Fourmile Creek Stream Channel and Floodplain Enhancement Project
Denver Water Property, Park County, CO
Channel Repairs Implementation Report

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Background

Fourmile Creek is a second order tributary to the South Fork of the South Platte River in South Park. Historically, much of the creek had been artificially straightened, channelized, and entrenched resulting in a severe loss of aquatic habitat and dehydration of adjacent wetlands. In 2004-5 The USFWS, in cooperation with Denver Water, COL and SPWFAC undertook an ambitious project to ameliorate this problem by reconstructing nearly 5 miles of naturally meandering stream to replace the existing straightened, entrenched channel. The project has been monitored for 6 seasons, with results indicating that the majority of the new channel is performing as designed. As a result, native riparian vegetation is returning to the functioning reaches. However, the monitoring also revealed that several segments of the restored channel are not functioning well due to an unnatural channel dimension (deeply entrenched, overwide, and lacking a suitable floodplain) and the lack of appropriate soil-binding riparian vegetation.

In the original restoration effort, a new meandering channel was cut in the lands NE of the existing ditched channel. basically, the new channel was constructed to follow a specific meandering course that was designed to meet important pattern criteria as well as maintain a consistent slope through the reach. The channel was cut to a design width of about 7 feet. This design worked well along most of the 5 miles where it was applied since the channel was constructed on historic floodplain or on locations where no terraces were present. However, the landscape contains terraces through which the design channel had to be run. At these locations, the landform is much higher than the historic floodplain, and since the channel was (necessarily)cut to a specified bed elevation to maintain consistent slope, the channel segments cut through terraces were much deeper and had much higher banks than would normally occur. That is, they were entrenched. Entrenched channels on meadows with weak soil are generally very unstable.

About 5000 feet of the new (2005) channel had been cut through an undulating high terrace of organic soils (an historic fen area). This segment contains deeply entrenched and unstable F-type channel that is incapable of handling even low flows without causing severe erosion. After 4 seasons of managed low flows through this site (2005-2008), the channel had widened from about 7 feet to more than 20 feet. The sediment produced by this rapid erosion is routed through the rest of Fourmile Creek and into the South Fork of the South Platte. Because of the extreme amount of sediment produced at this one site and its deleterious effects on downstream reaches, this segment was identified as one of the highest priorities for repair in a recent 2009 watershed survey for sediment pollution concerns. Furthermore, the success of the remaining 4 miles of restored Fourmile Creek channel would be at risk if this situation is not successfully remedied. Presently, flows are diverted into the restored Fourmile Creek channel from the old ditch via active management with a system of headgates. Until the unstable segment is fully treated, we are unable to run significant discharge through the new channel without creating intolerable levels of sediment from channel erosion. Therefore, repairs of the unstable segment are necessary before the natural flow regime can be restored to Fourmile Creek.

This report describes a 4-phase project to repair the problems on this unstable mile of channel by establishing an appropriately-sized E-type channel that has a suitable floodplain, appropriately-sized channel dimension with low banks, and dense native riparian vegetation. Phase 1 (completed in April 2010) included construction of a new channel and floodplain along the lower 2000 ft of the unstable reach. Phase 2 involved careful monitoring of this initial 2000 ft of improvements through the rest of 2009 and 2010 to evaluate performance of the treatments. The results of monitoring phase 1 treatments are described in this report, and the findings provided valuable information that was used to adapt our approach for phase 3. In phase 3, we treated approximately 2400 feet of channel to complete repairs on the entire unstable reach. This work was completed in August 2010. Phase 4 is continued monitoring of the entire project area, management of flows through the restoration site, and planning for any additional work needed to firmly establish the new, restored Fourmile Creek to a natural flow regime.

Ultimately, this project endeavors to restore the historical type-E channel characteristic of the site that would provide functional habitat, support adjacent wetlands, and be self-sustaining. Our plan seeks to replicate the aquatic and riparian ecology and habitat found in reference reaches by establishing the geomorphological conditions required for riparian recovery in the project reach. Success of the project will be thoroughly evaluated using a short-term PPA (Post Project Appraisal) and a detailed monitoring plan based on project objectives with specific target parameter criteria.

Treatments

channel and floodplain reconstruction

A map of all channel and floodplain treatments is illustrated in figures 1-7. The primary goal of the project was to create an appropriate channel dimension throughout the entire reach which meant constructing a much smaller channel with much lower bank heights that is not entrenched. The design of these repairs was severely constrained: We had to maintain existing bed elevations, and we had to keep the channel more or less within its existing belt. The best option available in these circumstances was to lower the elevation of the land adjacent to the channel and to narrow it.

On the lower segment (phase 1) we accomplished this by constructing **bank benches** (see figures 8-13) to an appropriate height within the existing wide, deep, enlarged channel. The constructed banks serve to define a much smaller bankfull channel, to provide appropriate growing conditions for streamside riparian plants, and to work as small floodplain areas. Later, the floodplain area was increased by widening the benches on the left side of the channel by excavating terrace material. (Excavated material was used to generate fill needed on an adjacent wetlands restoration project.) Bank benches and floodplain areas are shown in red on the maps in figures 1-7.

One lesson learned in phase 1 about building benches within the existing channel was that we would often end up with narrow benches on outside bends. Since we expect some bank erosion and channel migration (we do not intend to arrest these natural processes) narrow benches will have relatively shorter life spans. The risk of the channel breaching laterally into an adjacent terrace (or, worse yet, into the old ditched Fourmile channel) is proportional to the width of the bench along outside bends. Thus, we wanted the floodplain areas on the upper segment to be wider, especially along outside bends. To accomplish this, we shifted the channel towards the inside of bends to allow room for outside benches to be at least 8 ft wide.

On some sections of the upper segment (phase 3), historic floodplain areas were available within the constrained belt. On these areas (six in total), we simply cut a **new channel** within the floodplain area adjacent to the old channel and filling in the old channel to the floodplain elevation (see figures 14-16). By doing this, we instantly created an appropriately-sized channel dimension with established high-quality bank vegetation and wide floodplain benches. This treatment also resulted in very wide bench widths on outside bends. Areas where the channel location was shifted are depicted with a dotted black line in figures 1-7.

Vegetation treatments and reclamation efforts

In addition to channel and floodplain construction, our approach to channel stability relies heavily on establishing appropriate riparian vegetation. Generally, streamside vegetation was directly planted as sod. Wherever possible, we constructed bank benches from high quality sod with strong hydric species borrowed from nearby locations. In areas where quality sod was not easily available (or where its extraction would cause too much damage) we used lower quality sod and protected it with a layer of photo-degradable erosion-control fabric (figure 13). Most of the lower segment (phase 1) benches and about 1/3 of the benches on the upper segment (phase 3) were constructed with low-quality sod covered in fabric. The lower quality sod contains a higher proportion of weak-rooted mesic or xeric species, but we assume that hydric vegetation is present in this sod as part of the seed bank since it was historically wetland. Thus we expect the composition of vegetation to shift over time on these banks as more hydric species are expressed in their new floodplain position. To increase the odds of this shift, we also heavily seeded these banks with seed from wetland species.

The streamside portion of benches were revegetated by directly planting sod, but the distal bench and floodplain areas were typically constructed from cut or fill material. In general, these areas were planted with sod sprigs and mats to achieve instant 30-50% cover. All areas with less than 80% initial cover were also heavily seeded using a native high-altitude wet meadow wetlands seed mix combined with an equal proportion of high-altitude native erosion control grass mix. As an exception, the extended floodplain areas that were cut in spring on 2010 on the lower segment were not sprigged with sod. These areas were simply seeded and covered with a layer of mulching fabric. All of the sod borrow sites and fill areas on the upper segment were reclaimed by grading, sprigging with sod to a minimum of 30-50% cover, and heavy seeding using the mix described above (see figure 17).

We also planted a large number of willows (see figures 18-19). Approximately 1000 willow stems were planted on the constructed benches in the lower segment during construction in June 2009. An additional 2200 deep-planted dormant willow stem cuttings were planted using a waterjet stinger on the bench and floodplain areas of the lower segment in May, 2010. Finally, 1100 more willow stems were planted on bank benches during construction of the upper segment in August, 2010.

Monitoring

Our goal for monitoring is to quantify ecological improvements, to evaluate project performance, and also to learn more about stream restoration approaches in general. In this way, the project is seen as not only as a restoration and improvement effort, but also as an experiment. We applied a set of treatments, and monitoring the effects is an excellent opportunity to better understand and improve the science and practice of stream restoration. The learning potential is a very valuable component of this project and monitoring.

