Interim Monitoring Report for the Big Meadow Creek in Cookhouse Meadow Restoration Project

USDA Forest Service

Lake Tahoe Basin Management Unit

July 2009

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Executive Summary

In 2005 and 2006, the USFS implemented a stream channel/floodplain restoration project in Big Meadow Creek through Cookhouse Meadow, located adjacent Highway 89 just below Luther Pass. Restoration activities included the construction of 2,400 feet of new stream channel (designed as a Rosgen C stream channel type) to replace 1400 feet of existing deeply incised and eroding stream channel (classified as a Rosgen G channel). This restoration effectively raised the elevation of the stream channel by approximately 6 to 10 feet, and reduced the relative channel bed to bank height so that the riffle elevation is 1 to 1.5 feet from the top of bank. This conversion in channel type is expected to achieve the following two objectives.

1) Restore stream channel geomorphic function in terms of channel stability, and aquatic habitat features.

2) Restore floodplain connectivity which will;
   - Increase meadow surface flooding frequency, so that the surface floods two out of every three years on average,
   - Restore seasonal ground water levels and associated capillary rise in the central meadow to support growth of moist and wet meadow vegetation through August 15 under average hydrologic conditions, and reverse the trend of dry meadow grasses and conifer invasion.

This report provides an interim analysis of data collected to answer the following monitoring questions related to project goals/objectives as described below:

- Is the channel maintaining the desired characteristics of either a C4 or E4 channel, as defined by the Rosgen stream channel classification system? Is the channel evolving from the constructed C4 stream type to an E4 channel type?
- Is the meadow surface flooding at the 1.5 year reoccurrence interval frequency?
- Is the ground water level in the central meadow sufficiently shallow to support the colonization and maintenance of desired meadow species?
- Are dry meadow grass species and conifers in the central meadow being out competed and replaced with desired meadow species indicative of wetter hydrologic conditions?

Replacement of the old channel with a new channel successfully converted the channel type from an incised channel, experiencing accelerated bank erosion and effectively dewatering the meadow (“G” Rosgen channel type), to a stable channel form (“C” Rosgen channel type) that is now connected to the adjacent floodplain. Prior to restoration out of bank flows had not occurred in this meadow for approximately 30 years. During the three spring snowmelt seasons that have passed since completion of the restoration work, a relatively small amount of over bank flooding occurred for 6 days in 2008, and a larger amount of over bank flooding (approximately 50% of the meadow) occurred during a 21 day period following rain on snow events in May of 2009. Over bank flooding during the spring of 2009 was observed to have resulted in the deposition

of fine sediments and organic detritus throughout the floodplain. All three of these post project years were considered to be below average precipitation years, based on SNOTEL data.

In addition, the restoration project has resulted in dramatic increases in groundwater levels, increasing the duration of available water for meadow vegetation substantially. Photo points indicate that the meadow vegetation is already responding favorably to both increased groundwater levels and over bank flooding, although quantitative data measuring vegetation response is not available at this time. Quantitative data on stabilizing vegetation planted or salvaged as part of the project (sod harvesting, willow staking, willow mats) was obtained, and indicates a high success rate (approximately 90% survival). This is partially due to initial irrigation efforts during the dry season, as well as changes in groundwater and surface water hydrology.

Channel survey measurements (cross sections and longitudinal profiles) as well as visual observations indicate that the channel is maintaining both horizontal and vertical stability, and is maintaining the desired channel stability and habitat characteristics of a “C” Rosgen stream channel type. Visual observations note that lateral and point bar formation, as well as the development of scour and corner pools are occurring. The desired gravel dominant channel substrate is also being maintained (Rosgen class “4”).

I. INTRODUCTION

The purpose of this monitoring effort is to track the stream and meadow geomorphologic, hydro-geologic, and vegetative response to restoration actions completed in 2005 and 2006 on a reach of Big Meadow creek that passes through Cookhouse Meadow. This meadow is located in the Lake Tahoe watershed, off of Highway 88, between Meyers, CA and Luther Pass. (Figure 1)

In 2005, restoration activities included the construction of 2,400 feet of new Rosgen type C4 stream channel to replace 1400 feet of existing deeply incised and eroding stream channel (classified as a Rosgen G4 channel). In order to maximize the potential for rapid channel stability post-construction, meadow sod was carefully harvested and preserved during excavation of the new channel, and placed back along newly constructed channel banks. Riparian plantings were also implemented in 2005 including willow wattles perpendicular to the fall line of the floodplain, willow mattresses between the upper most blocks of stream bank sod, and willow stakes to secure the top stream sod layer. Additionally, vegetation plugs and willow wattles were installed in sod harvest areas to speed up surface vegetative recovery in those areas. The new channel was isolated from live flows in the first season, and was flood irrigated to increase wetness and enhance the establishment of transplanted vegetation.

In 2006, the restoration activities included the plugging of 1800 feet, and partial fill along 1400 feet, of existing channel. Flow was cut off from the old channel and diverted into the new channel by construction of a rock and earthen berm /wall reinforced with sheet piling. Engineered fill (utilized originally as access road material) was used as the base layer. Native topsoil, excavated during new channel construction, was used to cap the base layer. Because the amount of fill was not adequate to fill the old channel completely, a series of five ponds with earthen plugs (capped with meadow sod at the downstream end), were installed in the old channel. Filled areas between the earthen plugs were planted with meadow sod plugs, as was the material stockpile area located at the northwest corner of the construction area. These improvements are illustrated on Figure 2.

The goal of this project was to abandon the existing incised G4 channel, and construct a new C4 channel type within Cookhouse Meadow. This effectively raised the elevation of the stream channel by approximately 6 to 10 feet, and reduced the relative channel bed to bank height so that the riffle elevation is 1 to 1.5 feet from the top of bank. This conversion in channel type is expected to achieve the following two objectives.

1. Restore stream channel geomorphic function in terms of channel stability, and aquatic habitat features.

2. Restore floodplain connectivity which will;
   - Increase meadow surface flooding frequency, so that the surface floods two out of every three years on average,

- Restore seasonal ground water levels and associated capillary rise in the central meadow to support growth of moist and wet meadow vegetation through August 15 under average hydrologic conditions, and reverse the trend of dry meadow grasses and conifer invasion.

A monitoring plan was completed for the project that identified the monitoring questions we intend to answer to measure whether or not project goals/objectives were met. (Oehrli, 2006) The monitoring questions related to project goals/objectives are described below:

Goal: Convert channel in Cookhouse Meadow from a Rosgen G4 channel to a Rosgen C4 channel.

Objective 1: Restore channel stability and improve aquatic habitat.

- Is the channel maintaining the desired characteristics of either a C4 or E4 channel, as defined by the Rosgen stream channel classification system? Is the channel evolving from the constructed C4 stream type to an E4 channel type?

Objective 2: Restore channel/floodplain connectivity and subsequent riparian habitat response.

- Is the meadow surface flooding at the 1.5 year reoccurrence interval frequency?
- Is the ground water level in the central meadow sufficiently shallow to support the colonization and maintenance of desired meadow species?
- Are dry meadow grass species and conifers in the central meadow being out competed and replaced with desired meadow species indicative of wetter hydrologic conditions?

Watershed History

Cookhouse Meadow is a glacially formed meadow and the lowest in a chain of four glacial meadows within the Big Meadow Creek Watershed. The channel through the meadow became deeply incised, a classic reflection of cumulative land use impacts. In a cumulative effects scenario it is often difficult to single out the actual triggering mechanism that caused incision, rather it is often the combination of impacts. In this case it is the combination of human land use and the timing of damaging winter floods (1963, 64) that set the stage for gully channel formation in Cookhouse. A plausible disturbance hypothesis is 1) direct impacts to the channel from many decades of livestock grazing, 2) impacts to the channel from highway construction, 3) damaging winter floods that occurred shortly after the highway was constructed, 4) post-flood clearing and snagging operations in the creek itself. The cumulative effects of these actions weakened the resiliency of the meadow-channel system to a point were the creek could no longer maintain its cross section form and connection to the surrounding floodplain. Big Meadow creek through Cookhouse began to erode both vertically and horizontally, creating a deeply incised (6 to 12 feet) gully channel for a distance of 1,770 feet.

Figure 1. Location map for Cookhouse Meadow Restoration Project

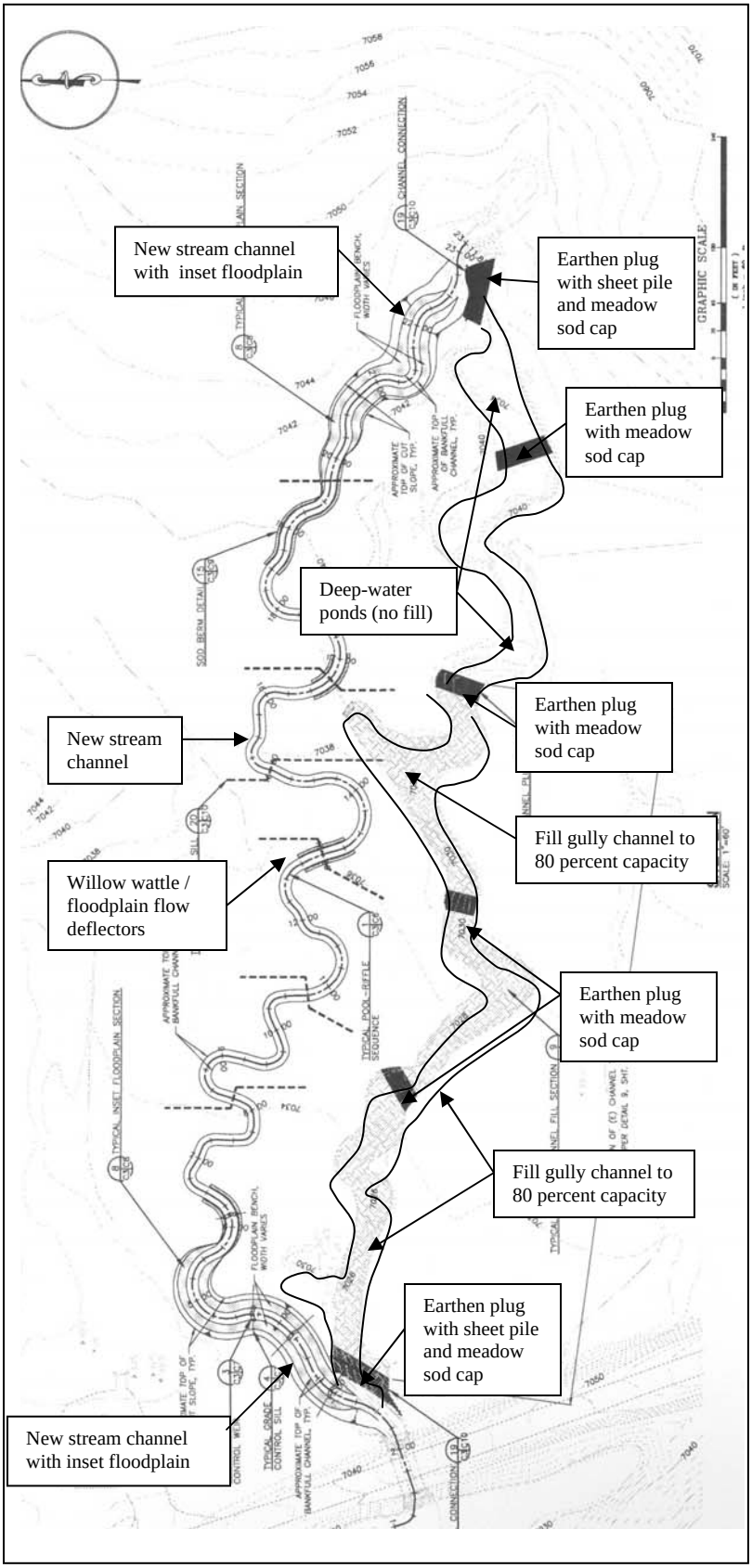

Figure 2. Engineering site plan of Cookhouse Meadow Restoration Project

We estimate the primary period of gully erosion to have occurred between 1968 and 1981, as displayed in Figure 3 below.

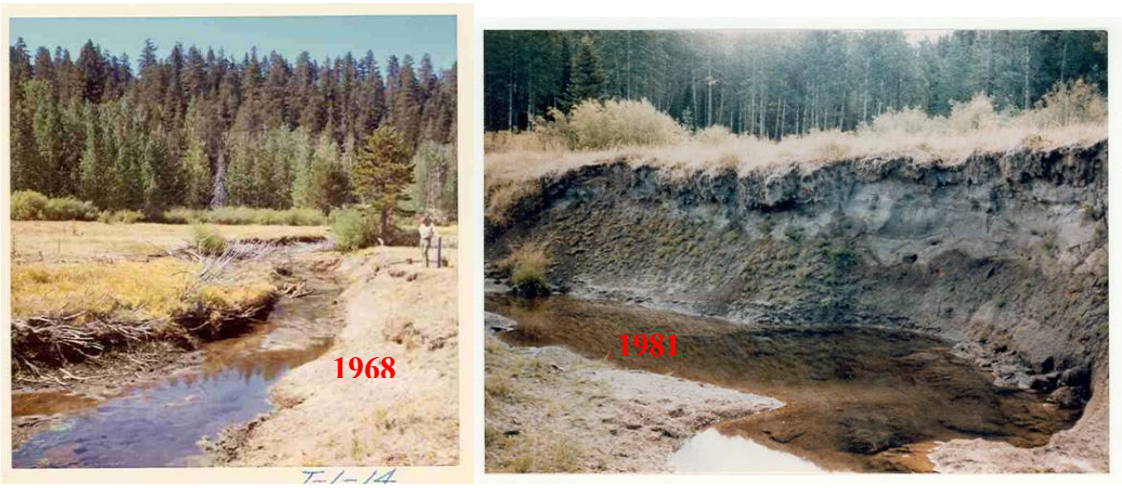

FIGURE 3. Photos of changes in stream channel condition in Cookhouse Meadow from 1968 to 1981

In 1982, the Forest Service implemented restoration actions including crib wall construction, gully wall reshaping, riparian plantings, and rock check dam grade control in the stream. Because of these actions, the gully corridor became heavily vegetated and channel erosion decreased. However, there were still occasional gully wall failures. Figure 4 below displays a 25 foot long bank failure that occurred along the outside of a meander bend during the spring snowmelt flood in 2000. Approximately 2 feet of the 7 foot high stream bank at this location was eroded during this spring runoff period.

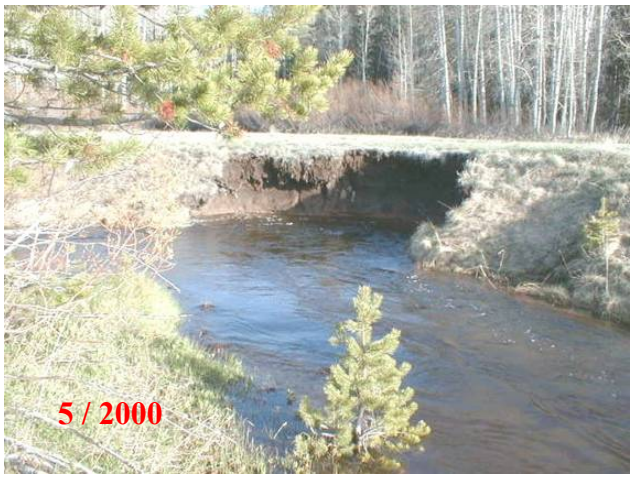

Figure 4. Photo of localized gully wall failure in Cookhouse Meadow, 5/2000.

In addition to these episodic bank failure events in the Cookhouse reach, the disconnected channel was still not able to flood into the meadow during high flow events, and therefore had little or no capacity to deposit fine sediment and nutrients generated in the watershed above.

Episodic gully wall failure is a long-term chronic impact, and LTBMU restoration staff estimated that it could take 20 to 50 years for the system to reach an equilibrium condition, without further intervention. In 2001, the LTBMU began the planning process to implement a more comprehensive project to restore stream channel and floodplain function within this reach. This report is the first attempt to evaluate the success of that project, described in the beginning of this section.

II. MONITORING APPROACH

The monitoring approach used by the LTBMU was to measure the hydrologic response of both the surface water and groundwater, the vegetation response within the meadow and along the new channel, as well as the physical characteristics of the new channel. The methodology used to collect and analyze these parameters, as it relates to the specific project objectives and monitoring questions, is presented below.

Goal: Convert channel in Cookhouse Meadow from a Rosgen G4 channel to a Rosgen C4 channel.

Objective 1: Restore channel stability and improve aquatic habitat.

