APPENDIX D

Revetment Maintenance Inspection Reports
No. 1 and No. 2

TETRA TECH

MEMORANDUM

TO: Jim Well, Ducks Unlimited

FROM: Mike Harvey, Ph.D., P.G.

SUBJECT: **M&T/ Llano Seco Fish Screen Facility Short-Term/Long-Term Protection Project (Project No. US-CA-62-2)**

Maintenance Inspection and Reports (Subtask 14.1)

Inspection Report No.1

Cc:

DATE: November 29, 2010

Introduction

Prior to implementation of a final solution, temporary bank protection consisting of approximately 1,500 LF of rock-toe/brush revetment was placed on the west bank of the Sacramento River on the U.S. Fish and Wildlife Service's Capay Unit in October 2007. The purpose of the revetment was to prevent further bank erosion and river migration (**Figures 1 through 5**), thereby preserving options for solution of the M&T/Llano Seco pump intakes and fish screens problems. Because the revetment was designed as an interim and temporary measure, there was an expectation that some maintenance would be required. The purpose of this memorandum is to report on the condition of the revetment and the need for any maintenance, if required.

Background

The interim revetment was designed to provide toe protection only to the eroding bank and there was a general expectation that the upper, nearly vertical and unprotected portion of the bank, would continue to erode until a lower bank angle developed that would be colonized by plants and, thereby, be stabilized. Approximately 5 tons/lineal foot of rock were placed at the base of the bank by excavators working from the top of the bank. The median size of the rock used was 0.75 feet, the 30th percentile was 0.63 feet and the 100th percentile was 0.94 feet. The top of the revetment was set an elevation of about 119 feet, which corresponded to a discharge of approximately 15,000 cfs, which has a 42-percent exceedence on the mean daily flow-duration curve at the Hamilton City gauge, located about 7 miles upstream (**Figure 6**). For environmental mitigation purposes, during construction woody debris was added to the structure at two elevations: (1) approximately Elevation 118 feet within the structure, which corresponds to a discharge of about 12,000 cfs (50-percent exceedence on the mean daily flow-duration curve), and (2) on the top of the structure. The top of the rock was sloped outwards (towards the river) at a grade of 10H:1V and the area between the top of the rock and the bank was

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backfilled with spoils from the tie-back excavations to prevent any entrapment of fish (**Figures 7 through 10**).

Photographs of the structure taken in March 2008 after the first period of high flows following construction are provided for reference purposes. **Figure 11** shows that the upstream end of the structure and pre-existing bank vegetation are intact. **Figure 12** shows that the woody vegetation emplaced on the top of the revetment is still in place and that there had been deposition of sediment (primarily fine sands and silts) on top of and within the upper layer of the rock. **Figure 13** shows that there was erosion and retreat of the unprotected portion of the bank, but there was no evidence of scour behind the rock. **Figure 14** shows that the within-rock woody material was still in place.

Field Inspection

The interim revetment was inspected on April 12, 2010, when the flow in the river was about 11,000 cfs. Since construction, the revetment has experienced peak flows of 56,000 cfs (1/26/08), 43,000 (2/17/09) and 64,000 cfs (1/26/10). During the course of the field inspection, the following conditions that could require maintenance were assessed:

1. Flanking of the upstream end of the structure,
2. Loss of rock from the structure itself dues to local scour at the base,
3. Loss of woody material incorporated within and placed upon the top of the structure,
4. Excessive erosion of the unprotected portion of the bank and scour along the contact between the rock toe and the bank, and
5. Excessive erosion off the downstream end of the structure.

Observations

1. **Upstream Flanking** – There is no evidence that there has been any erosion at the upstream end of the structure (**Figure 15**). Comparison with Figure 11 indicates that there has been little or no change at the upstream end of the site since construction.

2. **Loss of Rock** – There was no evidence of loss of rock at any location along the entire 1,500 feet of the structure (**Figure 16**). The crest of the rock was sharp along the entire revetment and there was no evidence of erosion scarps.

