Deepwater Slough Restoration Monitoring: Channel Cross-section Comparisons, 2000 - 2006

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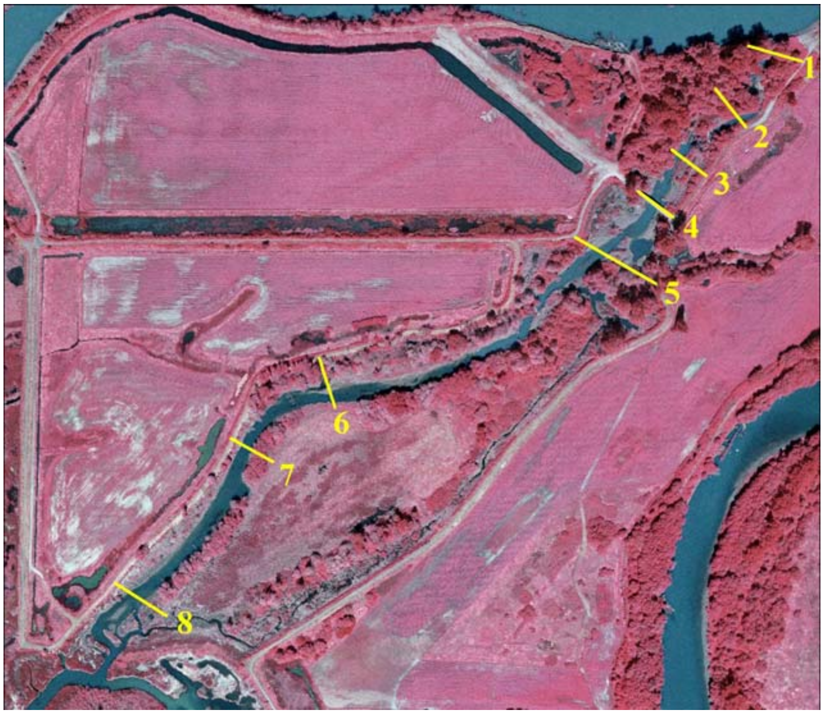

Figure 1. Location of surveyed channel cross-sections on Deepwater Slough.

Introduction

Deepwater Slough was restored through dike removal in the summer of 2000 to provide in-channel habitat and restore an important migratory corridor for juvenile Chinook and other salmon in the Skagit Delta. Dikes blocking the channel were removed from a site near the upstream end of the distributary channel and 1000m downstream from this location. Geomorphic changes quickly followed dike removal, particularly upstream of the upstream dike. Changes in planform geometry from 2000 to 2002 have been previously reported (Hood 2003). This report provides additional planform monitoring results for 2004 and comparisons of channel cross-section changes from 2000 to 2005. The monitoring results reported here are preliminary. The site will likely continue to evolve in coming years and increasingly resemble natural tidal marshes. The great unknown is, at what rate will change occur?

Methods

Channel cross-sections were previously measured by Skagit County (2000) and Bureau of Reclamation (2001) surveyors using survey-grade GPS (2 cm vertical and horizontal resolution). Survey benchmarks were established on site during these earlier efforts, and these benchmarks were recovered and used for the current effort. Cross-section transects established in 2000 were recovered by reference to recent orthophotos. Stakes set in 2000 marking the ends of the transects were not recovered, probably because they were destroyed by dike maintenance equipment (mowing) or flood events.

Channel cross-sections (Fig. 1) were surveyed using a laser level to acquire elevation data and a tape measure for horizontal location relative to the start of the transect. Map-grade GPS (post-processed to generate sub-meter resolution) was employed simultaneously to locate survey points, including start and end points of the cross-section transects.

Results and Discussion

Deepwater Slough Planform Changes

Planform changes along the Deepwater Slough distributary have occurred almost exclusively at the upstream end of the channel (Fig. 2). Dowstream areas, in contrast, have experience minor planform change. Upstream planform changes from 2002 to 2004 are difficult to discern precisely because forest canopy obscures much of the channel bank and channel. A canopy gap exposes some river water to aerial view and this gap has been widening from 2002 to 2004, indicating channel bank erosion and recruitment of riparian trees to LWD (large woody debris). The 2004 aerial photos and field observations indicate that much of this new LWD lies within the channel. The most significant geomorphic change occurred following the October 2003 flood, which carved a second channel (an avulsion) that diverges from Deepwater slough approximately 70m from its inlet and rejoins the channel approximately 105m downstream. The downstream portion of this new channel is revealed in the air photos by a gap in the forest canopy between transects 2 and 3.

Additionally, Freshwater Slough (the principal distributary of the South Fork Skagit River) is eroding near the inlet of Deepwater Slough. The river bank retreated by approximately 3m between 2002 and 2004. Likewise there has been significant bank erosion approximately 200m downstream along Freshwater Slough, that is threatening the integrity of the WDFW dikes protecting property currently managed for agricultural field-based waterfowl hunting. (WDFW has built set-back dikes in anticipation of dike failure.) Both of these erosional areas are located on the same cut-bank of a large bend in Freshwater Slough. The location of the Deepwater Slough inlet on a rapidly eroding cut-bank suggests that this inlet is exposed to high erosive energies and that further channel erosion is likely along both Freshwater and Deepwater Sloughs.