- Is the channel maintaining the desired characteristics of either a C4 or E4 channel, as defined by the Rosgen stream channel classification system? Is the channel evolving from the constructed C4 stream type to an E4 channel type?

<u>Channel Morphology</u>

Measurements of channel morphology were obtained through cross section measurements and topographic surveys. Sinuosity was measured using GIS data, width depth ratios and entrenchment ratios were calculated from three cross sections measured on the old channel and five cross sections measured at fast water reaches within the new channel (see Appendix A, Figure A2).

<u>Channel Stability and Habitat</u>

Channel habitat and stability were evaluated using a combination of measured and observed data (Appendix A, Figure A2). Longitudinal profiles were measured at three reaches of varying length, totaling 555 feet. Reach #1 is located at the upstream end of the restoration projects and is 160 feet long. Reach #2 is 205 feet long and is located near the middle of the new channel. Reach #3 is 190 feet long and is located near the downstream end of the new channel. Within these reaches 12 cross-sections were measured (4 in each of the 3 reaches). These measurements were taken in 2006 and 2008 data. All twelve cross sections were also re-surveyed after peak spring runoff flows in 2007. Observations of channel habitat feature development are also included in this analysis.

Pebble counts were collected at six riffles within the long profile reaches, in 2006 and 2008. At each pebble count location, one hundred particles were randomly selected and size class determined. Pebble counts were conducted near established channel cross sections

Objective 2: Restore channel/floodplain connectivity and subsequent riparian habitat response.

- Is the meadow surface flooding at the 1.5 year reoccurrence interval frequency?
- Is the ground water level in the central meadow sufficiently shallow to support the colonization and maintenance of desired meadow species?
- Are dry meadow grass species and conifers in the central meadow being out competed and replaced with desired meadow species indicative of wetter hydrologic conditions?

Surface Flow Response and Overbank Flooding

As articulated in the first monitoring question, the surface water response in terms of frequency of over bank flooding, as a result of constructing the new stream channel with a reduced flow capacity, was measured with a pressure transducer for measuring stage. In the spring of 2007 a pressure transducer was installed near the downstream end of the new channel. This device measures the depth of the water in the channel every 0.5 hours. If the reading for the water depth has changed greater than 0.01 feet, then the depth is recorded by the transducer. If the measured depth is the same as the previous measurement, then the depth is not recorded.

Surface flow was also measured at the pressure transducer site to establish a stage/discharge relationship. Flow was measured using the methods described in USDA General Technical Report RM-245+. Surface flow measurements used to establish this stage/discharge relationship were measured from the spring of 2007 through the spring of 2008. The measured stage is then compared to the floodplain elevation to determine the timing and duration of when overbank flows are occurring. Field visits were also made during high flow periods to help confirm when, and for how long the creek began to leave its banks. The stage discharge relationship is then used to compare the flows that occur at this stage, to the design flows for the constructed stream channel, and therefore whether overbank flows can be expected to occur at the design frequency.

Groundwater response

As articulated in the second bullet, the groundwater response from raising the elevation of the stream channel as it passes through cookhouse meadow was measured through a series of twelve groundwater monitoring wells. The locations of these wells are illustrated on the figure presented in Appendix B. The ground water level in the meadow has been recorded about once a month in these wells since December of 2002. This data measures changes in depth to the water table, as a result of the restoration project. The data from the twelve wells was analyzed to determine; 1) did the project change

groundwater to stream channel interactions, and 2) did the project change groundwater levels throughout the meadow relative to water year type and time of year.

To compare groundwater to stream channel interactions, two transects of groundwater monitoring wells were analyzed, one in the upper part of the meadow (wells 4, 5a, 6 and 7), and one in the lower part of the meadow (wells 11, 12 and 13a). The locations of these wells are displayed in Appendix E, Figure 29. The data from these transects are used to graphically display the influence raising the channel bed elevation has on adjacent groundwater levels.

Groundwater data was also used to map groundwater levels throughout the meadow, to compare groundwater changes for different times of the year, relative to water year type. Groundwater levels between measured wells is estimated based on topography and characteristic ground water hydraulic tendencies**.** Water year type was determined using the Echo Peak SNOTEL site that measures the overall precipitation and water content of the snow (also know as the snow water equivalent throughout the winter.

Vegetation Response

As described in question 3 and 4, the riparian vegetation response throughout the meadow, and along the stream banks was evaluated using a combination of photo point monitoring and vegetation transects.

A total of 13 photo points were established in 2004 and have been repeated at least once each year through 2008. The location of these photo points are also displayed in Appendix B. This series of photos were taken in the same location, typically during July or August of each year, to visually document vegetation change. Two of the photo points are located at higher elevations around the meadow, to document the overall density and extent of willow cover in the meadow. All photo point locations are documented in UTM coordinates and the directions that the camera is pointing is recorded in degrees from true north. Most (but not all) of the photo points are monumented with an aluminum post stamped with the photo point number on top. Photos taken at meadow level are used to document changes in types and density of vegetation at a smaller scale. Only two of these photo points are presented in this report.

The Weixelman plot transect protocol (USFS Region 5 Range Monitoring Project 2005 Report) was used to evaluate question 3, the overall status and trend of the riparian vegetation community throughout Cookhouse Meadow. This evaluation was conducted at five 10 by 25 meter plots in Cookhouse Meadow. Pre implementation data was collected in 2004 and 2005 and post implementation in 2007. Plant species composition, cover, and rooting depth were measured to determine the condition, classification, and trend of the meadow. Data collected to date has not been analyzed due to faulty analysis software applications. It is anticipated that by summer of 2009 the software problems will be resolved by the protocol developers, and an addendum to this report with that analysis will be produced at that time**.**

A modified Greenline method as described in "Monitoring the Vegetation Resources in Riparian Areas" (USDA General Technical Report RMRS-GTR-47, 2000) was used to answer question 4, the success of planted material along the new stream channel as defined by percent cover of live sod, and percent of live willow stakes and mats. These measurements were taken along the edge of the new channel in August, September and October of 2005, again in June and August of 2006, and lastly in June of 2007. The location of this Greenline reach is displayed in Appendix A, Figure A1. Two 1000 meter long transects were established, one on each bank, along the new channel at the bankfull elevation. Measurements were taken along this transect within 1 meter square plots every 10 meters. Because of the high degree of vegetation reestablishment success documented in 2006, and visually observed continued improvement in 2007, data points were only collected every 100 meters in 2007.

III. MONITORING RESULTS

Precipitation Regime

As part of analyzing the results of surface flow and groundwater monitoring, the precipitation regime was characterized by utilizing data for the Echo Peak SNOTEL site, which measures the snow water equivalent (SWE) throughout the winter. This data was used to determine the relative precipitation for any given water year, compared to the "average" for the period of record. The period of record used to calculate the "average" was, 1971 to 2000. SNOTEL information is displayed in Figure 5, and the results are incorporated into the discussion below.

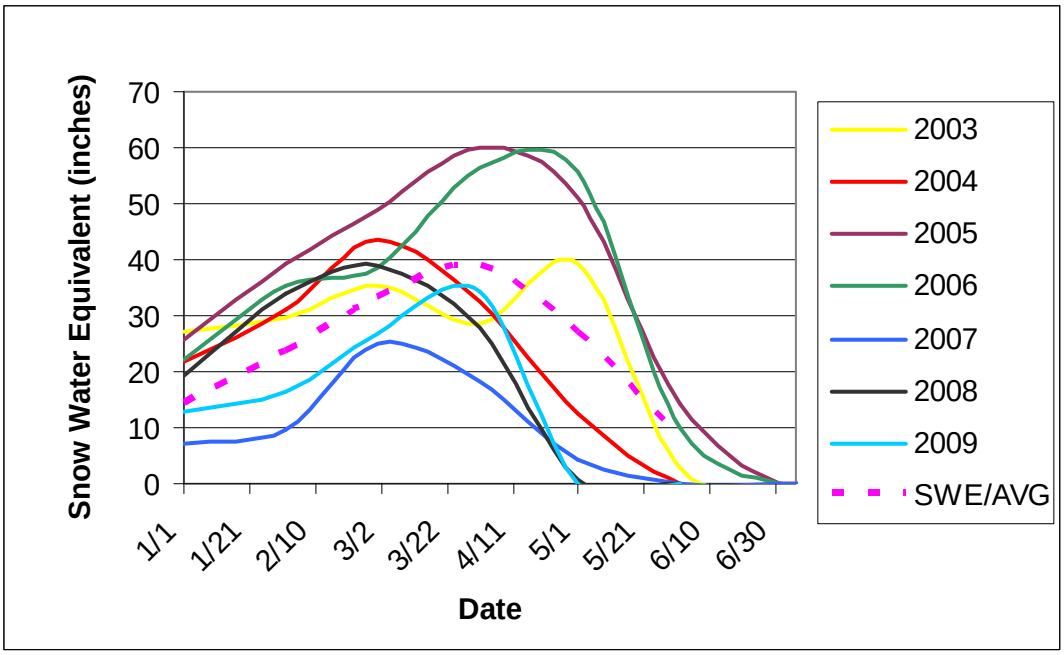

Figure 5. Snow water equivalent (SWE) for 2003 to 2009 as measured at the Echo Peak SNOTEL site. The SNOTEL site is located 5 miles to the northwest of Cookhouse Meadow.

Figure 5 illustrates that the pre-project years of 2003 and 2004 were below the period of record average for this site, 73% and 83% of average respectively. The two years during which the project was constructed, 2005 and 2006, were well above average, 154% and 144% respectively. All three post project years, 2007, 2008, and 2009 were below average, 46%, 71%, and 88% respectively. However as described later in this report, even though 2009 was a below average year, three major rain-on-snow events in May of 2009, resulted in over bank flows over a three week period.

Goal: Convert channel in Cookhouse Meadow from a Rosgen G4 channel to a Rosgen C4 channel.

Objective 1: Restore channel stability and improve aquatic habitat.

- Is the channel maintaining the desired characteristics of either a C4 or E4 channel, as defined by the Rosgen stream channel classification system? Is the channel evolving from the constructed C4 stream type to an E4 channel type?

Channel Conversion

As was described in the methodology, a comparison between the old and new channel was performed using data collected for three cross sections measured on the old channel and five cross sections measured on the new channel. The width depth ratios and entrenchment ratios were calculated using the measured cross section data, including notes identifying the location of bankfull indicators. Only cross sections established at fast water sections were utilized, since bankfull indicators are difficult to identify in slow water sections. These calculations are presented in Table 1 below.

The width/depth ratio is defined as the bankfull width divided by the average channel depth (from the bankfull elevation to the channel bed). Bankfull width is the width of the channel that contains the 2 to 5 year flow events, and is determined from bankfull indicators identified in the field such as flow scour lines, topography, and changes in vegetation. The width/depth ratio is key to understanding the distribution of available energy within a channel, and the ability of various discharges occurring within the channel to move sediment. This variable is considered to be one of the most sensitive and positive indicator of trends in channel instability (Rosgen, 1996).

The entrenchment ratio is calculated as the width of the flood prone area at a height of twice the bankfull depth, divided by the bankfull width. Entrenchment is defined as the vertical containment of a river, and the degree to which it is incised in the valley floor.

Sinuosity was measured from topographic channel design surveys, and is a measure of the ratio of valley length vs. channel length, and is described as the ratio of valley slope to channel slope. As channel gradient and dominant particle size decreases, there is generally a corresponding increase in sinuosity.

The old channel in Cookhouse meadow was classified as a Rosgen G4 channel type. According to the Rosgen classification system (Rosgen, 1996) this channel type is

characterized as deeply incised in depositional material comprised of unconsolidated heterogenous mixture of gravel some small cobble, and sand. This channel type is very unstable and generally has a very low width/depth ratio (<12), highly entrenched (entrenchment ratio of <1.4), and moderate sinuosity (>1.2). Bank erosion and bedload transport rates are typically high, and observed effects are vertical and lateral instability. The measurements taken in the old channel corroborate this channel type. The mean value for width depth ratio was 10.9, entrenchment ratio was 2.3, and sinuosity was 1.44.

The new channel was designed to evolve into a channel form to fit the description of a Rosgen C4 and/or E4 channel, depending on the specific reach of the channel. A C4 channel is described as a slightly entrenched, meandering, gravel-dominated, riffle/pool channel with a well developed floodplain. This channel type is susceptible to shifts in both lateral and vertical stability caused by direct channel disturbance and changes in the flow and sediment regimes of the contributing watershed. These channels generally have a moderate to high width/depth ratio (>12), entrenchment ratio of >2.2, and moderate to high sinuosity (>1.2). E4 channel types are classified as systems with high sinuosity, gentle to moderately steep channel gradients, with very low channel width/depth ratios. These stream types are hydraulically efficient channel forms and they maintain a high sediment transport capacity. The narrow and relatively deep channels maintain a high resistance to plan form adjustment which results in channel stability without significant down cutting. These channels are very stable unless the stream banks are disturbed, and significant changes in sediment supply and/or stream flow occur. These channels generally have a very low width/depth ratio (<12), slightly entrenched (entrenchment ratio of >2.2), and high sinuosity (>1.5). The main difference between C and E channel types is reflected by width/depth ratios, since the other geomorphic characteristics are very similar between these two channel types.

The measurements taken in the new channel indicate that the new channel currently demonstrates the characteristics of a C channel in terms of width/depth ratio, with the measured mean at 15.7. This represents an increase in width/depth ratio compared to the old channel, but is considered to be neutral change. Sinuosity was measured at 1.57 (which fits the characteristic of both E and C channels, and represents a 9% increase compared to the old channel and is also considered to be a neutral change Entrenchment ratios ranged between 2.5 and 18.3, with a mean of 9.1, which also fits the description for both C and E channels.

In addition, three of the new channel cross sections used for this analysis (XS 1, 3, 12) represent relatively small sections of the entire reach located at the upper and lower ends (500 feet, or approximately 21% of the restored reach) . This part of the channel was designed to be more entrenched to tie in to upstream and downstream reaches. The remaining two cross sections (XS 5 and 7) represent the remaining 1900 feet, or 79% of the channel reach. By applying these percentages to the data, it is estimated that the median overall entrenchment ratio for the new channel is around 15, a 7 fold decrease in entrenchment. This parameter represents the most significant, and positive change in channel morphology as a result of the project.

Table 1: Entrenchment and Width Depth Ratios for Old and New Channel

	Entrenchment Ratio	Width/depth ratio
OLD Channel		
XS1	2.72	11.52
XS2	2.46	17.13
XS3	1.67	3.93
Mean	**2.28**	**10.86**
Median	2.46	11.52
Std. Deviation	0.55	6.62
NEW Channel		
XS1	2.91	20.54
XS3	3.81	13.05
XS5	17.7	16.26
XS7	18.35	13.55
XS12	2.52	15.12
Mean	**9.06**	**15.70**
Median	3.81	15.12
Std. Deviation	8.20	2.99

- Is the channel maintaining the desired characteristics of either a C4 or E4 channel, as defined by the Rosgen stream channel classification system? Is the channel evolving from the constructed C4 stream type to an E4 channel type?

Channel Morphology

As described in the methodology, three longitudinal profiles, and twelve cross section measurements were used to determine if the channel is maintaining the desired geomorphic characteristics of either a "C" or "E" Rosgen stream channel type since construction. Most of the 12 cross sections (as displayed in figures E1 through E12 in Appendix E), indicate that little to no change has occurred in the new channel between 2006 and 2008. Out of the 12 cross sections, only two cross sections indicate noticeable change. In XS2 (located in a pool) a lateral bar is forming on the inside bend of a meander, resulting in a total of 1.7 feet of aggradation on the river left side of this pool. In XS6 (also located in a pool), a half foot of scour has occurred on the river right side of the pool. Neither of these changes indicates channel instability, but rather reflects the evolution of desired channel features as described in the previous section. None of the cross sections measured at the riffles illustrate degradation, indicating that the channel is currently both vertically and horizontally stable, and that the channel is currently still reflecting the width/depth ratios of the constructed "C" stream channel type.

The three longitudinal profiles (Appendix F) also show that the channel is maintaining vertical stability, and that the ratio of pools and riffles has changed slightly (6 pools in 2006 and 8 pools in 2008). In the uppermost longitudinal profile (Reach 1, Figure F1) aggradation has occurred in a pool located near the upstream end of the project. Approximately 0.5 to 1.7 feet of aggradation has occurred over a 20 foot length. Further downstream in Reach 2 another pool has deepened by approximately one foot. . In the most downstream longitudinal profile (Reach 3, Figure F3), a series of channel evolution changes have occurred as a result of the weir that marks the start of the profile. A 0.7 foot deep and 6 foot long plunge pool has formed below this weir. A new gravel bar has formed below this pool (about .7 feet high and 16 feet long). Below this newly formed gravel bar an existing pool has deepened and another pool has formed.