In 2008, we developed a monitoring plan for the project based on 4 primary goals. (See appendix 1.) Each goal is broken down into multiple objectives with measurable criteria and targets for different levels of performance (good, moderate, poor). Objectives reflect the physical changes and processes that must be effected in order to achieve each goal. Project performance, therefore, may be objectively appraised by comparing measured values to predetermined success criteria. In this report, we use pre-project and as-built monitoring results to evaluate how well the project was implemented. That is, we are able to explain whether the initial construction meets the criteria for success. Continued annual monitoring will be done in the future to follow the response through time to determine the short-term (2-

yr) and mid-term (4-yr) success of restoration. Finally, the data form a basis for ultimately evaluating long term (10+ yr) success if the commitment to monitoring lasts that long.

Monitoring methods

photopoints - About 40 monumented photopoints were set along the project reach so that we can document changes to the channel and riparian area by studying time lapse views. Photopoints are a good way to capture a great deal of qualitative information on the effectiveness of treatments.

channel surveys - To monitor physical condition and changes to the stream channel, we make annual surveys on 17 monumented cross sections (XS). On 8 XS, we have both pre- and post-project surveys, and the rest were added to monitor changes after implementation. In addition, longitudinal profile surveys were completed both prior to the project and after.

greenline vegetation sampling - We sampled the greenline along both banks of the entire project reach both before treatment and again in 2010 after all the treatments had been made. Greenline surveys quantify the relative proportions of different vegetation classes along the stream banks based on aerial cover. In our surveys, we classify vegetation among 4 different herbaceous categories: super-strong (various deep-rooted carex species), strong (hydric), moderate (mesic), and weak (xeric or upland), and 4 categories for woody vegetation based on shrub height: 0-1 ft, 1-3 ft, 3-5 ft, and >5 ft. We also separately kept track of canada thistle.

bank erosion - We use the BANCS model to estimate bank erosion along the entire project reach both before and after treatment. BANCS model estimates are validated by discrete annual erosion measurements on the 17 cross sections and by photopoint observations. Bank erosion estimates are updated annually.

Monitoring results

channel dimension - Channel survey data were used to calculate several important dimension parameters that describe channel condition both before and after treatment. These are summarized in tables 1-2 for both the upper and lower project segments.

streamside vegetation - Before and after greenline survey data were used to classify streamside vegetation composition for the pre-project and as-built condition. These data are summarized in table 3 for both the upper and lower project segments.

bank erosion - Results from our before and after reach-wide BANCS model surveys were used to calculate the estimated gross annual erosion rates and the proportion of bank length with predicted high erosion (> 0.6 ft/yr). These data are summarized in table 4 for both the upper and lower project segments.

performance appraisal - Monitoring results were used to quantify various parameters outlined in the monitoring and appraisal plan (appendix 1). By comparing measured values to pre-determined success criteria, we are able to objectively evaluate as-built performance of the project. These results are summarized in table 5. Implementation of the project treatments was scored in the "good" category for all objectives except one. On the objective for w/d ratio, project implementation scored "moderate". Specifically, the channel on two XS was built slightly wider and/or shallower than designed. In general, the channel treatments were constructed to meet standards.

Discussion

As-built performance appraisal

In general, an objective appraisal of project as-built conditions is good. Below, each of the project goals and objectives are discussed in greater detail.

1. **Goal : Create channel dimension that is similar to reference condition and stable.**

Since initial construction of the channel in 2004, weak streamside vegetation, tall banks and organic soils have all lead to high bank erosion rates and a consistently widening channel. These channel dimensions show increased cross sectional area, high W/D ratio, decreased sediment transport ability, a risk of bed aggradation and extreme bank erosion. Reestablishing appropriate channel dimension is a necessary first step towards restoring the natural processes that maintain channel form and function.

1.1 **Objective: Bankfull XS area is similar to reference condition and stable.** Appropriate XS area for this reach is 8-16 ft^2. For construction, we targeted a slightly smaller channel size (typically 6-10 ft^2) to allow for some erosion while the transplanted sod is becoming established and undercuts are formed. Additionally, we reasoned that the smaller channel size would be better accommodated by the lower flow rates that we plan to maintain for 1 or 2 years after implementation. Before treatment all of the monitored cross sections (XS) had areas greater than 16 ft^2. After construction, all XS have areas within the desired range. For its length, the channel is now sized to an appropriate dimension. We expect the channel to enlarge somewhat during the first few, but if bank vegetation does become firmly established we expect channel dimensions to become stable within the acceptable range.

1.2 **Objective: W/D ratio is similar to reference condition and stable.** Prior to the project, W/D ratios on all XS were 1.5 to 2 times greater than reference condition. Instead of being narrow and deep, the eroding channel had widened and become shallow. The overwide condition negatively effects stream stability, water temperature, fish habitat and streamside vegetation, particularly where the channel is also entrenched. Before treatment, all XS had W/D > 8, but 89% of XS on the upper segment of reconstructed channel and 60% on the lower segment now have W/D ≤ 8. The reconstructed cross sections with W/D > 8 are all still very close to the target (<9.5). W/D ratio has been effectively treated over most of the channel, but a few segments still appear to be slightly overwide. As a result, we expect an overall improvement to channel stability, sediment transport, temperature regime, and fish habitat.

2. **Goal: Restore hydrology to channel banks and adjacent floodplain area.**

Another problem of the oversized, entrenched channel that existed here before the project is that normal bankfull flows were unable to reach a floodplain. In this state, channel-adjacent areas were perched high above the creek bed where they would never receive overbank flows or the benefit of subirrigation This situation does not allow the establishment of normal hydric wetland or riparian plants, so xeric upland plant communities tend to dominate. Appropriate channel-floodplain connectivity is a process that is necessary for both channel stability and the support of native riparian vegetation. When properly functioning, an attached floodplain absorbs the energy of high flows as well as gathers material (sediment) carried down in the channel during high discharge events and floods.

1.1 **Objective: Increase the proportion of XS on the improved channel that has BHR ≤ 1.2**. Bank height ratio (BHR) compares the relative height of the lowest bank to the elevation of 'bankfull' flow. If the low bank height is the same as the bankfull elevation, BHR is 1, and the floodplain is considered to be perfectly intact with the channel. If BHR is ≤ 1.2, floodplain connectivity is relatively intact, but BHR values greater than 1.2 indicate floodplain connectivity impairment. Prior to construction, BHR on all XS was > 1.2. That is, there was a high level of impairment to channel-floodplain connectivity. The treatments appear to have adequately addressed this concern, as BHR values were all reduced to 1.0 or 1.1 on the as-built channel. Bankfull flows will now be capable of actually reaching "bank-full" and flooding onto a floodplain with regular occurrence once hydrology is totally restored

1.2 **Objective: Channel flows reach overbank elevation at discharge values between 25-60 cfs.** Modeled overbank discharge is another way of looking at the appropriateness of channel dimension and floodplain connectivity. On stable reference reaches, observed overbank (bankfull) flow is (40-60 cfs). It is the intent of the project that eventually all flows of Fourmile Creek will run in the new channel, so the channel must ultimately be able to adapt to the natural flow regime of the Fourmile Creek watershed. That is, it should overbank at the appropriate discharge of 40-60 cfs. Due to the enlarged and entrenched condition of the channel before construction, flows would have had to reach 100-300 cfs before overbanking (*i.e.* the floodplain would never activate). The target range for overbank discharge on the constructed channel is set somewhat lower than the ultimate target of 40-60 cfs. Again, this is due to our expectation for some channel enlargement during the initial few seasons while bean vegetation is becoming established and the channel is adjusting. Appropriate overbank discharge was indeed achieved on all monitored sections of the treated channel, so it appears that channel and floodplain processes may be come successfully restored.

3. **Goal: Improve condition of streamside vegetation.**

When floodplain connectivity is lost, it directly effects the vegetation along a stream. Without floodplain connectivity, streambanks become dominated by xeric species with weak rooting systems rather than strong-rooted hydrophytes. In short, for appropriate vegetation to establish and thrive along the stream, bank elevations must not be too much higher than the elevation of bankfull flow. In addition to its value from a habitat perspective, restoring appropriate native riparian vegetation is a keystone component to our plan for both short- and long-term channel stability on this reach of Fourmile Creek. In functioning stream systems, including our observed reference reaches, streamside vegetation is a driving force in stream stability, form and function.