3. **Loss of Woody Material** – Although the water surface was generally above the elevation of the woody debris included within the structure, there was evidence of its presence at a number of locations (**Figure 17**). The fact that the woody material was located below the water surface at a discharge (11,000 cfs) below the design discharge (12,000 cfs) suggests there may have been some bed scour along the revetment, but it could also easily be within the margin of error for the rating curve that was used for design purposes. From a biological perspective, the woody debris is being inundated and thus providing habitat for more than the designed 50 percent of the time. Woody debris piles placed on the top of the revetment are intact (**Figure 18**) and appear to be sites of preferential establishment of boxelders and other plants (**Figure 19**), probably because of their effects on local flow velocities.

4. **Excessive Bank Erosion** – Upper bank erosion is occurring at a number of locations along the site, as expected (**Figure 20**). The ongoing erosion is lowering the bank angle as the bank rotates backwards from the armored toe. However, there is no evidence of any scour along the contact between the rock and the bank (**Figure 21**), and it is clear that woody vegetation (primarily willows) has become established at the base of the bank and on the lower angle portions of the bank (**Figure 22**).

5. **Excessive Downstream Erosion** – Observation of the downstream end of the revetment did not indicate that there had been any significant erosion of the bank downstream of the revetment (**Figure 23**) and there does not appear to have been any loss of rock (**Figure 24**).

Conclusions and Recommendations

Based on the observations of the interim revetment on April 12, 2010, it is clear that there currently no requirements for maintenance of the site following a range of peak flows up to 64,000 cfs. However, it is recommended that the site be re-inspected following the winter high flows of 2010/2011. Inspection of the site should be done when flows are in the 6,000- to 8,000-cfs range so the outboard side of the revetment can be observed.

Figure 1. Photograph of the upstream end of the site prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

Figure 2. Photograph of the middle part of the site prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

Figure 3. Photograph of the apex of the eroding bend prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

Figure 4. Photograph of the middle part of the downstream part of the site prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

Figure 5. Photograph of the downstream end of the site prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