Visual observations were also documented as part of the assessment of whether the channel is beginning to evolve from a C to and E channel type. The following are observations taken from a field visit of the project reach on May 28, 2009.

- The design channel as constructed was uniformly flat across the channel bed. The first year after construction the thalweg in fast water sections was nearly in the center of the channel. Movement and deposition of bed material, has caused the thalweg to shift closer to the stream channel banks in some locations. It is estimated that the shifting of thalweg location is occurring in more than half of the fast water sections in the new channel. Four areas were observed where scour pools are starting to form underneath the channel bank as a result of thalweg shifting.

- Movement and deposition of bed material is resulting in some amount of point bar development in about half the pools located on meanders (the bends in the channel). Consequently pool depth is increasing on the outside bends of these meanders (corner pool development). Approximately five alternate bars are also beginning to form in the new channel.

The changes observed in channel features during this field visit indicate that the channel is starting to develop a variety of more diverse channel habitat features in the 2.5 years since the project was constructed, however it is too early to tell whether the channel is starting the process of shifting from a C to and E channel type. Visual observations note that all four grade control weirs have maintained their vertical and horizontal integrity in the 2.5 years since project construction, including the high flow events during the spring of 2009.

Channel Materials - Particle Size distribution

While channel bed and bank materials influence the cross-sectional form, plan-view, and longitudinal profile of rivers; they also determine the extent of sediment transport and provide the means of resistance to hydraulic stress. Additionally, an assessment of the nature and distribution of channel materials is critical for interpreting the biological function and stability of rivers. The channel in Cookhouse meadow was designed to

maintain a median particle size in the channel bed for gravels (identified as a 4 in the Rosgen classification system).

Particle size counts taken at six cross sections located in riffles (XS1, 3, 5, 7, 10, 12) were aggregated to calculate the median particle size in the channel for both 2006 and 2008. The median particle size (D50) was 21mm in 2006, and 27mm in 2008. Both of these sizes fit within the range defined for coarse gravels, therefore the channel is maintaining the desired condition related to channel bed material particle size.

Table 2 displays this aggregate particle size distribution for each year. This data illustrates that there has been a relatively minor shift in the percent of relative particle size distribution. The percent of gravels has decreased from 77% to 64%. Concurrently the percent of sand/silts has increased from 10 to 14%, and the percent of cobbles has increased from 13 to 22%. This is considered to be a neutral level of change.

Size/range	**Class**	**2006 %**	**2008 %**
1-2 mm	Sand/silt	10	14
>2-64 mm	gravel	77	64
>64-256 mm	Cobble	13	22
>256 mm	boulder	0	0

Table 2: Percent particles size distribution for 2006 and 2008

Objective 2: Restore channel/floodplain Connectivity and subsequent riparian habitat response.

- Is the meadow surface flooding at the 1.5 year re-occurrence interval frequency?

The pressure transducer for measuring stream stage was installed after the peak spring flows in 2007, and data recorded from that point indicates there were no out of bank events during the remainder of the 2007 water year. There was also no evidence of out of bank flows observed during field visits during the spring of 2007, before the transducer was installed. Based on snowtel data, collected at Echo Peak, the 2007 water year was considered to be a well below average precipitation year (46% of average). In May of 2008, Big Meadow Creek came out of its banks and flooded Cookhouse Meadow for the first time since the restoration project was completed. Water year 2008 was also considered to be below average (71% of average).

Figure 6, displays estimated flows during spring of 2008, based on the measured stage at this site. Meadow surface flooding was observed to occur when stage levels recorded by the pressure transducer was at 1.4 feet. Based on the stage/discharge relationship developed at this site, the flow that occurs at this stage is 26 cfs. Out of bank flows did not occur at the site where the pressure transducer is located, but was visually observed at several points along the stream. It is estimated that overbank flows at this stage occurred along approximately 10% of the channel, with flows extending 20 to 40 feet out into the

floodplain. The bankfull design for this channel was 30 cfs, so the observed bankfull flow is very close to design flows.

Modest flooding (peak flows did not exceed 30 cfs) occurred five separate times over a six day period in the spring of 2008 (Figure 6).

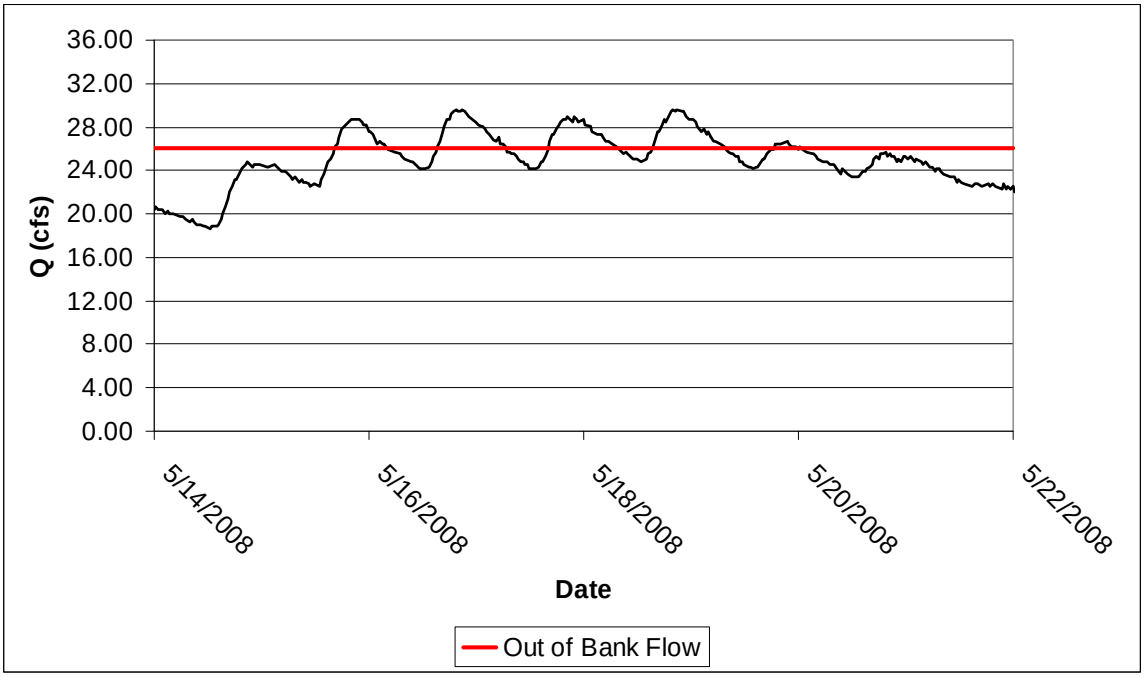

Figure 6. Peak Flow in Big Meadow Creek - 2008**.**

In May of 2009, Big Meadow Creek came out of its banks and flooded Cookhouse Meadow almost continuously from May 1 through May 21st. Water year 2009 was also considered to be below average (88%) but experienced several large rain on snow events during the month of May.

Figure 7, displays estimated flows during spring of 2009, based on the measured stage at this site. Once again meadow surface flooding was observed to occur when stage levels recorded by the pressure transducer was at 1.4 feet. The maximum stage observed during this period was 1.7 feet with an estimated Q of 34.7 cfs.

From field visits during this period, it is estimated that about 50 to 70 % of the meadow surface was flooded, with out-of-bank flows occurring along about 50% of the new channel. During a field visit after these peak flows, observations noted deposition of fine sediment throughout much of the flooded area, along with accumulations of pine needles, sticks, and other detritus. Since 2007 through 2009 are all considered to be a below average year water years it appears that meadow flooding is likely to continue at the 1.5 year recurrence interval.

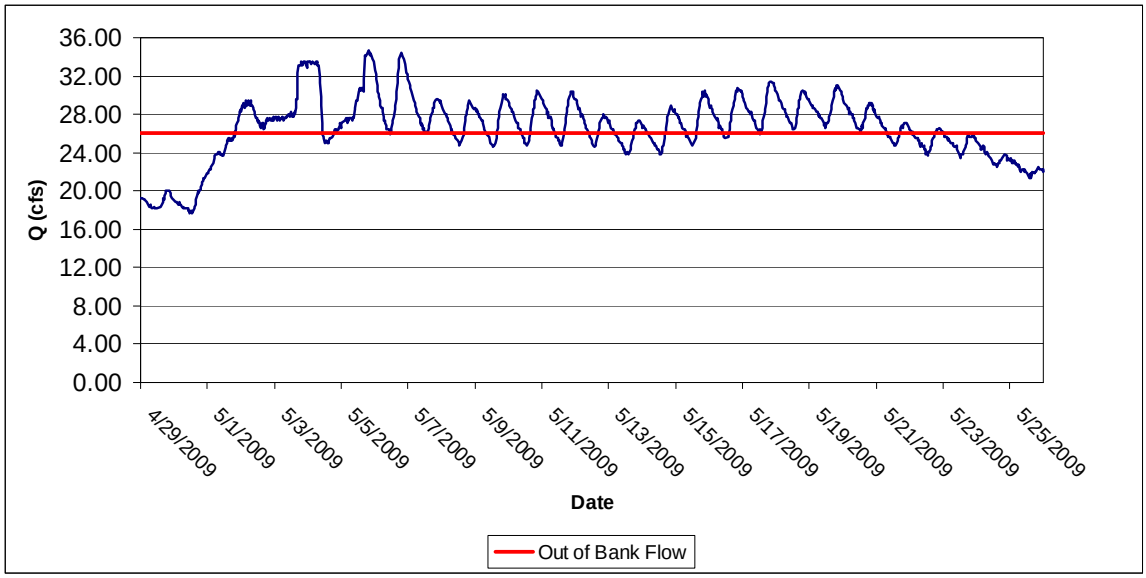

Figure 7. Peak flow in Big Meadow Creek - 2009

- Is the ground water level in the central meadow sufficiently shallow to support the colonization and maintenance of desired meadow species?

In order to determine if groundwater levels were sufficiently increased to support the desired vegetation response measured groundwater data was analyzed to determine 1) did the project change groundwater to stream channel interactions, and 2) did the project change groundwater levels throughout the meadow relative to water year type and time of year.

To compare groundwater to stream channel interactions, two transects of groundwater monitoring wells were analyzed, one in the upper part of the meadow (wells 4, 5a, 6 and 7), and one in the lower part of the meadow (wells 11, 12 and 13a). Figure B1 illustrates the location of the monitoring well transects.

Figures B2 and B3 display the average summer groundwater levels at the upper meadow, before and after the project and Figures B4 and B5 display the average summer groundwater levels at the lower meadow, before and after the project. Average summer groundwater levels were calculated by taking the mean of the monthly measurements collected from June through August for the period of record before the project (2003 and 2004), and after the project (2007 and 2008).

It is estimated that groundwater becomes available to plants in Cookhouse meadow when levels reach 4' below the ground surface, assuming a capillary rise of 100 cm. This is a conservative estimate suggested by C. W. Fetter (Fetter, 2001) who proposed 100 cm as the lower end of capillary rise for fine textured soils. The data clearly shows the drawdown of groundwater due to channel bed surface elevation was much greater pre-project than after the project. During the pre-project period, groundwater was drawn down to 5.5 feet below the meadow surface adjacent to channel at the well transect in the lower meadow, and was drawn down to 8 feet below the meadow surface at the well

transect in the upper meadow. Groundwater out in the meadow did not reach the level at which water would become available to plants until 250 feet from the channel in the lower meadow (Figure B2) and 190 feet in the upper meadow (Figure B4). During the post project summer period, groundwater was drawn down to only two feet adjacent to the new channel at the transect of wells in both the lower meadow and the upper meadow (Figures B3 and B5) and groundwater out in the meadow was consistently within 4 feet of the meadow surface along both transects after restoration. Based on the Echo Peak SNOTEL site, all of the years analyzed for this data, both pre project and post project, were below average precipitation years.

Groundwater data was also used to map groundwater levels throughout the meadow, to compare groundwater changes for different times of the year. Groundwater levels between measured wells is estimated based on topography and characteristic ground water hydraulic tendencies It is assumed that the soil in Cookhouse Meadow is homogenous and isotropic to estimate the elevation of the water table between the wells based upon the water surface at the wells along the transect.

Appendix C, Figures C1 through C6, illustrate groundwater levels throughout the project area, from 2003 through 2008. The month groundwater levels were highest for the year are displayed (April or May), as well as the month when the lowest static groundwater levels were reached (August or September). The month in which highest and lowest values were recorded in a year varied, depending on the precipitation regime in that year. Again 2003 and 2004 represent pre-project conditions, and 2007 and 2008 represent post project conditions. In 2005 and 2006 the new channel was constructed, but not yet activated, and irrigation was implemented throughout the site to maintain vegetation establishment.

These graphs illustrate that during spring runoff when the groundwater levels were highest, the area of meadow in which groundwater was available to plants (i.e. 4 feet below the ground surface) was similar throughout the meadow for the period record. The exception to this is adjacent to the pre project channel. Even during peak spring runoff the drawdown effect of the pre project channel reduced groundwater levels below the root zone because the elevation of the old channel bed was 6.5 feet below the surface of the meadow. It is estimated that this drawdown effect extended maybe 50 to 100 feet away from the channel edge, inhibiting vegetation growth in this area even during spring runoff.

These graphs also illustrate that during the late summer months when groundwater reached static lows, the area of meadow that still had groundwater levels available to plants starts to increase in 2005. Both 2005 and 2006 were above average precipitation years, which likely contributed to these higher groundwater levels later in the year. However the data in 2007 and 2008 also illustrate a higher percentage of meadow area with groundwater levels near the root zone compared to the pre-project years, even though the precipitation in both the pre- and post-project years was below average. The amount of increased “wetted” area was approximately 10 % in 2007 and 60% in 2008

located primarily in the western half of the meadow. Groundwater levels next to the new channel stayed well within the root zone throughout the year.

- Are dry meadow grass species and conifers in the central meadow being out competed and replaced with desired meadow species indicative of wetter hydrologic conditions?

As stated in the methodology section we are unable to evaluate project success in terms of species composition at this time, due to a current problem with the analysis software for evaluating the data collected using the Weixelman transect protocol. These results will be provided in the future as an addendum to this report. However some information can be gained from examination of photopoints.

While there have only been two growing seasons since the restoration work was completed, photo points seem to indicate a greener more robust meadow after restoration than before (Appendix D, Figure D1,D2)). In Figure D1, taken in July 2004 before restoration, the meadow appears to be well on its way to drying out for the season with shorter, less dense meadow vegetation. Comparing this to Figure D2, a photo taken in July (the same month) of 2008, the meadow seems much greener with taller and denser meadow vegetation.

Another change that can be seen in the photo point documentation is a trend for some of the lodgepole pines to be dying along the old channel and along the edge of the meadow (Figures D3,D4). The most significant die off is along the old channel where there now exist a series of ponds. This die off is likely due to the increased extent and duration of groundwater elevations as a result of the project. This is a desired outcome, as the vegetation community is evolving to desired wet meadow species.

- What is the response of planted vegetation in the project such as sod along the new channel, willow stakes and willow wattles?

The data collected using a modified Greenline method was analyzed to evaluate the success of planted material along the new stream channel as defined by percent cover of live sod, and percent of live willow stakes and mats. These measurements were taken along the edge of the new channel in August, September and October of 2005 and again in June and August of 2006, and lastly in June of 2007. The data is presented in Table 3 below.

Monitoring Date	% Sod Cover	% of Willow Stakes Sprouting	% Living Willow Mats
8/31/2005	50%	21%	79%
9/16/2005	57%	38%	91%
10/06/2005	66%	39%	90%
6/5/2006	69%	59%	43%
8/30/2006	88%	86%	91%
6/6/2007	85%	100%	No Data

Table 3. Greenline vegetation monitoring along the stream banks of the new channel.

Monitoring of vegetation along the new channel showed a high success rate. Sod cover was initially measured at 50% along the new channel in August of 2005 and increased to 88% cover by August of the following year, and maintained at 85% in 2007. Looking at the same dates for the percent of willow stakes that are sprouting, we see an increase from 21% initially to 86% sprouting the following year, and 100% in 2007. The willow mats along the channel also had a high success rate from the initial monitoring in August of 2006 with 79% sprouting. The following year that percentage increased to 91%. Willow mats were not captured in the 2007 data because of a change in sampling frequency (see methodology). This change in sampling frequency was a conscious decision based on the high degree of success documented in the previous year, and the obvious visual improvements in vegetation robustness observed during the 2007 monitoring effort. (Note * - The anomalous low value recorded for willow mats on 6/5/2006 is believed to be either a result of sampling error, or late spring budding.) The success of the vegetation established at an early stage along the banks is an important part of stabilizing a newly constructed stream channel.

