map created *immediately* before the project. Because our pre-project map lacked detail and was created three years before the project, it imposed limitations on our comparative analysis.

Creating our facies map in the field required juggling many mental tasks, including identifying particle sizes and other channel features, delineating regions, measuring dimensions, taking photographs and field notes, and other tasks. Because of the multidimensional nature of this exercise, our quality control step (see Methods section) was essential. Not surprisingly, we discovered missing features, imprecise measurements, and other inaccuracies when we double-checked our field map. We also found it helpful to split the labor between two people—one person to draw the field map and another to take measurements and identify features. Finally, creating a particle-classification scheme (i.e., cobble/gravel, sand/gravel, silt, and so on) in advance saved us the trouble of devising one during data collection.

Because our reach was relatively straight, we assumed that slight bends in the channel did not significantly contribute to longitudinal distance. However, if our reach had a higher degree of sinuosity, it would have been necessary to create a "pre-map" delineating the shape of the reach (i.e., a trace of the channel margins).

These lessons, our field methods, and the results of our detailed survey map provide a basis for future monitoring at the Redwood Creek restoration site. These lessons and our methods can also be applied to mapping at other sites.

V. Conclusions

Overall, the Redwood Creek restoration project at the Banducci site was successful in meeting its goals after only one rainy season (2003-2004). There was greater channel complexity and an increase in the number and size of pools, and the newly graded floodplain was inundated during a possible “bankfull” flow on December 29, 2003. While these short-term results are encouraging, further monitoring is needed to measure long-term changes to fish habitat in this system. Future studies that replicate our mapping techniques can investigate changes over time.

Our project is one of many efforts to monitor and evaluate the overall success of this stream restoration project. This summer, there are plans for post-project channel surveys to quantitatively measure channel changes since the installation of the weir structures. There are also planned fish surveys to document changes in fish populations in the Redwood Creek watershed, and planned vegetation mapping and monitoring of riparian and upland areas to document the overall degree of re-establishment of native flora and the stability of the banks. Streamflow gages and suspended sediment gages measured changes in flow and suspended sediment downstream of the restoration site over the winter of 2003-04. These combined efforts may help to create a more complete picture of project success and the suitability for salmonid fish in Redwood Creek.

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Figure Captions

Figure 1. The location of the Redwood Creek watershed (Redwood Creek Watershed Vision Team, 2002)

Figure 2. An aerial photograph showing the stream network of Redwood Creek and its tributaries

Figure 3. Aerial photographs of Banducci Site (light area adjacent to the creek) showing location of the mapped 'Bowling Alley' reach

Figure 4. Pre-project Geomorphic Survey Map from PWA Feasibility Report

Figure 5. Pre-project and Post-project Geomorphic Survey Maps

Figure 1. The location of the Redwood Creek watershed (Redwood Creek Watershed Vision Team, 2002)

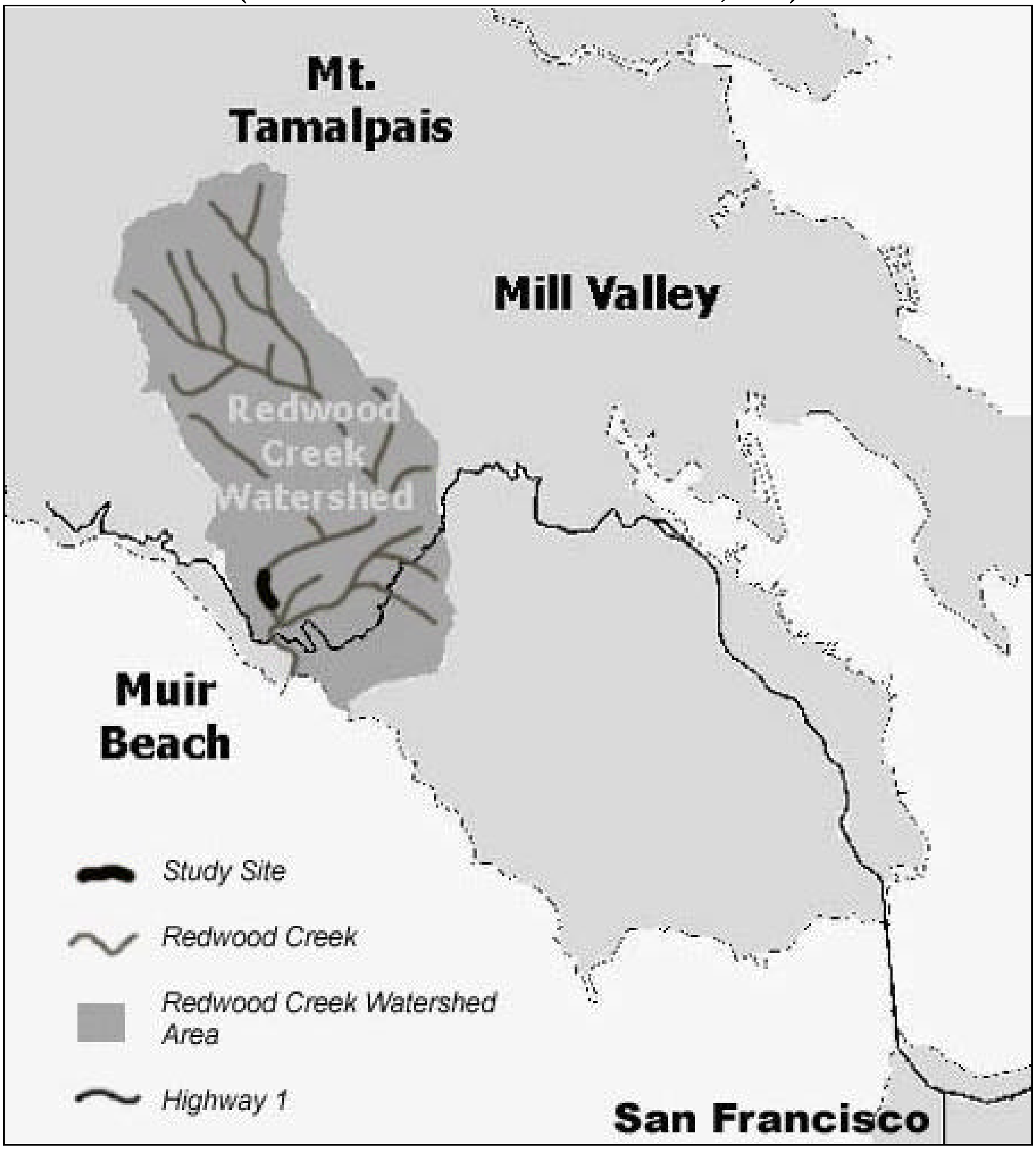


Figure 2. An aerial photograph showing the stream network of Redwood Creek and its tributaries