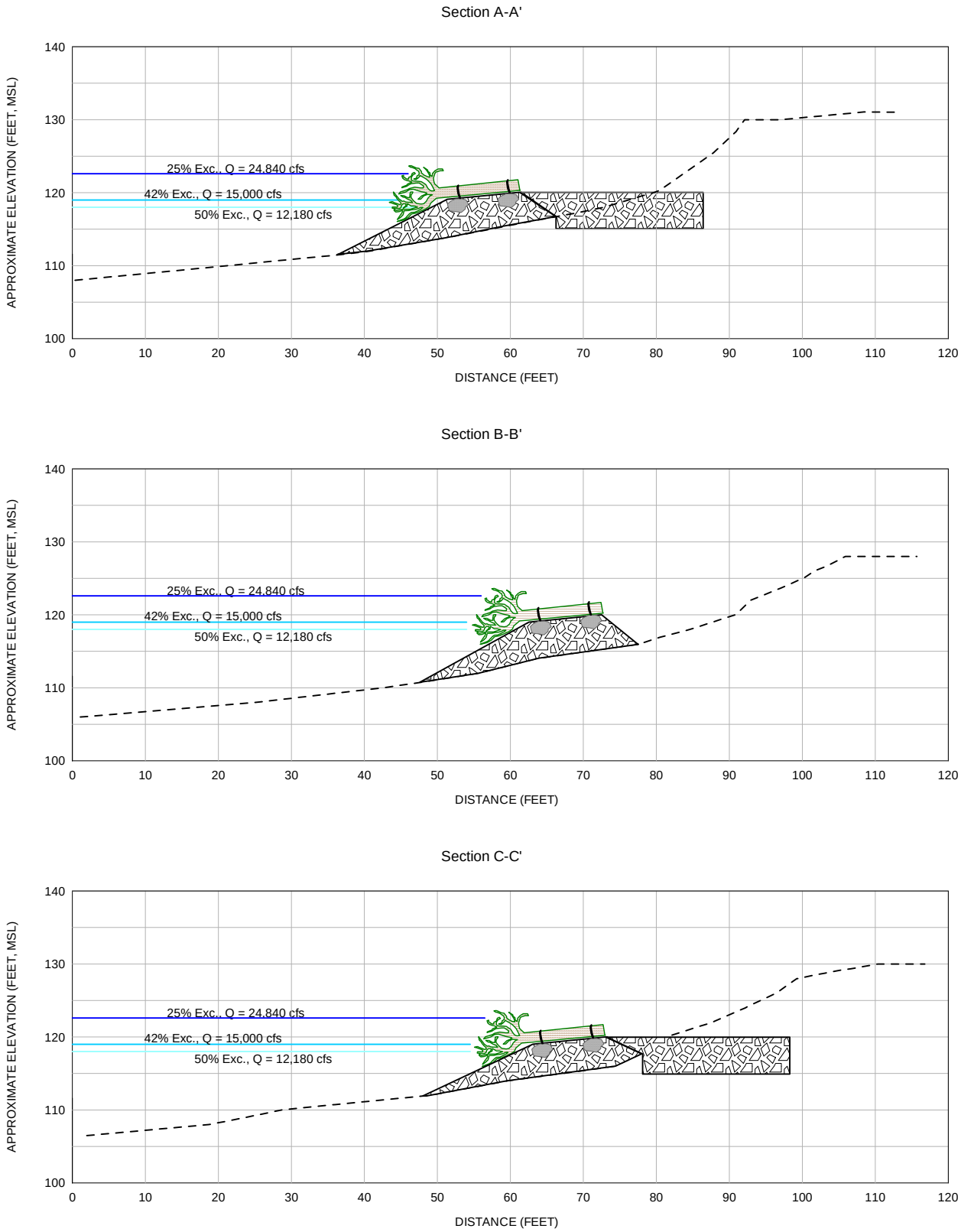

Figure 6. Typical sections of the rock-toe/brush revetment showing design flows and elevations.

Figure 7. View downstream of the rock toe being emplaced during construction of the revetment. The top of the rock is at Elevation 119 feet (Photo taken on 10/30/2007).

Figure 8. View upstream of the rock toe being emplaced during construction of the revetment. Note the woody material incorporated into the revetment at about Elevation 117 feet (Photo taken on 10/30/2007).

Figure 9. View of woody material being placed on the top of the revetment at about Elevation 119 feet during construction of the revetment (Photo taken on 10/30/2007).

Figure 10. View upstream of backfill in place between the rock revetment and the bank slope during construction (Photo taken 10/30/2007).

Figure 11. View upstream of the upstream end of the revetment showing the presence of the pre-construction vegetation on the upstream bank (Photo taken on 03/12/2008).

Figure 12. View of intact woody debris on top of the revetment as well as sediment deposition on top of the rock following the first higher winter flows after construction (Photo taken on 03/12/2008).

Figure 13. View downstream of bank erosion caused by the first higher winter flows after construction (Photo taken on 03/12/2008).

Figure 14. View of top of revetment showing the presence of woody material both on top of the revetment and encased within the structure following the first higher winter flows after construction (Photo taken on 03/12/2008).

Figure 15. View of the upstream end of the revetment and the pre-construction riparian vegetation growing on the bank upstream of the structure. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 16. View upstream of the revetment showing the presence of the woody debris piles that were constructed on top of the structure. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 17. View of the top of submerged woody material that was incorporated into the revetment at about Elevation 117 feet. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2008).

Figure 18. View downstream of the top of the revetment showing the woody debris piles that were placed and cabled onto the revetment. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2008).

Figure 19. Close up view of a woody debris pile cabled onto the top of the revetment showing volunteer woody plants growing within and around the debris pile. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 20. View downstream of eroding upper bank above the top of the revetment that is causing the bank angle to be reduced. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 21. View downstream showing eroding upper bank but no evidence of any scour of the backfill material at the base of the bank. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2008).

Figure 22. View upstream of willow growth along the top of the revetment and at the base of the eroding bank. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 23. View downstream of the downstream part of the revetment with vegetation growing at the toe of the bank and on the top of the revetment. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 24. View upstream of the downstream end of the revetment and the downstream tie back. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

MEMORANDUM

TO: Jim Well, Ducks Unlimited

FROM: Mike Harvey, PhD, PG

SUBJECT: **M&T/ Llano Seco Fish Screen Facility Short-Term/Long-Term Protection Project (Project No. US-CA-62-2)**

Maintenance Inspection and Reports (Subtask 14.1)

Inspection Report No.2

DATE: May 8, 2012

1 Introduction

Prior to implementation of a final solution, temporary bank protection consisting of approximately 1,500 LF of rock-toe/brush revetment was placed on the west bank of the Sacramento River on the U.S. Fish and Wildlife Service's Capay Unit in October 2007. The purpose of the revetment was to prevent further bank erosion and river migration (**Figures 1 through 5**), thereby preserving options for solution of the M&T/Llano Seco pump intakes and fish screens problems. Because the revetment was designed as an interim and temporary measure, there was an expectation that some maintenance would be required. The purpose of this memorandum is to report on the condition of the revetment and the need for any maintenance, if required.