IV. CONCLUSIONS AND RECOMMENDATIONS

While it has only been two and half years since the completion of restoration work on Big Meadow Creek at Cookhouse Meadow, we are starting to see dramatic results.

As stated in the introduction, the goal of this project was to abandon the existing incised G4 channel, and construct a new C4 channel type within Cookhouse Meadow. This effectively raised the surface water elevation of the stream channel by approximately 6 to 10 feet, and reduced the relative channel bed to bank height so that the riffle elevation is 1 to 1.5 feet from the top of bank. This conversion in channel type was expected to achieve the following two objectives.

1) Restore floodplain/ connectivity which will;
   - Increase meadow surface flooding frequency, so that the surface floods two out of every three years on average,
   - Restore seasonal ground water levels and associated capillary rise in the central meadow to support growth of moist and wet meadow vegetation through August 15 under average hydrologic conditions, and reverse the trend of dry meadow grasses and conifer invasion.

2) And restore stream channel geomorphic function in terms of channel stability, and aquatic habitat features.

Replacement of the old channel with a new channel successfully converted the channel type from an incised channel, experiencing accelerated bank erosion and effectively dewatering the meadow (“G” Rosgen channel type), to a stable channel form (“C” Rosgen channel type) that is now connected to the adjacent floodplain.

Prior to restoration out of bank flows had not occurred in this meadow for approximately 30 years. During the three spring snowmelt seasons that have passed since completion of the restoration work, a relatively small amount of over bank flooding occurred for 6 days in 2008, and a larger amount of over bank flooding (approximately 50% of the meadow) occurred during a 21 day period following rain on snow events in May of 2009. Over bank flooding during the spring of 2009 was observed to have resulted in the deposition of fine sediments and organic detritus throughout the floodplain. All three of these post project years were considered to be below average precipitation years, based on SNOTEL data.

In addition, the restoration project has resulted in dramatic increases in groundwater levels, increasing the duration of available water for meadow vegetation substantially. Based on groundwater data collected throughout the meadow, the increased wetted area with available water for plants during the late summer is estimated to have increased 10% in 2007 and 60% in 2008. Photo points indicate that the meadow vegetation is already responding favorably to both increased groundwater levels and over bank flooding, although quantitative data measuring vegetation response is not available at this time. Quantitative data on stabilizing vegetation planted or salvaged as part of the project (sod harvesting, willow staking, willow mats) was obtained, and indicates a high success rate (approximately 90% survival). This is partially due to initial irrigation efforts during the dry season, as well as changes in groundwater and surface water hydrology.

Channel survey measurements (cross sections and longitudinal profiles) as well as visual observations indicate that the channel is maintaining both horizontal and vertical stability, and is maintaining the desired channel stability and habitat characteristics of a "C" Rosgen stream channel type. Visual observations note that lateral and point bar formation, as well as the development of scour and corner pools are occurring. The desired gravel dominant channel substrate (Rosgen channel bed material classification of "4") is also being maintained.

In conclusion, as compared to the old G4 channel as illustrated in the photos in Figures 3 of this report, the new channel C4 as illustrated in the photos in figures 8 and 9 below, help visually display the desired outcomes of this restoration effort, in terms of channel stability and floodplain connectivity.

At this time there is no additional work that is required in Cookhouse Meadow. The channel is adjusting, but at a rate and in locations that were anticipated and desired. Continued monitoring is planned to document long term benefits and effectiveness of restoration efforts, particularly as manifested by riparian vegetation and wildlife community response. These variables require longer time frames to adequately quantify and assess long term project effects. Pre and post project monitoring of wildlife response related to this project has been conducted through a contractor from 2004 through 2008. A summary of the annual post project results from this wildlife monitoring effort for 2007 and 2008 are presented in the LTBMU Annual Forest Monitoring reports, which can be found along with this report, at http://www.fs.fed.us/r5/ltbmu/publications/. In the

two years post construction very little measurable wildlife community response appears to have occurred, with the exception of an increase in songbird species richness.

Periodic monitoring of hydrologic and geomorphic variables are also planned to continue to assess channel stability and surface water and groundwater response during and after above average precipitation years. As previously stated in this report, an addendum is planned in 2010, to evaluate vegetation plot data that was not able to be analyzed for this report, due to problems with the analysis software. The next full project effectiveness report, to evaluate long term trends, is scheduled for 2013.

Figure 8. Big Meadow Creek through Cookhouse Meadow, August/2008.

Figure 9. Big Meadow Creek through Cookhouse Meadow, August/2008**.** with grade control weir and alternate bar.

References

Oehrli, Craig. 2006. Cookhouse Restoration Project Monitoring Plan. Lake Tahoe Basin Management Unit, South Lake Tahoe, CA.

(Fetter, 2001)??

Rosgen, Dave. 1996. Applied River Morphology. Wildland Hydrology, Pagosa Springs, Colorado.

APPENDIX A

Maps of Monitoring Locations

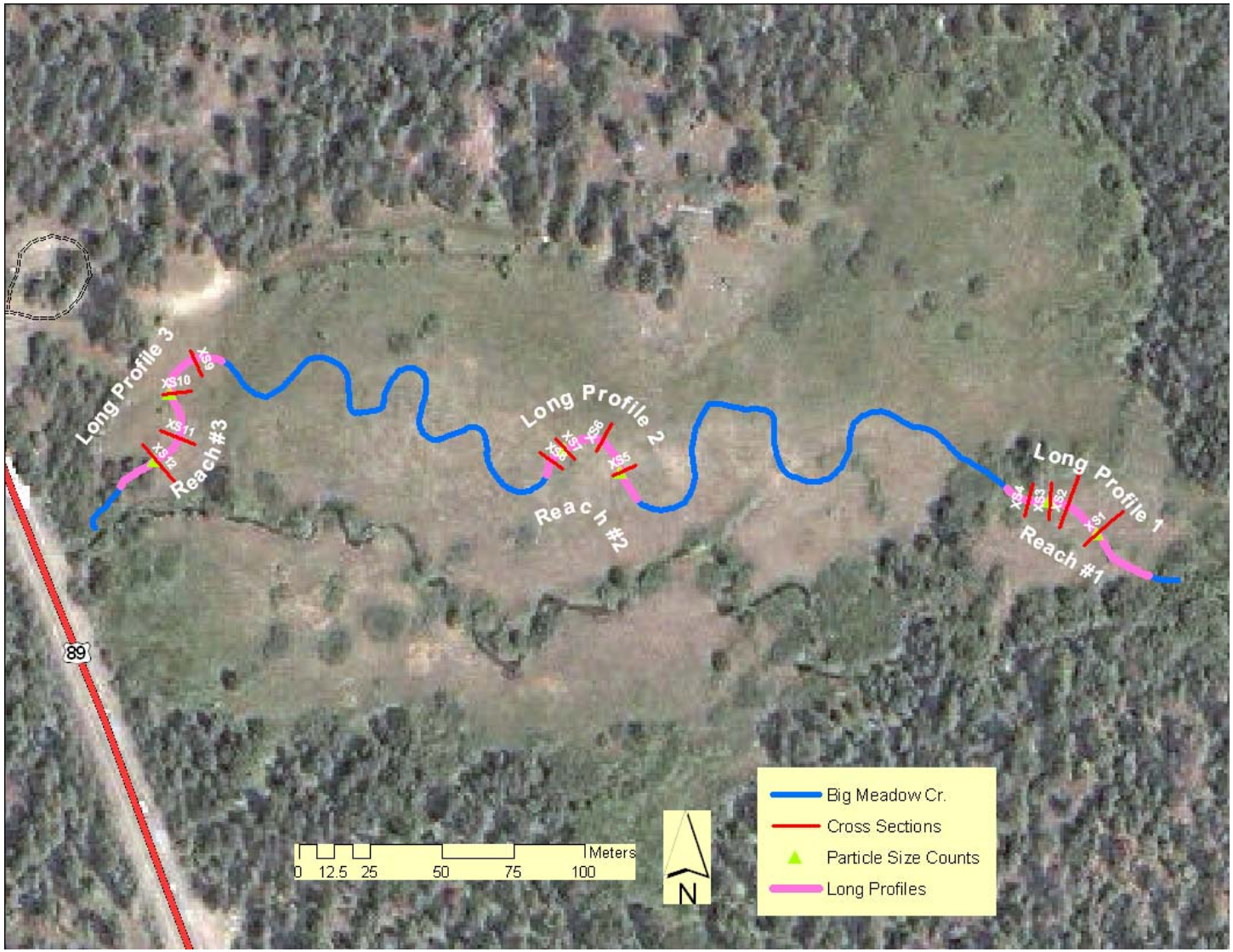

Figure A1. Monitoring locations of channel cross sections, particle counts, and longitudinal profiles.

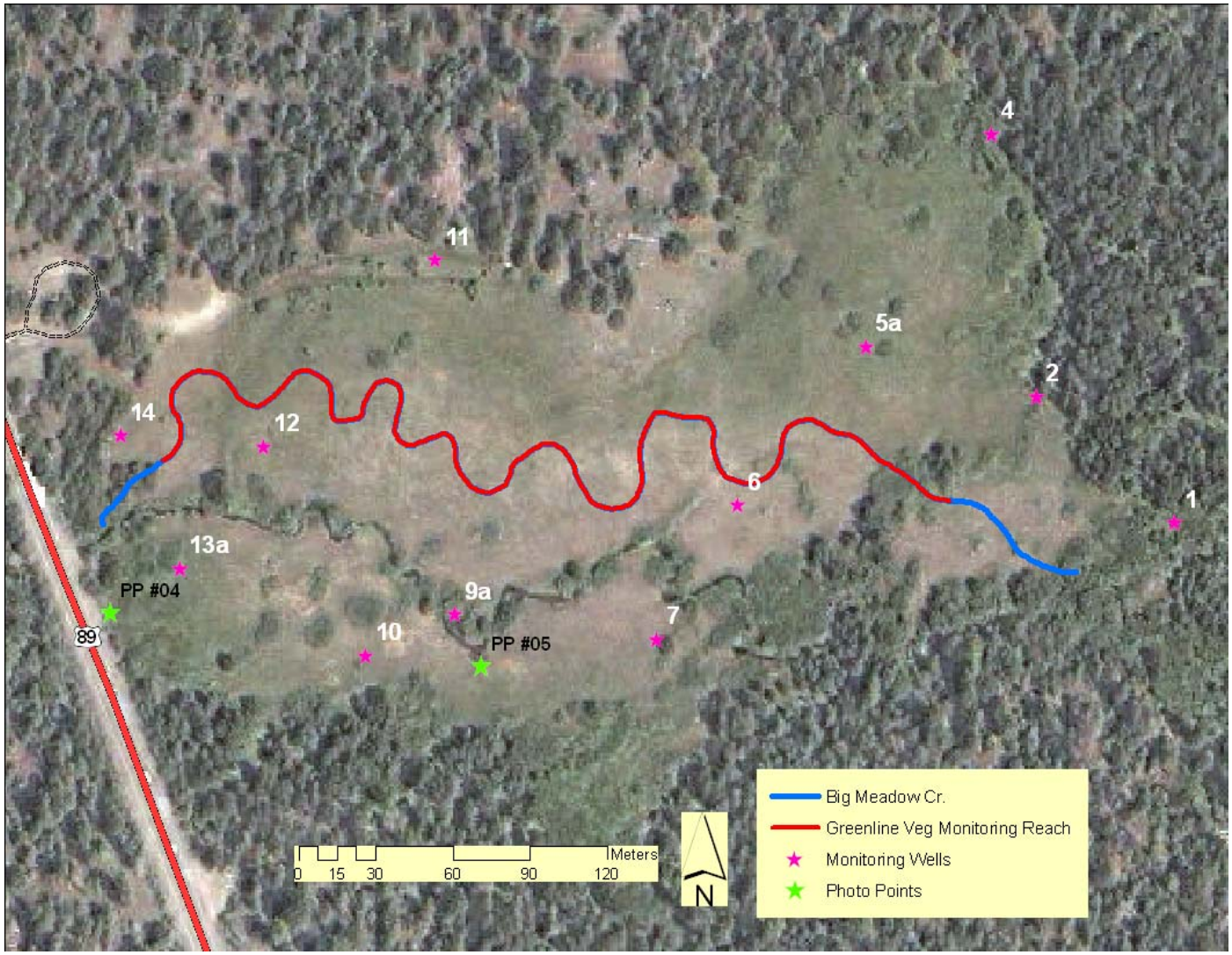

Figure A2. Monitoring locations for Greenline vegetation monitoring reach, groundwater monitoring wells and photo points.

APPENDIX B

Groundwater Transects

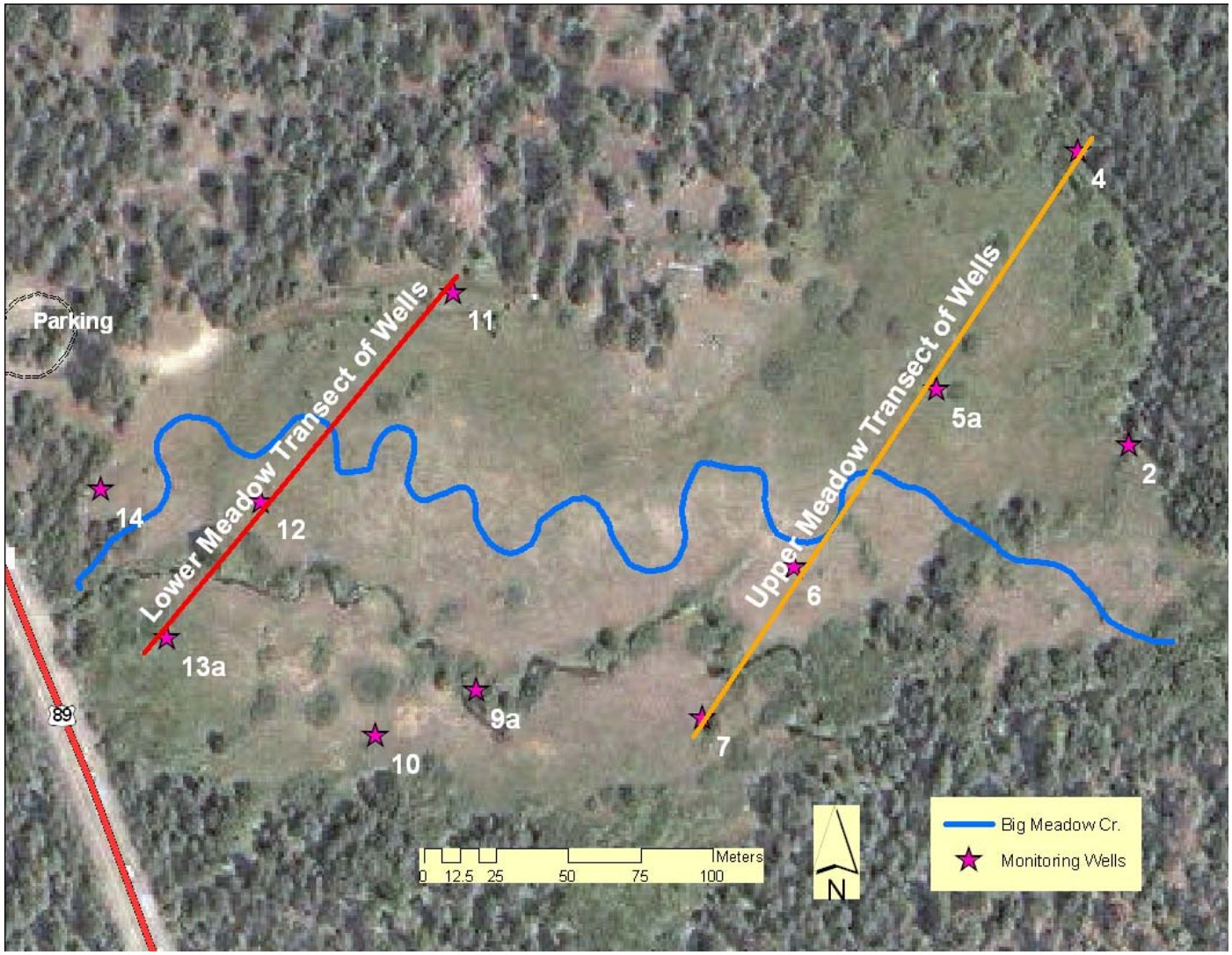

Figure B1. Map showing the two transects of wells that were used to graph the potentiometric surface. The transect of wells in the lower meadow crosses wells 11, 12, and 13. The transect of wells in the upper meadow crosses wells 4, 5a, 6 and 7.