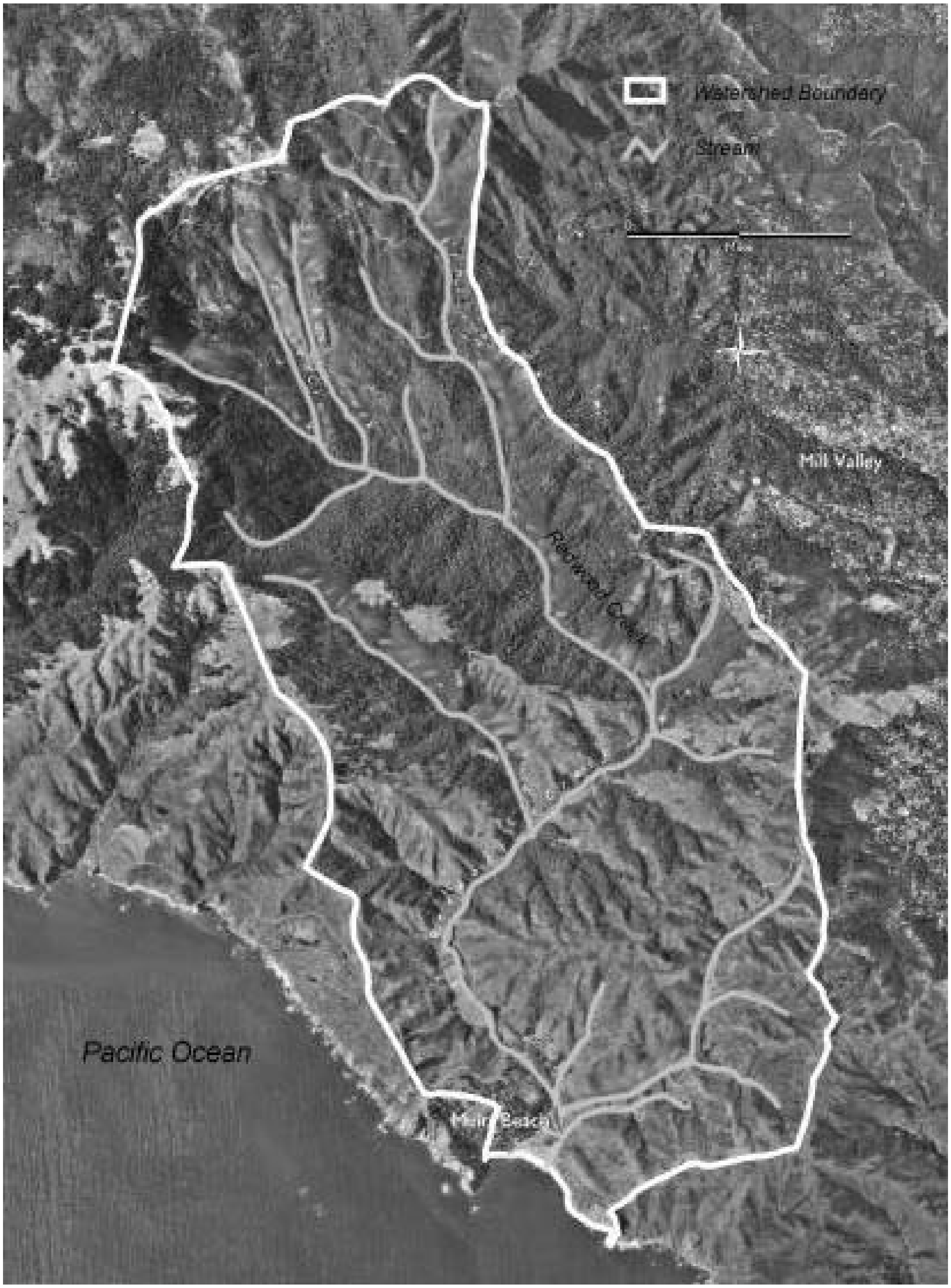


Figure 3. Aerial photographs of Banducci Site (light area adjacent to the creek) showing location of the mapped 'Bowling Alley' reach