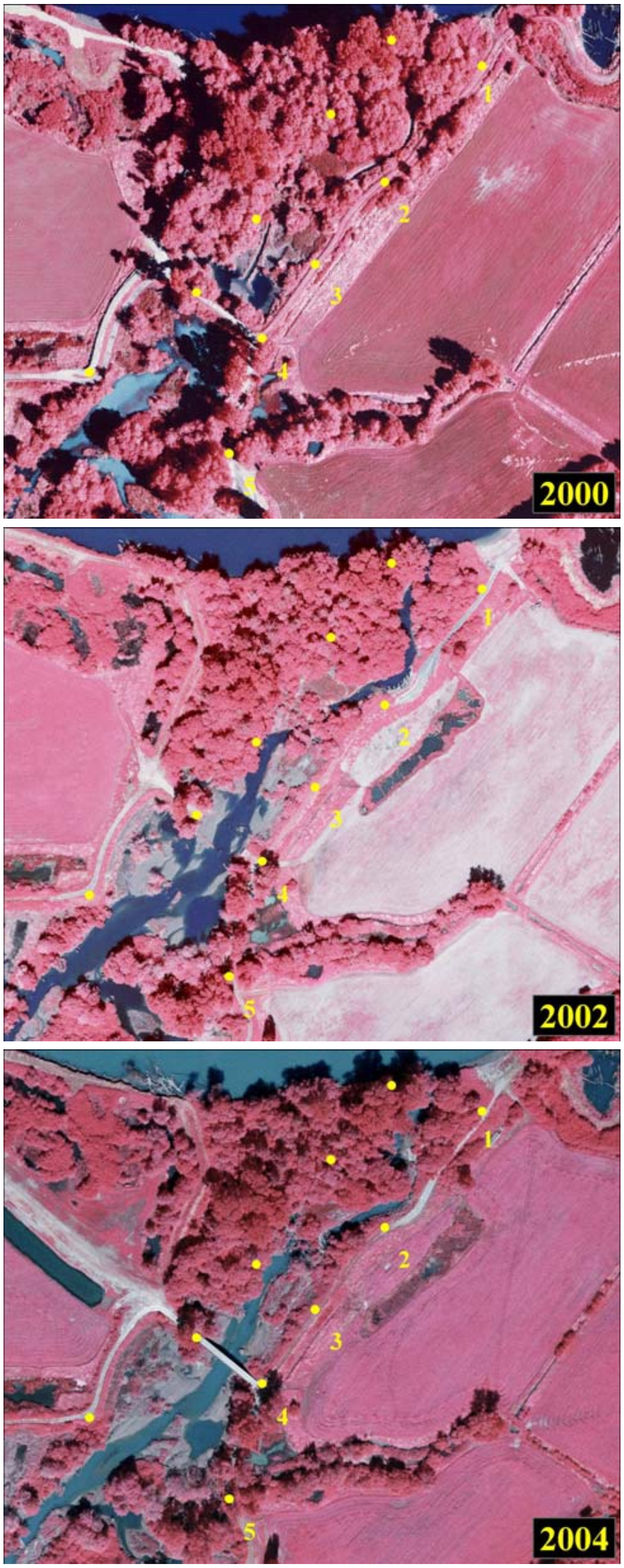

Figure 2. Planform comparisons of the dynamic upstream portion of Deepwater Slough. Cross-section transect start and end points are denoted by numbers and dots respectively.

Deepwater Slough Cross-section Changes

An entirely new cross-section transect was established near the upstream mouth (inlet) of Deepwater Slough (Fig. 3), so no comparisons with previous transects can be made. This transect was established to document future changes in channel form in this area. Cross-section 2 shows the expected channel development from 2000 to 2001 and the dramatic development of an avulsed side-channel (caused by the October 2003 flood) by 2005. Ground surface elevation has declined by about ½ meter on the left bank and increased by about ½ meter on the right, in an area that is now an island. The left bank erosion is consistent with even greater erosion immediately upstream in 2001 that threatened the adjacent dike and resulted in WDFW installing rip-rap (visible in 2002 and 2004 photos, see Fig. 2). The increased elevation in the area that is now an island is likely due to sediment deposition during floods. This pattern is consistent with the transect location in a slight meander bend. The left bank is a cut bank and the current island is a depositional point bar that has been cut off on its back side by the 2003 channel avulsion. Hardening of the left bank, or cut bank, with rip-rap probably led to the channel avulsion. Flood energy that would otherwise have been dissipated by enlarging the channel meander was instead redirected toward the avulsion.

Cross-section 3 shows a steady increase in channel cross-section area as expected. There is also a decrease in marsh surface elevation of approximately ¾ meter on the right bank of the channel over a width of 5m, and a 1m increase in marsh surface elevation on the left bank over a width of about 25m. Field observations indicate that the left bank has received extensive deposits of sand that during 2001-2002 smothered cattails and which now is being colonized by willows (*Salix* spp.) and sweetgale (*Myrica gale*). The marsh surface erosion and deposition patterns are consistent with the slight channel meander present in this area.

Cross-section 4 is located where the upstream dike used to be and where a bridge is currently located. No channel was present in 2000, so there is no transect for that year. The 2001 transect represents a broad unchannelized plain that remained when the dike was removed. The 2005 transect shows a clearly developed channel. Incidentally, the aerial photos show a clear channel in 2002, comparable to the channel in 2004.

Cross-section 5 is located just downstream of the bridge and is an area that has been accumulating sediments in the channel, particularly on the right bank (looking downstream) (Fig. 4). The cross-sectional information combined with the planform photos suggest that dike removal was followed by vegetation destruction on the right bank particularly, likely due to the combined stresses of increased inundation and burial by sediments. These accumulated sediments appear in the 2004 photo as gray sands.

Cross-section 6 is located on a channel bend and shows some bank erosion high on the right (cut) bank, while a natural flood levee appears to be forming lower on the marsh adjacent to the right channel bank.

Cross-section 7 is located in the relatively stable (from a planform perspective) channel reach downstream of the bridge. However, the channel is shoaling by about ¾ meter over most of the cross-section.

Cross-section 8 is located in a reach where the channel blends into tidal marsh on its left bank. However, in recent years this cross-section appears to be developing a natural flood levee on its left bank (about ½ meter higher than previously) and depositing sediment on the right bank. The development of this natural levee is an additional indication that natural flood processes have been restored to this channel reach.