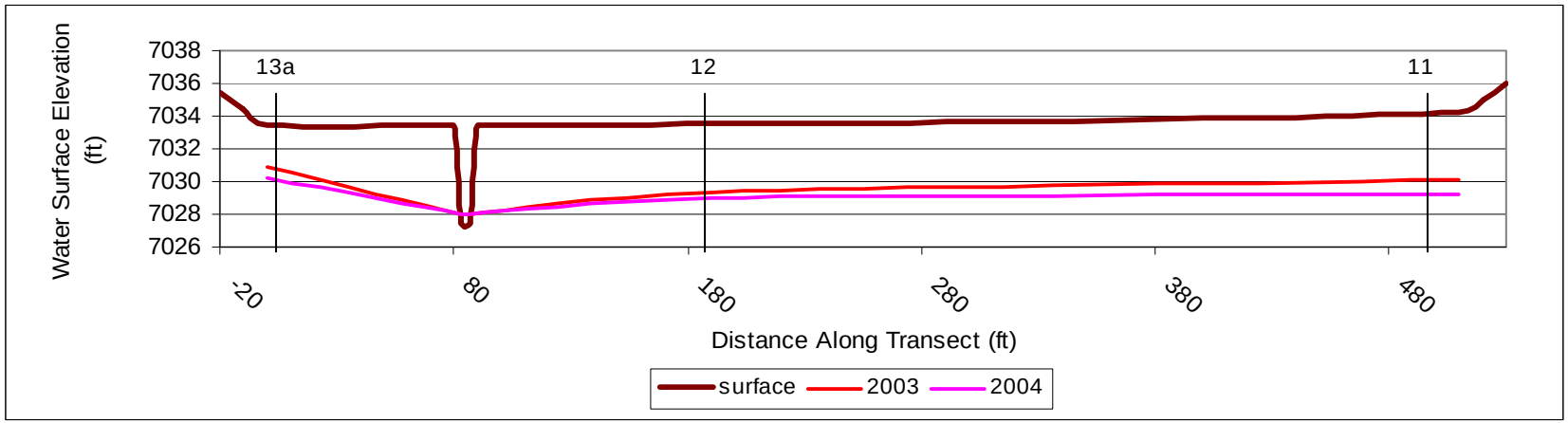

Figure B2. The estimated groundwater surface along a transect at wells 11, 12 and 13a (see Figure B1) in the lower part of Cookhouse Meadow. Each line represents the average groundwater level measured at these three wells in June, July and August in 2003 and 2004 (before the restoration project). The approximate depth of the old channel is included.

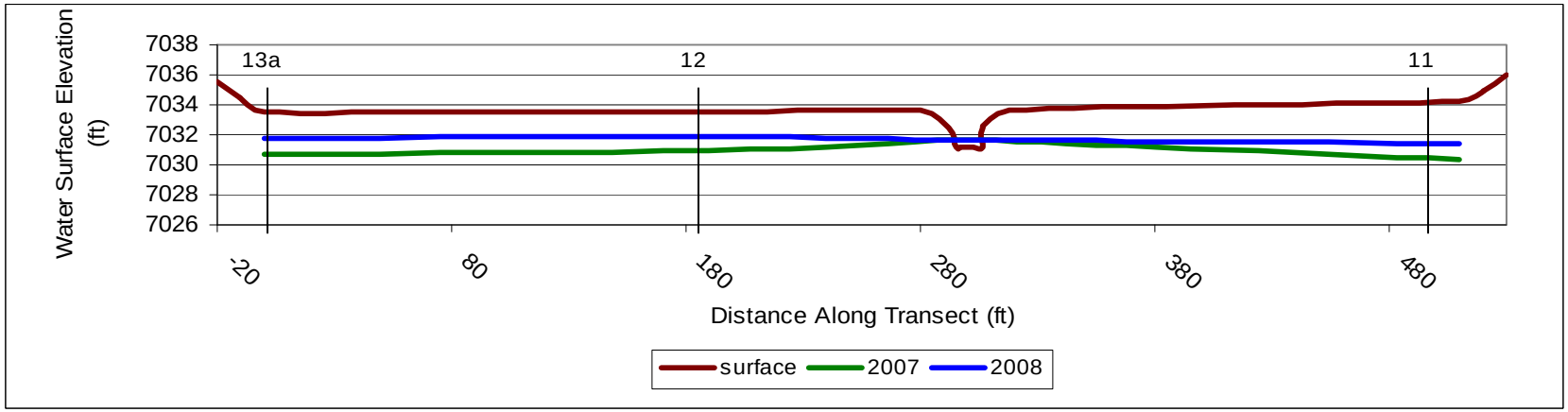

Figure B3. The estimated groundwater surface along a transect at wells 11, 12 and 13a (see Figure B1) in the lower part of Cookhouse Meadow. Each line represents the average groundwater level measured at these three wells in June, July and August in 2007 and 2008 (after the restoration project). The approximate depth of the new channel is included.

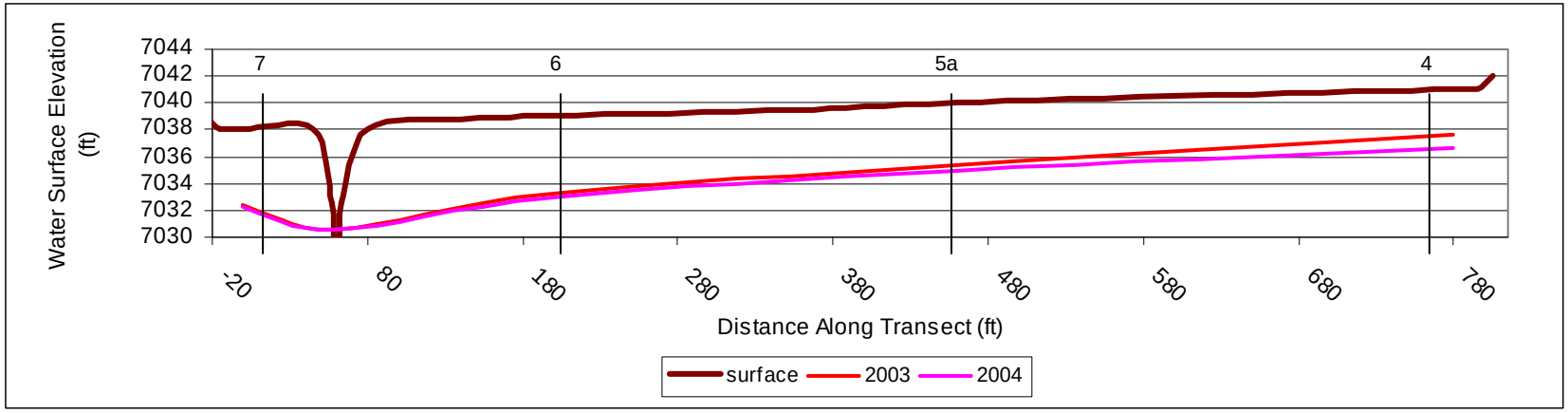

Figure B4. The estimated groundwater surface along a transect at wells 4, 5a, 6 and 7 (see Figure B1) in the upper part of Cookhouse Meadow. Each line represents the average groundwater level measured at these three wells in June, July and August in 2003 and 2004 (before the restoration project). The approximate depth of the old channel is included.

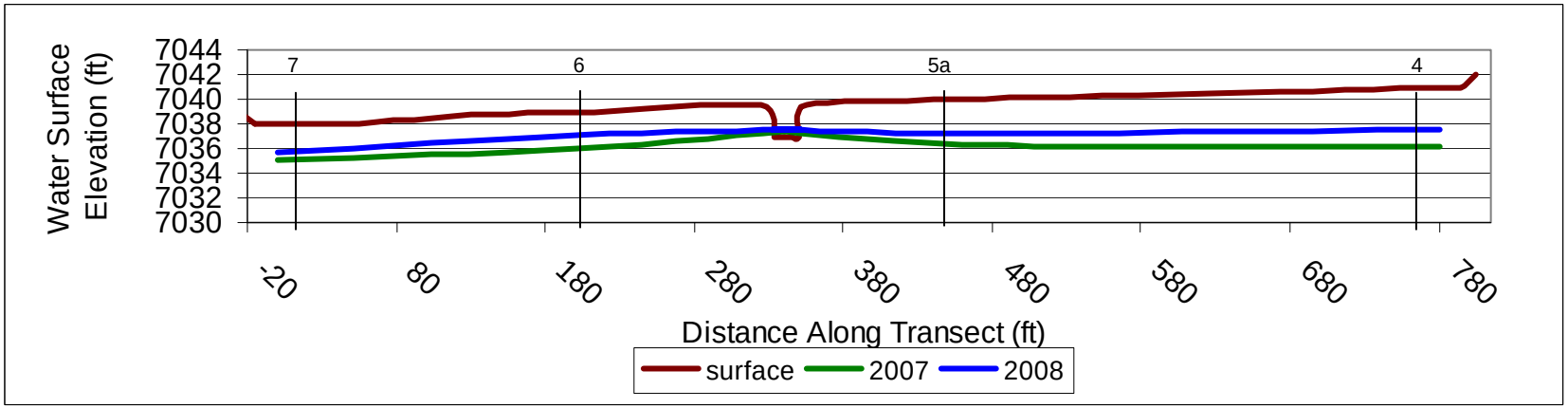

Figure B5. The estimated groundwater surface along a transect at wells 4, 5a, 6 and 7 (see Figure B1) in the upper part of Cookhouse Meadow. Each line represents the average groundwater level measured at these three wells in June, July and August in 2007 and 2008 (after the restoration project). The approximate depth of the new channel is included

APPENDIX C

Groundwater Maps

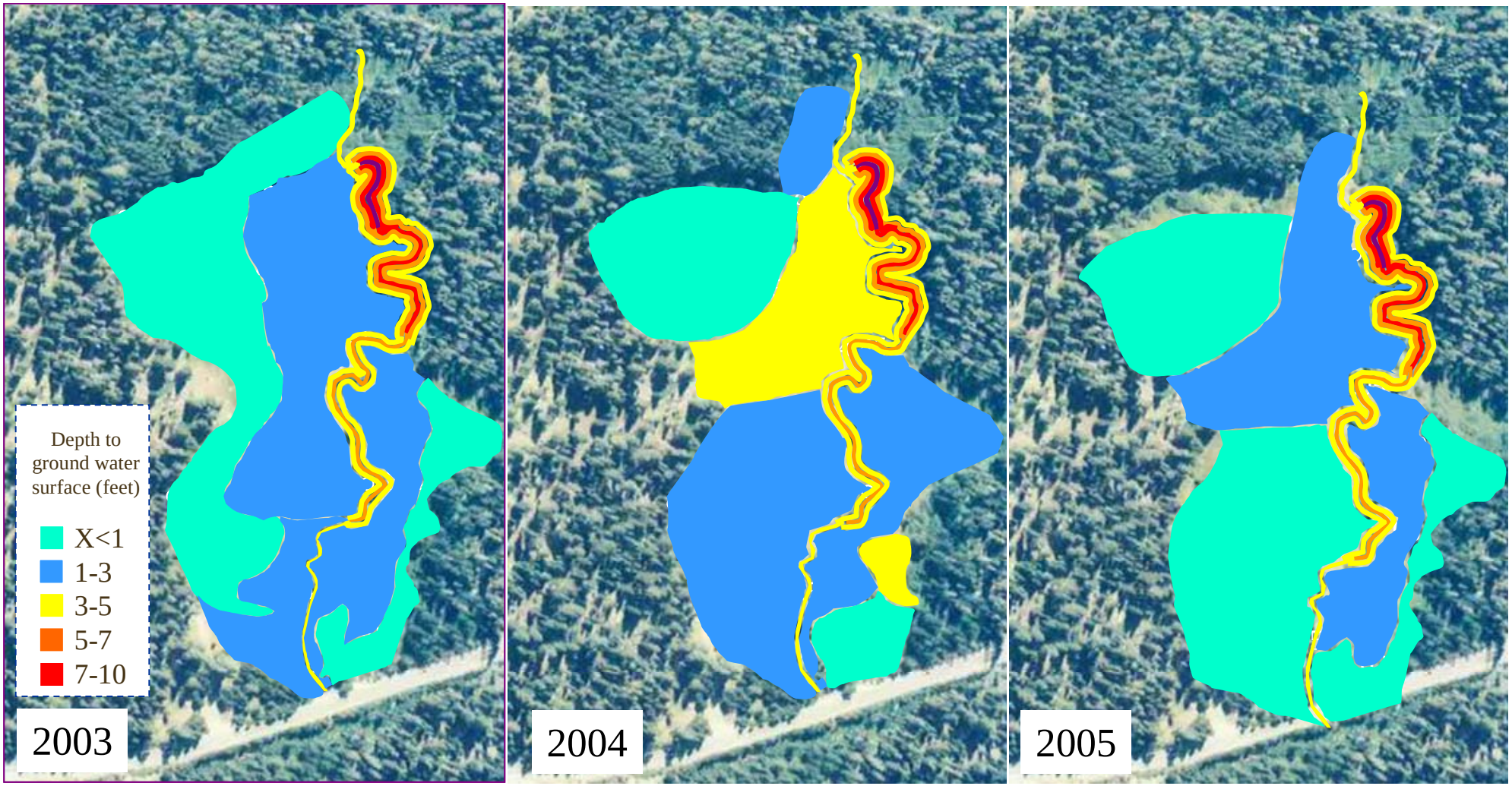

Figure C1. Depth to groundwater found in Cookhouse Meadow during spring peak runoff (April/May) pre-project (2003 and 2004), and the first year of project construction (2005).

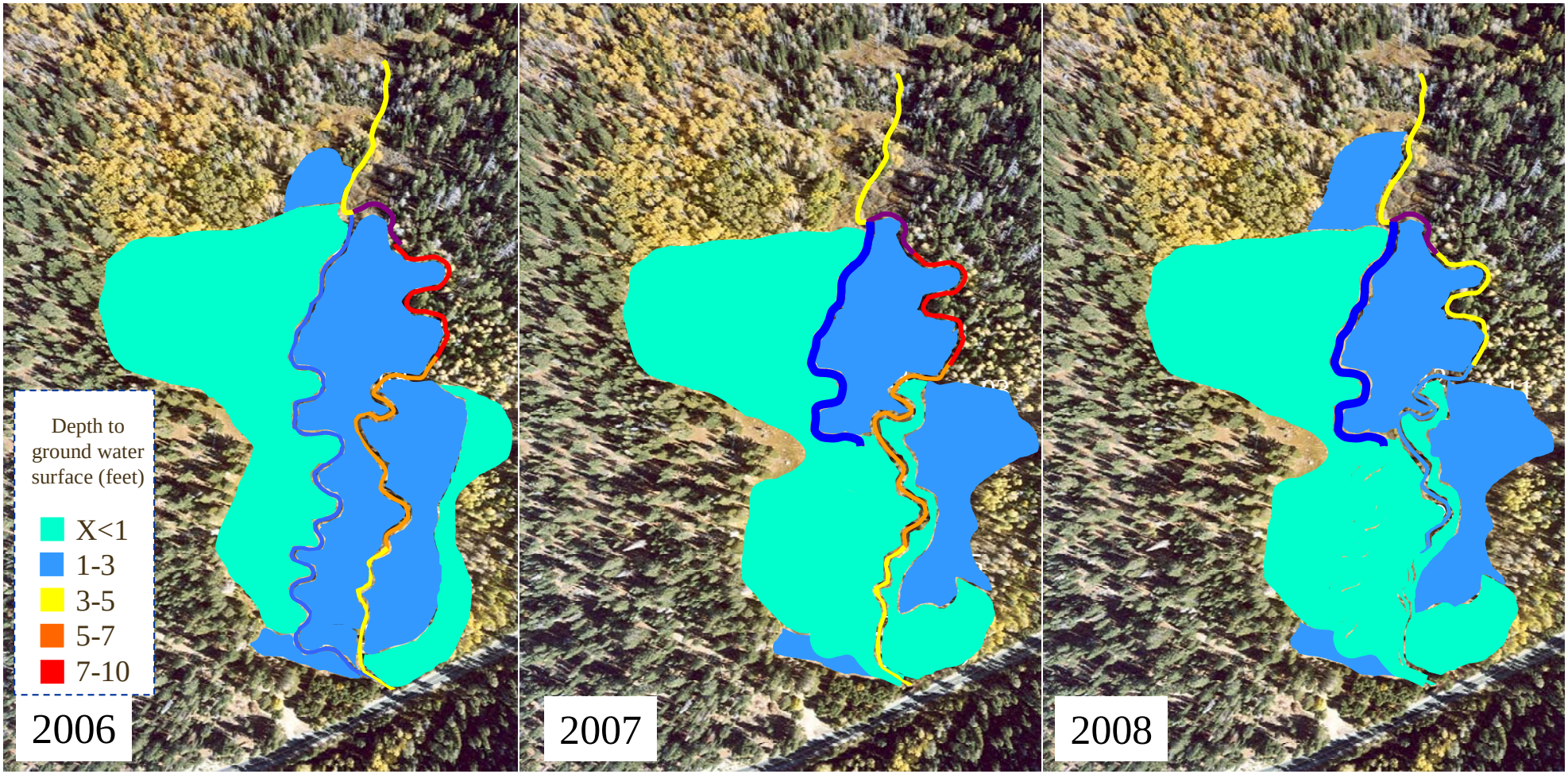

Figure C2. Depth to groundwater found in Cookhouse Meadow during spring peak runoff (April/May) pre-project (2003 and 2004), and the first year of project construction (2005).