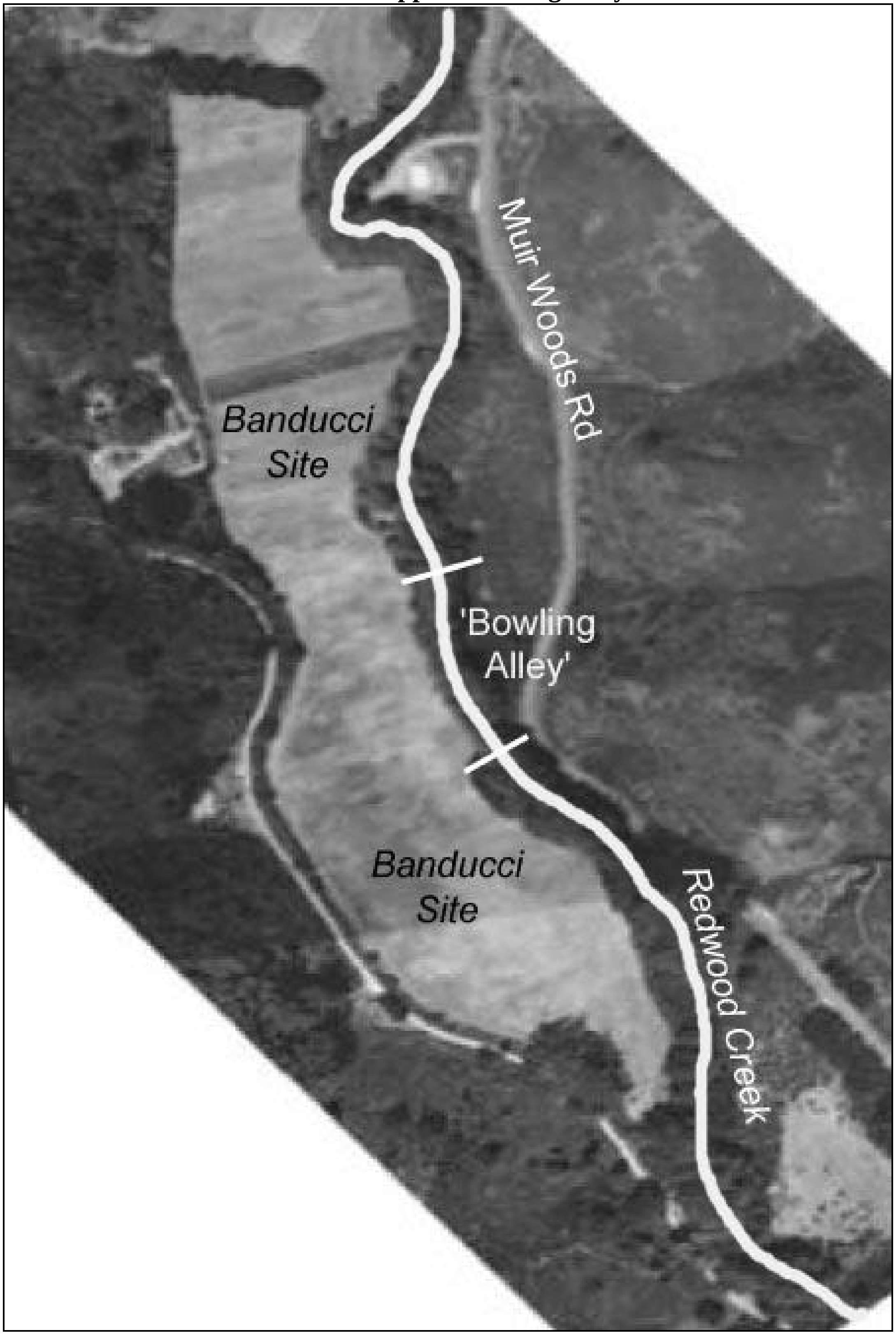
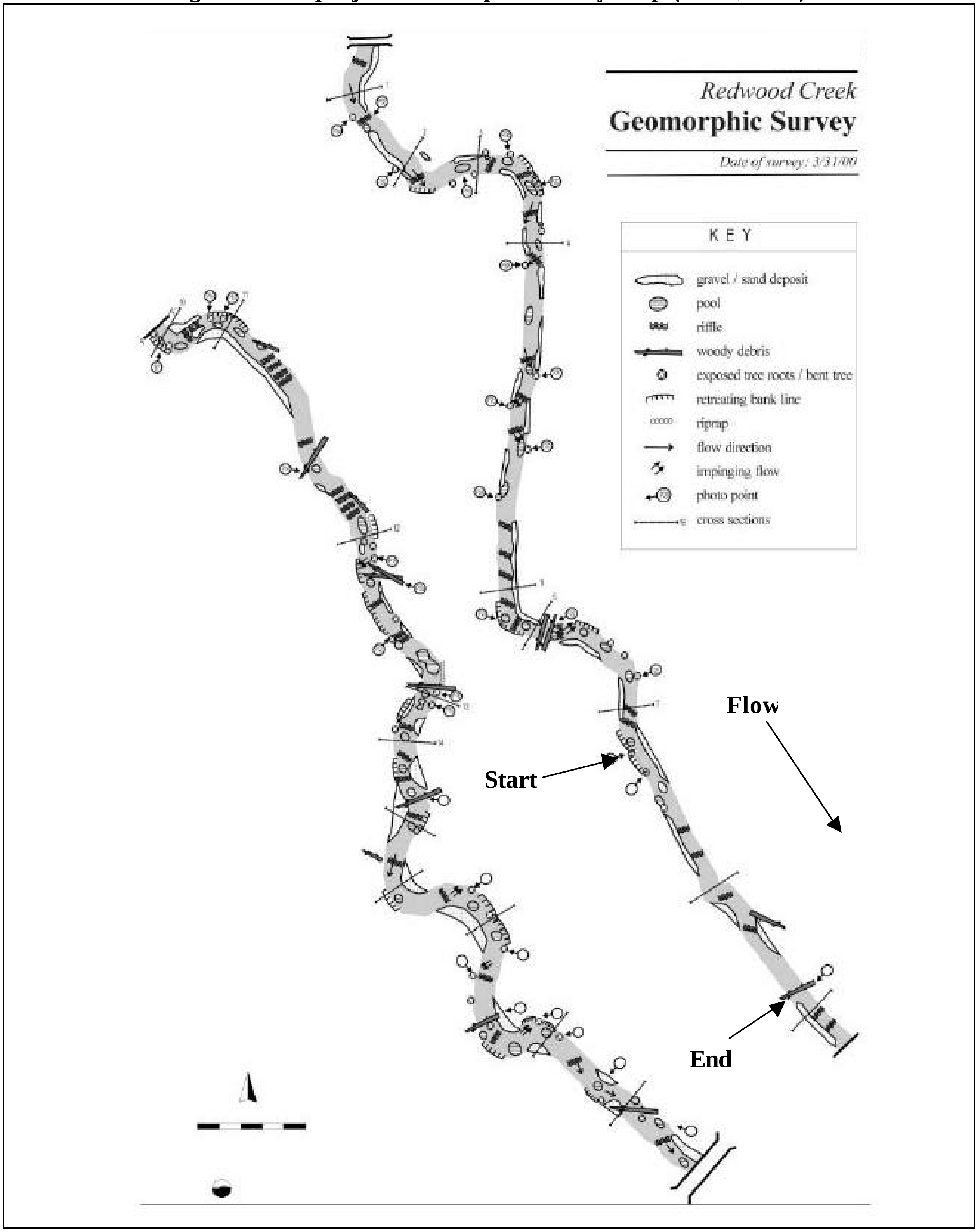
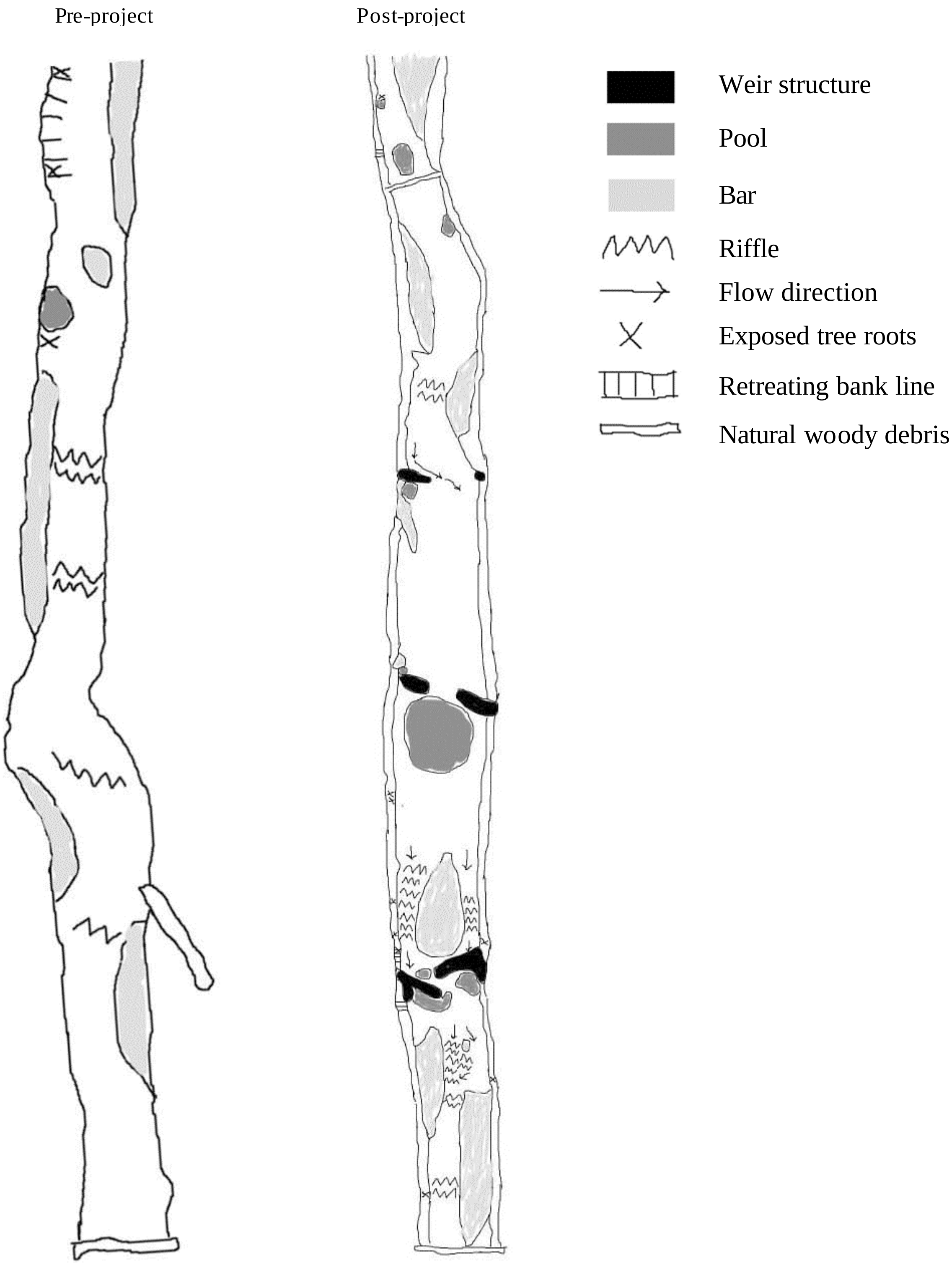