3.1 Objective: Proportion of bank length on improved channel that is within 0.5 ft of bankfull elevation for at least 2.0 ft width. This objective is concerned with the length of bank that is shaped appropriately to support hydric species. In addition to the proper elevation, bench width is important. A minimum bench width allows for some erosion over time and establishment of a wider riparian community. Before treatment, only 32% of the upper and 35% of the lower segment greenlines were within 0.5 ft of bankfull elevation for at least 2 ft width. That is, most of the channel banks were not in a condition that could support native riparian vegetation. After treatment, 100% of the greenline on both sites meets the elevation and width requirements for riparian vegetation support. This condition will make it possible for streamside vegetation to continue to improve along the channel length.

3.2 Objective: Proportion of bank length on improved channel vegetated with native hydric gramminoids or shrubs. Before treatment, many of the streambanks on this reach were dominated by upland plant species that do not offer soil stabilizing root systems. These communities are classified as 'weak' in our greenline vegetation surveys. In order to meet goal # 3, the proportion of streamside vegetation would have to be shifted to communities with more hydric gramminoids and shrubs. This is accomplished either by transplanting good vegetation along existing streambanks, by relocating banks onto existing sites with good vegetation, or by natural succession.

Prior to treatment, the desired hydric vegetation made up only 34% of the upper and 37% of the lower segment greenlines. By contrast, weak or xeric vegetation or canada thistle made up 21% and 33%, respectively. Following implementation of the treatments, the proportion of hydric vegetation along the greenline increased to 87% on the upper segment and 50% on the lower segment which greatly exceeds expectations for good implementation. The proportion of weak/xeric vegetation on these segments also dropped correspondingly to 2% and 5%. Finally, the proportion of woody species is already beginning to show up substantially as planted stems have begun to grow. The greenline on the lower segment now has 10% woody cover, where no woody species existed at all before treatment. The condition of streamside vegetation is very significantly improved, and this is important since long-term stability and improvement are both tied to this keystone parameter.

4. **Goal: Reduce sediment and soil loss caused by bank erosion of the channel.**

The extensive amount of bank erosion and resulting morphological changes to the channel were the initial observation that highlighted the degree of instability on this reach. Moderate flows, far less than bankfull, were causing several feet of erosion per year, a value that corresponds to hundreds of tons of sediment input to the Fourmile and South Fork system from this reach alone. After monitoring cross sections and quantifying the data, it became clear that the level of sediment pollution due to bank erosion was beyond tolerable limits. The effects of bank erosion could be observed miles downstream, and as a result we have been unwilling to push anything but bare minimum flows through this reach until it could be repaired.

Restoration of stable banks and the processes that maintain them are the key to long-term control of bank erosion in the natural channel setting. Our approach is an attempt to control bank erosion in this way. Rather than trying to artificially harden banks, we are trying to reestablish the natural components that provide bank strength and resistance to erosion. Proper channel dimension and appropriate riparian plant species are the two key components. Because the treatments applied did effectively improve these two factors, BANCS model erosion predictions went down accordingly. Continued low bank erosion rates will depend upon how well our planted vegetation self-maintains and whether channel dimension proves to be stable.

4.1 Objective: Field-validated BANCS model estimates of reach-wide bank erosion on the improved reach compared to pre-project values. Prior to treatment, this reach was extremely susceptible to high erosion. Fortunately, we have been able to control erosion, to some degree, on this reach by limiting the frequency, duration, and magnitude of high flows. That is, we were able to actively manage for low flows so that the channel would not unravel and produce too much sediment pollution downstream. However, this is an unacceptable solution for the long term. Ultimately we need a solution that will allow for all the flows of Fourmile to be run through this new channel. If our reconstructed banks and planted vegetation do firmly establish, the BANCS model predicts 10-fold decreases in erosion to levels that are perfectly tolerable. Thus, we should soon be able to confidently run high flows through this channel and therefore realize the benefits from the rest of the 4 miles of restored channel that have been deprived of water for several years.

4.2 Objective: Decrease the proportion of bank length with high to extreme erosion rates. Many bank segments throughout the project reach had predicted and measured erosion rates that were high or extreme prior to treatment, and the negative impacts of rapid channel enlargement and migration have already been discussed. On this reach, we are particularly wary of segments that erode rapidly since the belt width is especially narrow. That is, there is not much room for the channel to move right or left without it going into a high terrace or into the old ditched Fourmile channel. While some breaches of the existing belt are inevitable, we hope that these occurrences will be minimal since a breach of this sort may have to be mechanically repaired. Thus, the amount of bank with high lateral erosion rates may be seen as a measure of risk that additional repair work would be needed. At present, this appears to be within tolerable levels (the predetermined success criteria for this parameter is 7% immediately and 13% for the short-term). Another way of decreasing the risk of a breach is to build wider benches/floodplains adjacent to banks where erosion is expected. For this reason, on the upper segment (phase 3) we constructed benches along outside bends as wide as possible.

The restoration process and importance of monitoring

The treatments implemented in this project so far (channel reconfiguration and revegetation) are not the final product of restoration. They are, however, a necessary first step towards the recovery of natural processes. Our approach has been to reestablish an appropriate channel morphology to the best extent possible given the constraints, and to reintroduce the appropriate riparian vegetation. Based on this appraisal, these factors have been successfully implemented. The next key step is time. Time to allow these components to function together. If restoration of these natural processes is successful, we can ultimately expect continued channel stability, naturally sustaining riparian vegetation communities, improved aquatic habitat, and better water quality. Continued monitoring will reveal whether this is indeed the case.

Ongoing monitoring is a key component to this restoration effort. By repeatedly measuring key parameters over time, the ultimate success of restoration will be revealed. This project will be monitored for at least 2 years to evaluate short-term success according to the monitoring plan presently in place. We also recommend extended monitoring beyond this time frame to appraise long term success.