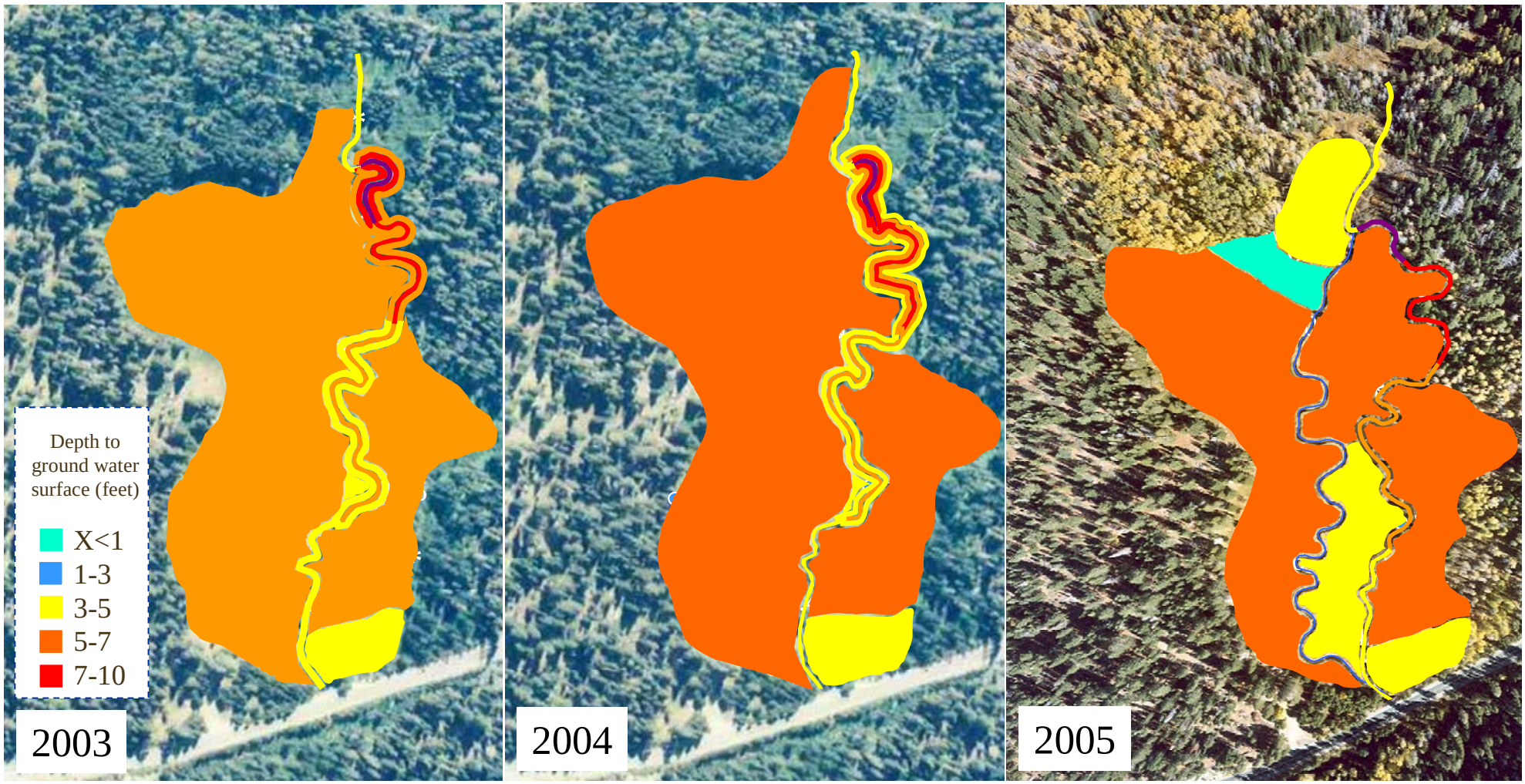

Figure C3. Depth to groundwater found in Cookhouse Meadow during end of summer (August/September) pre-project (2003 and 2004), and the first year of project construction (2005).

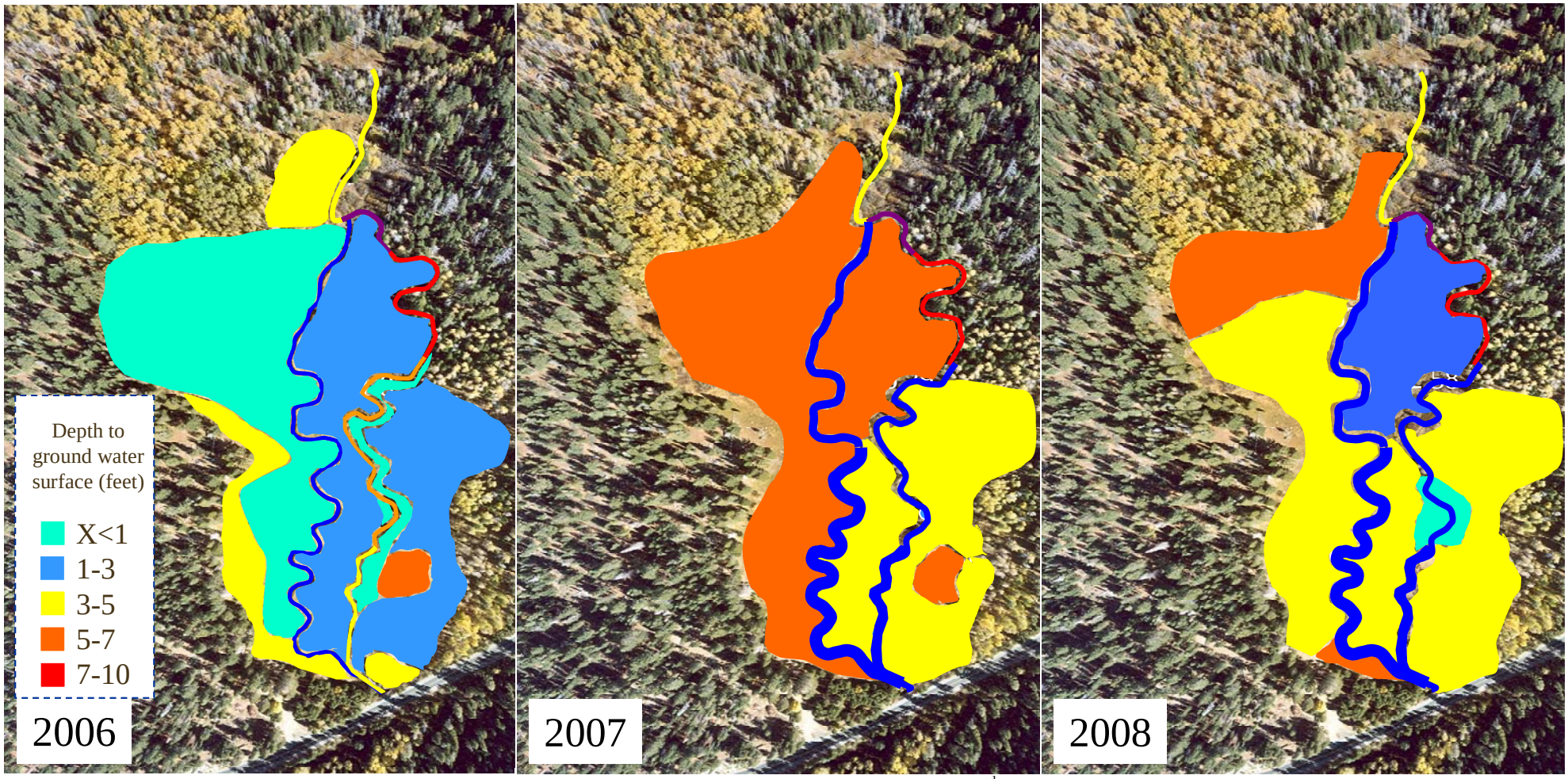

Figure C4. Depth to groundwater found in Cookhouse Meadow during end of summer (August/September) for the 2nd year of construction (2006) and post project (2007, 2008).

APPENDIX D

Photos

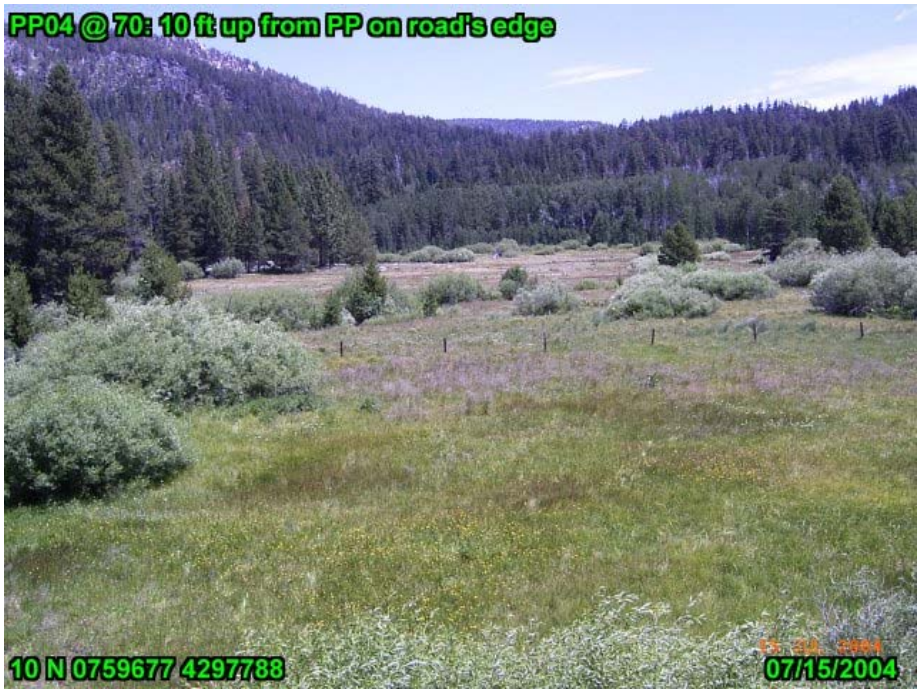

Figure D1. Photo point #04 photo taken July 2004 looking east from the edge of highway 89 out on to Cookhouse Meadow. Photo is before restoration.

Figure D2. Photo point #04 photo taken July 2008 looking east from the edge of highway 89 out on to Cookhouse Meadow. Photo is after restoration work was done. Note that there are a few conifers starting to turn brown in this photo that were not present in the July 2004 or 2006 photos.

Figure D3. Photo along an eroding section of the old channel taken July 2004. Photo is looking downstream from the left bank. Note that the conifers growing on the steep bank are green and appear healthy.

Figure D4. Photo along a plugged section of the old channel after restoration work taken November 2008. Photo is looking down the meadow. . Note that the conifers growing on what was the bank of the old channel are continuing to die back and loose their needles. The groundwater elevation recorded at a near by well (well #9) shows a rise in groundwater elevation after restoration and the water level stays at that higher elevation for a longer period of the year. These trees are likely dying from the change in depth to groundwater here.

APPENDIX E

Cross Sections

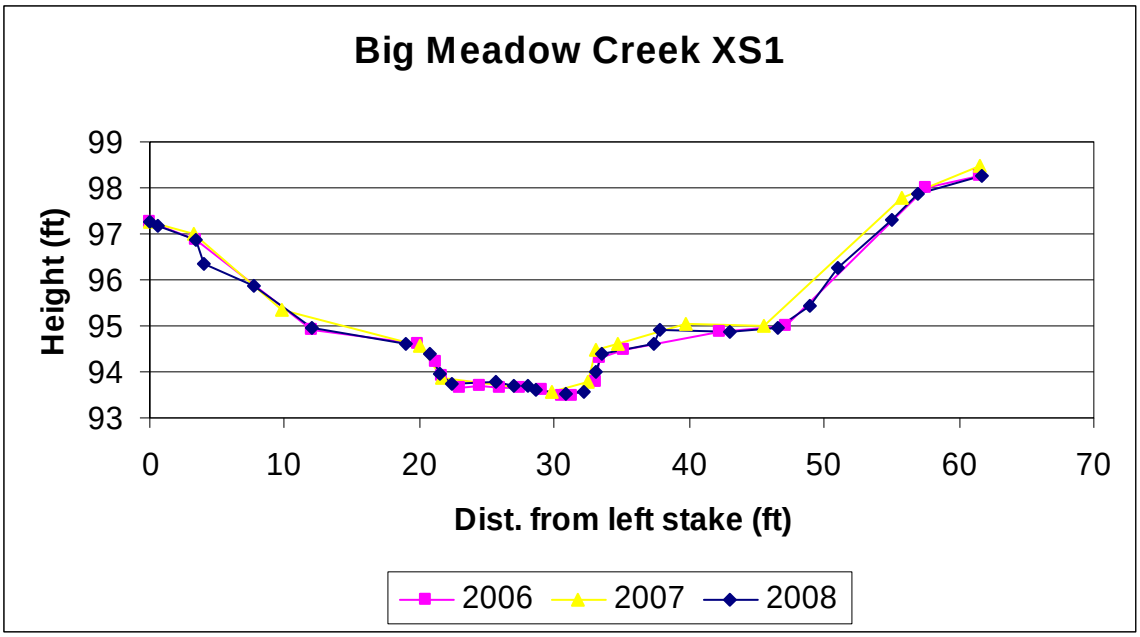

Figure E1. Cross section # 1 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

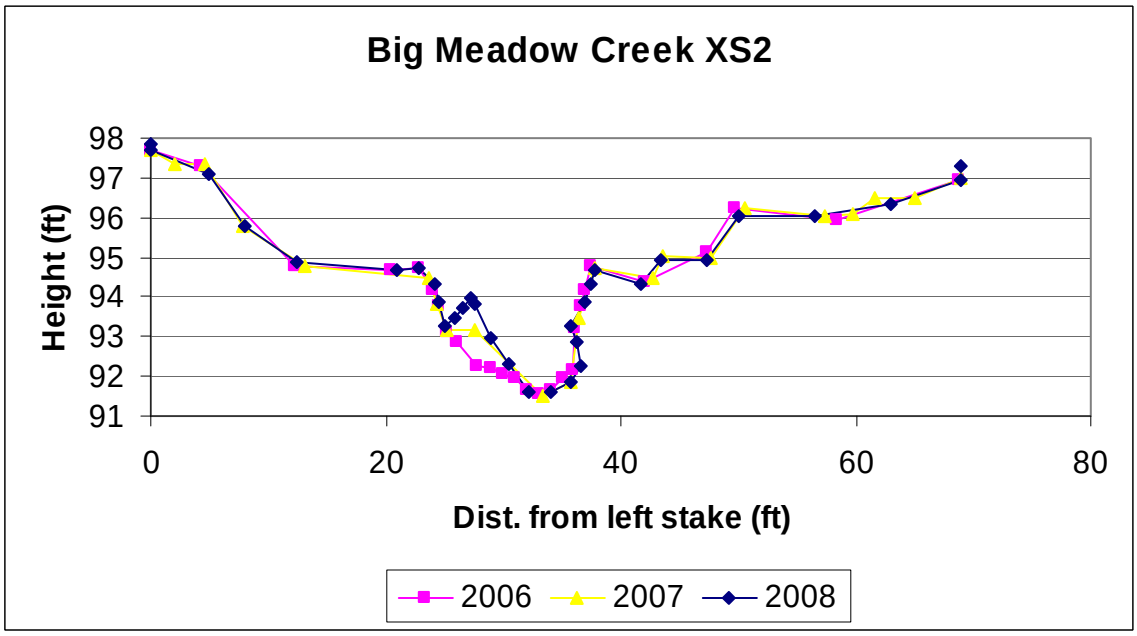

Figure E2. Cross section # 2 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