Figure 4. Pre-project Geomorphic Survey Map (PWA, 2000)



NOTE: This map shows the entire restoration site. The arrows indicate the start and end points our 432-foot study reach.

Figure 5. Pre-project and Post-project Geomorphic Survey Maps side-by-side for comparison at same scale



Appendix A
Photographs

Map Key for Features in Photograph Captions

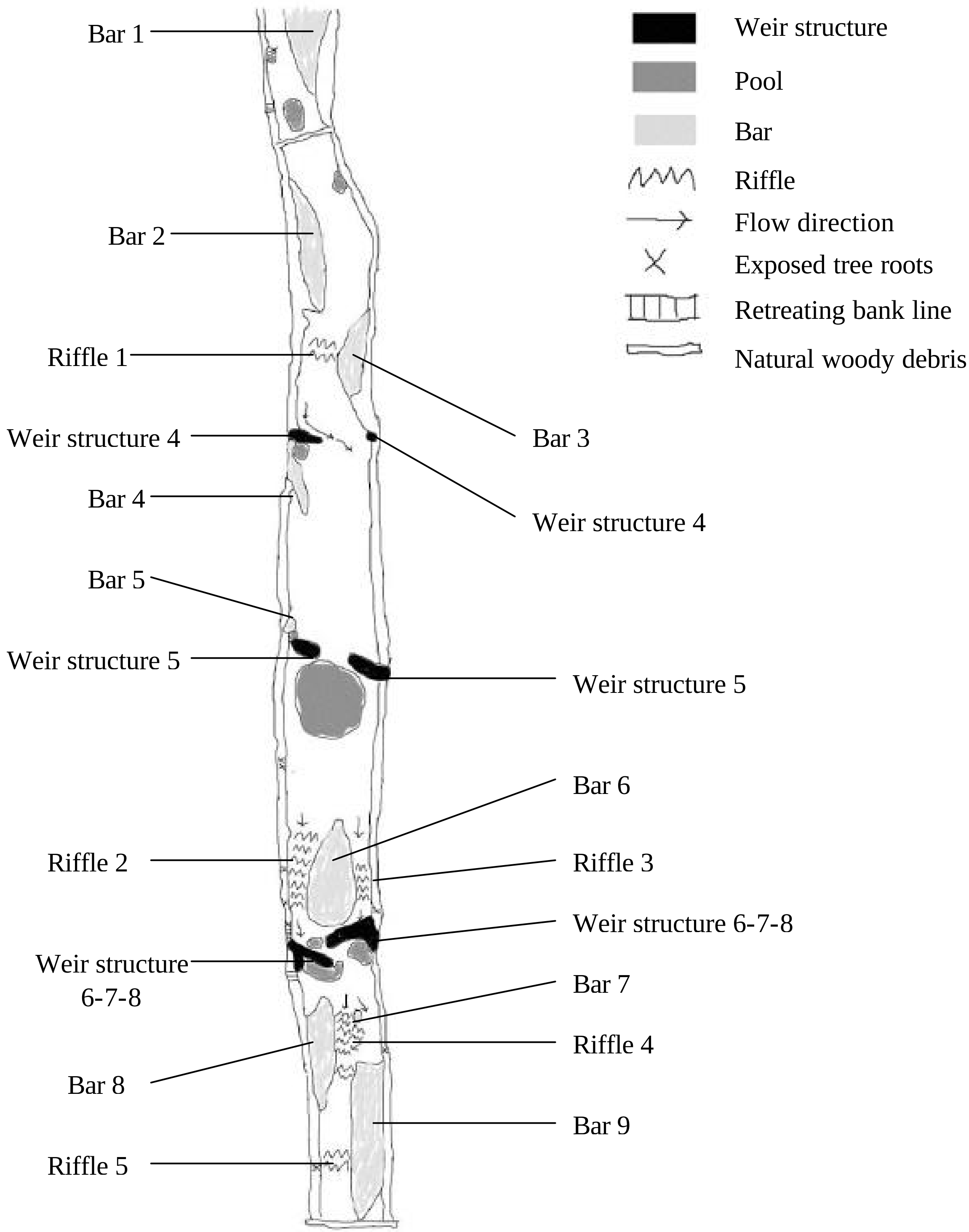


Photo 1. Looking northeast at Redwood Creek watershed from the ridgeline along Hwy 1. Banducci site is field visible in center of photograph and Redwood Creek is line of trees.

Photo 2. Looking north at upstream portion of Redwood Creek watershed. Banducci site is field in center of photograph. Tree line through the center of the canyon is the stream channel of Redwood Creek.