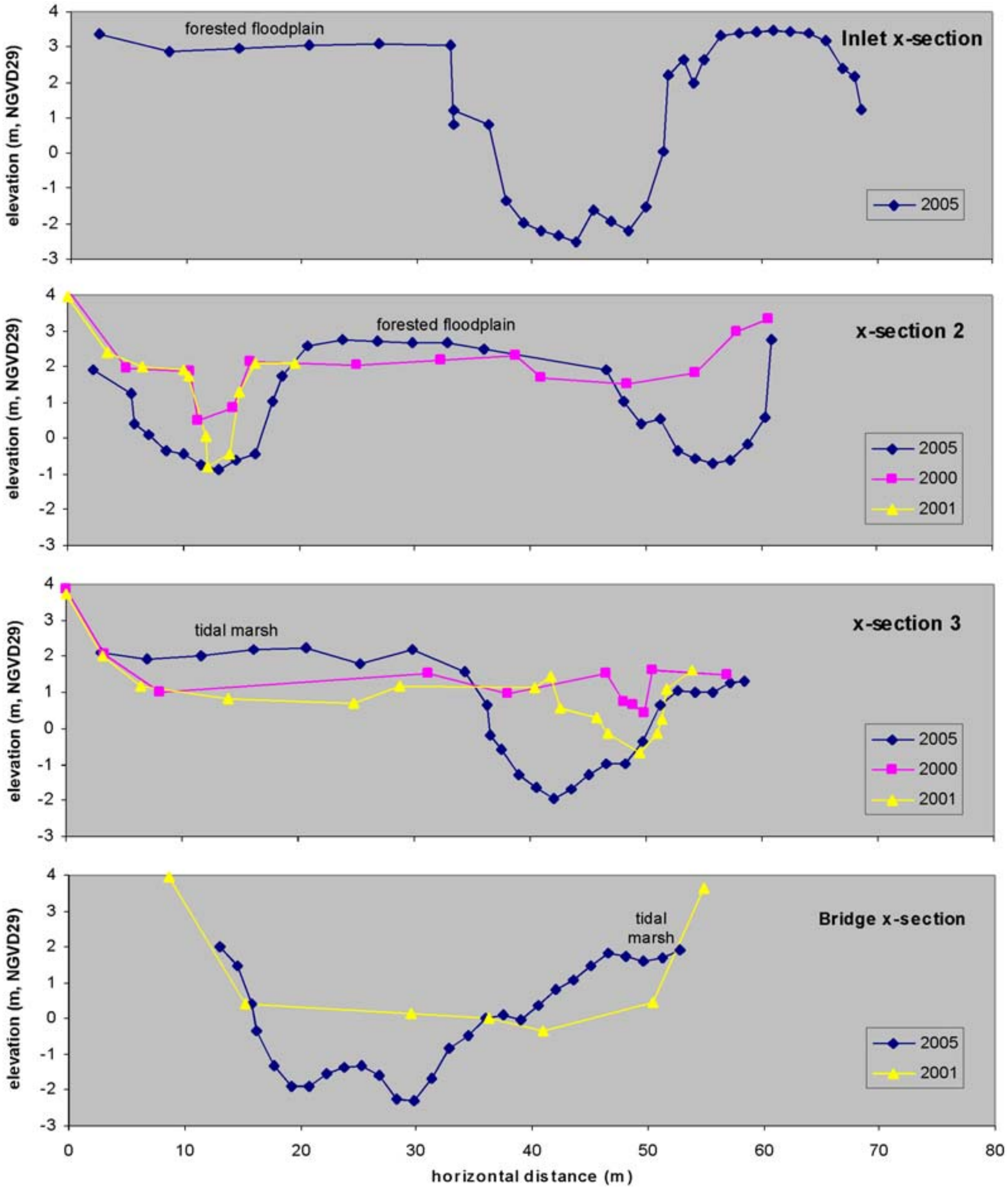

Figure 3. Channel cross-sections for transects 1-4. View is directed downstream.

Channel cross-section area (Table 1) was determined relative to the elevation of the lowest channel bank of a transect. Cross-section area was not calculated for cross-section 8 in 2000 and 2001 because there was no clearly defined left bank; the channel graded into tidal marsh.

Except for cross-sections 5 and 6, cross-section area was relatively constant among the 2005 cross-sections, averaging 34.7m^2 with a standard deviation of 2.0m^2. In contrast, cross-section area was more variable in 2000 and 2001. Channel cross-section area has increased dramatically in the upstream reach (cross-sections 2-4), but decreased

