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Colusa Basin Watershed Streambank Analysis

FINAL REPORT

February 25, 2010

Prepared for

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Oblique aerial view to east looking downstream to North Branch Sand Creek approx. 1.3 miles upstream from the Tehama-Colusa Canal. Sutter Buttes in far background. Photo by Kondolf. (November 12, 2009)

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1. Colusa Basin Watershed Streambank Analysis Project Overview

In Checkpoint #1 work, **geomorph**, H.T. Harvey & Associates, and G.M. Kondolf Ph.D. (Project Team) used expert air photo interpretation and extensive ground-truthing to map existing stream bank erosion and woody riparian and invasive vegetation conditions along the mainstem alluvial lengths of 36 streams draining the Coast Range foothills to the Colusa Basin Drain within the approx. 1,634-square mile Colusa Basin Watershed (Figure 1). We produced a Checkpoint #1 interim draft report and maps (Figures 2-4) dated December 21, 2009 and received CCRCD-compiled comments to these submittals on January 11, 2010. We responded to comments and made revisions to the resource conditions report and maps in the Checkpoint #2 submittal.

✓Checkpoint #1	Resource Mapping
✓Checkpoint #2	Critical Management Reaches
✓Checkpoint #3	Reference Reaches

In Checkpoint #2 work, the Project Team used the resulting revised resource conditions maps and underlying GIS database in to develop a technical rationale for selecting “critical management reaches” – individual foothill stream reaches which appear to offer the best opportunities to improve the extent of contiguous quality woody riparian habitat, check the spread of invasives, reduce stream bank erosion, and protect water quality through multi-objective management. We prepared a watershed scale map showing the 24 individual Critical Management Reaches (CMRs) we selected (Figure 5). Table 1 lists basic attributes of the CMRs.

We produced a Checkpoint #2 interim draft report and maps dated January 20, 2010 containing the CMR map and revised maps from Checkpoint #1 resource mapping. We received several verbal comments and suggestions to the Checkpoint #2 results at presentations we made in Dunnigan on January 19, 2010 and Colusa on January 20, 2010. We also received CCRCD-compiled comments to the Checkpoint #2 report and maps on February 2, 2010. We responded to comments and made revisions to the report and maps in the Checkpoint #3 submittal.

In Checkpoint #3 work, the Project Team used basic field geomorphic and biological site assessment and air photo imagery to document the opportunities and constraints for restoration and management of three “reference reaches” we selected to be generally representative of the range of conditions occurring within the critical management reaches (Figures 6-8). We produced a Checkpoint #3 interim draft report and maps dated February 8, 2010 which described the selected reference reaches, and discussed the opportunities and constraints for bank erosion reduction and riparian habitat management and restoration with special emphasis on the reference reaches. We received comments to the Checkpoint #3 report and maps on February 16, 2010. We responded to comments and made revisions to the report and maps in this Final Project Report submittal. We delivered the Final Project Report and Maps to the CCRCD in Colusa with the Final Presentation on February 25, 2010.

2. Checkpoint #1 Field Work

In general, ground-truthing was conducted at road crossings and along reaches of the streams that closely bordered roads. Matt Smeltzer of **geomorph** completed nine (9) days of field ground-truthing for mapping bank erosion conditions on November 7-12, 2009 and December 1-3, 2009, evaluating conditions affecting bank erosion potential at more than 215 field stops.

Dr. Matt Kondolf conducted field work with Matt Smeltzer on November 12, 2009, including a 2.5-hour aerial flyover originating from Willows Airport. The flight turned south from Black Butte Reservoir to run along the foothill front to Esparto, and returned to Willows approx. along the Glenn-Colusa Canal. This flight allowed us to inspect many reaches within private properties that could not be accessed on the ground. We also made oblique aerial photographs of individual stream reaches from the plane. In many cases these photos provided information needed to better remote sense bank erosion potential in reaches that could not be accessed on the ground. Oblique aerial photos are generally better than vertical non-stereo air photos for remote sensing bank erosion potential. This is because the oblique angle view from a low-altitude plane allows for evaluation of the height and shape of stream banks, whereas are vertical air photos generally made from high-altitude vertical angled photo viewpoints do not detect the height and shape of especially near-vertical erosion-prone banks. This is unless they are stereo-pair air photos.

Matt Smeltzer and Matt Kondolf also attended the November 12, 2009 Field Trip No. 1 with Patti Turner of CCRCD and Jack Alderson of NRCS, and Cathy Little of H.T. Harvey & Associates. Field Trip No. 1 visited otherwise inaccessible sites along private roads in the foothill inner valley sections of Cortina Creek, Walters Creek, and Spring Creek. The field trip provided an opportunity to discuss preliminary results of ground-truthing and remote sensing work and refine definitions for resource mapping to better meet project objectives. These refinements were documented in the November 25, 2009 mapping methods memorandum, much of which has been incorporated in the interim drafts and final report.

A restoration/plant ecologist from H. T. Harvey & Associates conducted seven (7) days of field ground-truthing and assessment for mapping riparian habitat quality and invasive severity on November 12-13, 2009, November 17-19, 2009, and December 2-3, 2009.

With Jack Alderson of NRCS, Matt Smeltzer, Max Busnardo, and Matt Kondolf attended the January 20, 2010 Field Trip No. 2 inspecting accessible portions of the three Reference Reaches on Cortina Creek, Elk Creek, and Little Buckeye Creek. Heavy rainfall prevented some access via unimproved roadways but afforded field observations of site-specific hydraulics, recent bar migration and other sediment deposition, and sediment concentration during relatively high streamflow.

3. Selected Air photo imagery

We obtained the 2009 NAIP coverage for the entire Colusa Basin Watershed and used the imagery for field navigation, field ground-truthing imagery signatures for remote sensing, and in-office remote sensing mapping of the resource classifications. The attached final report maps show the 2009 NAIP coverage as the air photo underlay, and the final delivered working GIS database also contains the NAIP coverage files.

4. Selected Foothill Streams

We selected the 36 most prominent USGS-mapped and named foothill streams to map and evaluate in the Streambank Analysis Project to: (1) achieve a roughly even distribution of streams occurring within the individual counties and also by relative size of geomorphic provinces delineated by the 2008 Watershed Assessment; (2) include streams affording some amount of physical field access for ground-truthing; and (3) include streams we believed contained reaches which may be identified as critical management reaches during Checkpoint #2 work. The selected streams are listed below and categorized by geomorphic provinces delineated by the 2008 Watershed Assessment. They are shown in watershed scale map format in Figure 1.

<u>Northwest Dissected Terrace</u> (9)

1. North Fork and Mainstem Walker Creek
2. South Fork Walker Creek
3. Wilson Creek
4. White Cabin Creek
5. Sheep Corral Creek
6. French Creek
7. Hayes Hollow Creek
8. Nye Creek
9. South Fork Willow Creek

- Mainstem Willow Creek was not included because it is entirely operated as an irrigation water conduit.
- Salt Gulch Creek was not included because there is almost no public access for ground truthing.
- North Fork Willow Creek was not included because it is not a USGS-mapped and named stream.

<u>North-Central Dissected Terrace</u> (10)

10. North Fork Logan Creek
11. Logan Creek
12. Hunters Creek
13. Funks Creek
14. Stone Corral Creek
15. Lurline Creek
16. Glenn Valley Slough
17. Manor Slough
18. Freshwater Creek
19. Salt Creek (North)

<u>South-Central Fans</u> (6)

20. Spring Creek
21. Walters Creek
22. Cortina Creek
23. Sand Creek North Branch
24. Sand Creek South Branch
25. Mainstem Sand Creek (upstream and downstream sections)

- Chamisal Creek was not included because there is almost no access for ground truthing.

<u>Southern Dissected Fans</u> (7)

26. Whisky Creek
27. Mainstem Elk Creek
28. Salt Creek (south)
29. Petroleum Creek
30. Little Buckeye Creek
31. Buckeye Creek
32. South Fork Buckeye Creek

- North Fork Elk Creek was not included because it has a relatively minor contribution to Mainstem Elk Creek drainage area.

- Brush Creek tributary to Mainstem Elk Creek and Wildcat Creek were not included because there is almost no public access for ground truthing.

- Clark's Ditch was not included because it is an artificial constructed channel with lesser restoration potential than other streams in this province.

Dunnigan Hills (4)
33. Dunnigan Creek
34. Mainstem Bird Creek
35. Mainstem Oat Creek
36. Willow Spring Creek

- North Fork, Middle Fork, and South Fork Bird Creek and North Fork and South Fork Oat Creek were not included because including these five forks with their mainstems would have resulted in there being 9 named streams evaluated within the relatively small portion of the watershed comprised by the Dunnigan Hills geomorphic province.

5. Mapped Stream Alignments

At the beginning of the project, the best available GIS data layer for stream lines was an ESRI origin regional streams database used by the 2008 Watershed Assessment. Upon closer inspection, we found it contains numerous inconsistencies with the named blue line stream alignments shown in the USGS quadrangles. In general, it is also of too low resolution to produce accurate reach-scale maps of the streams. Most importantly, many foothill stream sections have been re-aligned by channelization projects since the mapping which the original streams data layer was produced from.

Therefore, we took the opportunity to produce an updated and improved stream line GIS data layer by digitizing the 36 foothill stream lines within the study extents along the centerlines of the streams shown in the 2009 NAIPs at maximum 1:12,000 scale to improve resolution and capture recent changes to stream alignments caused by channelization within agricultural properties. We referred to naming and labeling shown on the USGS quadrangles to resolve, e.g., which of generally equivalent sized multiple channels is the mainstem stream, etc.

6. Downstream Extent of Ground-Truthing & Mapping

We determined the downstream extent of ground-truthing by visiting successively downstream road crossing locations until either the downstream-most road crossing was visited or field conditions and air photos suggested that relatively uniform conditions prevailed downstream to the Colusa Basin Drain. The foothill streams are commonly channelized and exhibit relatively uniform resource characteristics in their downstream extents. Particularly in Glenn County and Northern Colusa County, the downstream extents of the streams were both channelized and operated as deep-water flowing irrigation conduits, which appeared to generally diminish the potential for management to reduce bank erosion and restore woody riparian habitat, especially by establishment of woody riparian vegetation on the channel banks. We somewhat reduced ground-truthing in irrigation conduit stream reaches in favor of increasing ground-truthing elsewhere in the watershed. However, we did use air photo interpretation and limited ground-truthing to map the resource conditions in these reaches all the way down to the Colusa Basin Drain. We did not produce resource classification mapping for sections of the streams within the National Wildlife Refuges, those being under current management by another agency.