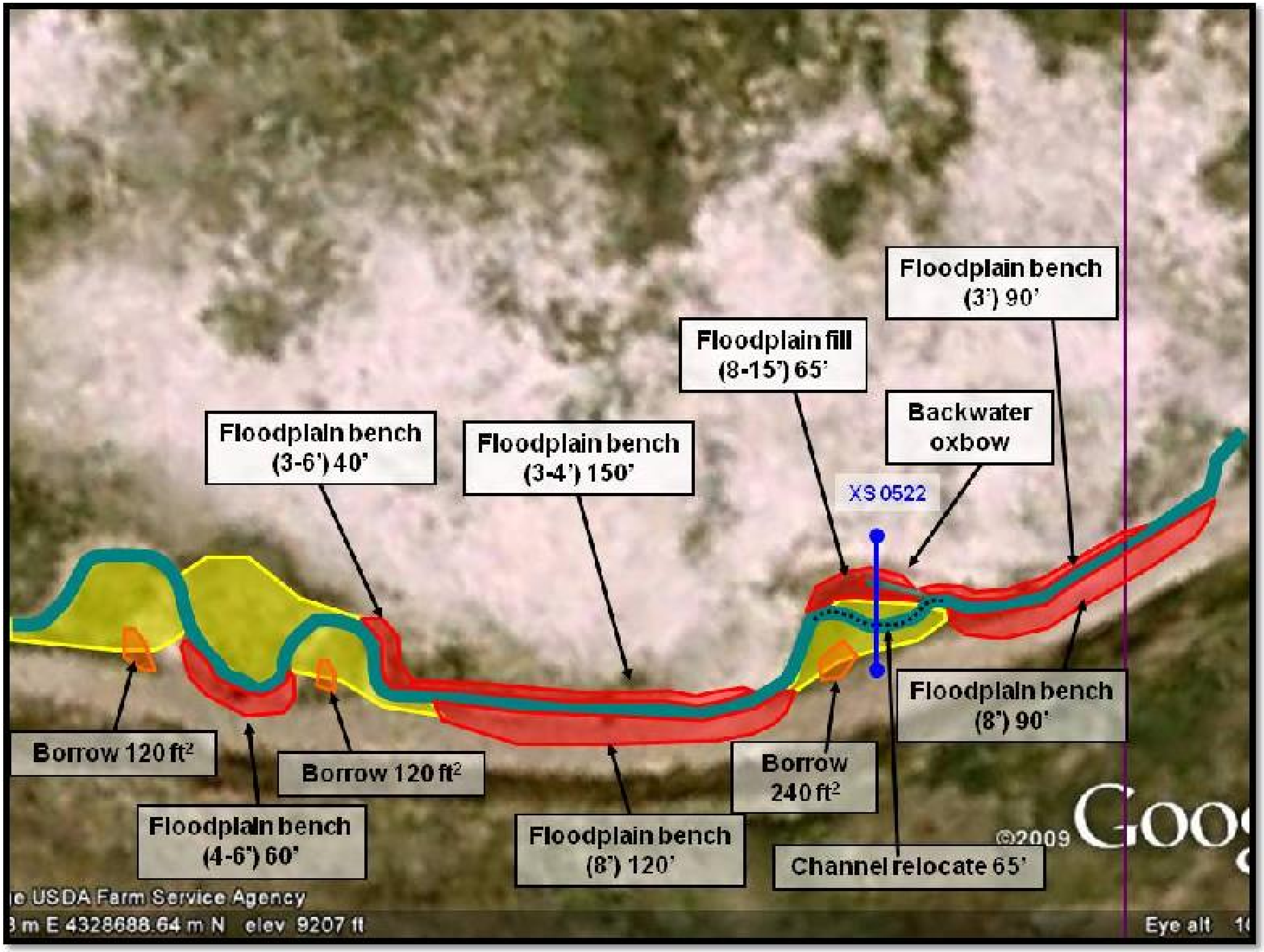

Figure 1: Channel treatments map 1

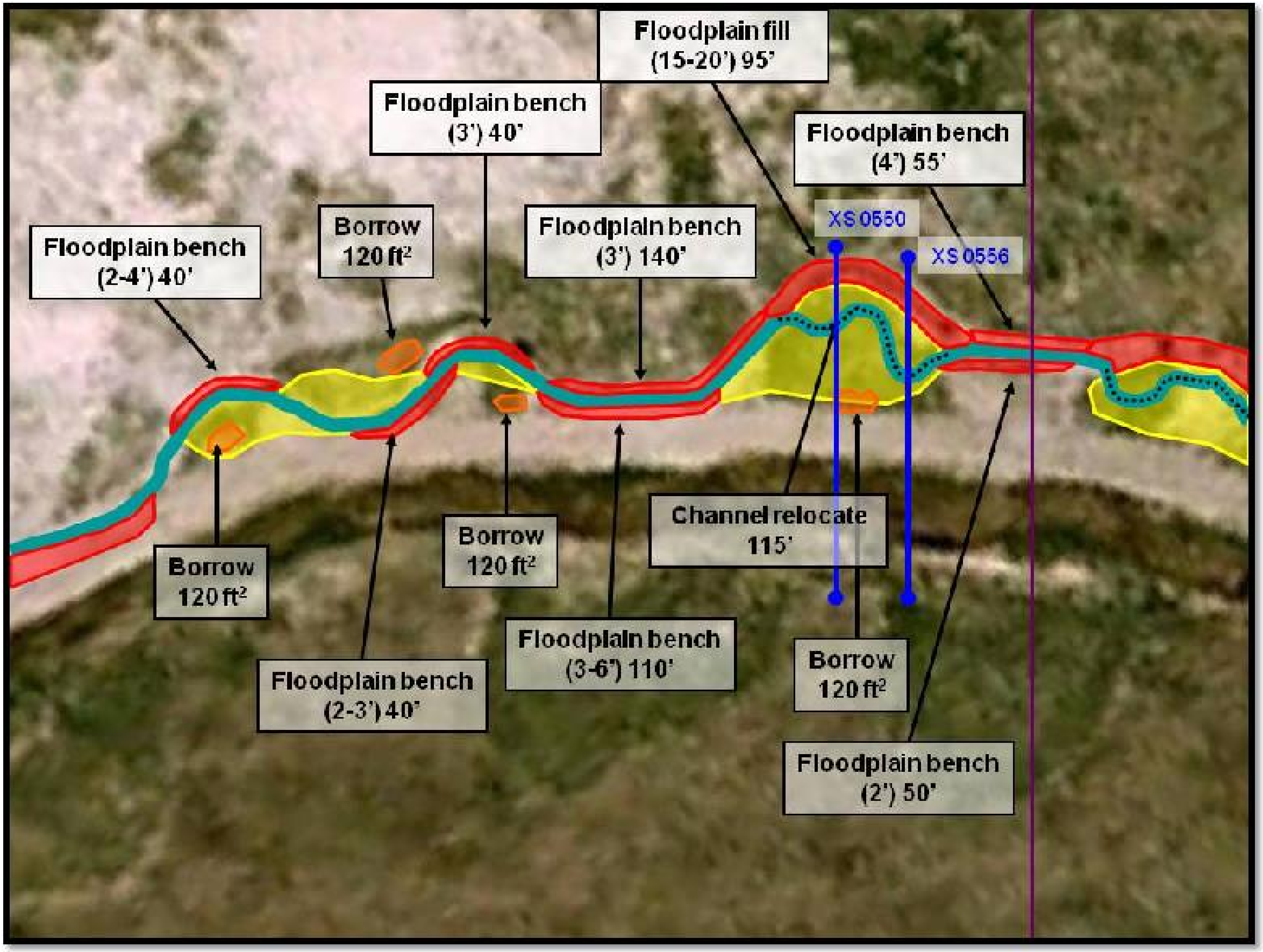

Figure 2 Channel treatments map 2

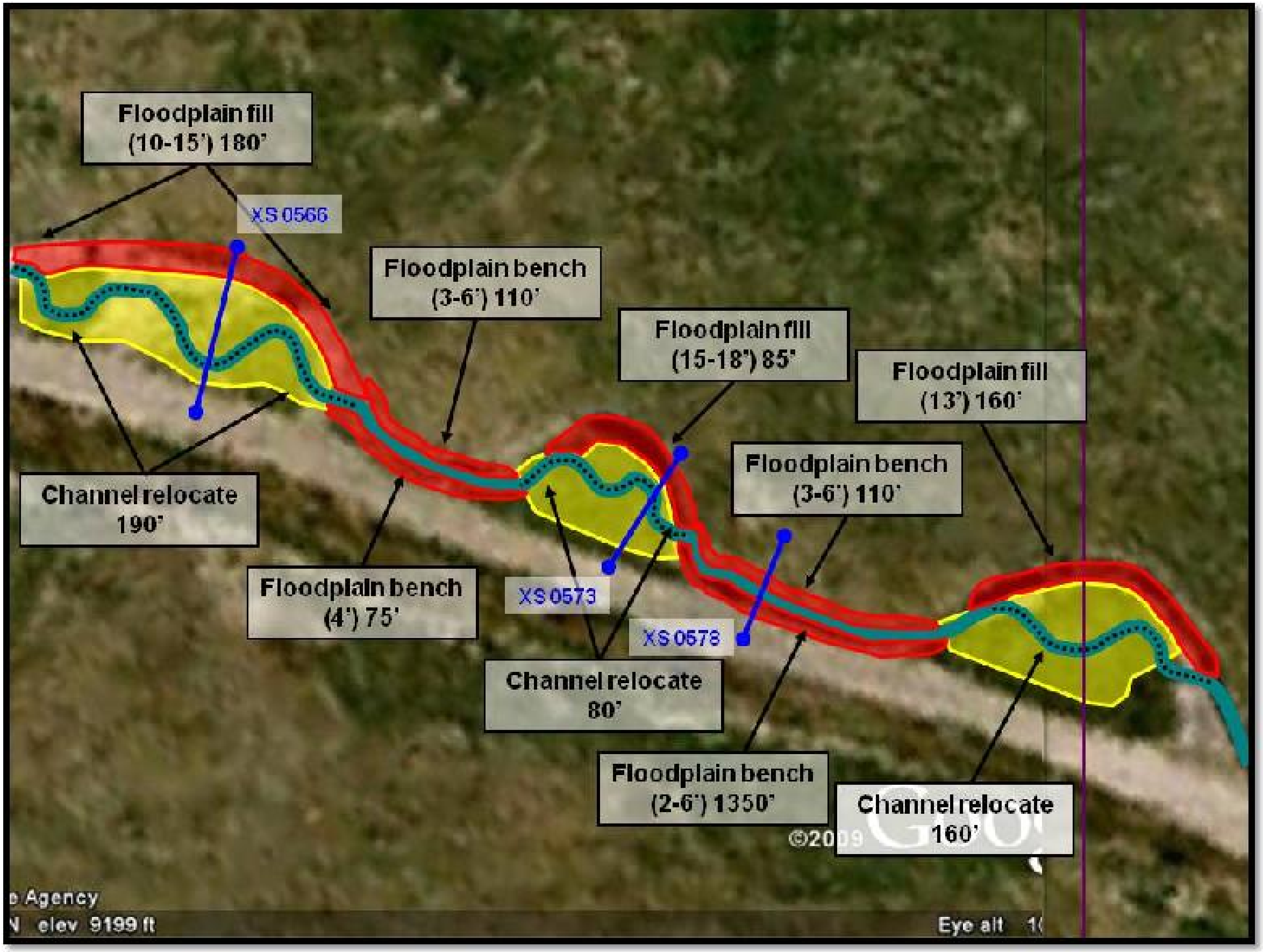

Figure 3 Channel treatments map 3

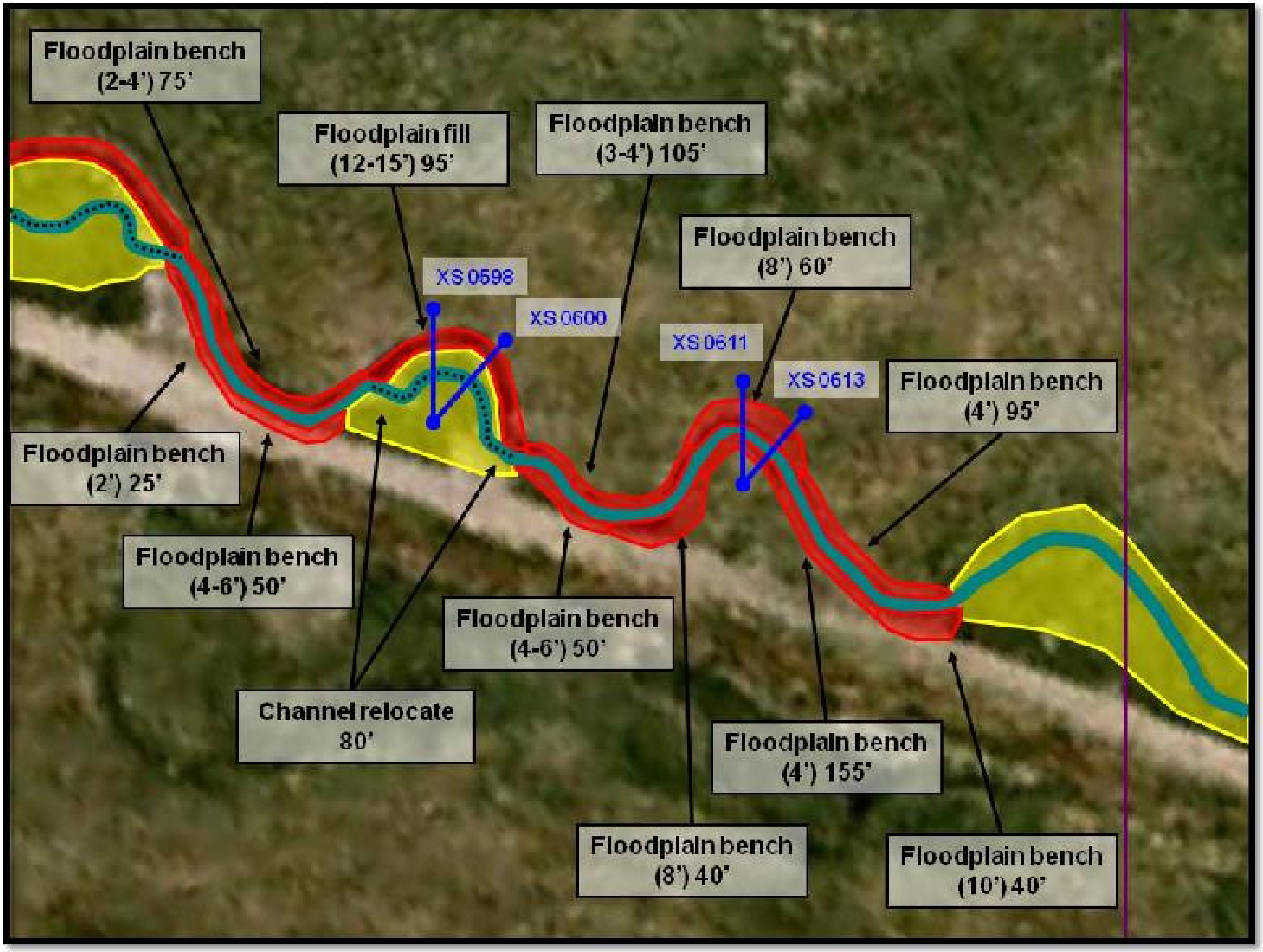

Figure 4 Channel treatments map 4

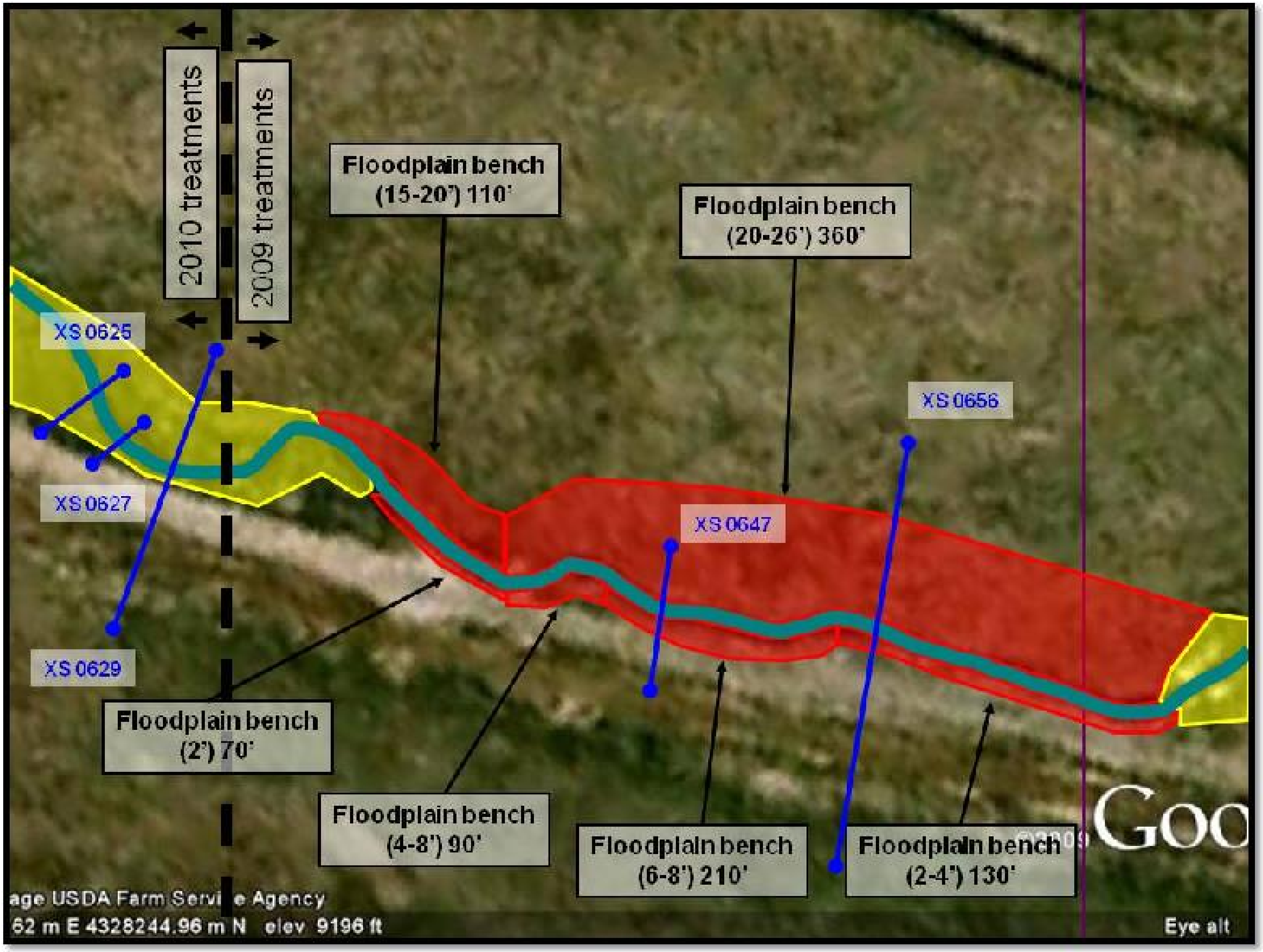

Figure 5 Channel treatments map 5

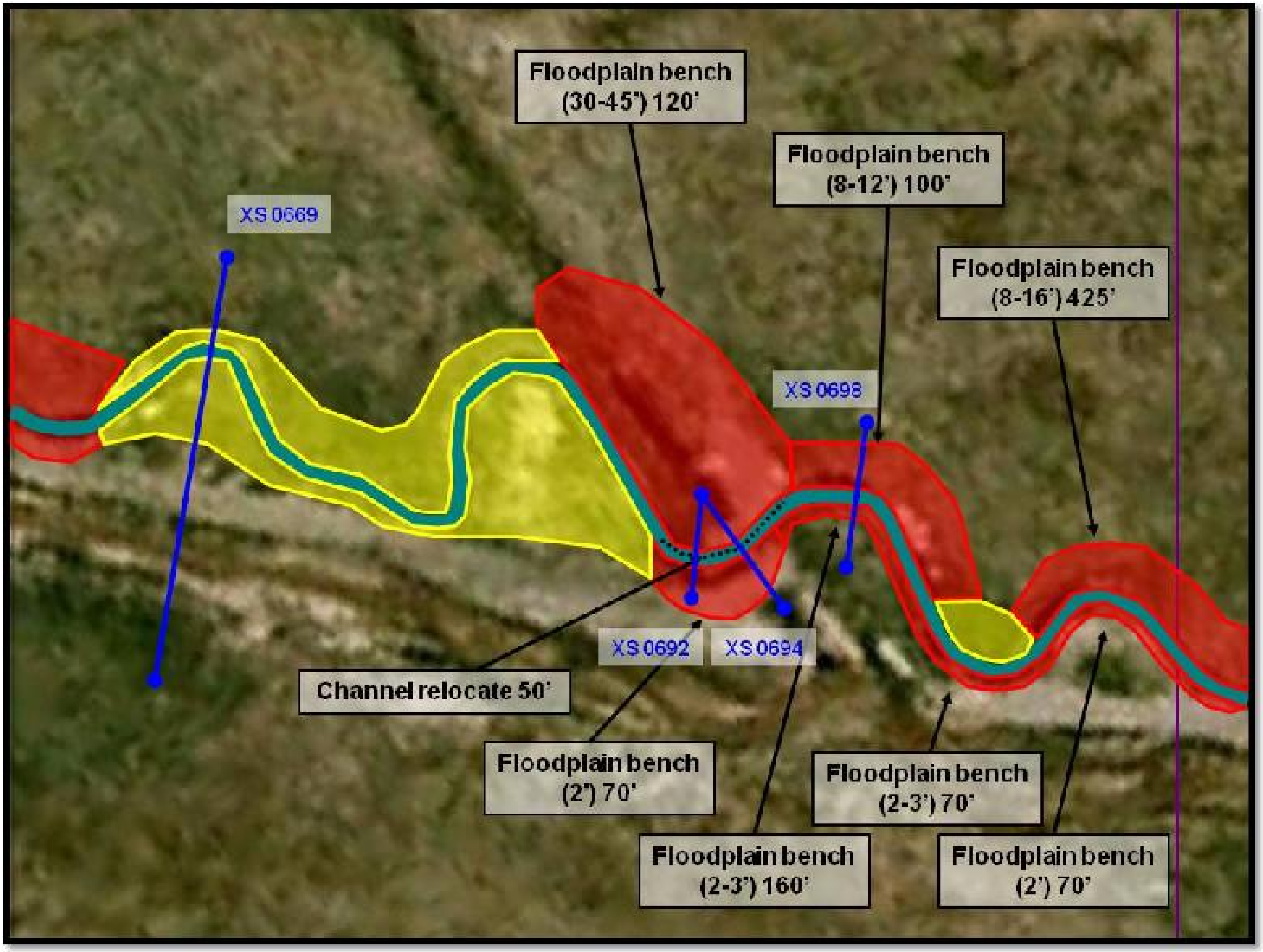