Photo 3. Looking downstream at weir structures 6, 7, and 8. A cobble/gravel bar has formed directly upstream of the structure.

Photo 4. Looking towards the right back at weir structures 6, 7, and 8. A pool has scoured directly downstream of the structure.

Photo 5. Vegetation of native riparian plants with deer guards on the right back floodplain of Redwood Creek.

Photo 6. Riparian vegetation planted through an erosion control mat to stabilize banks.

Photo 7. Looking downstream at the measuring tape placed parallel to the creek on the right bank.

Photo 8. Sediment class sizes of a cobble/gravel bar in Redwood Creek.

Photo 9. Pool immediately downstream of weir structure 5 (view from right bank).

Photo 10. Looking downstream at bar 6, riffles 2 and 3, split channel, and weir structure 6-7-8.

Photo 11. Looking downstream at riffle 1, bar 3, and weir structure 4.

Photo 12. Exposed tree roots and eroding bank area on right bank upstream of weir structure 6-7-8.

Photo 13. Looking upstream at riffles 5 (foreground) and 4, bars 9 (foreground) and 8, and structure 6-7-8. (View from log at endpoint of study reach)

Photo 14. Exposed tree roots on left bank near weir structure 6-7-8. Bar 6 in foreground.

Photo 15. Looking upstream at flow direction change along weir structure 4.

Photo 16. Silt deposition on left bank (view from right bank).

Photo 17. Looking downstream at silt deposition adjacent to weir structure 4 (left bank).

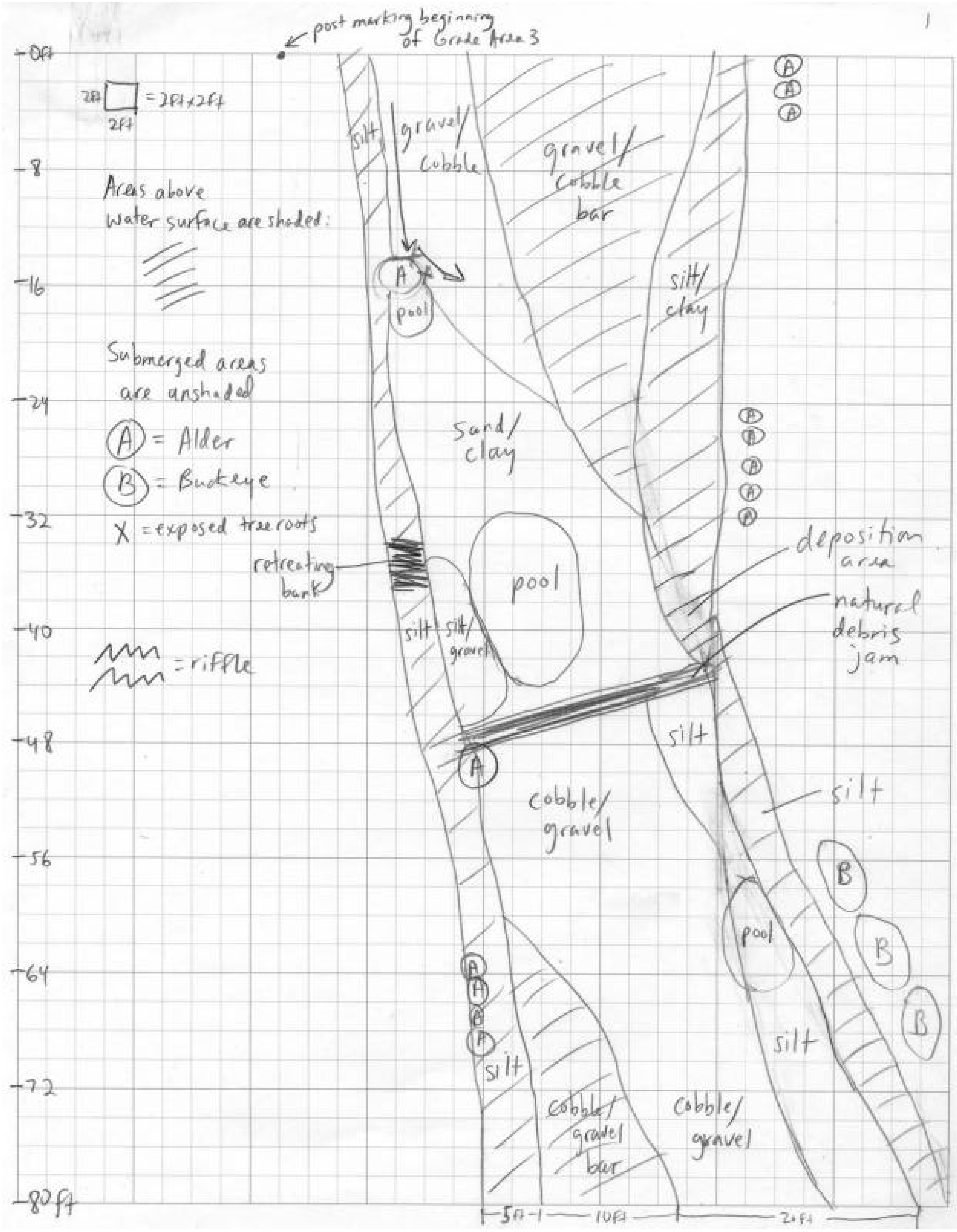
Photo 18. Looking downstream at bar 2 (foreground), bar 3, and riffle 1