7. Upstream Extent of Ground-Truthing & Mapping

We determined the upstream extent of ground-truthing by visiting successively upstream road crossing locations until access by road was blocked by gated private property or private property signed "no trespassing". We mapped resource classifications along the mainstem foothill streams as far upstream as the upstream end of continuous recent alluvium (i.e., alluvium younger than the Tehama Formation). To delineate the upstream terminus of recent alluvium, we used Helley and Harwood (1985) as the definitive or highest resolution map of surficial alluvial deposits in the watershed. In general, the upstream extents of the foothill streams were largely inaccessible upstream from the Tehama-Colusa Canal and resource classification mapping thus relied on remote sensing using the 2009 NAIP air photo imagery. Exceptions were South Fork Walker Creek, Nye Creek, South Fork Willow Creek, Stone Corral Creek, Freshwater Creek, and Cortina Creek (via access to private property provided during Field Trip No. 1), and Sand Creek. We did not ground-truth or resource map Funks Creek above Funks Reservoir because the reservoir traps sediment produced by bank erosion thus limiting watershed benefits of management to reduce bank erosion upstream from the reservoir.

8. Minimum mapping unit

We used a 1,000 ft long minimum reach mapping unit for resource classification, finding a shorter unit not reliably accurate given considerable access limitations for ground-truthing large portions of individual stream lengths, as well as limitations of the July 2009 NAIP imagery, both in resolution for identifying individual geomorphic features, and time of year for sensing tamarisk, e.g.

9. Resource Classification Categories in the GIS Database

We prepared more detailed and customized resource classification categories than were described in the contract scope of work in order to better characterize the breadth of field conditions we found according to more meaningful definitions, both for this study to locate the priority critical management reaches and for useful interpretation by future managers. Per the scope of work, we produced maps showing Bank Erosion Potential (Figure 2), Riparian Habitat Quality (Figure 3), and (combined) Tamarisk and Arundo Infestation Severity (Figure 4). The final delivered GIS database will contain database and shape files and can be used to prepare maps of the other resource classification categories.

Bank Erosion Potential

We delineated the individual sections of the 36 foothill streams according to our expert evaluation of susceptibility to erosion or erosion potential, which can be considered a proxy for near future sediment production rate. Thus, reaches showing evidence of past severe erosion may not have been mapped as having severe or high erosion potential, in as much as past erosion indicates past sediment production which, by processes of self-stabilization, often mitigates future production rate. This way we focused bank erosion potential mapping on identifying degrees of water quality effects from probable future sediment production.

High. Channel banks appear to be continuously or nearly continuously very steep and largely unvegetated with loose, non-cohesive unconsolidated bank material. Often occurring in naturally dynamic streams with non-cohesive unconsolidated alluvial banks and very recently constructed, and unvegetated narrow channelized streams with steep banks constructed of native local especially non-cohesive material.

Moderate/High. Channel banks appear to be nearly continuously somewhat or variably vegetated and only locally very steep and unvegetated, such as outside bend locations. Erosion production rate may appear to be mitigated by processes of self-stabilization, especially for narrow channelized stream sections constructed at least several years ago which have widened somewhat by numerous bank failures and vegetation established on remainders of slump deposits. Erosion production rate may appear to be mitigated also by partly-cohesive or partly-consolidated bank material, which is more stable at steeper bank slopes. Often occurring in naturally dynamic streams with non-cohesive unconsolidated alluvial banks. Also often occurring in somewhat recently constructed, and unvegetated narrow channelized streams with steep banks constructed of native local especially non-cohesive material.

Low/Moderate. Channel banks appear to be continuously somewhat or variably vegetated and only locally steep and unvegetated, such as outside bend locations. Erosion production rate may appear to be mitigated by processes of self-stabilization, or partly-cohesive or partly-consolidated bank materials. Often occurring in wider, less disturbed sections of naturally dynamic streams often where they are cut in older, partly-consolidated alluvial deposits. Also common where eroding banks contain mostly gravel-sized sediment considered to produce lesser water quality impacts than erosion of fine-grained banks. Also common in older construction channelized stream sections which appear to have substantially self-stabilized, and/or are generally dominated by cohesive or partly-cohesive bank materials.

Low. Channel banks appear to be continuously gradually sloped and somewhat or variably vegetated. Erosion production rate may appear to be mitigated by processes of self-stabilization, or partly-cohesive or partly-consolidated bank materials. Commonly occurs in wider, shallower, less disturbed sections of naturally stable or naturally dynamic streams, especially where they are cut in older, partly-consolidated alluvial deposits. Also occurs on channelized streams with fine-grained partly cohesive banks in agricultural areas where irrigation return water supports dense bed and bank vegetation, or where banks have been armored with rip-rap or other type of bank protection.

For the bank erosion potential mapping to be meaningful within the GIS database, we found it necessary to also delineate the foothill streams according to four additional subcategories. These additional subcategories were determined for characterizing the degree to which the streams have been altered by, and current bank erosion potential affected by, channelization, top of bank levees, bank material cohesiveness, and irrigation water management – factors we found strongly influence both the meaning of mapped erosion potential and the selection of critical management reaches. Specifically, we found it necessary to distinguish between: (1) "natural", "channelized", and “natural-leveed” stream sections. We did not also delineate “grazed” and “ungrazed” reaches although this distinction was observed to make a large difference in apparent bank erosion potential, and more strongly in presence/absence of woody native riparian trees and general riparian habitat quality; (2) reaches that are dry in the summer/fall or moist/flowing due to the influence of natural groundwater or more commonly agricultural return flow – and some channelized reaches are subject to deep-water flows and rapidly fluctuating water levels where they are operated as irrigation water conduits as may greatly increase their erosion potential and reduce the potential for establishing woody riparian vegetation on the banks; (3) partly cohesive and non-cohesive bank materials, the latter of which are in places slow to erode because they are partly cemented/consolidated older alluvium; and (4) geology of surficial deposits forming stream banks in the reach, which indicates both the relative content of fine-grained sediment in the banks and the degree to which consolidation or cohesiveness might mitigate bank erosion potential. Therefore, we map delineated the foothill streams not just by erosion potential but also by these additional four sub-category physical factors according to the definitions given below:

<u>Corridor Disturbance</u>

Natural. Channel appears to be in approximate natural, pre-development alignment without top of bank levees.

Natural/Leveed. Channel appears to be in approximate natural, pre-development alignment but with top of bank levees or levee roads and generally some degree of fill encroachment on the corridor resulting from levee road construction and maintenance.

Channelized. Channel appears to have been reconstructed in place or in an alternate straightened alignment with a typically uniform narrow cross-section and steep-sided constructed banks with or without top of bank levees.

Bank Erodibility

Non-Cohesive. Channel banks are composed of non-cohesive materials (i.e., lacking substantial fine silt and clay content). Loose, non-cohesive bank materials are typically unstable at slopes greater than 1:1 without vegetation cover.

Partly Cohesive. Channel banks appear to be composed of cohesive or partly cohesive bank material (containing substantial percentage clay and fine silt). Cohesive and partly-cohesive soils may be relatively stable without vegetation cover at slopes greater than 1:1.

Partly Consolidated. Channel banks appear to be composed of partly consolidated or compact (typically older) alluvial deposits in the watershed (e.g., Tehama Formation, Red Bluff Formation, and Lower Riverbank Formation, and to a lesser degree the relatively compact Upper Riverbank Formation).

Dry Season Hydrology

Dry. Channel bed appeared dry during late fall field work.

Natural Spring Flow. Channel bed appeared moist or flowing without probable influence of irrigated agriculture.

Ag Return Flow. Channel bed appeared moist or there was a measureable low flow during late fall field work, evidently from high groundwater table supported by and/or direct irrigation return flow.

Irrigation Conduit. Channel contained variably deep backwatered flow caused by downstream sluice gate(s). Operated as a conduit for irrigation water.

Surficial Geology

We delineated the stream lines according to the intersections they made with surficial geologic formations mapped at the 1:62,500 scale by Helley and Harwood (1985). Where applicable, attempts were made to discern by ground-truthing and remote sensing if the broader underlying geologic formation were exposed on the bed and banks beneath a shallow veneer of the surficial deposits forming the valley flat.

Riparian Habitat Quality

H. T. Harvey & Associates used the following rating categories for riparian habitat quality. These categories were created to be compatible with the project goal to rapidly assess as much as 600 miles of stream channel habitat using the best available aerial photography while at the same time being grounded in biology. Stream channels were ground-truthed at public access crossings and where streams were in view from adjacent roads. However, a large proportion of the stream channel habitat quality was assessed through aerial photograph interpretation. The accuracy of the aerial photograph interpretation was dependent on the resolution and timing of the aerial photograph used for mapping. For the purpose of this assessment, riparian habitat was broadly defined as woody vegetation (trees and shrubs) growing within and adjacent to watercourses. Riparian habitat included both "obligate" riparian plant species such as willows (*Salix sp.*) and Fremont cottonwood (*Populus fremontii*) that require elevated soil moisture throughout the growing season, as well as drought-tolerant woody species such as oak species (*Quercus sp.*). Drought-tolerant woody species were included in our definition of riparian habitat because the many of the surveyed stream reaches are ephemeral and do not support obligate riparian plant species. Additionally, drought-tolerant woody species provide riparian functions when they occur adjacent to watercourses. These functions include the provision of shade over the watercourse, wildlife habitat in proximity to water, and inputs of organic matter and course woody debris. Finally, it should be noted that our definition of riparian habitat did not include emergent wetland habitat (areas dominated by herbaceous wetland species such as cattails (*Typha sp.*) and tules (*Scirpus sp.*). Therefore, there are reaches mapped as low quality riparian habitat due to the low cover of woody species that may support high quality wetland habitat.

High Quality. Native riparian tree or shrub canopy greater than 50% cover with less than 5% cover of invasive plant species that can be detected from color aerial photograph interpretation (e.g. arundo, tamarisk, eucalyptus).