1.1 Background

The interim revetment was designed to provide toe protection only to the eroding bank and there was a general expectation that the upper, nearly vertical and unprotected portion of the bank, would continue to erode until a lower bank angle developed that would be colonized by plants and, thereby, be stabilized. Approximately 5 tons/lineal foot of rock were placed at the base of the bank by excavators working from the top of the bank. The median size of the rock used was 0.75 feet, the 30th percentile was 0.63 feet and the 100th percentile was 0.94 feet. The top of the revetment was set an elevation of about 119 feet, which corresponded to a discharge of approximately 15,000 cfs, which has a 42-percent exceedence on the mean daily flow-duration curve at the Hamilton City gauge, located about 7 miles upstream (**Figure 6**). For environmental mitigation purposes, during construction woody debris was added to the structure at two elevations: (1) approximately Elevation 118 feet within the structure, which corresponds to a discharge of about 12,000 cfs (50-percent exceedence on the mean daily flow-duration curve), and (2) on the top of the structure. The top of the rock was sloped outwards (towards the river) at a grade of 10H:1V and the area between the top of the rock and the bank was backfilled with spoils from the tie-back excavations to prevent any entrapment of fish (**Figures 7 through 10**).

Photographs of the structure taken in March 2008 after the first period of high flows following construction are provided for reference purposes. **Figure 11** shows that the upstream end of the structure and pre-existing bank vegetation are intact. **Figure 12** shows that the woody vegetation emplaced on the top of the revetment is still in place and that there had been

deposition of sediment (primarily fine sands and silts) on top of and within the upper layer of the rock. **Figure 13** shows that there was erosion and retreat of the unprotected portion of the bank, but there was no evidence of scour behind the rock. **Figure 14** shows that the within-rock woody material was still in place.

2 Field Inspections

2.1 April 12, 2010 Inspection

The first post-construction inspection of the revetment was conducted on April 12, 2010, when the flow in the river was about 11,000 cfs. Since construction, the revetment had experienced peak flows of 56,000 cfs (1/26/08), 43,000 (2/17/09) and 64,000 cfs (1/26/10). During the course of the field inspection, the following conditions that could require maintenance were assessed:

1. Flanking of the upstream end of the structure,
2. Loss of rock from the structure itself due to local scour at the base,
3. Loss of woody material incorporated within and placed upon the top of the structure,
4. Excessive erosion of the unprotected portion of the bank and scour along the contact between the rock toe and the bank, and
5. Excessive erosion off the downstream end of the structure.

2.2 Observations from April 12, 2010 Inspection

1. **Upstream Flanking** – There was no evidence that there has been any erosion at the upstream end of the structure (**Figure 15**). Comparison with Figure 11 indicates that there has been little or no change at the upstream end of the site since construction.

2. **Loss of Rock** – There was no evidence of loss of rock at any location along the entire 1,500 feet of the structure (**Figure 16**). The crest of the rock was sharp along the entire revetment and there was no evidence of erosion scarps.

3. **Loss of Woody Material** – Although the water surface was generally above the elevation of the woody debris included within the structure, there was evidence of its presence at a number of locations (**Figure 17**). The fact that the woody material was located below the water surface at a discharge (11,000 cfs) below the design discharge (12,000 cfs) suggests there may have been some bed scour along the revetment, but it could also easily be within the margin of error for the rating curve that was used for design purposes. From a biological perspective, the woody debris is being inundated and thus providing habitat for more than the designed 50 percent of the time. Woody debris piles placed on the top of the revetment were intact (**Figure 18**) and appear to be sites of preferential establishment of boxelders and other plants (**Figure 19**), probably because of their effects on local flow velocities.