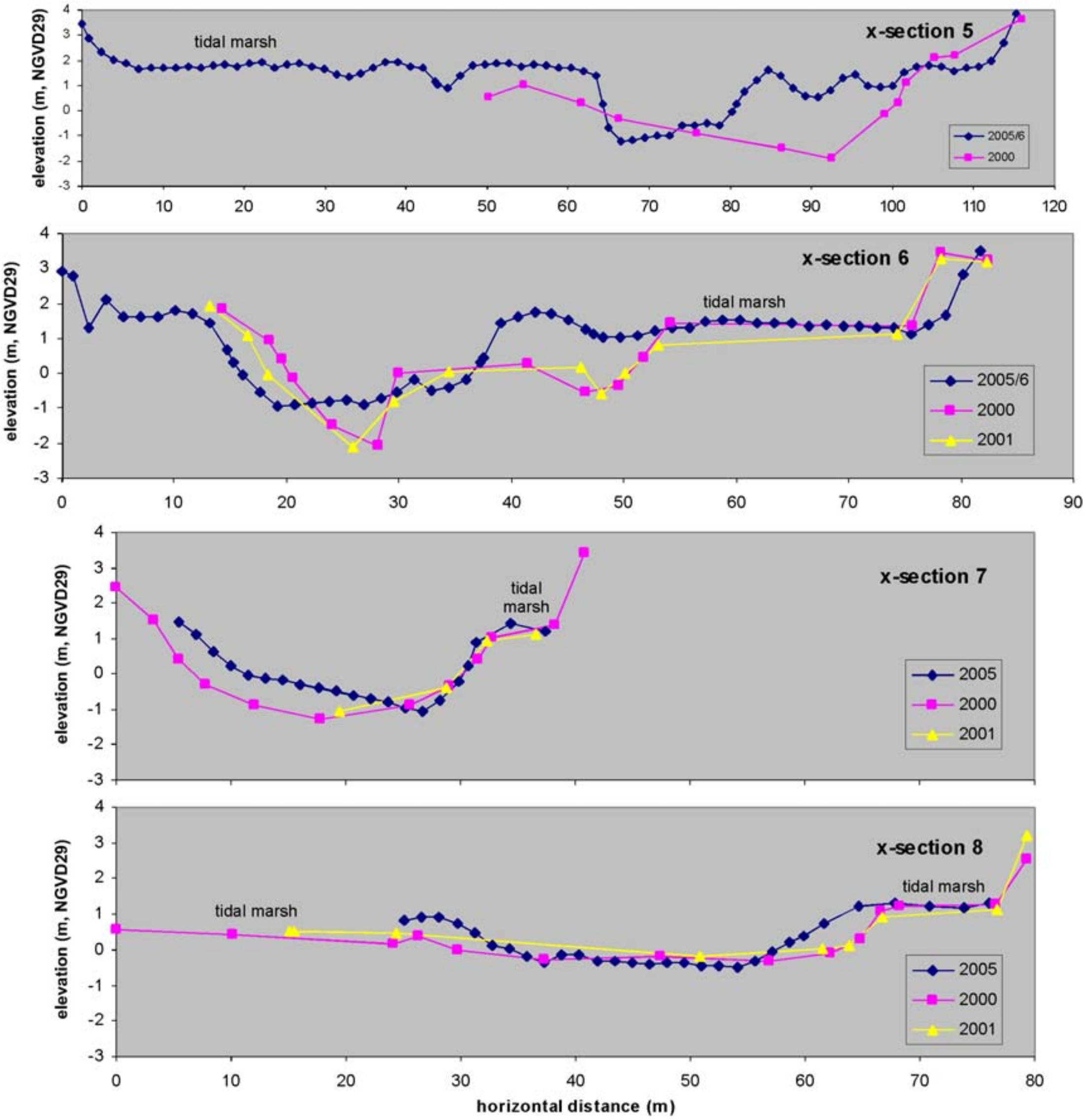

Figure 4. Channel cross-sections for transects 5-8. View is directed downstream. Note, the x and y scales of transect 5 is 70% of that of the other transects.

in the downstream reach (cross-sections 5-7). The large downstream cross-section area in 2000 likely reflects historical (pre-dike) distributary discharge, since this reach was likely little disturbed while it was isolated by upstream and downstream dikes from tidal and riverine flooding. Upstream channel widening reflects channel accommodation to restored river discharge distributed from Freshwater Slough, through the erosion of sediments that had accumulated in this backwater area while dikes blocked Deepwater Slough for the past century. Downstream channel sedimentation indicates that this channel reach is currently accommodating reduced river discharge compared to historical (pre-dike) conditions. Similar cross-section area in upstream (1-4) and downstream (7-8) reaches suggests these areas are now in equilibrium with each other. Cross-sections 5 and 6 may still be in relative disequilibrium compared to upstream and downstream reaches because their original cross-sectional areas were so large. If the upstream reach continues to widen and deepen the lower reach will also widen; perhaps both areas will ultimately return to their historical width and depth.

Table 1. Channel cross-sectional area (m^2). Note that in 2005 two channels were present in cross-section 2. "xs" = "cross-section."

	2000	2001	2005
xs2	4.5	8.5	19.2 + 16.4 = 35.6
xs3	2.6	13.8	32.1
xs4	NA	10.5	37.3
xs5	78.0	-	49.6
xs6	60.7	43.0	54.4
xs7	47.2	-	35.2
xs8	NA	NA	33.5

Protochannel Development

The two largest protochannels developing on the restoration site were mapped along their centerline with GPS to groundtruth aerial photo interpretation. Channel cross-sections were also surveyed in several locations (Fig. 5). Protochannels are channels that were unplanned and unforeseen during site restoration. These channels are cutting across the former dike footprint as a result of natural tidal processes, without any encouragement from artificial channel excavation. The two largest channels are actually extensions of pre-existing channels that were located outside of, and immediately adjacent to, the original dikes (now removed). Their channel branches now clearly extend beyond the dike footprint, more so for the southern protochannel than the northern one. This result suggests some predictability. Pre-existing external tidal channels are perhaps likely to extend through headward erosion into a restoration site if no dikes impede their potential. This is the logical result of restoring significant tidal prism to their locality. Thus, at a minimum, dike breaches should be located near any and all external tidal channels that might be present, regardless of their size. Even small channel may become significantly larger given increased tidal prism.

Channel cross-sections were measured near the mouths (outlets) of the two protochannels and across each of two major forks in each protochannel (Fig. 6). These cross-sections were measured for the first time this year and will serve as comparisons for future cross-section surveys to monitor channel growth. Comparisons of the pre-restoration photo of 2000, later photos and the field surveys, indicate channel width of the northern outlet appears to have increased from approximately 1.5 m (2000 photo) to 5.2 m (2002 photo) and 4.7 m (2004 photo) to 7.3 m (2005/6 survey), while the right fork (which extends into the restoration site) cross-section width appears to have increased from approximately 1 m (2000 photo) to 2.6 m (2002 photo) and declined back to 1.7 m (2004 photo) and 1.8 m (2005/6 survey). The left fork is indistinct in the photos due to significant plant cover, so photo-based measures of channel width are unreliable. Similar comparisons for the southern protochannel indicate that its outlet width grew from 0.7 m

(2000 photo) to 3.5 m (2002 photo), 3.0 m (2004 photo), and 5.5 m (2005/6 survey). The right fork, which crosses the dike footprint into the restored marsh, appeared to be 0.5 m wide in the 2000-2002-2004 photos, but field surveys indicate it was 3.0 m wide in 2005/6. The left fork, which remains outside the dike footprint grew slightly from 1.8 m in 2000 and 2002 to 2.7 m in the field surveys of 2005/6. The 2004 photo had too much vegetation coverage to distinguish channel banks clearly.