We calibrated the above definition of high quality habitat to be commensurate with the density/cover of native woody vegetation that is typically supported by the ephemeral streams that dominate the survey area. Therefore, we reduced the threshold of native woody vegetation percent cover to 50% for this project, whereas our threshold would have been higher if our survey area was dominated by perennial streams with abundant soil moisture. In addition, our high quality definition does not account for differences in corridor width. Some of the reaches that are considered to represent the highest quality riparian habitat within the study area include segments on Main Stem Walker Creek, and upstream sections of Nye Creek, South Fork Willow Creek, and Freshwater Creek.

Riparian Habitat Quality Category	Native Riparian Tree or Shrub Canopy Cover	Invasive Species Cover
High Quality	>50%	<5%
Moderate Quality	25% - 50%	<5%
	>50%	5% - 25%
Low Quality	<25%	
	25% - 50%	5% - 25%
	>50%	>25%

Moderate Quality. Native riparian tree or shrub canopy between 25% and 50% cover with less than 5% cover of invasive plant species that can be detected from color aerial photograph interpretation (e.g. arundo, tamarisk, eucalyptus); *or* native riparian tree or shrub canopy greater than 50% cover with between 5% and 25% cover of invasive plant species that can be detected from color aerial photograph interpretation.

Low Quality. The reach has high invasive species abundance or is dominated by non-riparian or non-native riparian habitat such as grassland habitat, herbaceous wetland habitat, ruderal habitat, bareground, crops, invasive plant species, or hardscape. Native riparian tree or shrub canopy less than 25% cover; *or* native riparian tree or shrub canopy between 25% and 50% cover with between 5% and 25% cover by invasive plant species that can be detected from color aerial photograph interpretation (e.g. Arundo, Tamarisk, Eucalyptus); *or* native riparian tree or shrub canopy greater than 50% cover with greater than 25% cover of invasive plant species that can be detected from color aerial photograph interpretation.

<u>Tamarisk and Arundo Infestation Severity</u>

H. T. Harvey & Associates used the following rating categories for arundo/tamarisk infestation severity. Arundo and tamarisk were lumped for the purpose of this mapping effort. As described above, these categories were created to be compatible with the project goal to rapidly assess approximately 500 miles of stream channel habitat using the best available aerial photography while at the same time being grounded in biology. As described above in the riparian habitat section, stream channels were ground-truthed at public access crossings and where streams were in view from adjacent roads, but a large proportion of the arundo/tamarisk infestation severity mapping was assessed through aerial photograph interpretation. The accuracy of the aerial photograph interpretation was dependent on the resolution and timing of the aerial photograph used for mapping. Therefore, infestations may not have been detected. In particular, tamarisk was difficult to identify via aerial photograph interpretation when in low abundance. In addition, arundo located in areas adjacent to the streams within the study area, but was not mapped for this project. Determining unmapped tamarisk locations along creeks and these adjacent pockets of arundo will be valuable for future control efforts.

High. Arundo and/or tamarisk are at high abundance in the riparian corridor habitat; greater than 25% cover of arundo and/or tamarisk.

Moderate. Arundo and/or tamarisk are moderately abundant in the riparian corridor habitat; between 5% and 25% cover of arundo and/or tamarisk.

Low. Arundo and/or tamarisk are at low abundance in the riparian corridor; between 1% and 5% cover by arundo and/or tamarisk

None Observed. No arundo and/or tamarisk were observed or easily detected through aerial photograph interpretation.

10. Results and Discussion of Resource Conditions Mapping

The following is a summary of the landscape-level patterns that emerge from our resource condition maps which have a bearing on future resource management.

Results and Discussion – Bank Erosion Potential

On most streams there is a longitudinal pattern in bank erosion potential from the foothills to the valley flat. Figure 2 shows the resulting mapped distribution of streambank erosion potential along 36 foothill streams in the Colusa Basin Watershed. Most of the foothill streams showed a similar longitudinal pattern of bank erosion potential from the foothills to the low plains: we typically detected low to moderate erosion potential in the foothills, moderate to high erosion potential in the vicinity of the foothill front, and low to moderate erosion potential in the lower-gradient channel sections on the low plains where the streams grade into the Sacramento River floodplain and the Colusa Basin. This longitudinal pattern is typical of streams draining the inner Coast Range mountains to the Sacramento River floodplain. Up in the foothills, the streams are typically cut in relatively shallow alluvium laid down within relatively narrow inner valleys. The stream beds in places and most of the outside bend streambanks are cut in bedrock – either the compact Tehama Formation or the Cretaceous marine sandstones and shales of the Great Valley Sequence. Erosion potential is higher where some of the larger foothill streams have cut-and-filled deeper alluvial deposits within wider inner valleys. Nye Creek and South Fork Willow Creek are examples of larger foothill streams with wider inner valleys and long reaches of moderate to high streambank erosion potential.

Near and downstream from the foothill front where the bedrock inner valley confinement gives way to broad alluvial fans, the foothill streams are commonly relatively deeply incised, steeply sloped, and naturally dynamic. That is, the tendency for periodic massive coarse sediment deposition and channel meandering near the foothill front generates naturally higher streambank erosion potential. The rate of bank erosion on the alluvial fans is moderated in places where the banks are cut in older, partly consolidated alluvial fan deposits. The streambank erosion potential is generally lesser farther downstream where the stream bed slope is more gradual, the streams are shallower, and the bank materials are finer and often more cohesive and vegetated. Bank erosion potential remains relatively high on the downstream ends of some of the steeper better developed alluvial fans, such as Salt Creek (south) and Sand Creek in South Colusa County, because among other things the better developed fan surfaces and channels are still relatively steep close to where they grade into the Colusa Basin near the Colusa Basin Drain. These stream sections are naturally prone to bank erosion induced by channel meandering and channel switching forced by periodic massive coarse sediment deposition on their beds. This effect may be magnified where there has been increased bank erosion upstream. Maintenance of flood conveyance and sediment transport through a channel fixed by poorly coordinated channelization projects appears to be a difficult management problem on the distal ends of the larger, steeper alluvial fans.

Highest streambank erosion potential generally occurs in three geomorphic settings. This study found the highest streambank erosion potential generally occurred in three geomorphic settings. First, as mentioned above, we commonly identified moderate to high bank erosion potential along the larger foothill streams within the wider upland inner valleys. Generally higher bank erosion potential was noted in foothill inner valleys cut in Cretaceous marine sedimentary rocks of the Great Valley Sequence compared to those cut in Tehama Formation, partly owing to the greater depths of fine-grained contemporary alluvium present. Perhaps the longest continuous segments of moderate to high bank erosion potential occur in the relatively wide upland inner valleys of Nye Creek and South Fork Willow Creek, both underlain by marine sedimentary bedrock. Funks Creek, Stone Corral Creek, and Freshwater Creek are the other larger foothill streams cut in marine sedimentary bedrock. Substantial portions of the upland inner valley sections of these streams showed moderate to high bank erosion potential. The foothill streams generally show lesser bank erosion potential where they are draining the narrower upland inner valleys in both Great Valley Sequence and Tehama Formation watersheds. Moderate and high erosion potential was identified on foothill sections of streams in south Colusa County draining principally Tehama Formation uplands: Cortina Creek, Sand Creek, Salt Creek (South), Petroleum Creek, Little Buckeye Creek, Buckeye Creek, and South Fork Buckeye Creek. Not coincidentally, these foothill streams have laid down the most massive and steepest alluvial fan deposits in the watershed.

Secondly, as has also been discussed, moderate and high bank erosion potential was also commonly identified in the naturally dynamic and steep channels near the foothill front and on the larger and steeper sloped alluvial fans occurring in the southern part of Colusa County and the very northern part of Yolo County. This is generally the case for the larger streams with the better developed alluvial fans listed above: Cortina Creek, Sand Creek, Salt Creek (South), Petroleum Creek, Little Buckeye Creek, Buckeye Creek, and South Fork Buckeye Creek. Moderate and high bank erosion potential was identified on individual sections of streams with the better developed alluvial fans, even several miles east of the mountain front, such as sections of Salt Creek (South) east of Interstate 5. Sand Creek and Salt Creek (South) appear to be particularly dynamic in their downstream sections where their fans are strongly coalesced down to the south against the massive Petroleum Creek fan and relict Salt Creek (South) fan surface in delivering recent coarse alluvial deposits to within close proximity of the Colusa Basin Drain.

Lastly, narrowly channelized reaches often showed higher erosion potential than still natural reaches, and especially on alluvial fans and within foothill inner valleys where the stream bed and valley slopes are naturally high and channelization works require frequent maintenance. A good example of this occurs on Oat Creek along road 12A in Yolo County (see ground photo at page 37.) Oat Creek is primarily in a near natural channel-floodplain configuration, except for one section of the creek where it is has been straightened and relatively narrowly channelized along the south edge of Road 12A. Straightening of the creek evidently steepened its slope and led to unanticipated channel bed incision. A headcut is advancing upstream through the channelized reach. The rate of downcutting and headcut advance appears to be moderated by the compact clayey material now exposed at the toe of the bank – evidently the strongly weathered upper horizon of the underlying Tehama Formation. It is notable that the same distinctly medium gray colored Tehama Formation exposed on the bed of Oat Creek is also exposed on the bed where South Fork Buckeye Creek cuts down to the south into the Tehama Formation forming the northern edge of the Dunnigan Hills geomorphic province. The gray-colored outcrops of the Tehama Formation appear to have significantly higher clay content and may be considered lenses within the more massive and commonly exposed tan and reddish-colored deposits.

Canal design and maintenance influences bank erosion potential of channelized reaches. In the south part of Colusa County, the relatively massive alluvial fan deposits with their naturally dynamic streams extend nearly all the way to the Colusa Basin Drain. Elsewhere in the watershed east of the foothill front, the streams generally have relatively short sections cut in poorly developed, low-gradient alluvial fans and relatively long downstream sections cut in the gradually sloping low plains and the interfan basin areas grading into the Colusa Basin valley flat. Away from the steep fans in south part of Colusa County, the foothill streams are practically universally channelized downstream from the foothill front and the Tehama-Colusa Canal. The factors that appear to most strongly influence bank erosion potential in channelized reaches are less natural geomorphic and hydrologic factors, and more those of canal design, age, and maintenance. For example, channels made too narrow and/or with too steep banks have higher bank erosion potential than channels made sufficiently wide. A channel made too narrow some time ago may have indeed undergone significant bank erosion over the years, such that today it may appear to have relatively low erosion potential, it having widened and self-stabilized, aided by establishment of vegetation on slump deposits, etc. The newest constructed channels may have the highest erosion potential because they are completely unvegetated and just beginning a new cycle of toe erosion and self-stabilization. The Oat Creek example could be viewed in this way – it being a relatively new channel still in the phase of adjusting to its human-imposed slope and configuration. Decades from now, without interventions, it may appear to have low to moderate bank erosion potential.