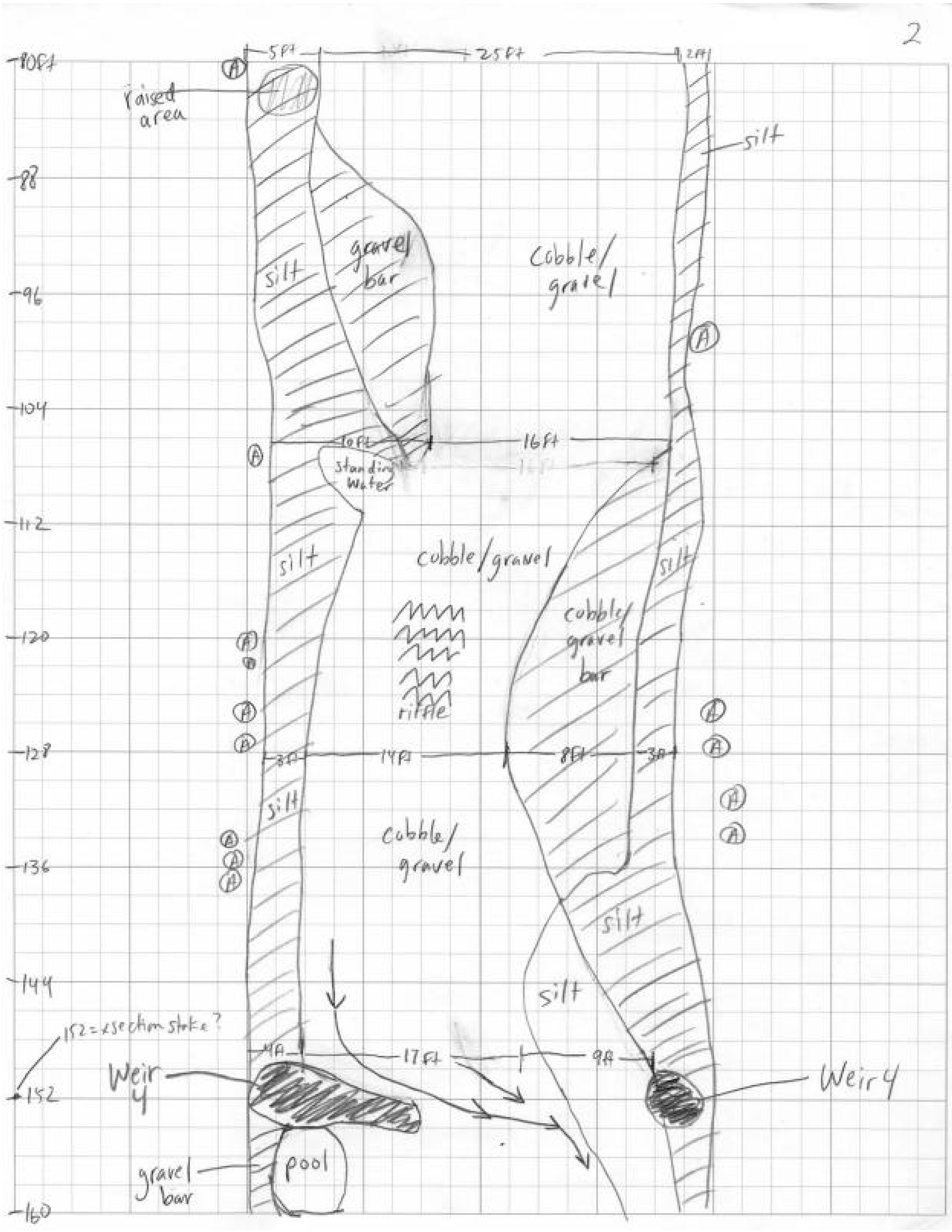
Photo 19. Pool and bar 4 along right bank, immediately downstream of weir structure 4.(view from left bank).

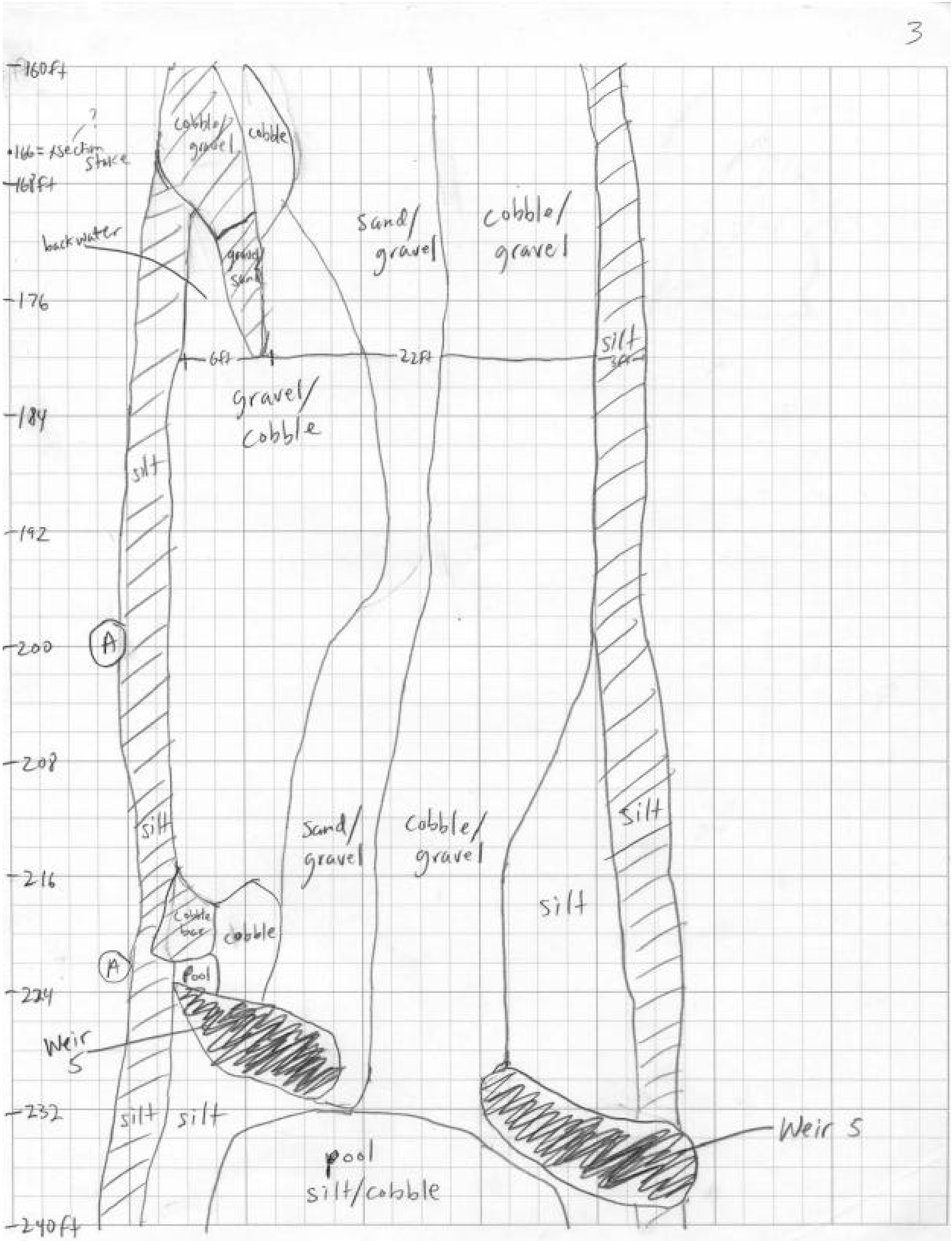
Photo 20. Pool immediately downstream of structure 6-7-8.