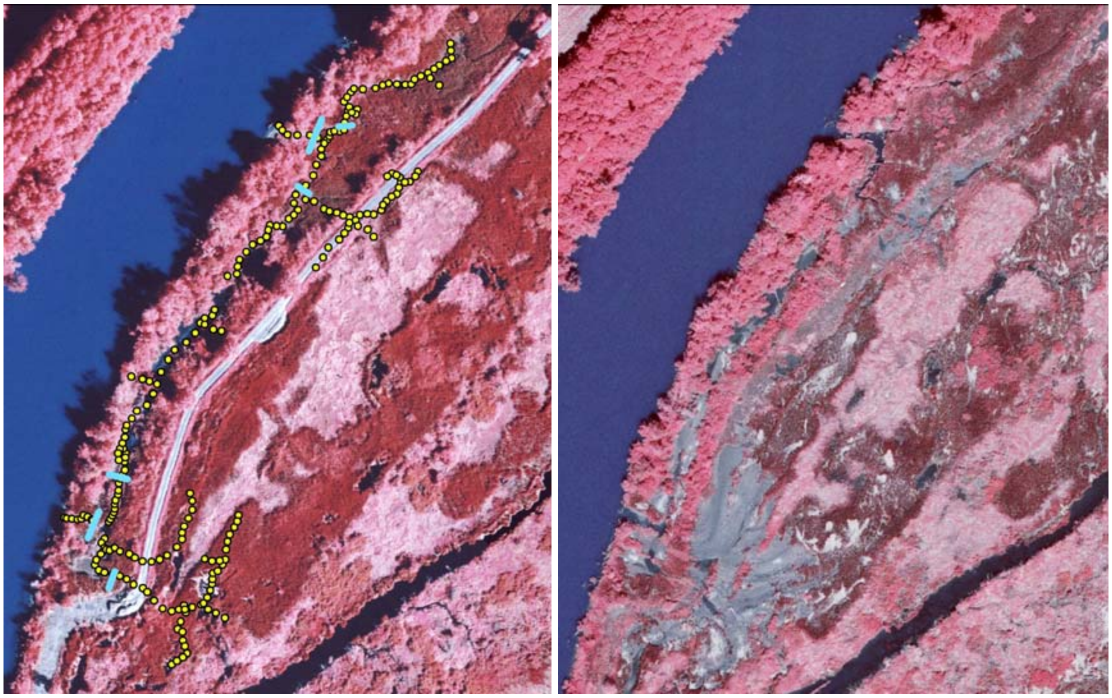

Figure 5. Current (2005/6) channel courses (yellow GPS points) of the two largest protochannels developing on the restoration site. Surveyed cross-sections (2005/6) are shown as light blue lines. The background photo is from 2000 and shows the dike in the process of being removed. The photo to the right is 2002 and shows a sediment splay in the lower left corner (gray sands) delivered by a 5-yr flood event.

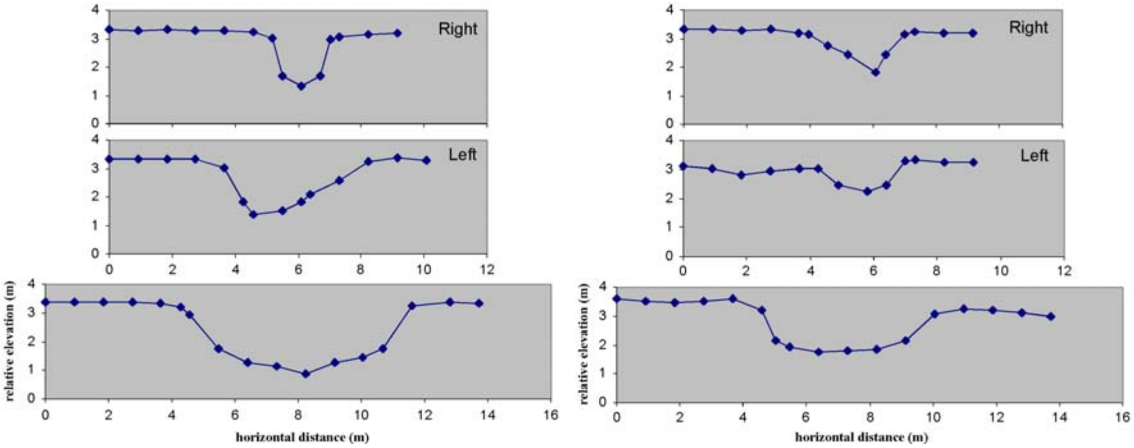

Figure 6. Channel cross-sections of protochannels depicted in Figure 5. Cross-sections on the left are those of the northern protochannel, those on the right are of the southern protochannel. Left and right channel forks are from the perspective of viewing the channel upstream from the mouth.