Cortina Creek downstream from Meckfessel Road appeared narrowly confined within massive levees during our November field assessment. Dense woody riparian vegetation was established on both inner banks. The presence of dense vegetation appeared to somewhat mitigate the erosion potential of the narrowly confined reach and indicate that the channel construction is aged and undergone some initial phases of self-stabilization. Soon after our field assessment this vegetation was removed to restore the original design flood flow capacity of the channel from Hwy 99 to about 100 ft downstream from the Lone Star Road crossing. Vegetation removal created freshly graded banks with increased erosion potential. During recent high flows the levee banks failed in the still vegetated reach downstream from the vegetation clearing work. It's likely that the existing vegetation was outflanked by the higher velocity flows conveyed by the cleared reach, producing debris jams in the still vegetated reach and resulting in massive levee bank erosion. This example highlights that establishing riparian vegetation on streambanks is not practical or desirable along stream segments that serve a flood control function – not without also significantly reconstructing and probably widening the channel. This example also highlights that future erosion potential and riparian tree density of channelized reaches is strongly linked to maintenance cycles.

Where they are cut in low-gradient interfan basin areas and formed in partly cohesive bank materials, we often observed that straight channelized reaches showed lesser bank erosion potential than reaches that were channelized in the historical natural meandering alignment. This appeared to be because the natural meandering alignment produces concentrated erosion potential at outside bends – concentrated erosion potential that is moderated in natural streams by wide inside bend point bars and high flows escaping onto the floodplain. Inside bend point bars and floodplain flows are eliminated when a natural meandering stream is channelized in its natural meandering alignment. The outside bend bank is made higher and steeper by construction of a levee road along the top of bank, and the inside bend point bar is eliminated by fill construction of an equal elevation levee road along the inside bend.

That said, natural geomorphic and hydrologic factors do influence the bank erosion potential of channelized stream reaches. In general, streams in the north part of Colusa County and the south part of Glenn County draining the Cretaceous marine sedimentary foothills produce finer-grained sediment and have finer-grained, more cohesive banks. Canals formed in these materials are relatively erosion resistant compared to canals formed in loose, unconsolidated gravelly- or sandy-loam deposits. Where bank materials are strongly cohesive and canal slopes are gradual, bank erosion potential appears less influenced by canal design, age, and maintenance.

Elsewhere, on the steeper, better developed alluvial fans of South Colusa County, North Yolo County, and North Glenn County, channelized reaches typically showed moderate to high bank erosion potential. Straight channelized reaches typically showed higher bank erosion potential than did reaches channelized in their natural alignment, typically because straight reaches typically are made narrower and made to conform to unnatural slopes running along the rectilinear pattern of road and property boundaries. The steeper streams with non-cohesive bank materials are naturally more dynamic and more difficult to maintain in channelized form. For example, air photos show a meandering pattern developing in a straight section of Clark's Ditch constructed adjacent to Eddy Road. Clark's Ditch, as named on USGS quadrangles, is the rectilinearly channelized section of Petroleum Creek downstream from the Tehama-Colusa Canal.

Practically everywhere downstream from the Tehama-Colusa Canal, the lands on both sides of the foothill streams are developed for agriculture and there are levee roads constructed along the top of one or both banks of the streams. These levees cause deeper flood flows to be contained within the channels without spilling out onto the natural pre-development floodplains. Levees and levee roads thereby cause higher shear stresses on the beds and banks of the streams, and higher bank erosion potential. Where the levee roads are frequently eroded into the channel by bank erosion, they are probably also frequently maintained by grading – the uncompacted earth sidecast onto the banks during maintenance grading can be likened to a ‘conveyer belt’ of sediment, sediment pouring into the channel during high winter flows only to be replaced by later levee road and bank maintenance.

Geomorphic setting influences the effect flood flows have on bank erosion potential. Geomorphic setting influences bank erosion potential by affecting how much the downstream, often channelized stream reaches are subjected to channel-full flood flows. Walker Creek gathers flood flows contributed by numerous foothill streams north of Willows and routes them along the edge of the Stony Creek alluvial fan. In general, the stream and adjacent floodplain areas appear appropriately sized to convey large flood flows, but individual channelized sections and crossings appear undersized and thus promote higher than natural flood flow velocities and higher than natural bank erosion potential. Somewhat similarly, South Fork Willow Creek gathers flood flows from foothill streams west and north of Willows and routes them to the northeast around the massive outcrop of Lower Riverbank Formation lying to the southeast from the foothill front. Some sections of South Fork Willow Creek downstream from the foothill front appear to have been channelized and leveed to provide sufficient flood flow conveyance. For example, the section upstream and downstream from Highway 162 due west of Willows appears was constructed probably just after the 1998 flood. Farther downstream at the Road 48 crossing, the South Fork Willow Creek cross-section is perhaps only 30% as large. Seemingly, much of the flood flow is expected to be on the floodplain in this vicinity, reducing erosion pressure on the streambanks. In the south part of Glenn County and the north part of Colusa County, the low-gradient streams are contained in constructed canals that appear too small to convey the total flood flows produced by their foothill watersheds. Seemingly, again, much of the flood flows are conveyed on the floodplains and probably more importantly by other drainage canals tracing the low plains. This is as opposed to streams draining the well developed alluvial fans in south part of Colusa County and the north part of Yolo County, some of which due to geomorphic factors contain large percentages of their total flood flows. Salt Creek (South) drains a steep alluvial fan surface down to the south against the anomalously broad and massive Petroleum Creek fan. Where Sand Creek and Salt Creek (South) nearly pass over each other downstream from Arbuckle, Salt Creek (South) has a relatively narrow floodplain. Indeed, in this vicinity, the Salt Creek (South) channel is exceptionally deep and wide and dynamic, with high bank erosion potential. Downstream channel maintenance to route Salt Creek (South) flood flows into the Colusa Basin Drain appear to have encouraged some channel incision and exacerbate the bank erosion potential in this vicinity.

Prior to Euro-American settlement, “Old” Cortina Creek historically flowed to the northeast via multiple channels on its contemporary alluvial fan surface where it commonly flooded Williams. Today, Cortina Creek flood flows more to the due east via one of the old creek’s distributary channels beginning at or near the Tehama-Colusa Canal crossing. It is unknown whether Cortina Creek was intentionally diverted to the east, or if it captured its own east-flowing distributary channel by channel avulsion – a natural process characteristic of alluvial fan environments. The present Cortina Creek is cut in relatively low-gradient interfan basin deposits in a series of mainly east-flowing channelized stream segments extending to near the Colusa Basin Drain. Downstream from Highway 99, the required levees rise perhaps 10 or more feet above the surrounding landscape. In places, the bed elevation is perhaps only 2-3 feet below the surrounding landscape. As described above, the channelized section downstream from Highway 99 is prone to levee failure and resulting flooding and massive sedimentation of adjacent former floodplains, and should be considered to have high erosion potential in general – perhaps more than was detected or predicted by this study made prior to recent erosion events. It appears that narrow channelization of Cortina Creek is particularly difficult because the channel must carry relatively high flood discharges over low-gradient interfan basin deposits – in the absence of channelization works Cortina Creek would be naturally wide and shallow.

To the south, on the other side of the anomalously massive Petroleum Creek alluvial fan, Buckeye Creek gathers flood flows from a relatively large watershed area and conveys them to the Colusa Basin Drain through a series of channels constructed downstream from Interstate 5. Moderate to high bank erosion potential was identified on the straight east-flowing Buckeye Creek channel downstream from Road 89 (Figure 2d). Like the Cortina Creek example discussed above, the downstream section of Buckeye Creek presents a difficult channel design and maintenance problem – it is supposed to carry a high flood discharge of coarse sediment laden waters across low-gradient interfan basin deposits grading into the Colusa Basin valley flat. The Dunnigan Water District maintains pipelines running parallel with the Buckeye Creek channel that are in places subject to high bank erosion potential. Like the downstream segment of Cortina Creek discussed above, the downstream segment of Buckeye Creek should be considered to have high erosion potential in general – perhaps more than was detected or predicted by this study.

Irrigation influences bank erosion potential and riparian vegetation restoration potential. Irrigation practices have multiple influences on bank erosion potential. Importing water via the Tehama-Colusa Canal had general effects on streambank erosion potential and downstream sediment loads. Some long-time residents have observed that the foothill streams began carrying heavier sediment loads after the completion of the Tehama-Colusa Canal. Indeed, the rapid proliferation of irrigated agriculture on the generally steeper lands lying between the Tehama-Colusa Canal and the Glenn-Colusa Canal was accompanied by increased bank erosion where attempts were made to channelize the stream and expand agriculture into the former stream corridors. Preventing overbank flows onto new agricultural lands by constructing levees and levee roads along the tops of banks increased bank erosion potential of these reaches. Increased upstream bank erosion caused heavier coarse sediment loads to pass through the leveed channels farther downstream, in places causing exacerbated sediment deposition and resulting bank erosion in the downstream reaches. Of course, a large part of the increased sediment load, perhaps finer-grained sediment, was also from overland runoff from the newly cultivated lands and headcutting in new drainage ditches.

Importing irrigation water via the Tehama-Colusa Canal also significantly reduced groundwater pumping and allowed groundwater table recovery, bringing groundwater closer to the channel bed surface along sections of some of the foothill streams. Increased irrigation return flow probably further increased the groundwater table elevation and the extent to which moist channel bed or flowing conditions occur, as may support establishment of new riparian vegetation.

Many channelized streams in the south part of Glenn County and the north part of Colusa County are used to convey irrigation water via diversion structures to laterals irrigating rice fields on both sides. Conveying deep-water, irrigation water flows prevents establishment of woody riparian vegetation on the canal banks because the vegetation cannot withstand prolongued inundation. The canals are typically drawn down in the fall season. Drawdown induces slump failures of the still saturated banks. It is common to see water seeping out of upper banks above the flow level in the channel because after flows are drawn in the channel the rice fields on either side may be still flooded or still saturated.