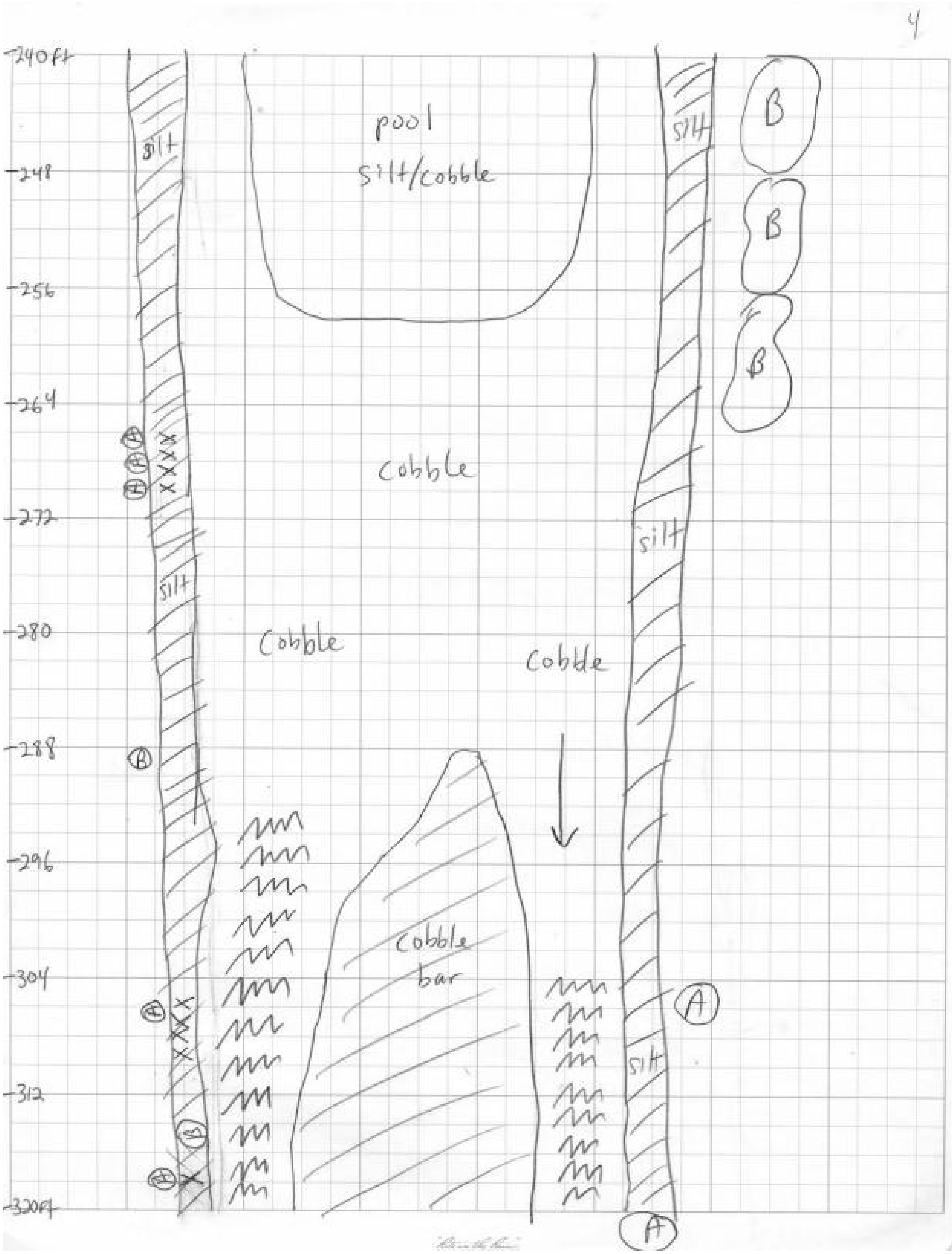
Appendix B
Facies Map

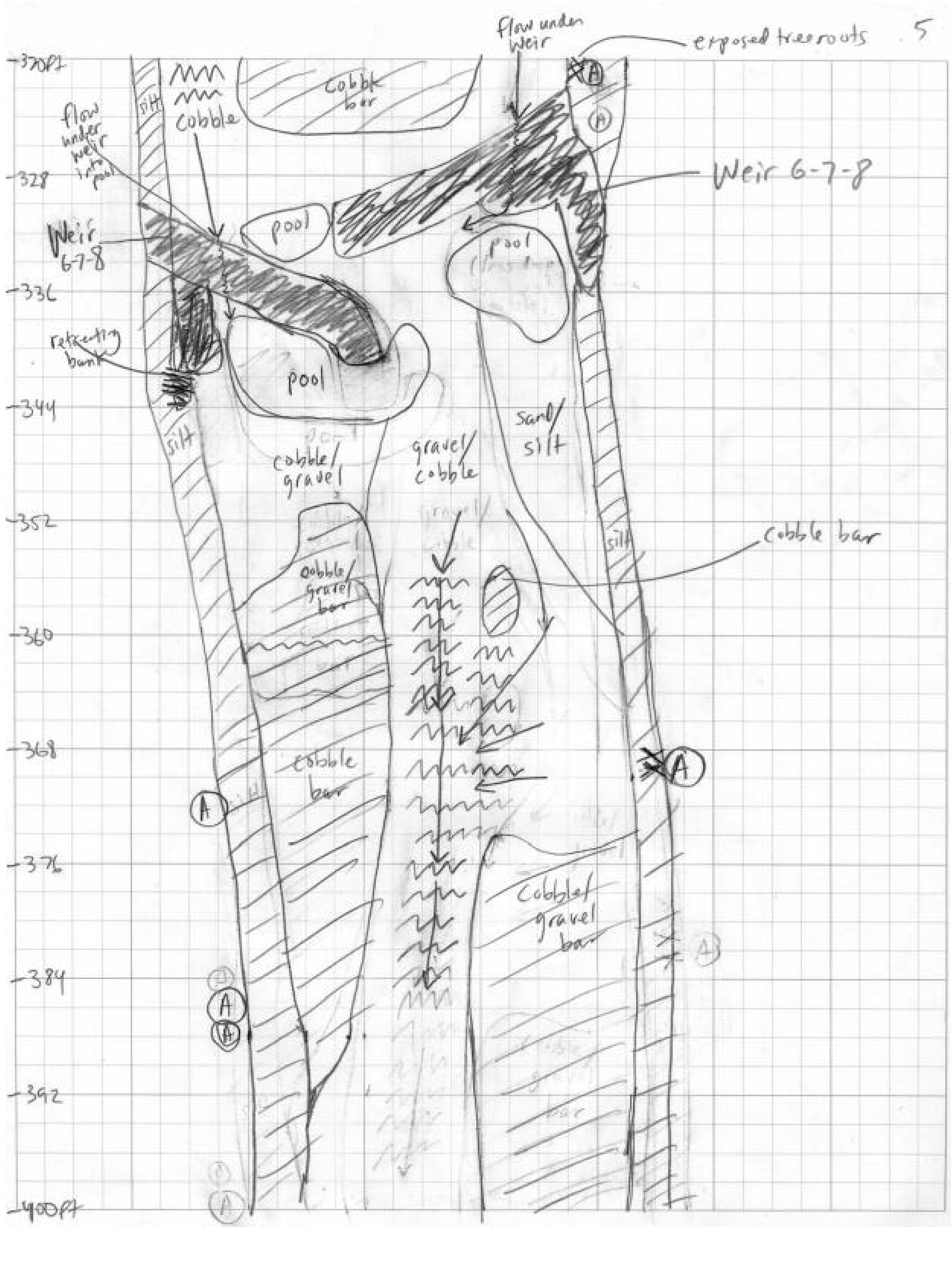
NOTE: We have reduced the size of our original field maps to fit them on the pages of this appendix.