Established Blind Channel Development

When dikes were removed in the summer of 2000, several channel networks within the restoration site were reconnected to their historic outlets by excavating the filled channel beneath the dike footprint. This excavation matched the channel cross-section of the remnant channel outside of the dike. These reconnected channels are now resizing, adjusting to restored tidal prism and sediment supply. Channel cross-section comparisons between 2000 (Sept) and 2006 (Mar) (Figs. 7 and 8), show that cross-sections near the channel outlets are getting larger to accommodate restored tidal prism (Fig. 9). Mid-channel cross-sections are generally filling with sediments (Figs. 10 and 11), while most upstream channel sections appear to be relatively stable, though some small channels close to sediment sources are filling in. (Fig. 12).

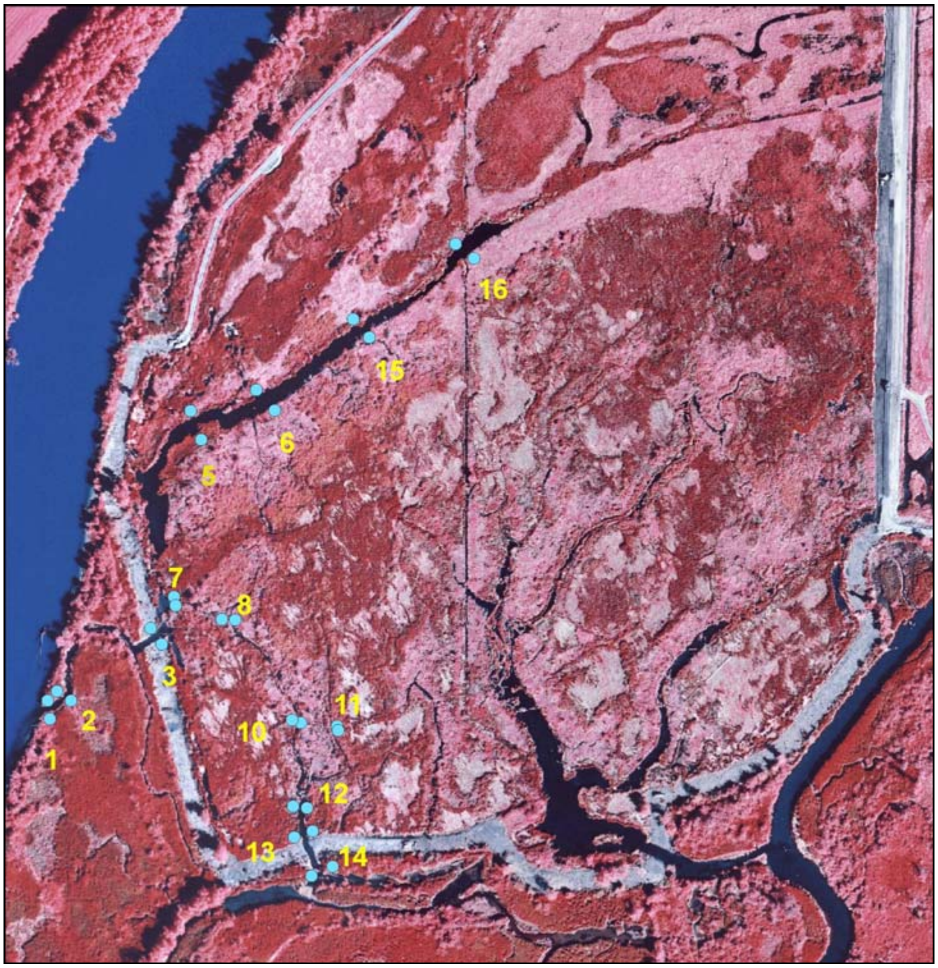

Figure 7. Location of channel cross-section comparisons between 2000 and 2006. End-points of cross-sections are denoted by light blue dots and yellow numbers. Cross-sections 4 and 9 are not shown because their 2006 locations were sufficiently misaligned with the 2000 locations to make comparison questionable. Dike footprint = blue-gray stripe (e.g., between x-sections 13 and 14, and at x-section 3). Note x-sections 1, 2, and 14 are located outside of the restoration site. Photo is from summer of 2000.