Due to these observed effects of irrigation water conveyance, we mapped moderate to high bank erosion potential on some of the affected streams despite their low bed slopes and partly cohesive bank materials. Although woody vegetation cannot be established on the bank surfaces for reducing erosion potential, it could be established on the top of bank because there is probably sufficient moisture present year-round to support obligate riparian vegetation such as willow and cottonwood. Vegetation established on and adjacent to the top of bank will grow roots down into the soil and out toward the channel. These roots can help to stabilize the deeper soil lower on the stream banks by adding tensile strength and by increasing the cohesive forces of the soil by drying it.

As discussed below in this report, the presence of extensive irrigation systems within tens of feet from the top of bank along large portions of the streams downstream from the Tehama-Colusa Canal provides the opportunity to install drip-irrigation to initiate establishment of riparian vegetation on stream banks at a marginal cost that is reasonably low by typical stream restoration project standards.

Channel incision near the foothill front increases erosion potential, but much of the incision may be natural, only exacerbated by land use impacts. More deeply incised channels have higher bank erosion potential. The larger foothill streams are more deeply incised in their alluvial fans and upstream within their inner valleys than the smaller streams. Some investigators have suggested that alluvial fan and foothill inner valley incision may be contemporary with Euro-American settlement, citing probable effects of grazing on foothill watershed production of peak flood flows and sediment by hillslope processes. However, there is insufficient documented evidence to substantiate whether or not channel incision is contemporary or not with Euro-American settlement. Our observations in preparing the 2008 Watershed Assessment and this study suggest that the timing and degree of channel incision in the foothills and near the foothill front need to be evaluated on a case-by-case basis for each foothill stream watershed. At least one relatively deeply incised stream reach may have been caused in substantial part by Euro-American land use impacts, but not necessarily grazing. Sand Creek in Colusa County is incised about 12-15 ft below the top of the Lower Modesto Formation downstream from Sand Creek Road and at grade with the road upstream. It is possible that this amount of channel bed incision could have been caused by historical instream sand-and-gravel mining on Sand Creek downstream from Cortina School Road crossing. Historical instream mining on Cortina Creek may have caused some amount of channel bed incision on that stream near the foothill front and upstream into the inner valley, but it is unclear. As described above, local channel bed incision has occurred on streams elsewhere in the watershed due to poorly configured channelization work. In general, grazing probably has caused some amount of channel bed incision and increased bank erosion and bank erosion potential on some of the foothill streams.

Most of the high bank erosion potential is caused by natural factors, but some is made worse by land uses. Actively eroding streambanks are generally viewed as a management problem for several reasons. Bank erosion may wash away acres of riparian habitat or prime agricultural soils perched at the top of bank along an outside bend and replace it with an equivalent area of new, relatively sterile riverwash deposits on the inside bend. Bank erosion often threatens to destabilize public infrastructure such as road crossings and electric transmission tower foundations. Bank erosion increases the sediment load carried by streams which may cause excessive sediment deposition and require dredging in downstream flood prone or designated flood control channels. Increased sediment load, especially fine sediment load, is a water quality impact with potential negative biological effects for the downstream reaches and receiving waters. The California State Water Resources Control Board may designate a stream as impaired if its sediment concentration is more than a reasonable multiple of the estimated natural background rate. And in general, actively eroding streambanks have aesthetic impacts. Actively eroding streambanks imply failed management and stewardship, such as overgrazing by cattle. Gradually sloped, densely vegetated banks not only look better, they provide riparian habitat for insects, birds, and terrestrial wildlife – habitat that is scarce in this part of California.

However, the degree to which bank erosion is natural versus human-induced depends on the geomorphic conditions and land use history of the particular stream. Fluvial geomorphologists recognize that bank erosion is a natural geomorphic process on meandering alluvial streams. Foothill streams in the Colusa Basin Watershed drain inner Coast Range mountains underlain by erodible bedrock units known to produce very high sediment yields by global standards. Over the past several hundred thousand years, many of the foothill streams have cut and filled their inner valleys several times over leaving terraces perched several tens of feet above modern stream beds. Especially in the south part of Colusa County, the streams have built up massive alluvial fans rising hundreds of feet in elevation above the Sacramento River valley floor. These alluvial fan surfaces are traced with hundreds of former stream channels created by active channel bank erosion and frequent (in geologic time) channel switching by avulsion. Prior to Euro-American settlement, these alluvial fan channels were variably incised in their fan deposits and more or less prone to severe bank erosion by channel meandering. High, steep, unvegetated banks would have been common sights on many streams.

Elsewhere the fans are poorly developed or more completely buried by, with rising sea level, rising deposits of the Sacramento River floodplain, the Colusa Basin, and the slightly higher interfan basin areas. Prior to Euro-American settlement, these low plains were scribed by dozens of shallow sinuously meandering channels with natural sandy levees. Like alluvial fan channels, these backwater or delta channels are prone to frequent channel switching by avulsion. Bryan (1923) characterized the low plains of the Colusa Basin Watershed as being "channel-ridged" – traced with former stream channels. While dynamic in forming multiple abandoned channels and channel ridges, these streams might have produced less sediment transport throughput to the Colusa Basin because of their depositional behavior over so much of their length in the interfan basin areas upslope from the Colusa Basin.

We find that the stream reaches with highest bank erosion potential occur in the same geomorphic settings as we believe they did prior to Euro-American settlement – along the widest and deepest cut-and-filled inner valleys, and on the steepest and best developed alluvial fans. Even still relatively natural stream sections in the foothill inner valleys and on the steeper alluvial fans show moderate to high erosion potential and particularly severe erosion potential at outside bends. To some extent their erosion potential may have been increased by historical effects of cattle grazing and instream mining, but the majority appears relatively natural and generally not alarming by fluvial geomorphic standards.

High bank erosion potential also occurs on the downslope portions of the steepest and best developed alluvial fans. Again this appears mostly the result of naturally dynamic geomorphic processes but more significantly exacerbated by land use activities. Naturally high and elevated coarse sediment loads and steep slopes create high bank erosion potential and difficulty with maintaining flood flow conveyance and sediment transport continuity through road crossings. This management difficulty is made more difficult by imposing on the radial stream alignment a rectilinear property line and road network. In general, conforming the naturally dynamic channels to a narrower footprint within rectilinear patterns appears to have significantly increased overall bank erosion potential. Levees and agricultural access road prisms were constructed within portions of the former natural active stream beds and floodplain bars, often by placement of non-engineered native or artificial fill to form new, easily eroded stream banks. The result of individual interventions on individual properties is a longitudinally uncoordinated series of often poorly configured channelized reaches, with many steep erosion-prone bank segments. Preventing overbank flows onto agricultural lands on the upstream part of the alluvial fan by constructing levees and levee roads along the tops of banks increased bank erosion in the upstream stream sections, causing heavier coarse sediment loads to pass through the leveed channels farther downstream, only to exacerbate the natural potential for local massive sediment deposition and resulting potentially severe bank erosion in the downstream reaches.

In the central part of the watershed where the fans are poorly developed or more completely buried by basin deposits, the streams are almost universally channelized east of the foothill front and the Tehama-Colusa Canal. As discussed above, these streams were also dynamic in creating multiple abandoned channels and channel ridges, but also strongly depositional over much of their length between the foothills and the Colusa Basin. Their bank erosion potential is moderated where the native bank materials are partly cohesive. Owing to these same factors, channelization appears to have generally subdued the natural bank erosion potential of some of these streams. Overall, however, the nearly universal channelization of these streams appears to have increased their bank erosion potential compared to prior to Euro-American settlement, if nothing else by disconnecting the streams from their natural floodplains and causing more throughput of fine sediment. Bank erosion potential appears to have increased particularly where the bank materials are less cohesive and the channels have been made too narrow, configured in a way that increases erosion potential at outside bends, or used as deep-water flowing conduits for irrigation water. Future canal maintenance has a strong influence on their bank erosion potential.

Results and Discussion – Riparian Habitat Quality

Low quality riparian habitat is predominant. The predominance of low quality riparian habitat is likely a function of both the intrinsic character of the ephemeral, foothill-stream landscape and anthropogenic impacts to riparian habitat.

Best quality riparian habitat is located in northern and southern portions of survey area and primarily in the eastern rangelands. High quality riparian habitat tends to be located along Walker, Wilson, Nye, and S. Fork Willows Creeks in the northern portion of the survey area and along Walters, Cortina, Whiskey, Elk, Salt, Bird Creeks in the southern portion of the survey area. The longest stretch of high quality riparian habitat in the survey area is located along Walker Creek amidst croplands on the valley floor. Interestingly, this same reach of Walker Creek likely supported extensive riparian habitat prior to Euro-American settlement (H. T. Harvey & Associates et al. 2008), With the exception of this reach, the majority of the high quality riparian habitat is located in the eastern, rangeland portion of our survey area.

Results and Discussion – Tamarisk and Arundo Infestation Severity

Arundo and Tamarisk distribution is limited within the survey area. Arundo and tamarisk have yet to substantially invade much of the survey area. We did not detect arundo or tamarisk throughout most of the rangelands portion of the survey area. However, as noted in the Methods, the spatial extent of small patches of arundo and tamarisk is likely greater than that shown in our maps because much of our mapping was done via aerial photograph interpretation.

Creek	Invasive Species Identified
N. Fork Walker	arundo
Walker Creek (Main Stem)	arundo, eucalyptus
Wilson Creek	arundo
French Creek	tamarisk
South Fork Willow Creek	arundo
Funks Creek	arundo, tree of heaven
Stone Corral Creek	tamarisk, arundo
Lurline Creek	arundo
Freshwater Creek	arundo, tree of heaven
Salt Creek (North)	arundo
Spring Creek	tamarisk, arundo, eucalyptus
Cortina Creek	tamarisk, arundo
Sand Creek (South Branch)	arundo
Whisky Creek	arundo
Elk Creek	arundo
Salt Creek (South)	arundo
Petroleum Creek	tamarisk
Little Buckeye Creek	tamarisk
Buckeye Creek	tamarisk, arundo, eucalyptus
Bird Creek	arundo, tree of heaven
Willow Spring Creek	arundo

Walker, Wilson, and Stone Corral Creeks harbor spatially extensive, low-severity infestations. Long, contiguous reaches of Walker and Wilson Creeks are infested with scattered patches of arundo. A long, contiguous reach of Stone Corral Creek is infested with scattered patches of arundo and tamarisk.