4. **Excessive Bank Erosion** – Upper bank erosion was occurring at a number of locations along the site, as expected (**Figure 20**). The ongoing erosion is lowering the bank angle as the bank rotates backwards from the armored toe. However, there was no evidence of any scour along the contact between the rock and the bank (**Figure 21**), and it is clear that

woody vegetation (primarily willows) has become established at the base of the bank and on the lower angle portions of the bank (**Figure 22**).

5. **Excessive Downstream Erosion** – Observation of the downstream end of the revetment did not indicate that there had been any significant erosion of the bank downstream of the revetment (**Figure 23**) and there does not appear to have been any loss of rock (**Figure 24**).

2.3 Conclusions and Recommendations Following April 12, 2010 Inspection

Based on the observations of the interim revetment on April 12, 2010, it was clear that there were no requirements for maintenance of the site following a range of peak flows up to 64,000 cfs. However, it was recommended that the site be re-inspected following the winter high flows of 2010/2011. It was recommended also that inspection of the site should be done when flows are in the 6,000- to 8,000-cfs range so the outboard side of the revetment could be observed.

3 November 1, 2011 Inspection

The second post-construction inspection of the revetment was conducted on November 1, 2011, when the flow in the river was about 7,190 cfs. Since construction, the revetment had experienced peak flows of 56,000 cfs (1/26/08), 43,000 (2/17/09), 64,000 cfs (1/26/10) and 102,528 cfs (03/21/11). During the course of the field inspection, the following conditions that could require maintenance were assessed:

1. Flanking of the upstream end of the structure,
2. Loss of rock from the structure itself due to local scour at the base,
3. Loss of woody material incorporated within and placed upon the top of the structure,
4. Excessive erosion of the unprotected portion of the bank and scour along the contact between the rock toe and the bank, and
5. Excessive erosion off the downstream end of the structure.
6. Toe scour along the revetment.

3.1 Observations from November 1, 2011 Inspection

1. **Upstream Flanking** – There was no evidence that there has been any erosion at the upstream end of the structure (**Figure 25**). Comparison with Figures 11 and 15 indicates that there has been little or no change at the upstream end of the site since construction.

2. **Loss of Rock** – There was no evidence of loss of rock at any location along the entire 1,500 feet of the structure (**Figures 26, 27, 28, 29**). The crest of the rock was sharp along the entire revetment and there was no evidence of erosion scarps.

3. **Loss of Woody Material** – The water-surface elevation at a discharge of 7,190 cfs is below the large woody debris included within the structure at construction (Figure 6). Woody debris piles placed on the top of the revetment and within the revetment were intact along the entire site (**Figures 30, 31, 32, 33**). The large woody debris piles anchored on the top of the structure appears to be sites of preferential establishment of boxelders, sycamore and willows (**Figure 34**), probably because of their effects on local flow velocities.

4. **Excessive Bank Erosion** – Upper bank erosion continues to occur at a number of locations along the site, as expected (Figures 20, 21). The ongoing erosion is lowering the bank angle as the bank rotates backwards from the armored toe. However, there was no evidence of any scour along the contact between the rock and the bank (Figure 21), and it is clear that woody vegetation (primarily willows) has become established at the base of the bank and on the lower angle portions of the bank (Figure 22).

5. **Excessive Downstream Erosion** – Observation of the downstream end of the revetment did not indicate that there had been any significant erosion of the bank downstream of the revetment (**Figure 35**) and there does not appear to have been any loss of rock (**Figure 36**).

6. **Toe Scour along the Revetment** – Comparison of the January 2010 and June 2011 bathymetric surveys of the M&T reach (**Figure 37**) indicate that the high flows of March 2011 may have caused about 2 feet of scour along the revetment. However, the field inspection did not reveal any loss of rock resulting from the toe scour.

3.2 Conclusions Following November 1, 2011 Inspection

Based on the observations of the interim revetment on April 12, 2010 and November 1, 2011, it is clear that there were no immediate requirements for maintenance of the site following a range of peak flows up to 102,528 cfs. At the highest discharge experienced since construction, the left overbank above the toe rock revetment was overtopped in 2011 but there was no evidence of either accelerated erosion of the upper bank or damage to the revetment itself. Both the upstream and downstream transitions into and from the revetment show no signs of significant erosion. Significant numbers of riparian plants have volunteered onto both the top of the rock revetment and onto the reduced-angle lower bank slope above the contact with the revetment. There does not appear to have been any loss of large woody debris from the structure. Based on the field observations it appears that the toe rock revetment is performing well and continues to maintain the current river alignment.