Figure 6 Channel treatments map 6

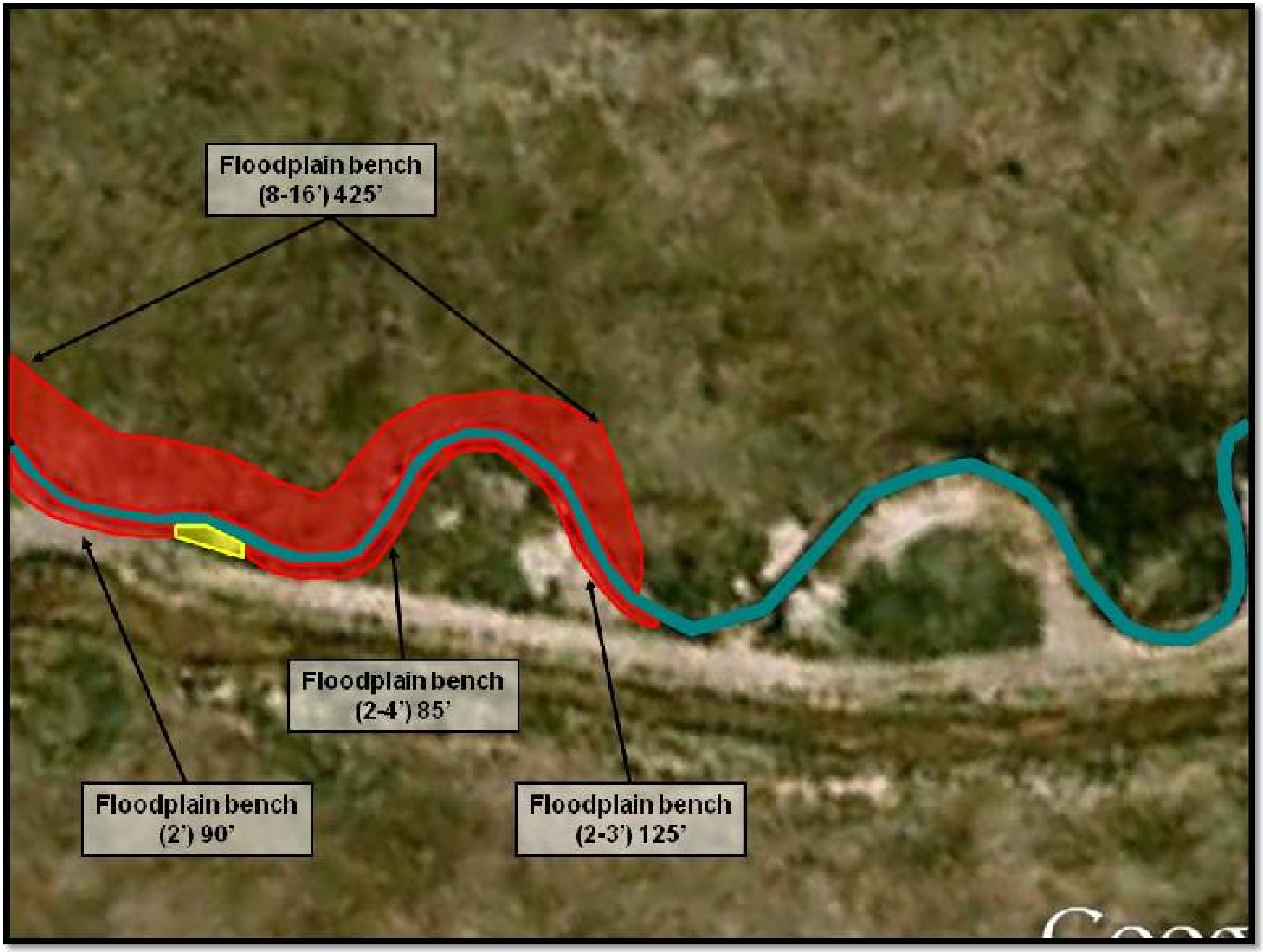

Figure 7 Channel treatments map 7

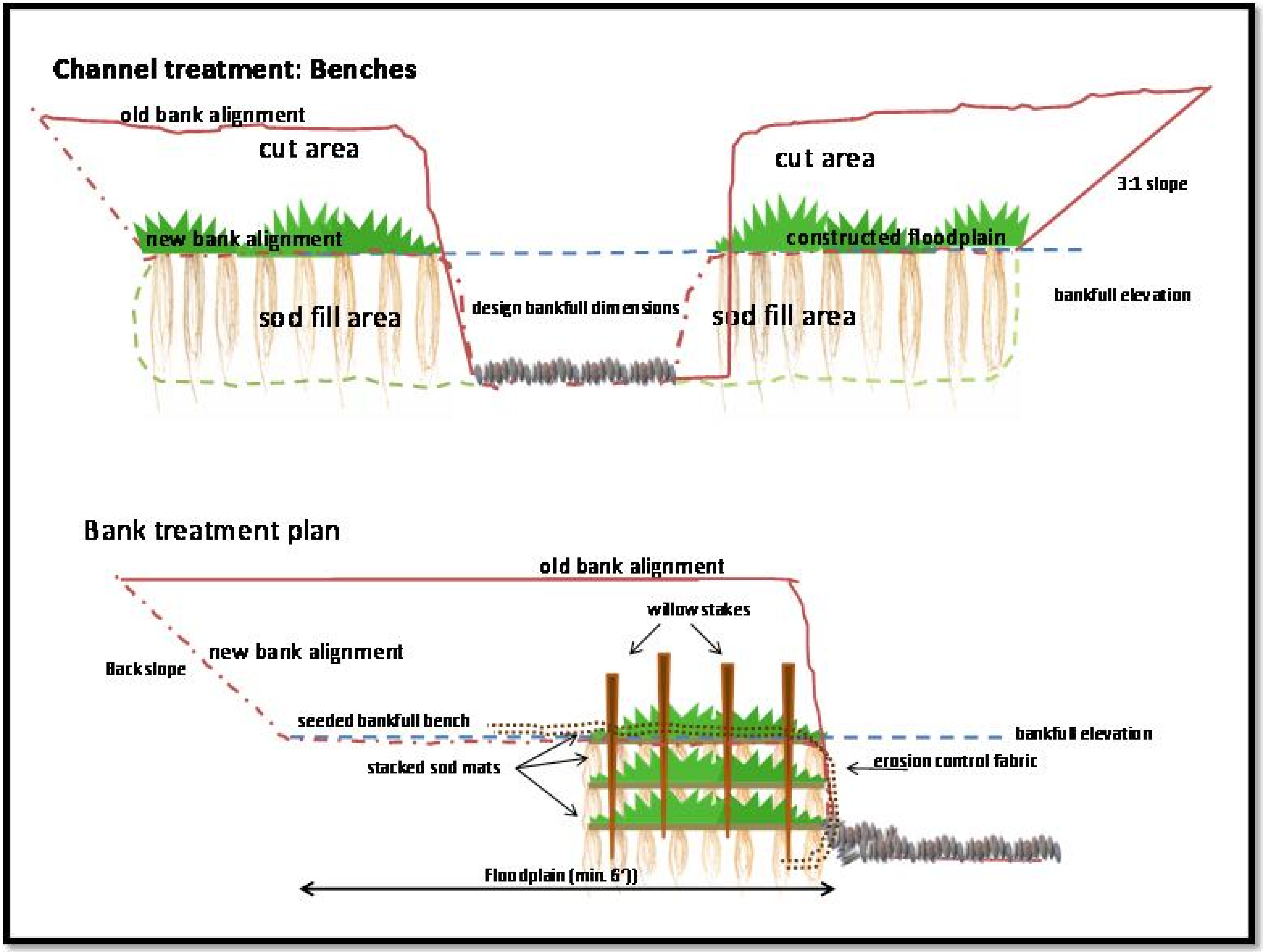

Figure 8 Schematic of general bank bench treatment

Figure 9 Before-after of bench/floodplain treatment on the upper segment just after construction in August, 2010

Figure 10 Before-after of bench/floodplain treatment on the upper segment just after construction in August, 2010