Freshwater Creek - extensive, high-severity infestations. The downstream, cropland reaches of the Freshwater Creek harbors the longest stretches mapped as high infestation severity. This creek is infested with arundo.

Yolo County portion of survey area- spatially-limited, low-severity infestations. The abundance and distribution of arundo and tamarisk appear to be notably low in the Yolo County portion of the survey area. Arundo and tamarisk abundance were low, where they were detected, with the exception of a reach of high-infestation severity on Buckeye Creek east of Old Highway 99.

As noted in the methods section, the infestation severity maps lump arundo and tamarisk. However, the above table provides information from our field notes on observations of arundo, tamarisk, and other woody invasive species by creek.

11. Technical Rationale for Selecting Critical Management Reaches

The Project Team was joined by Dan Stephens, Pat Reynolds, and Cathy Little of H. T. Harvey & Associates in Office Meeting 1 at H. T. Harvey & Associates offices in Los Gatos, California, on January 12, 2010 to develop a technical rationale for selecting Critical Management Reaches (CMRs) and then to select and map them. First, we prepared responses to the comments received the previous day to the Checkpoint #1 resource conditions mapping work and then made according revisions to the resource conditions maps (Figures 2-4). Then, we developed the following criteria for selecting CMRs according to where there are opportunities to:

- Remove or control invasive vegetation at the upstream end of its infestation area. Seek opportunities to completely remove invasive vegetation in the upstream-most affected reaches of streams.

- Improve connectivity of high quality riparian habitat where there are gaps in substantial high quality habitat by restoring and enhancing riparian vegetation in low and/or moderate quality habitat in the gaps. Seek opportunities to improve habitat in relatively short gaps between relatively long reaches with high or nearly high quality habitats, such that the least restoration maximizes the ultimate length of high quality habitat.

- Reduce bank erosion potential or arrest bank erosion at sites with the highest erosion potential in the watershed, especially sites with bank materials dominated by sediment grain sizes known or thought to have the greatest water quality impacts in the Colusa Basin and Sacramento River watersheds.

- Conserve reaches within the agricultural zone which have not yet been completely channelized – the remaining stream reaches with natural or lightly disturbed channel and floodplain forms and intact geomorphic processes.

- Achieve multiple or all of the above objectives.

12. Selected Critical Management Reaches

Based on the above criteria, the revised resource conditions map data, and knowledge gained from field assessment and ground-truthing and preparing the 2008 Watershed Assessment, we selected and mapped 24 CMRs. The resulting distribution of CMRs is shown in Figure 5. Table 1 summarizes the recommended management objectives for each CMR, and lists invasive and native riparian species present within each. The 24 CMRs comprise a total stream length of approx. 106 miles, or about 20% of the total length of the 36 streams mapped by this study.

In general, the highest ranking or highest priority CMRs will depend on current and future management priorities of the resource agencies and landowners, but may first be listed as those which can achieve all of the three major management objectives explored by this study. Table 1 indicates which of the CMRs achieve all three or some subset of the three major management objectives. The CMR labels in Figure 5 also denote the recommended management objectives for each of the CMRs using the following shorthand notation:

EC – Stream Bank Erosion Control
HC – Riparian Habitat Connectivity
IC – Invasive Vegetation Control

The Project Team understands that all of the reaches are completely or nearly completely comprised of private property, such that landowner interest and willingness will be important factors for determining which CMRs merit immediate consideration for further evaluation.

13. Selected Reference Reaches

In Checkpoint #3 work, the Project Team designated three of the 24 CMRs as "Reference Reaches" (Figure 5):

1. Reference Reach / CMR 16 Cortina Creek near the foothill front
2. Reference Reach / CMR 17 Elk Creek near Arbuckle
3. Reference Reach / CMR 20 South Fork Buckeye Creek on Durst Ranch

The Project Team made field observations at the accessible portions of the Reference Reaches during the January 20, 2010 Field Trip No. 2, accompanied by Jack Alderson of the NRCS. Each of the designated Reference Reaches present opportunities to address each of the three major management objectives explored by this study – bank erosion reduction, restoring riparian habitat connectivity, and controlling invasive vegetation infestation. Overall, the Project Team deems the Reference Reaches to be generally representative of the range of conditions within the CMRs identified in the Colusa Basin Watershed. Each of the Reference Reaches contains one or more private properties, with at least one probable willing landowner.

Figures 6, 7, and 8 show air photos and mapped resource conditions for each Reference Reach. Subsequent report sections discuss the opportunities and constraints for bank erosion reduction and riparian habitat management and restoration exemplified by the Reference Reaches. The Project Team outlined the general opportunities and constraints in collaboration with Jack Alderson of NRCS, both during field visits and subsequent follow-up conversations. For broadest application, we generalized the opportunities and constraints across the study area, and made specific references, where applicable, to the individual Reference Reaches.

Brief summary descriptions of the selected Reference Reaches are given in the following three pages.

Cortina Creek looking upstream from the top of the left bank to the downstream end of the upland inner valley reach. The left bank just out of view in the middle ground are Upper Modesto Formation deposits actively retreating by bank erosion, allowing the formation of the mid-channel bar colonized by several young cottonwoods. Grazing and groundwater availability may reduce successful establishment of cottonwood in the reach. (January 20, 2010).

Reference/Critical Management Reach ID: **Reference Reach / CMR 16**
Stream: **Cortina Creek**
Location Description: **Cortina Creek near the foothill front**
Reach Description: Cortina Creek including the grazed, Tamarisk-infested foothill inner valley reach downstream through the naturally dynamic, moderately to severely incised fanhead channel reach flanked by orchards downstream to the Tehama-Colusa Canal crossing. The approx. 5.4-mi-long inner valley reach is relatively widely cut in Tehama Formation and filled primarily with recent alluvium flanked in places by remnants of partly consolidated deposits of the Upper and Lower Riverbank Formation perched 100-200 ft above the valley floor. Outside bend bank erosion is checked in places by Tehama Formation but more rapid outside bend bank retreat noted by hanging fences along the tops of high terraces of the younger alluvium, including the compact Lower Riverbank Formation. The Tamarisk infestation is low abundance but spatially extensive. The channel is most severely incised on the Lower Riverbank Formation fanhead immediately downstream from the Tehama-confined inner valley and in Upper Riverbank Formation, Upper Modesto Formation and Holocene alluvium within the vicinity of Cortina Vineyard Road and the transmission towers crossing. It is unclear to what extent the present degree of incision can be partly attributed to historical aggregate mining in this vicinity. The approx. 0.9-mi-long downstream reach is strongly meandering but relatively narrowly confined with fine-grained erosion-prone near-vertical banks, and flanked closely on both sides by orchards. Part of the downstream orchard-flanked reach is shown in an oblique aerial photo on p. 36. See Figure 6 for air photos and mapped resource conditions of this Reference Reach.
Reference Reach Length: 6.3 river miles
Recommended Management Objectives: EC, HC, IC

Elk Creek looking south upstream to the right bank in a locally braided reach from the channel bed approx. 300 ft downstream from the North Fork Elk Creek tributary confluence. (January 20, 2010).

Reference/Critical Management Reach ID: **Reference Reach / CMR 17**
Stream: **Elk Creek**
Location Description: **Elk Creek near Arbuckle**
Reach Description: Elk Creek from approx. 1 mile upstream from the North Fork Elk Creek confluence downstream to Elk Creek's confluence with Salt Creek (South) near the Town of Arbuckle. The reach is naturally steep (S=0.007) and dynamic and shallowly incised (2-3 ft) in Upper Modesto and Holocene gravelly floodplain deposits of the coalesced Elk Creek and Salt Creek (South) alluvial fans. The reach is almost entirely flanked by orchards on both sides. Portions of the reach have been leveed, straightened, and narrowly confined, without widespread severe bank erosion consequences noted in initial field reconnaissance. There are several separate individual parcels adjoining the creek channel that are not currently in agricultural production. Some of the parcels host variable quality woody riparian habitats. Tributary North Fork Elk Creek hosts perhaps the longest extent of contiguous high quality riparian habitat (oak woodland) among Colusa County streams east of the foothills. The North Fork Elk Creek riparian corridor extends down to where it is tributary to Elk Creek. There is a natural vegetated island bar on Elk Creek at the North Fork Elk Creek confluence, and the reach is wide enough here to be locally braided. Properties are commonly subdivided into 10-acre minimum parcels in this vicinity, such that the Elk Creek Reference Reach contains numerous individual property owners. Its proximity to the Town of Arbuckle provides an opportunity to restore a more contiguous woody riparian corridor that improves wildlife habitat as well as the overall natural integrity of the landscape as an amenity for local residents. See Figure 7 for air photos and mapped resource conditions of this Reference Reach.
Reference Reach Length: 4.3 river miles
Recommended Management Objectives: EC, HC, IC

South Fork Buckeye Creek from the top of right bank looking north upstream to meanders cut in Tehama Formation forming the right bank below the view and Red Bluff Formation forming the left bank in the background. The broad floodplain bars overflow during relatively frequent floods and are in places colonized by dense stands of native woody riparian vegetation, such as Buckeye in the middle of the view. (January 20, 2010).

Reference Reach/Critical Management Reach ID: **Reference Reach / CMR 20**
Stream: **South Fork Buckeye Creek**
Location Description: **South Fork Buckeye Creek on the Durst Ranch**
Reach Description: An approx. 2.4-mi-long reach of the South Fork Buckeye Creek foothill inner valley, from where upper South Fork Buckeye Creek joins the larger Wildcat Creek, downstream through to the downstream end of the Durst Ranch property. The variably 400-1000-ft-wide meandering stream and active floodplain forms the valley floor inset at least 40-50 feet deep within Tehama Formation to the south and Red Bluff, Lower Modesto, and Tehama Formation to the north. The stream and valley floor are relatively steeply sloped (S=0.008). The Tehama Formation to the south is the northern edge of the Tehama Formation comprising the Dunnigan Hills geomorphic province. Massive dense gray-colored clay lenses within the Tehama Formation outcrop at the toes of the bank where the stream cuts into the edge of the Dunnigan Hills. Moderate and high bank erosion potential occurs with the highest erosion potential in outside banks. Moderately high bank erosion potential occurs in the Tehama Formation as well as the younger deposits. The corridor is used as grazing pasture. There are sections of high quality woody riparian habitat at the upstream and downstream ends of the reach and less vegetation established in the middle part of the reach. See Figure 8 for air photos and mapped resource conditions of this Reference Reach.