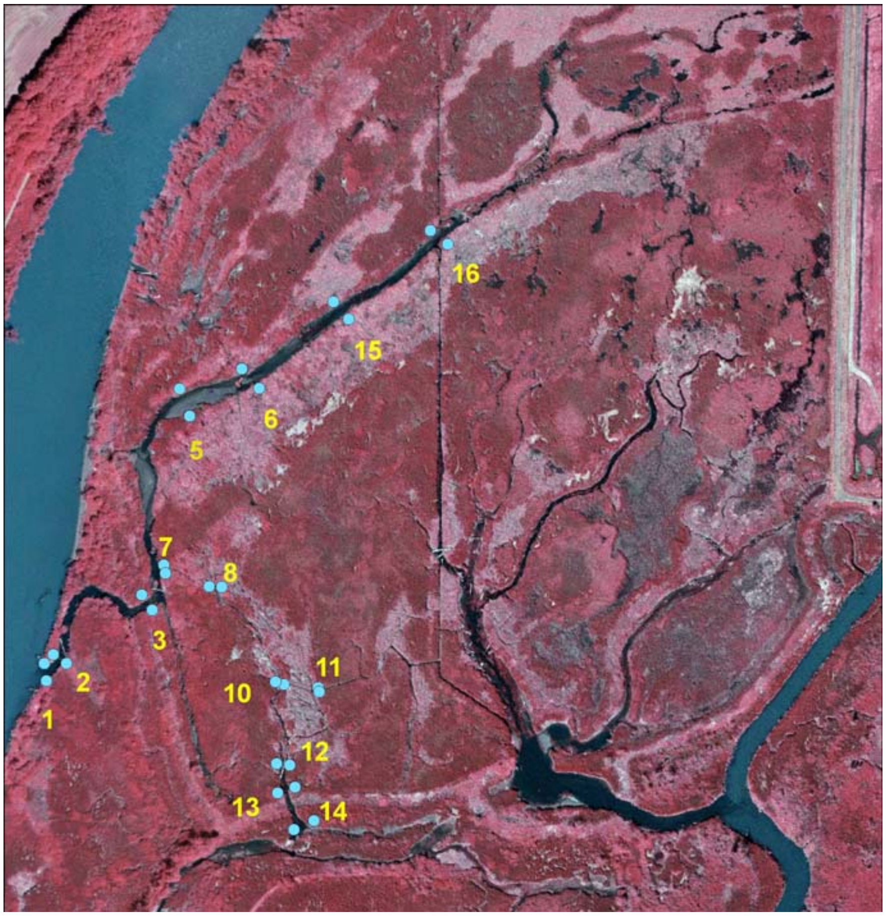

Figure 8. Location of channel cross-section comparisons between 2000 and 2006. End-points of cross-sections are denoted by light blue dots and yellow numbers. Cross-sections 4 and 9 are not shown because their 2006 locations were sufficiently misaligned with the 2000 locations to make comparison questionable. Note x-sections 1, 2, and 14 are located outside of the restoration site. Photo is from summer of 2004.

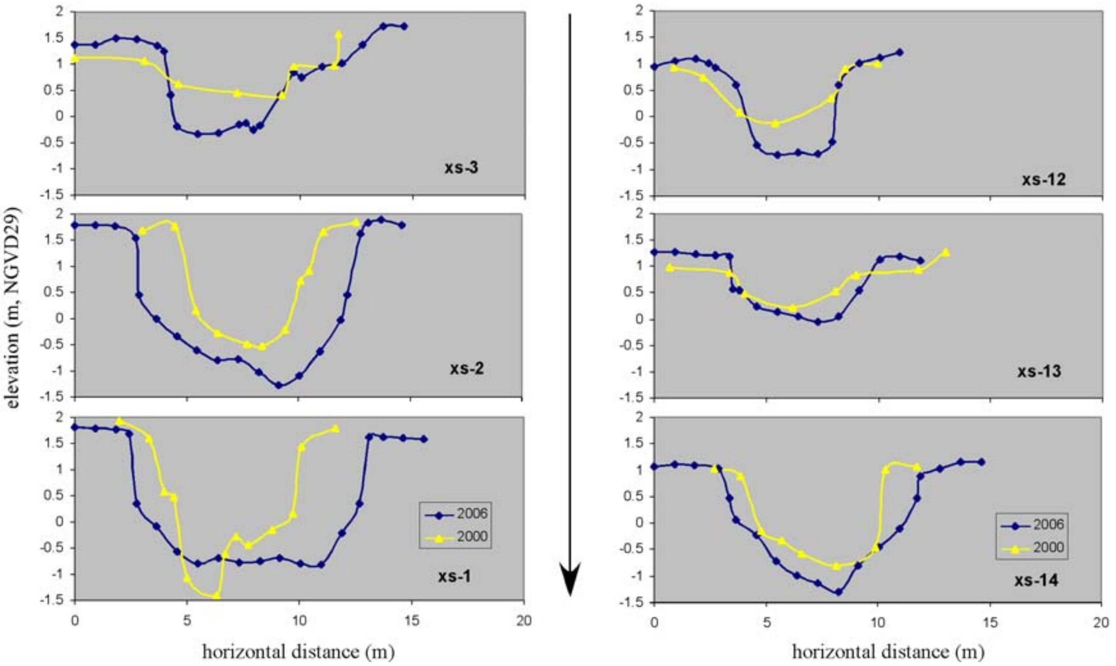

Figure 9. Channel cross-sections at or near channel outlets for two restored blind channel networks. The arrow shows ebb-tide flow direction. See Figure 8 for cross-section locations. Blue = 2006, yellow = 2000.

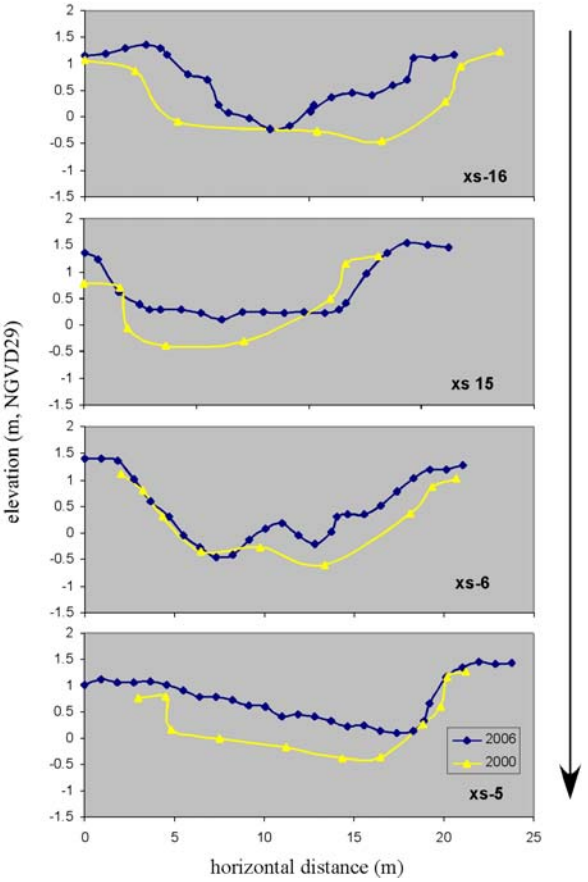

Figure 10. Mid-channel cross-sections, showing considerable sedimentation between 2000 (yellow) and 2006 (blue). See Figure 8 for cross-section locations. The arrow indicates ebb-tide flow direction for the channel cross-section sequence.