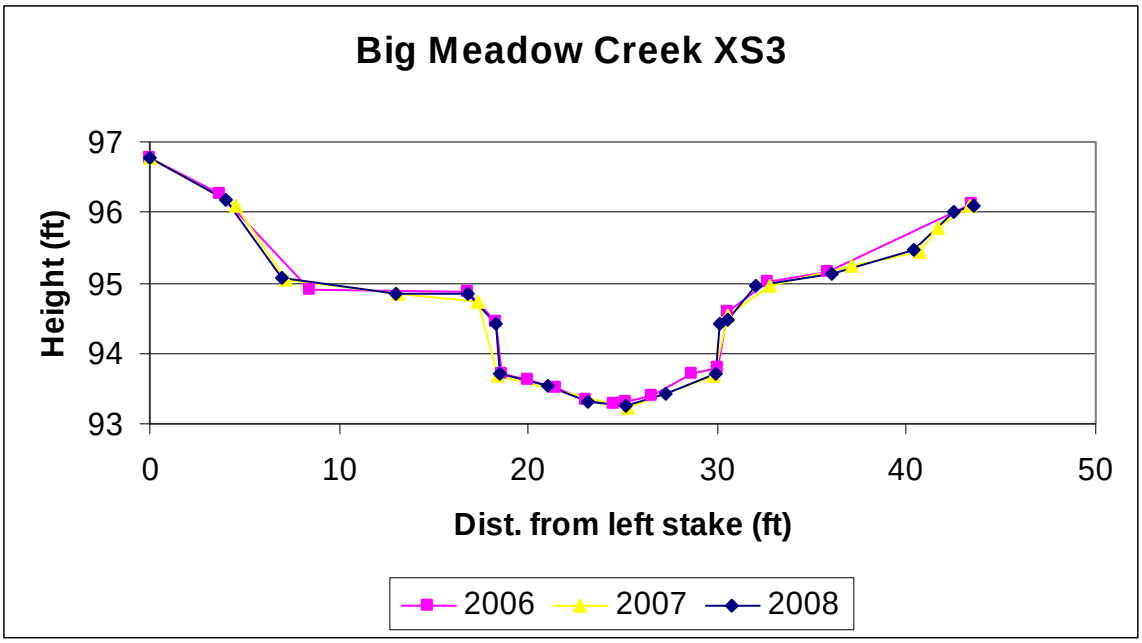

Figure E3. Cross section # 3 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

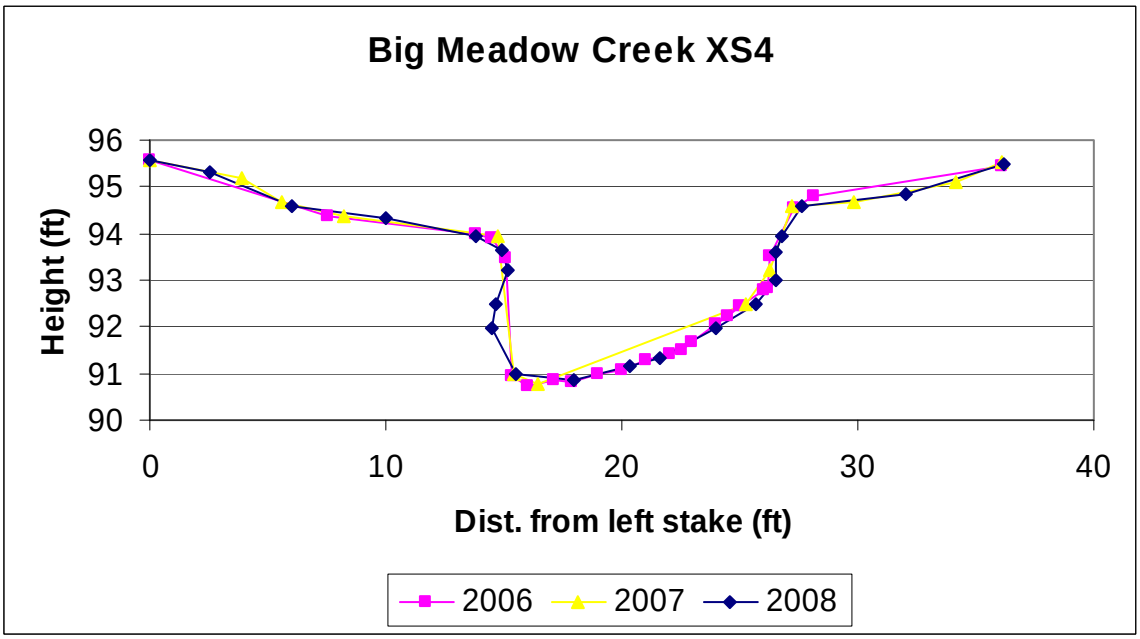

Figure E4. Cross section # 4 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

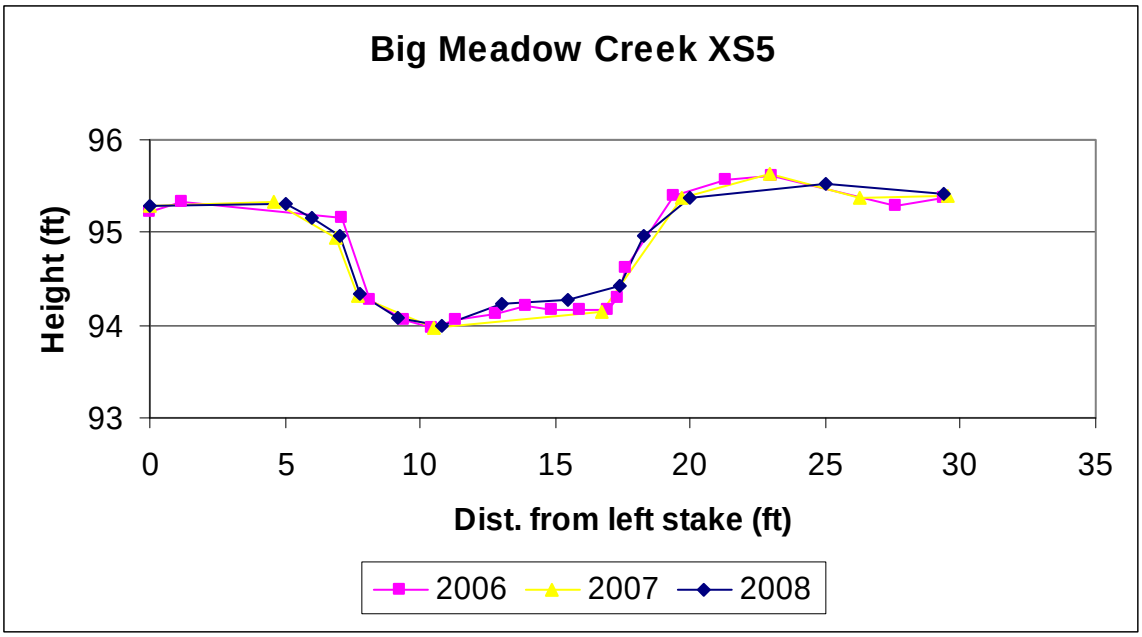

Figure E5. Cross section # 5 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

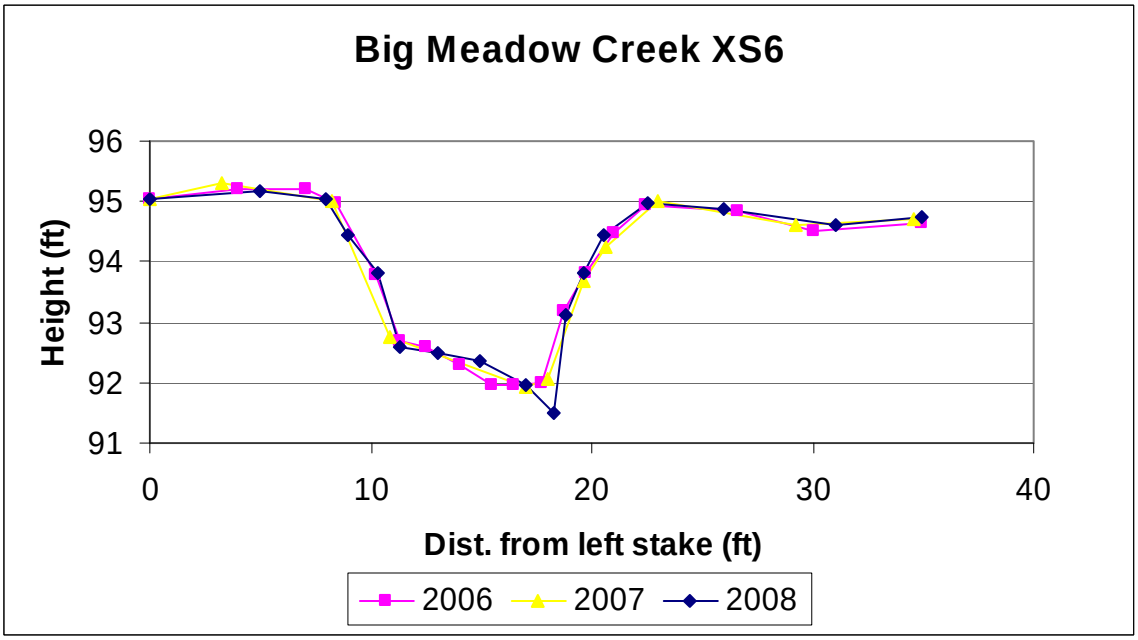

Figure E6. Cross section # 6 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

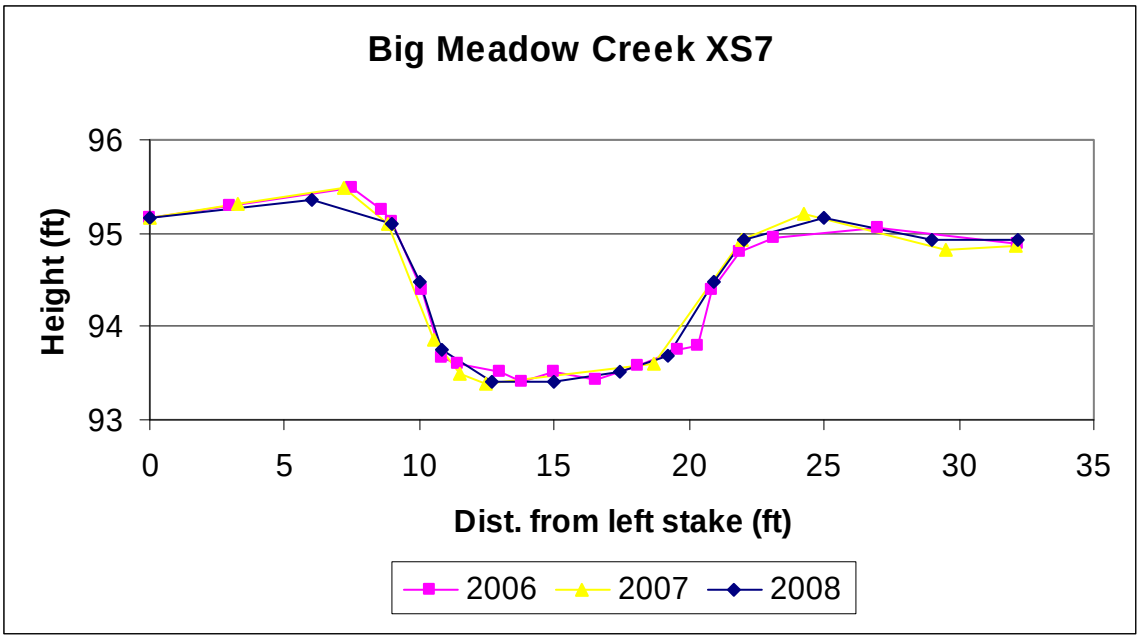

Figure E7. Cross section # 7 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

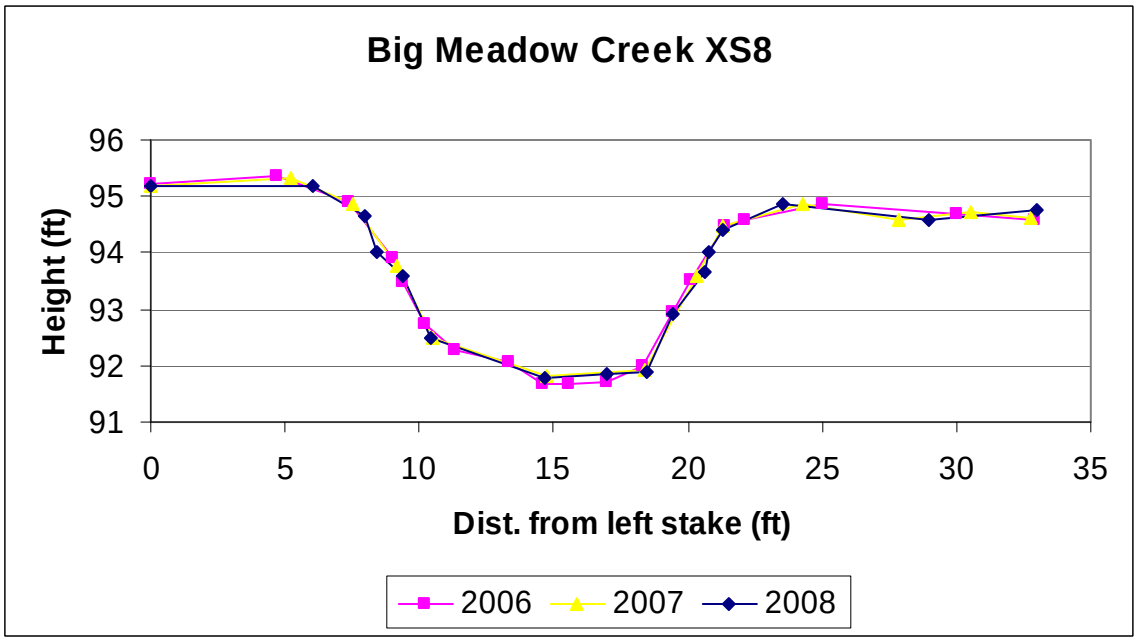

Figure E8. Cross section # 8 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

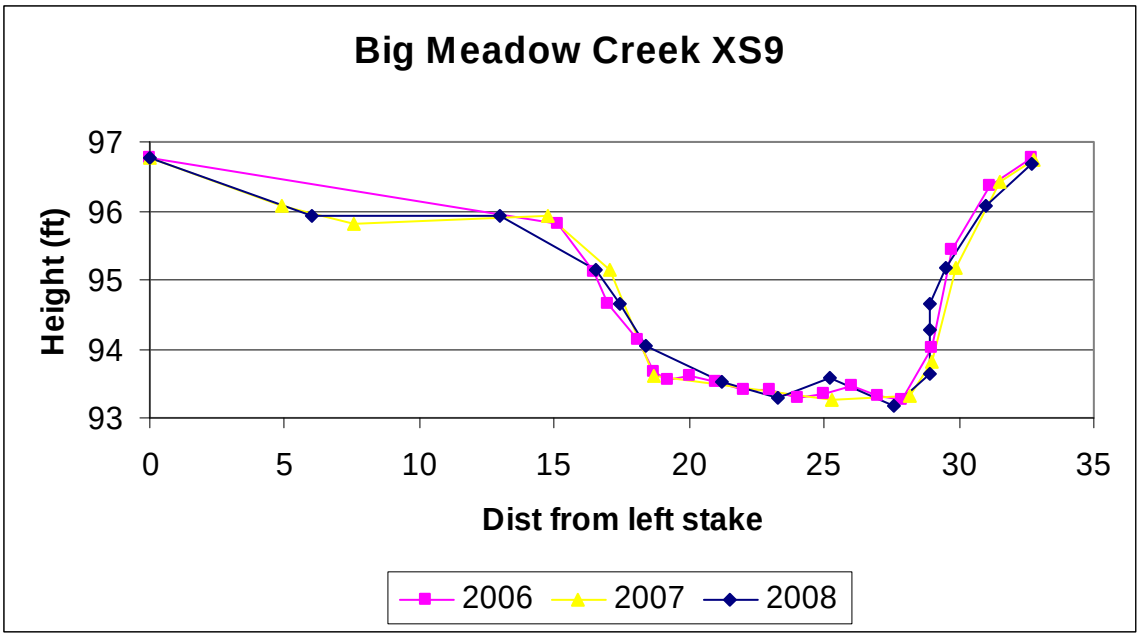

Figure E9. Cross section # 9 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