Reference Reach Length: 2.4 river miles
Recommended Management Objectives: EC, HC, IC

14. Streambank Erosion Reduction and Riparian Management and Restoration Opportunities and Constraints

We understand that the CCRCD is about to embark on the preparation of an Integrated Watershed Management Plan for the Colusa Basin Watershed. Therefore, the following section illustrates the riparian management and restoration opportunities and constraints that we have observed both from our findings during the mapping effort and our reconnaissance of the three Reference Reaches; CMRs 16, 17, and 20 (Figure 5). Examples from the Reference Reaches are woven into the below discussion, where appropriate.

Our scope of work was limited to the presentation of general management and restoration opportunities and is not intended to provide conceptual plans for restoration or arundo/tamarisk control. The preparation of conceptual restoration plans will be the subject of future phases of work toward implementing projects in the watershed.

Streambank erosion reduction opportunities and constraints

Address the highest bank erosion potential sites first but only as far as practically feasible considering other resource management objectives. The reaches with the highest bank erosion potential are expected or predicted to produce more potential sediment-related water quality impacts than other reaches. All things being equal, these reaches should be addressed first to prevent downstream water quality impacts. But for multiple reasons discussed throughout this section, including cost, prioritization of bank erosion reduction work should also consider:

- opportunities to achieve multiple resource objectives including restoring riparian habitat;
- reaches where the bank erosion potential is directly exacerbated by existing land use impacts that can be relaxed at the site as part of a lower-cost passive restoration approach promoting of riparian vegetation establishment and habitat restoration;
- reaches that produce the most severe potential water quality impacts according to more precise definitions of water quality impacts prioritized for avoidance, such as the highest problem range of sediment grain sizes, sensitive receiving waters, and any biological considerations re. timing or seasonality of impacts.

Differentiate between natural and human-induced or land use exacerbated bank erosion potential and relax land use impacts as part of a comprehensive lower-cost strategy to reduce bank erosion potential. As discussed above in this report, many of the reaches with the highest bank erosion potential are in reaches that we expect were naturally high bank erosion potential reaches prior to Euro-American settlement, due to largely unchanged geomorphic and hydrology factors. Grazing, in-stream mining, and channelization have definitely increased the erosion potential of some reaches, sometimes drastically. Comprehensive, lower-cost strategies for reducing bank erosion potential will seek to remove or relax these land use impacts, such as by:

- Implementing Riparian Pasture Management (i.e., flash cattle grazing) approaches described in the below section “Riparian Habitat Management and Restoration Opportunities”;
- Discouraging in-stream sand-and-gravel mining in favor of off-stream mining except for purposes of flood conveyance maintenance in aggrading reaches at road crossings, or as necessary to improve otherwise poor flood conveyance at poorly configured road crossings, etc.;
- Encourage channel and levee management approaches that avoid placement of fill within the natural active channel and floodplain, or, although expensive, remove past fill to achieve a fluvial geomorphic channel design that reduces long-term flooding potential, water quality impacts, and channel maintenance costs, and as far as practically feasible allows for establishment of riparian vegetation for erosion reduction and habitat restoration.

- Where feasible, reduce outside bend bank erosion first by vegetation establishment techniques described in the below sections "riparian habitat management and restoration opportunities and constraints" and "additional vegetation considerations".

Often, identifying and relaxing or removing land use impacts allows for erosion reduction and stream restoration to occur by natural geomorphic processes (i.e., passive restoration) at a lower up-front and future ongoing maintenance cost than more traditional, relatively expensive grading-intensive streambank reconstruction and vegetation restoration projects (i.e., active restoration). Certainly, passive restoration techniques should be applied first, and then, if funding is available and there is landowner interest, specific direct physical interventions can be made to further reduce bank erosion in the most problematic parts of the reach.

Active restoration projects require earth-moving to restore natural channel and floodplain geometry and/or more gradually sloped, less erosion-prone banks. Active restoration techniques are much more expensive because of the construction cost of cut and fill and installation of erosion protection and irrigated vegetation. Active restoration may be warranted where adequate funding or in-kind services are available. Active restoration may be revealed as practically necessary along entire reaches where chronic stream bank and levee erosion problems force landowners to consider reconstructing the channel in a configuration that will reduce long-term maintenance costs. When such large-scale channel reconstruction is required, a geomorphically designed channel configuration should be considered as an alternative to a narrow, straightened, levee-confined channel. A geomorphically-designed channel is typically wider and taking up of more potentially productive agricultural land than a narrower channel, but the reduced future maintenance costs may partially offset the increased investment. Often, large-scale channel repairs are forced to occur on an emergency basis immediately following bank and levee failures during floods. A geomorphically-designed plan prepared in advance can be roughly implemented under emergency conditions.

A geomorphic design could be prepared for individual foothill streams using first principles of fluvial geomorphology and historical geomorphic analysis to develop minimum toe and top widths for the stream and identify discontinuities or irregularities in the longitudinal bed profile caused by past channelization projects. The geomorphic design would describe the target geometry for a long-term equilibrium, minimized erosion, maximized riparian habitat channel. That "target channel" may be created incrementally over time if individual landowners each elect to create that geometry on their parcels when channel maintenance work is required.

Identify problem sediment grain sizes and specific water quality impact vectors to prioritize bank erosion reduction efforts and target specific foothill stream watersheds and reaches. Some eroding banks are producing primarily coarse-grained sediment and some are producing primarily fine-grained sediment. To avoid water quality impacts by bank erosion reduction, it should first be determined what kind or size of sediment, going to what places in the watershed, and when, creates the most problematic water quality impacts. We made a primary purpose of this analysis to identify bank erosion potential in terms of probable future gross flux of sediment into the foothill streams, regardless of sediment size and destination and other legacy effects. We did assume in general that erosion of finer-grained bank materials may produce greater water quality impacts than erosion of coarser gravelly bank materials, and in some cases assigned greater erosion potential to eroding reaches with fine-grained bank materials than equally eroding reaches with coarse-grained bank materials.

More analysis of landscape denudation – water quality linkages would be helpful for better understanding and increasing the water quality improvements borne by bank erosion reduction projects. It would be helpful to compare what percentage of the problem grain size sediment is produced by mainstem streambank erosion compared to streambank erosion on tributaries, and upland erosion from multiple various sloped terrains present in most foothill watersheds: natural ungrazed foothill areas; natural grazed foothill areas; grazed and ungrazed foothill inner valleys; cultivated foothill areas; cultivated fan surfaces; cultivated low plains and interfan basin surfaces; etc.

Without more detailed analysis, it seems in general that chronic severe erosion of banks containing fine-grained sediment produces more problematic water quality impacts for the Sacramento River, the Colusa Basin Drain, and other downstream receiving waterbodies. This would suggest that the greatest watershed-scale water quality benefits to be gained from bank erosion reduction would focus on the highest bank erosion potential reaches mapped within: (1) the deeply incised upland inner valley sections of foothill streams draining the larger foothill watersheds underlain by the Cretaceous marine sedimentary bedrock; and (2) the channelized and levee-confined reaches of foothill streams in South Glenn County and North Colusa County lying downstream from the Tehama-Colusa Canal.

- Recall that his study identified high fine-grained bank erosion potential along the upland inner valley sections of South Fork Willow Creek, Nye Creek, and Freshwater Creek. The upper inner valley of Stone Corral Creek also has sections with moderate and high bank erosion potential. We did not map erosion potential of the upper reaches of Funks Creek lying upstream from Funks Reservoir, but fine sediment may be a Funks Reservoir water quality concern, and fine sediment might also route through Funks Reservoir and Tehama-Colusa Canal. Most of these upland inner valley reaches are grazed. Opportunities and constraints for bank erosion reduction and riparian habitat improvement through passive restoration techniques including Riparian Pasture Management (described below in this report) may be immediately applicable.

- Recall that this study also identified sections of high fine-grained bank erosion potential in the channelized and levee-confined reaches of foothill streams in South Glenn County and North Colusa County lying downstream from the Tehama-Colusa Canal. Bank erosion severity appeared to be a function of canal design, age, and maintenance. Simply establishing more continuous and dense vegetation on channel banks would reduce bank erosion in many of these reaches. As discussed above in this report, particularly extensive and severe bank erosion was also identified where the channels are operated as deep-water flowing irrigation conduits. It appears that woody riparian vegetation cannot be established on the banks because of the prolongued seasonal inundation, but much for the same reason, to similar erosion reduction effect, willows and cottonwoods and other vegetation might be rather easily established within a buffer if allotted at the top of bank.

This is while chronic severe erosion of banks containing coarse-grained sediment is seen to produce perhaps lesser water quality impacts and more problems of downstream sediment deposition in the downstream flood-prone sections of the foothill streams and the downstream receiving Colusa Basin Drain.

- Recall that his study identified high coarse-grained bank erosion potential along the larger foothill streams cut in the steeper, better developed alluvial fans in South Colusa County and North Yolo County, including especially North Branch Sand Creek, Salt Creek (South), Cortina Creek, Petroleum Creek, Little Buckeye Creek, Buckeye Creek, and South Fork Buckeye Creek. Opportunities and constraints for bank erosion reduction and riparian habitat improvement through passive restoration techniques including Riparian Pasture Management (described below in this report) occur where the streams have not yet been channelized. The most severe erosion potential occurs where the streams have been channelized, sometimes narrowly. Where channelized, long-term erosion reduction may require active restoration techniques including net cut grading to restore wider, more naturally configured and shaped channel geometry and channel-floodplain interactions where feasible.

Outside bend bank erosion is a natural process that relieves erosion and flooding pressure and creates riparian habitat. Some investigators have observed that some modes of bank erosion should be viewed as “beneficial” (e.g., Florsheim et al. 2008). Erosion of outside bends by meandering streams can be viewed as beneficial in so far as it relieves bank erosion and flooding pressure and creates new riparian habitat. That bank erosion washing riparian trees into the stream puts large woody debris on the bed and bank which increases the complexity of aquatic habitat and provides cover for fish. And those resulting fresh deposits of riverwash along the inside bend are surfaces for new woody riparian vegetation to colonize. Where bank materials are in large part gravel-sized sediment, their erosion injects coarse bed material into the system for bar formation suitable for colonization by woody riparian vegetation and more suitable substrate for salmonids, both for successful spawning and for colonization by preferred benthic invertebrate food species.