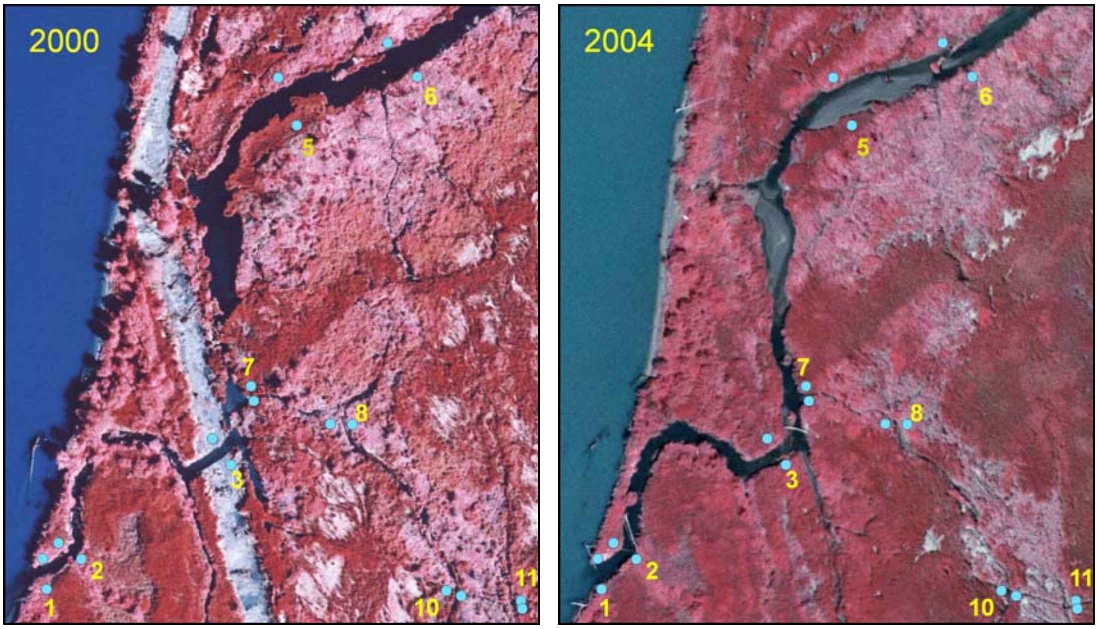

Figure 11. Detail of blind tidal channel which was reconnected to tidal influence. End-points of cross-sections are denoted by light blue dots and yellow numbers. Note obvious sediment accumulation in the channel at cross-sections 5 and 6, and between sections 3 and 5. Sediment has also accumulated at sections 7 and 8, but not at 10 and 11. This is probably due to the proximity of sections 7 and 8 to a sediment source, i.e., the lower reach of a large tidal channel to which they are directly connected.

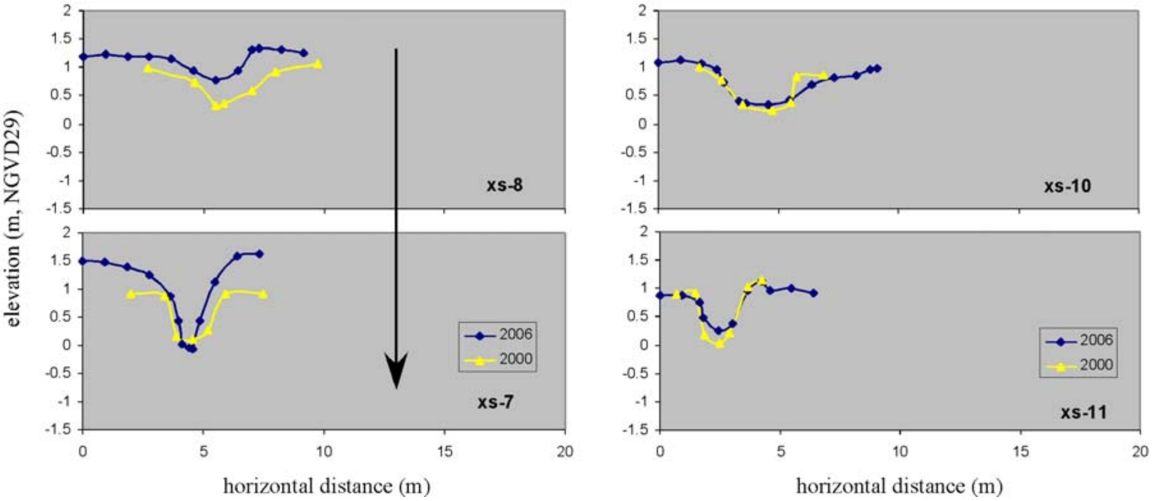

Figure 11. Headward channel cross-sections, showing considerable sedimentation between 2000 (yellow) and 2006 (blue) for two cross-sections close to a sediment source (left) and relative stability for small channels far from sediment sources (right). See Figure 8 for cross-section locations. The arrow indicates ebb-tide flow direction for the channel cross-section sequence xs-8 and xs-7. The other two channels cross-sections are not sequentially associated.

Summary

Tidal and distributary channels associated with the Deepwater restoration project are rapidly adjusting to dike removal. Many of these changes can be followed clearly through remote sensing, i.e., high resolution aerial photos, but periodic channel cross-section surveys are useful to link observed planform changes to hydraulic geometry, particularly at channel outlets. Channel changes appear to be much more rapid than vegetation changes. Site vegetation appears to have changed little in the last six years, with cattail (*Typha* spp.) and reed canarygrass (*Phalaris arundinacea*) still dominating the site (cf. Hood 2003). Continued monitoring of this site is important to compare the development of tidal channels in a site where dikes have been completely removed with those where dikes have merely been breached (the more typical restoration scenario). Future monitoring needs (at a minimum) include high resolution infra-red orthophotos in 2006 or 2007 and further channel cross-section surveys in 2008 or 2009.

Citations

Hood WG. 2003. Deepwater Slough Restoration Monitoring Report: 2000-2003. Report to the USACE-Seattle District. Skagit River System Cooperative, LaConner, Washington.