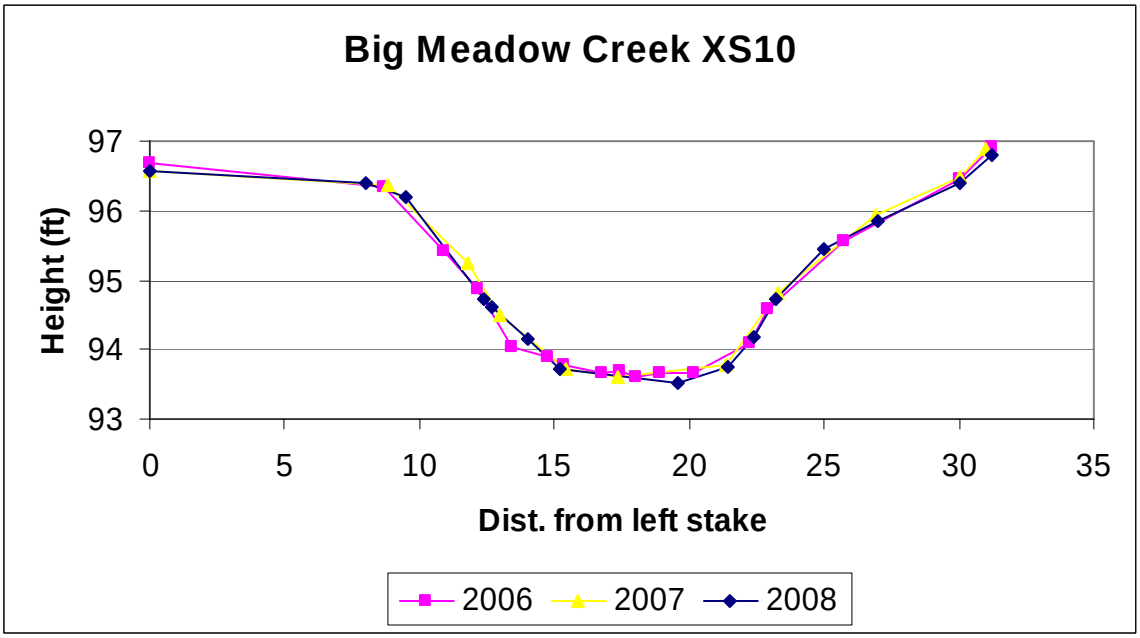

Figure E10. Cross section # 10 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

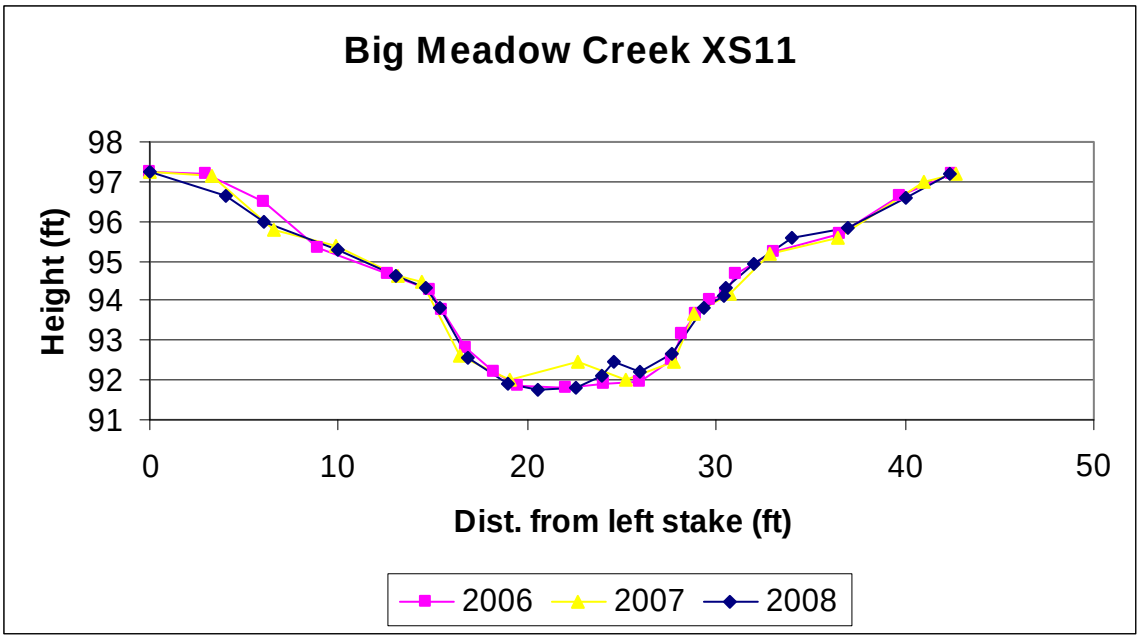

Figure E11. Cross section # 11 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

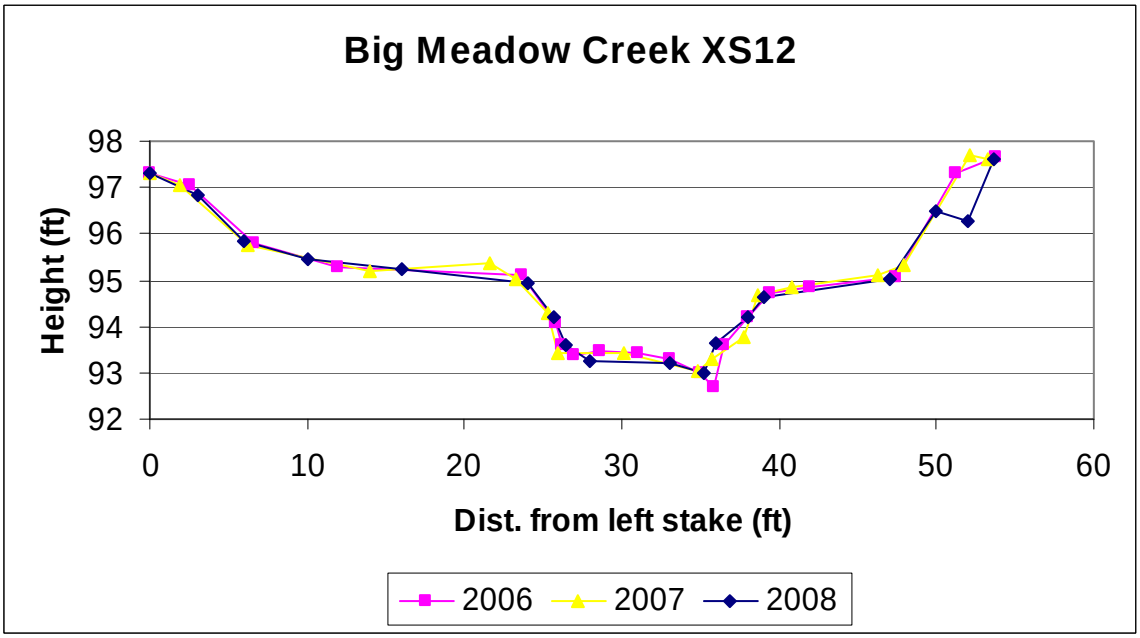

Figure E12. Cross section # 12 of Big Meadow Creek for 2006, 2007 and 2008. Units are in feet.

APPENDIX F

Long Profiles

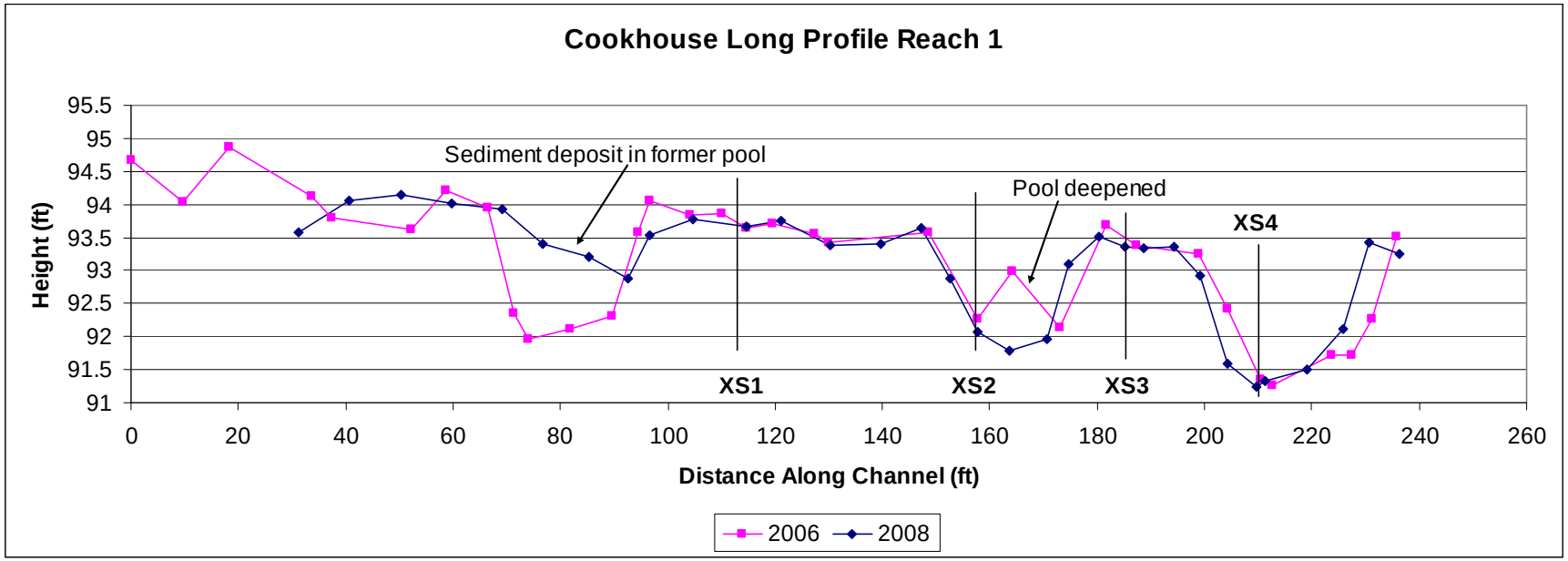

Figure F1. Long profile for reach #1 of Big Meadow Creek for 2006 and 2008. This profile crosses through cross sections 1, 2, 3 and 4. Units are in feet.

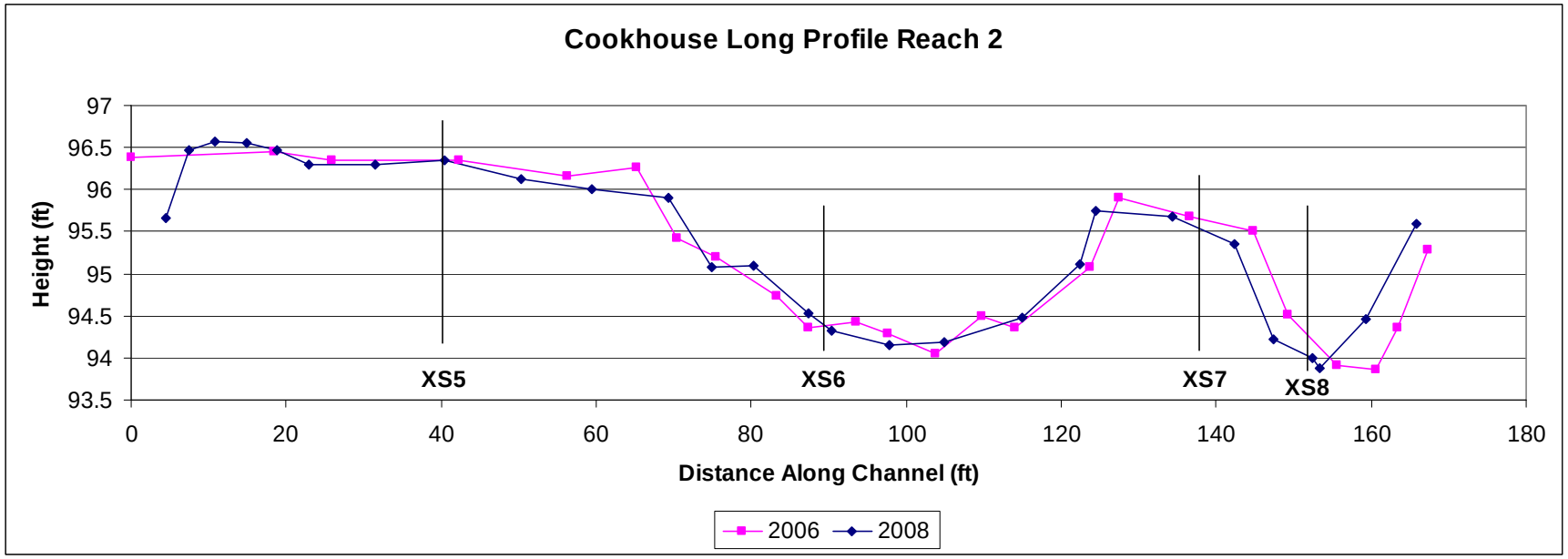

Figure F2. Long profile for reach #2 of Big Meadow Creek for 2006 and 2008. This profile crosses through cross sections 5, 6, 7, and 8. Units are in feet.

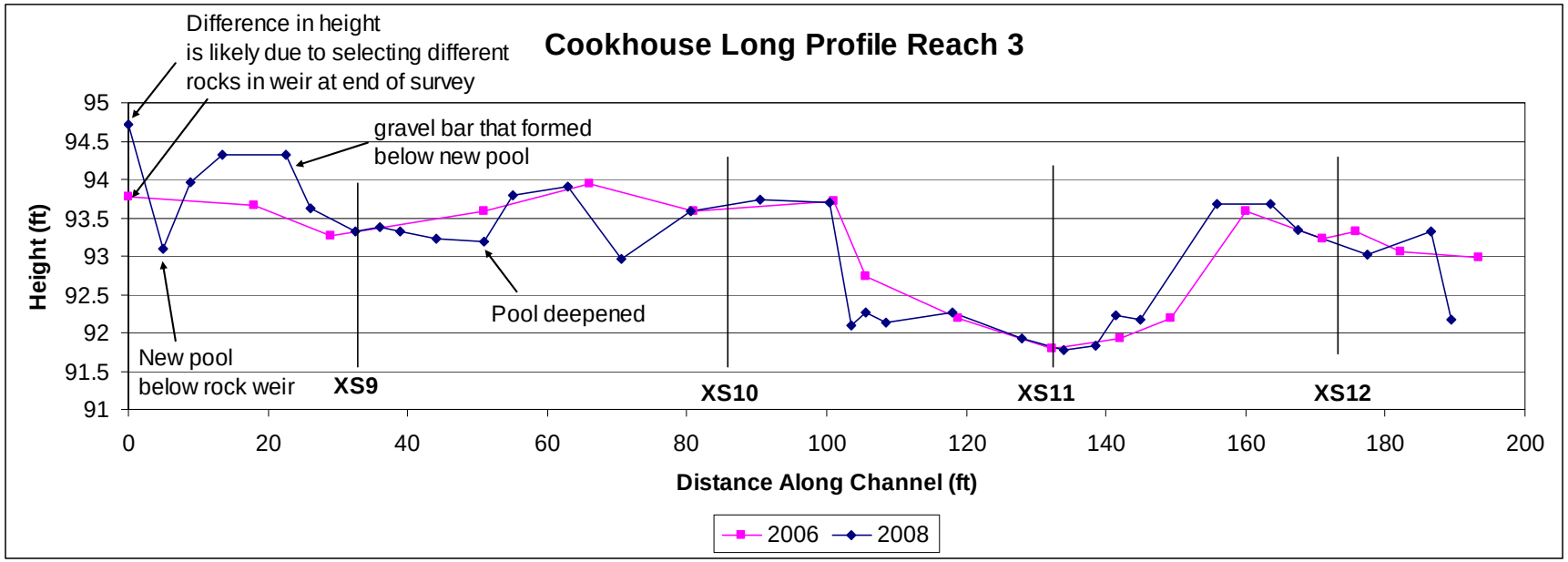

Figure F3. Long profile for reach #3 of Big Meadow Creek for 2006 and 2008. This profile crosses through cross sections 9, 10, 11, and 12. Units are in feet.