Figure 1. Photograph of the upstream end of the site prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

Figure 2. Photograph of the middle part of the site prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

Figure 3. Photograph of the apex of the eroding bend prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

Figure 4. Photograph of the middle part of the downstream part of the site prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

Figure 5. Photograph of the downstream end of the site prior to construction of the rock-toe/brush revetment (Photo taken on 10/24/2006).

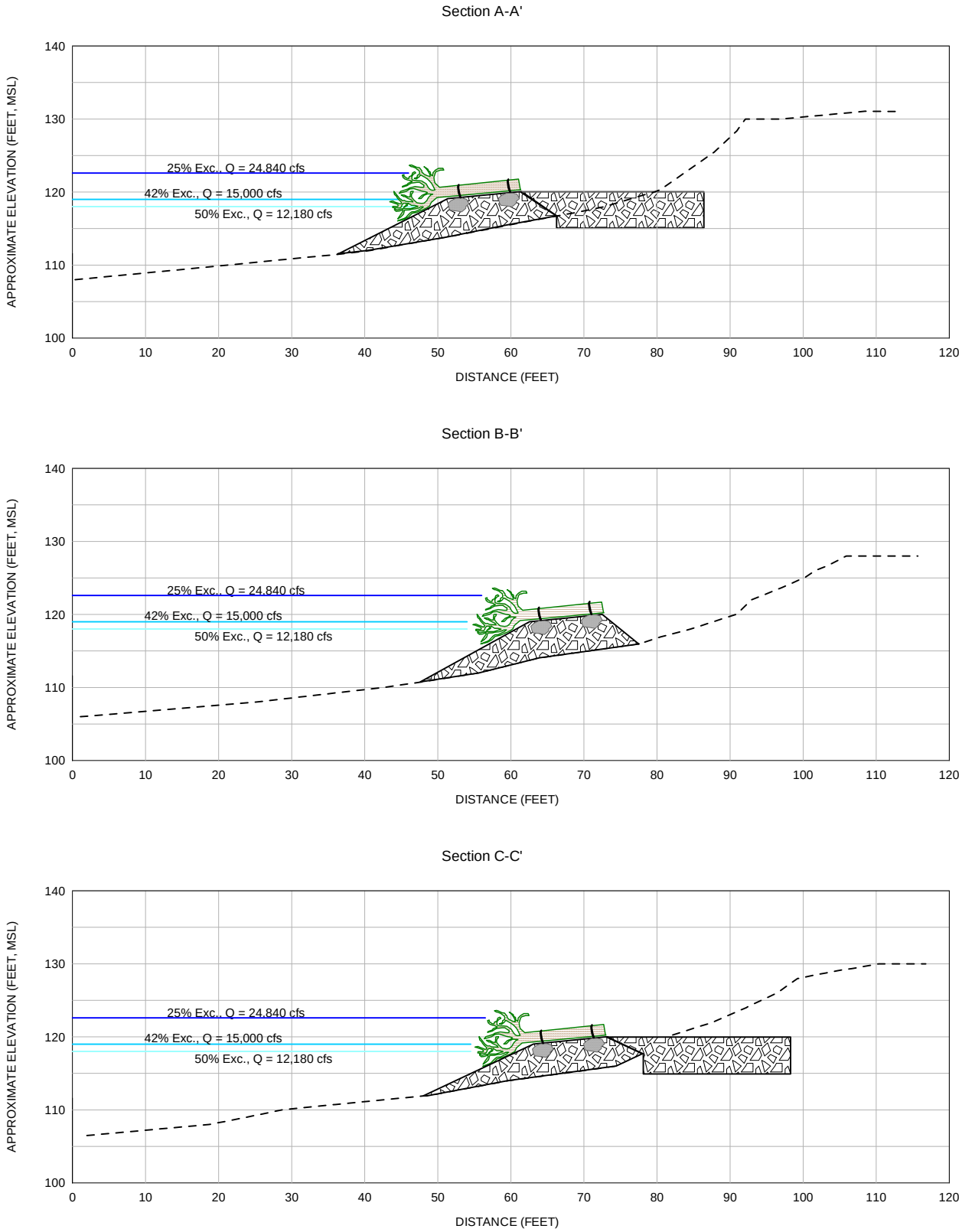

Figure 6. Typical sections of the rock-toe/brush revetment showing design flows and elevations.