Figure 11 Before-after of bench/floodplain treatment on the upper segment just after construction in August, 2010

Figure 12 Before-after of bench/floodplain treatment on the upper segment just after construction in August, 2010

Figure 13 Before-after of bench/floodplain treatment on the lower segment just after construction in June, 2009. The lower photos show the same treatment during the first season after construction in 2010.

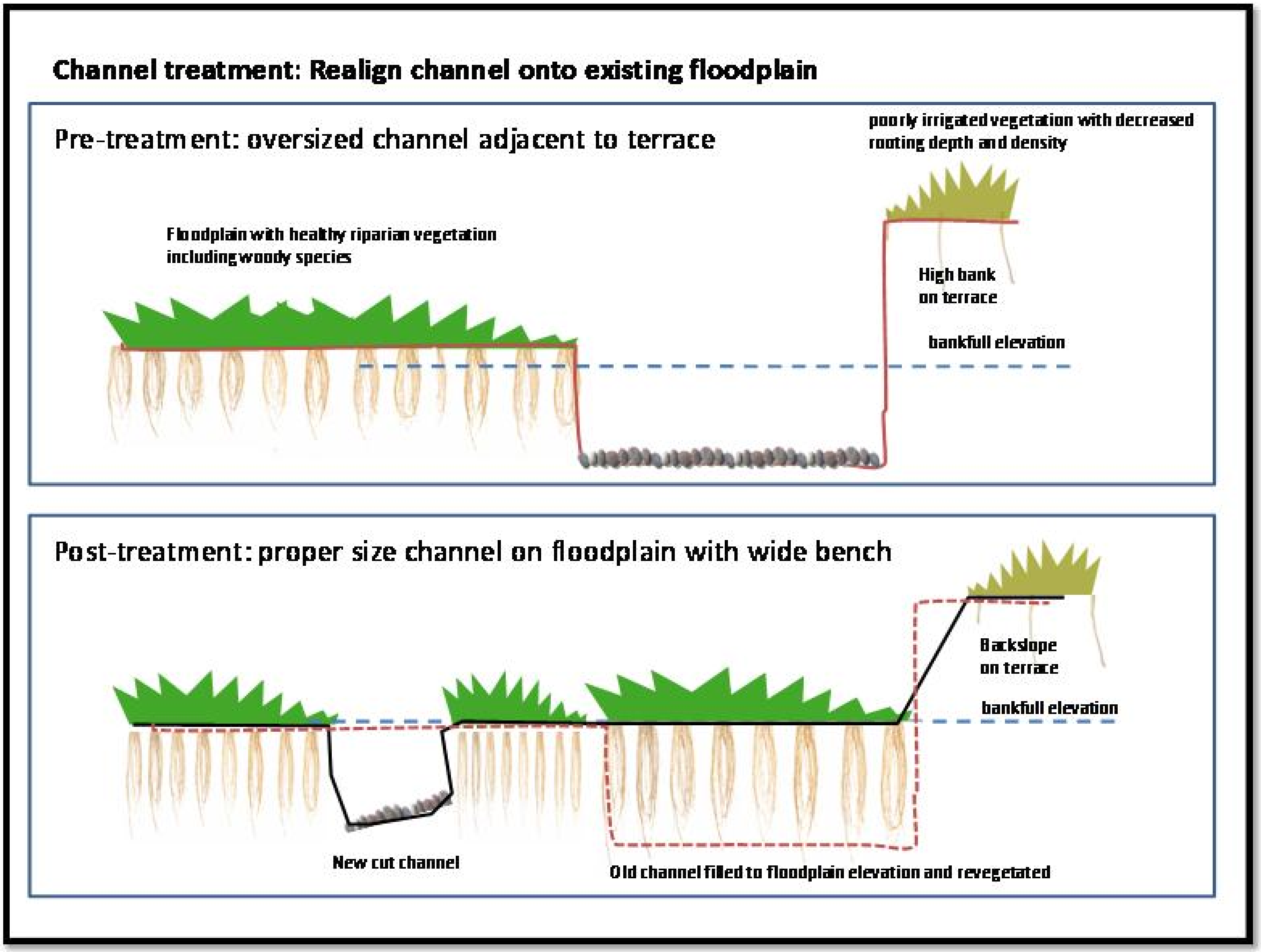

Figure 14 Schematic of channel realignment treatment

Figure 15 Before-after of channel realignment treatment on the upper segment just after construction in August 2010.

Figure 16 Before-after of channel realignment treatment on the upper segment just after construction in August 2010.