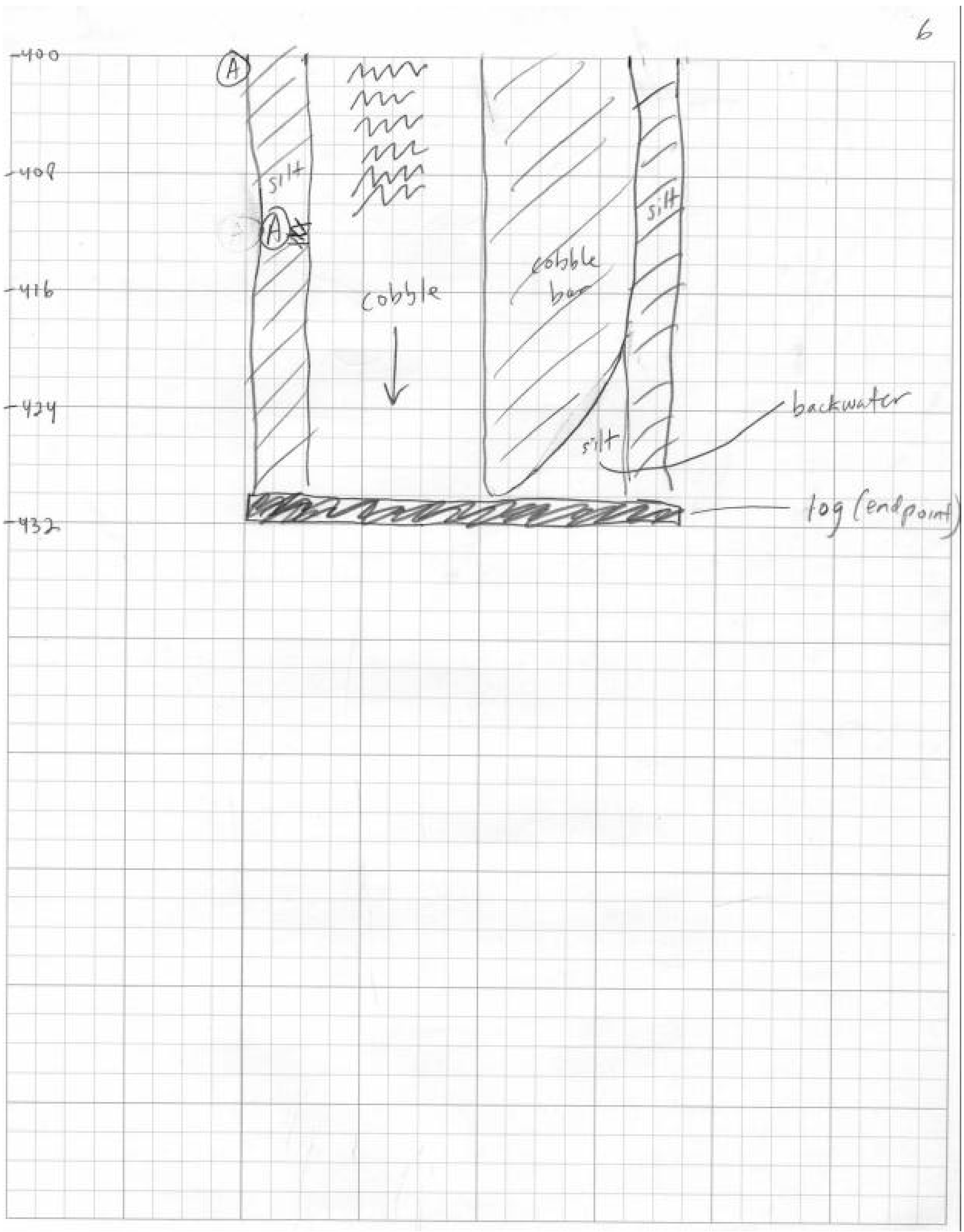

post marking beginning of Grade Area 3
1
0ft
2ft = 2ft x 2ft
2ft
8
Areas above water surface are shaded:
16
Submerged areas are unshaded
24
A = Alder
B = Buckeye
32
X = exposed tree roots
retreating bank
40
= riffle
48
56
64
72
80 ft
silt
gravel/ cobble
gravel/ cobble bar
pool
silt/ clay
sand/ clay
pool
deposition area
natural debris jam
silt
silt/ gravel
silt
cobble/ gravel
silt
pool
silt
silt
cobble/ gravel bar
cobble/ gravel
5ft
10ft
20ft


2
80ft
88
96
104
112
120
128
136
144
152
160
5ft
25ft
2ft
raised area
silt
gravel bar
silt
cobble/ gravel
10ft
16ft
standing water
silt
cobble/gravel
riffle
cobble/ gravel bar
silt
3ft
14ft
8ft
3ft
silt
cobble/ gravel
silt
silt
152 = xsection stake?
4ft
17ft
9ft
Weir 4
Weir 4
gravel bar
pool


3
160ft
166 = xsection stake
168ft
cobble/gravel
cobble
backwater
sand/gravel
cobble/gravel
176
6ft
22ft
silt
gravel/cobble
184
silt
192
200
A
208
silt
sand/gravel
cobble/gravel
silt
216
silt
cobble
pool
A
224
Weir 5
232
silt
silt
pool
silt/cobble
Weir 5
240ft


4
240 ft
248
256
264
272
280
288
296
304
312
320 ft
silt
pool
silt/cobble
silt
B
B
B
cobble
silt
silt
Cobble
Cobble
cobble
bar
A
silt
A


5
flow under weir
exposed treeroots
-320ft
-328
-336
-344
-352
-360
-368
-376
-384
-392
-400ft
cobble
cobble bar
flow under weir into pool
silt
Weir 6-7-8
Weir 6-7-8
pool
pool
pool
retreating bank
silt
sand/ silt
cobble/ gravel
gravel/ cobble
cobble bar
cobble/ gravel bar
silt
cobble bar
A
A
cobble/ gravel bar
A
A


6
400
408
416
424
432
A
silt
A
cobble
cobble bar
silt
silt
backwater
log (endpoint)