Figure 7. View downstream of the rock toe being emplaced during construction of the revetment. The top of the rock is at Elevation 119 feet (Photo taken on 10/30/2007).

Figure 8. View upstream of the rock toe being emplaced during construction of the revetment. Note the woody material incorporated into the revetment at about Elevation 117 feet (Photo taken on 10/30/2007).

Figure 9. View of woody material being placed on the top of the revetment at about Elevation 119 feet during construction of the revetment (Photo taken on 10/30/2007).

Figure 10. View upstream of backfill in place between the rock revetment and the bank slope during construction (Photo taken 10/30/2007).

Figure 11. View upstream of the upstream end of the revetment showing the presence of the pre-construction vegetation on the upstream bank (Photo taken on 03/12/2008).

Figure 12. View of intact woody debris on top of the revetment as well as sediment deposition on top of the rock following the first higher winter flows after construction (Photo taken on 03/12/2008).

Figure 13. View downstream of bank erosion caused by the first higher winter flows after construction (Photo taken on 03/12/2008).

Figure 14. View of top of revetment showing the presence of woody material both on top of the revetment and encased within the structure following the first higher winter flows after construction (Photo taken on 03/12/2008).

Figure 15. View of the upstream end of the revetment and the pre-construction riparian vegetation growing on the bank upstream of the structure. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 16. View upstream of the revetment showing the presence of the woody debris piles that were constructed on top of the structure. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 17. View of the top of submerged woody material that was incorporated into the revetment at about Elevation 117 feet. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2008).

Figure 18. View downstream of the top of the revetment showing the woody debris piles that were placed and cabled onto the revetment. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 19. Close up view of a woody debris pile cabled onto the top of the revetment showing volunteer woody plants growing within and around the debris pile. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 20. View downstream of eroding upper bank above the top of the revetment that is causing the bank angle to be reduced. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 21. View downstream showing eroding upper bank but no evidence of any scour of the backfill material at the base of the bank. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 22. View upstream of willow growth along the top of the revetment and at the base of the eroding bank. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 23. View downstream of the downstream part of the revetment with vegetation growing at the toe of the bank and on the top of the revetment. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 24. View upstream of the downstream end of the revetment and the downstream tie back. Flow in the river was about 11,000 cfs (Photo taken on 04/12/2010).

Figure 25. View of the upstream end of the rock revetment and transition to unprotected bank. Note the presence of the willows growing on the bank indicating that there has been little or no erosion at the upstream end of the revetment.

Figure 26. Upstream view of the upstream end of the toe rock revetment. Note presence of riparian vegetation as well as the large woody debris emplaced within the rock during construction. There is no evidence of loss of rock. Note the larger anchor boulders that were used to secure the large woody debris emplaced on the top of the revetment.

Figure 27. Upstream view of the upper section of the toe rock revetment. Note the large woody debris emplaced on the top of the rock and within the rock during construction and the riparian vegetation that has volunteered onto the top of the rock especially in the vicinity of the large woody debris placed on the top of the rock.

Figure 28. Close up view of the rock toe within the middle section of the revetment. There is no evidence of loss of rock.

Figure 29. Close up view of the rock toe within the lower end of the revetment. There is no evidence of loss of rock.

Figure 30. Close up view of the upper section of the toe rock revetment. There is no evidence of loss of rock.

Figure 31. Upstream view of the middle section of the toe rock revetment. Note the large woody debris emplaced on the top of the rock and within the rock during construction.

Figure 32. Upstream view of the middle section of the toe rock revetment. Note the very dense volunteered riparian vegetation species growing on the top of the rock and the presence of the emplaced large woody debris on the top of the rock and within the rock.

Figure 33. Upstream view of the lower (downstream) end of the toe rock revetment. Note the presence of volunteered riparian vegetation species including sycamore, box elder and willows on the surface of the rock.

Figure 34. Upstream view of the lower end of the toe rock revetment. Note presence of volunteered riparian vegetation species as well as emplaced large woody debris on the top of the rock and within the rock. There is no evidence of loss of rock from the revetment.