Figure 17 Sod borrow areas were reclaimed by grading and planting sod sprigs and sod mats to for immediate 30-50% cover. They were also heavily seeded.

Figure 18 Willow stem plantings on the lower segment

Figure 19 Willow stem plantings on the lower segment

Table 1 Detailed dimensional data from channel cross sections. Values for dimensionless ratios are given for the channel locations both before and after treatment.

Channel dimension analysis: Fourmile Creek - DW fen reach

XS ID		Intended facet	Treatment	Area (ft^2)	Width (ft)	d (ft)	W/D		$Q_{overflow}$ (cfs)		BHR		ER		Channel Type	
reference riffle		riffle	none	11.6	7.1	1.7	4.2		35 - 45		1.0		> 10		E	
riffle design (ultimate)		riffle	n/a	9.8	6.5	1.5	4.3		35 - 50		1.0		> 2.7		E	
implementation target		riffle	n/a	7.0 - 9.0	3.5 - 6.0	1.0 - 2.0	≤ 8.0		25 - 50		≤ 1.2		> 2.7		E	
							before	after	before	after	before	after	before	after	before	after
Upper Fen Segment - implemented 2010 (as-built)	XS 0522	pool	new cut	8.8	4.9	1.8	14.0	2.7	~90	35	1.4	1.0	> 10	> 10	C	E
	XS 0550	riffle	new cut	8.0	4.8	1.7	12.0	2.8	~ 80	29	1.4	1.1	> 10	> 10	C	E
	XS 0556	pool	new cut	10.0	4.9	2.1	13.0	2.3	~ 110	40	1.6	1.0	> 10	> 10	C	E
	XS 0566	pool	new cut	8.3	5.5	1.5	14.0	3.7	~ 150	33	1.7	1.0	> 10	> 10	C	E
	XS 0578	riffle	benches/fp	7.0	7.2	1.0	10.4	7.2	290	25	2.5	0.8	1.3	2.7	G_C	E
	XS 0598	riffle	new cut	7.3	6.9	1.0	17.0	6.9	~ 200	25	2.1	1.0	4.0	> 10	C	E
	XS 0600	pool	new cut	6.6	4.4	1.5	17.0	2.9	~ 200	24	1.9	1.0	4.0	> 10	C	E
	XS 0611	riffle	benches/fp	8.0	7.8	1.0	13.3	7.8	302	29	3.2	1.0	1.3	3.0	F	E
	XS 0613	riffle	benches/fp	8.3	8.4	1.0	14.2	8.4	310	31	3.3	1.0	1.2	3.0	F	E
Lower Fen Segment - implemented 2009 (year-1)	XS 0625 (ref)	riffle	none	7.7	6.1	1.3	4.7	4.7	29	29	1.0	1.0	9.9	9.9	E	E
	XS 0629 (ref)	riffle	none	12.8	9.1	1.4	6.5	6.5	53	53	1.0	1.0	10.6	10.6	E	E
	XS 0647	riffle	benches/fp	8.0	7.2	1.1	15.6	6.5	325	29	2.9	1.0	1.2	5.3	F	E
	XS 0656	riffle	benches/fp	6.2	5.7	1.1	19.7	5.2	270	26	2.8	1.0	1.0	5.2	F	E
	XS 0669 (ref)	riffle	none	14.0	10.2	1.4	7.3	7.3	49	35	1.0	1.0	> 10	> 10	E	E
	XS 0692	riffle	benches/fp	9.3	8.8	1.1	17.0	8.0	~ 220	35	2.3	1.0	1.2	> 10	F	E
	XS 0694	pool	benches/fp	8.6	8.4	1.0	15.0	8.4	~ 220	29	2.3	1.0	1.1	> 10	F	E
	XS 0698	riffle	benches/fp	7.7	8.4	0.9	17.0	9.3	~ 200	26	2.1	1.0	1.2	3.5	F	E

Table 2 A summary of channel dimension success criteria

Percent of sampled channel meeting criteria	Objective 1.1		Objective 1.1		Objective 1.2		Objective 2.1		Objective 2.2					
	XS area implementation criteria: 6-16 ft^2		XS area long-term criteria: 8-16 ft^2		W/D criteria: ≤ 8		BHR criteria: ≤ 1.2		$Q_{overflow}$ criteria: 25 - 60 cfs		Entrenchment ratio criteria: ≥ 2.7		Channel type criteria: E-channel	
target values (as-built)	100		100		100		100		100		100		100	
target values (mod term - 4 years)	≥ 80		≥ 80		≥ 80		≥ 80		≥ 80		≥ 80		≥ 80	
	before	after	before	after	before	after	before	after	before	after	before	after	before	after
upper fen segment (implemented 2010)	0	100	0	67	0	89	0	100	0	100	67	100	0	100
lower fen segment (implemented 2009)	0	100	0	80	0	60	0	100	0	100	0	100	0	100

Table 3 A summary of streamside vegetation success criteria

Percent of greenline for various vegetation classes	Objective 3.1		Objective 3.2							
	% appropriate bank elevation		% desired vegetation classes		% strong/hydric herbs		% woody plants		% weak/xeric herbs and thistle	
target values (as-built)	≥ 80		≥ 40		n/a		n/a		n/a	
target values (mod term - 4 years)	≥ 80		≥ 60		n/a		n/a		n/a	
	before	after	before	after	before	after	before	after	before	after
upper fen segment (implemented 2010)	35	100	34	87	34	87	0	0	21	2
lower fen segment (implemented 2009)	32	100	37	50	37	40	0	10	33	5

Table 4 A summary of bank erosion success criteria

bank erosion BANCS model parameters	Objective 4.1			Objective 4.2		
	bank erosion: gross volume			% bank length with erosion > 0.6 ft/yr		
target values (as-built)	**≥ 75% decrease**			**≥ 75% decrease**		
target values (mod term - 4 years)	**≥ 75% decrease**			**≥ 75% decrease**		
	before	after	%	before	after	%
upper fen segment (implemented 2010)	**12385**	**1194**	**90%**	**25**	**5**	**80%**
lower fen segment (implemented 2009)	**10195**	**595**	**94%**	**26**	**0**	**100%**

Table 5 summary of as-built performance criteria and an appraisal of project performance.

Goal	Objective	Measure	Success criteria	As built condition	As built performance rating
1. Create channel dimension that is similar to reference condition and stable	**Objective 1.1:** Bankfull XS area is similar to reference condition and stable	**Measure 1.1.1:** Proportion of riffle XS on improved channel that meets target for XS area between 6-16 ft^2	100%	100%	GOOD
	Objective 1.2: W/D ratio is similar to reference condition and stable	**Measure 1.2.1:** Proportion of riffle XS on improved channel that meets target for W/D ≤ 8	≥80%	89%	MODERATE
2. Restore hydrology to channel banks and adjacent floodplain.	**Objective 2.1:** BHR values are less than or equal to 1.2	**Measure 2.1.1:** Proportion of riffle XS on improved channel that meets target for BHR ≤ 1.2	100%	100%	GOOD
	Objective 2.2: Channel flows reach overbank elevation between 25-60 cfs	**Measure 2.2.1:** Proportion of riffle XS on improved channel that are observed or estimated to flow overbank between 25 and 60 cfs	100%	100%	GOOD
3. Improve condition of streamside vegetation	**Objective 3.1:** Streamside elevations are appropriate for desired plant species	**Measure 3.1.1:** Proportion of bank length on improved channel that is within 0.5 ft of bankfull elevation for at least 2.0 ft width	≥80%	100%	GOOD
	Objective 3.2: Proportion of desired plant species on the greenline of the improved channel is significantly increased	**Measure 3.2.1:** Proportion of bank length on improved channel vegetated with native hydric gramminoids or shrubs	≥40%	50%- 87 %	GOOD
4. Reduce sediment and soil loss caused by bank erosion on the channel	**Objective 4.1:** Grosse volume of sediment produces by the reach from active bank erosion is reduced.	**Measure 4.1.1:** Field-validated BANCS model estimates of reach-wide bank erosion on the improved reach compared to pre-project values	≥75% decrease	90%- 94 %	GOOD
	Objective 4.2: The proportion of bank length with high to extreme erosion rates is significantly reduced.	**Measure 4.2.1:** Proportion of bank length on improved channel with estimated lateral extension rates > 0.6ft/yr	≥75% decrease	80%- 100 %	GOOD