Figure 35. Downstream end of revetment. Note presence of willows growing on the bar which indicates there has been no retreat of the bank downstream of the toe rock.

Figure 36. Close up view of the downstream end of the toe rock. Rock is intact and there appears to be little loss of rock at the downstream end.

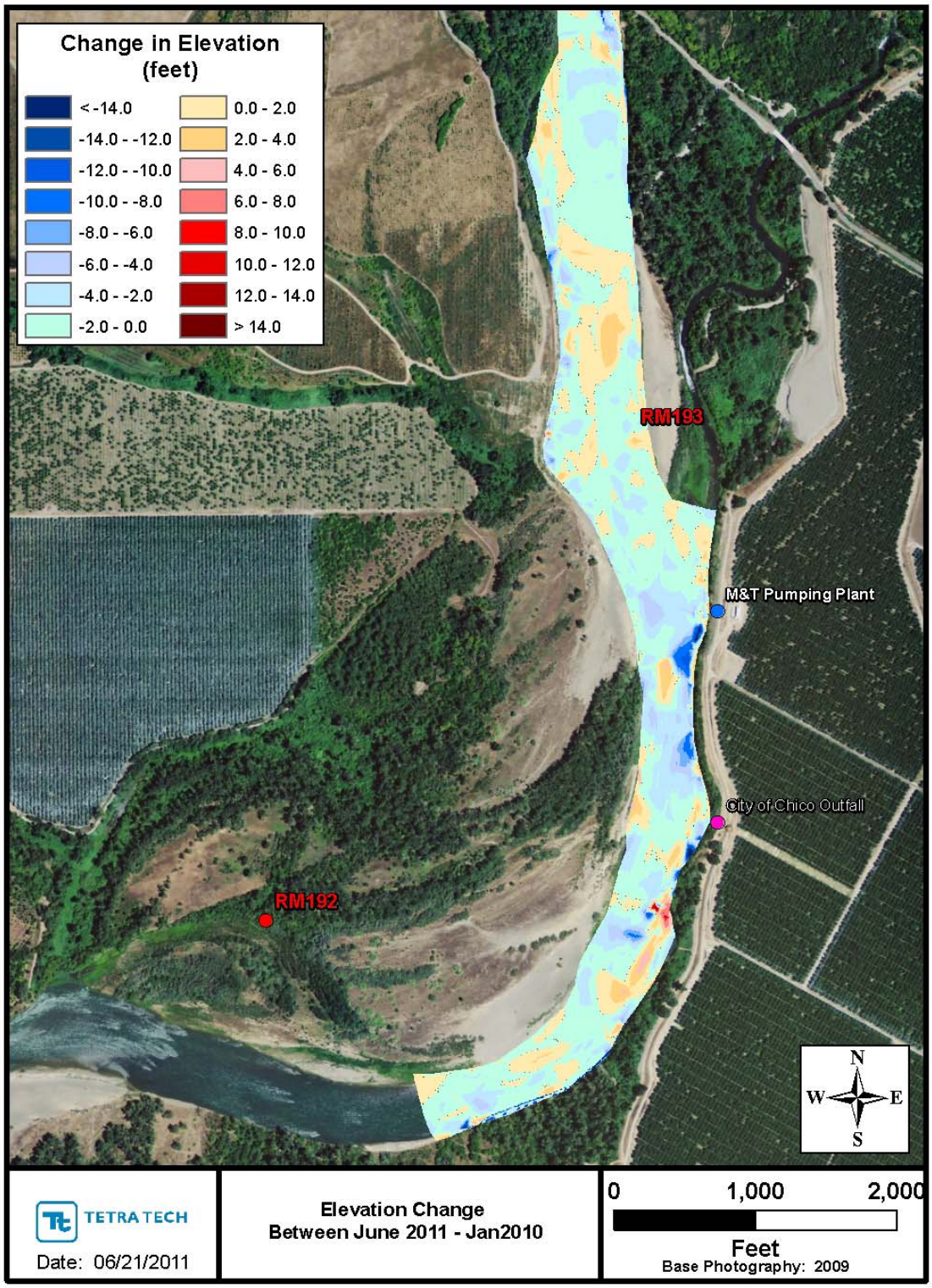

Figure 37. Elevation changes in the M&T/Llano Seco reach between the January 2010 and June 2011 surveys.