Aquatic habitat for salmonids and invertebrates is not a concern in the ephemeral foothill streams of the Colusa Basin Watershed, none of which are believed to host salmonid populations. However, woody plant colonization of gravel bars does occur and seems quite ecologically valuable. There are also less permanent gravel-bed plants such as *Heterotheca oregona*, *Mentzelia laevicaulis*, and *Heliotropium curassavicum* that benefit.

Efficient agricultural production is vital to the economy in the Colusa Basin Watershed. Land is almost universally in production to within tens of feet from the top of bank and the tens of feet of top of bank buffer lands are almost always occupied by levees and/or equipment access roads. So that outside bend bank erosion washes away access roads and margins of lands in production. Those new riverwash deposits along the inside bend are great surfaces for woody riparian vegetation to colonize, but not for agriculture. Bank materials washed into the streams may contribute to excessive sediment deposition in downstream bank erosion and flood prone reaches of the foothill streams and sedimentation within the Colusa Basin Drain.

A wider, more stable channel has lower long-term maintenance costs and supports riparian forest and vegetation providing habitat for bees and other insects and wildlife that may be beneficial to some adjacent agricultural operations. It was noted above that more sustainable and lower-maintenance geomorphically-designed channels are wider than erosion-prone, frequently maintained narrow channels. Indeed, almost all cost-effective long-term successful bank erosion reduction in narrowly channelized reaches will require rededication of some of the land currently in agricultural production back to the riparian corridors from which it was originally reclaimed.

Promote uniform guidelines for channel construction and maintenance projects and road crossing replacements. An opportunity exists to reduce long-term bank erosion by promoting improved and uniform design guidelines for future public infrastructure projects and channel improvement work on private properties. First, many of the existing road crossings appear too narrow and otherwise promote local flooding and reach-scale streambank erosion by requiring streams to make near 90-degree bends. Individual road crossing replacement projects should be reviewed to identify opportunities for reach-scale stream restoration that increases sediment and woody debris continuity, reduces future bank erosion, reduces flooding, reduces dredging maintenance requirements, and restores permanent native riparian vegetation. The Road 89 crossing over Buckeye Creek near Dunnigan appears to be an example of a crossing that could be replaced as part of a reach-scale stream restoration project that reduces the severity of the bend the stream is forced to make and restores a 2-stage channel that supports riparian vegetation not conflicting with flood control. Second, streambank erosion potential is often increased by individual private properties having channelized stream reaches much narrower than the often more stable channels on upstream and downstream properties. Promoting guidelines for bridge replacement and isolated channelization projects including recommended minimum toe and top widths for individual streams and reaches may be helpful in preventing additional erosion potential increases by future channelization projects.

Putting in place uniform guidelines would encourage incremental changes organized around a long-term goal for an individual stream. A custom geomorphic design could be prepared for individual foothill streams using first principles of fluvial geomorphology and historical geomorphic analysis to develop minimum toe and top widths for the stream and identify discontinuities or irregularities in the longitudinal bed profile caused by channelization projects. It could also take into consideration design lessons learned by long-time landowners on the individual streams, and use demonstrably stable channelized reaches as design analogs if appropriate. A custom geomorphic design would describe the target design geometry for a channel that would practically minimize bank erosion and maximize suitability for self-sustaining riparian habitat. The target design geometry may be created over time if individual landowners each create that geometry on their parcels.

Because implementing the design geometry on individual parcels would often require landowners to dedicate acreage back to the stream from which it was reclaimed sometimes several generations ago for agricultural productivity, a financial mechanism may need to be developed to compensate landowners for reduced productivity. For most reaches, reduced long-term channel maintenance costs do not appear to be enough incentive.

Riparian Habitat Management and Restoration Opportunities

Riparian Pasture Management to increase the surface area and quality of riparian habitat. Cattle ranching is the principal land use in the western, upstream portion of the Colusa Basin Watershed's tributaries. Riparian Pasture Management practices provide opportunities for mutual benefits to both cattle ranching and riparian habitat. This approach involves a shift in the timing and duration of cattle grazing in the riparian zone to facilitate both the harvest of available herbaceous forage, help control invasive exotic pest plants and facilitate the natural recruitment and establishment of riparian trees and shrubs (i.e. flash grazing). Under a flash grazing regime, cattle grazing in the riparian zone would occur in the spring to early summer window when annual grasses and forbs are actively growing and prior to the senescence of this herbaceous forage. The riparian zone would be left ungrazed from summer through winter. It should be noted that flash grazing must be actively and carefully managed to obtain the benefits described below, with adjustments to timing and intensity of grazing on an as needed basis. The specific timing and duration of grazing would be tailored to site-specific conditions including yearly rainfall patterns and landowner goals to facilitate the following benefits:

- harvest of abundant, actively growing herbaceous forage;
- control of weeds that compete with woody riparian vegetation;
- facilitation of selective grazing on abundant green forage as opposed to naturally recruiting tree and shrub seedlings/saplings in the riparian zone (woody seedlings/saplings are less susceptible to grazing in spring when abundant herbaceous forage is present), and;
- protection of water quality by limiting grazing during the rainy season.

Implementation of flash grazing regimes in riparian zones will require the installation of livestock exclusion fencing to separate the riparian/flash grazing zone from the surrounding uplands. Fencing alignment plans should consider the following site-specific factors:

- incorporate landowner input, including desired density of cattle for grazing in the riparian zone which will influence the surface area of the flash grazing zone, locations of gates, need for installation of new drinking water locations, etc.;
- maximize use of existing fence alignments;
- fit fence alignments to the site topography;
- include active floodplains within the flash grazing/riparian zone (for example, several broad, active floodplains are present in Reference Reach/CMR20 (Figure 8) that would benefit from inclusion in the riparian/flash grazing zone);
- include existing native riparian vegetation patches within the riparian/flash grazing zone, and;
- maintain a minimum 50 ft buffer between fence alignments and the top of creek banks when feasible where these are distinctly defined in the field.

For ranchland projects where additional financial resources are available beyond that needed for fence installation, funds could be allocated to increase the rate of establishment through the installation of individual, welded-wire foliage protection cages around the most vigorous of the naturally recruited riparian trees. Foliage protection cages can reduce browse from cattle and deer and thereby increase the survival rate of target vegetation. These cages could then be periodically moved to other seedlings in need of browse protection, when the trees are large enough to withstand livestock grazing and tall enough to exceed deer browsing height. Additionally, where funding is available, active revegetation of woody riparian species can be implemented as described below.

Revegetation to increase length and width of contiguous high to moderate quality riparian habitat and increase the rate of riparian habitat regeneration. Riparian habitat connectivity refers to the lineal extent of contiguous or near-contiguous native, woody riparian vegetation (trees and shrubs) along a watercourse. The restoration of riparian habitat connectivity along streams is beneficial to riparian-associated wildlife, aquatic organisms, and water quality (via the reduction of erosion and steam water temperature). While natural recruitment rates of woody plant species will likely increase "passively" via Riparian Pasture Management activities, active revegetation can substantially increase the rate of habitat establishment. The riparian habitat quality map results reveal numerous streams with a patchy distribution of high and moderate quality riparian habitat punctuated by patches of low quality habitat. Therefore, these locations present opportunities to increase the connectivity of high to moderate quality riparian habitat via the revegetation of the low quality habitat gaps. This approach maximizes the value of riparian revegetation efforts by limiting revegetation activities to smaller, low-quality habitat gaps and thereby, capitalizes on the distribution of existing high quality habitat.

For example, a gap of low quality habitat is present in the middle of Reference Reach-CMR20 with high and moderate quality habitat at the upstream and downstream ends (Figure 8). All other constraints being equal, active riparian revegetation efforts would yield higher value if they are initially focused on the low quality habitat gap. If/when additional funding became available, revegetation efforts could then focus on improving the moderate quality habitat area at the upstream end of Reference Reach-CMR20, and/or on expanding the width of the riparian corridor.

Revegetation to reduce soil erosion in the riparian zone. In general, the root systems of native riparian trees and shrubs are deeper and stronger than the non-native grasses and forbs that dominate the cover of the low to moderate quality habitat areas. Therefore, active revegetation with native woody species can be employed to slow the rate of soil erosion in the riparian zone. The following are a few general examples of how revegetation can be employed to slow soil erosion. Where dry season soil moisture is adequate, obligate riparian species such as willows and cottonwoods can be installed along the toe of eroding creek banks. These species, particularly willows, can also be integrated with bioengineering treatments where appropriate. Drought tolerant oak woodland and chaparral species can be installed in strategic locations along the top of bank, upslope of areas with active bank erosion to slow or potentially arrest the upslope migration of erosion. Finally, eroded slopes/banks can be broadcast seeded with native shrub and grass seed and covered with weed-free straw (using shovels to crimp the straw into the soil) in September/October, at the onset of the rainy season.

<u>Additional Revegetation Considerations</u>

Development of Planting Plans. A restoration ecologist or plant ecologist should develop planting plans, where funds are available for riparian planting projects. Planting plans should include selection of planting sites based on the above habitat connectivity considerations, as well as upon factors to maximize successful plant establishment such as:

- relatively gentle topography (slopes 3H:1V or gentler)
- access for plant installation, weed control and irrigation
- favorable soil conditions (e.g. lower and thereby potentially moister floodplains where available, low soil compaction, deeper soils)

The species selected for planting (i.e. plant species palette) should be adapted to survival in the physical conditions of the planting sites without long-term maintenance. The plant species palette, percent species composition, and planting density, should be based upon surveys of "model" sites with existing naturally recruited, high-quality riparian habitat. Model sites should be located within the same tributary watershed (or nearby similar watersheds) as the planting sites and in reaches with similar physical conditions to the planting sites to the extent feasible.

The planting palette in areas adjacent to orchards should be tailored to avoid negative effects on the growth of orchard trees via shading. Therefore, short-statured species should be planted in closer proximity to orchard trees and tall native trees should be planted in locations that will not substantially shade orchard trees.

Scientific Name	Common Name	Growth Form
Adenostoma fasciculatum	chamise	Shrub
Aesculus californica	California buckeye	Tree
Baccharis pilularis	coyote brush	Shrub
Heteromeles arbutifolia	toyon	Shrub
Lotus scoparius	California broom	sub-shrub
Quercus douglasiana	blue oak	Tree
Quercus lobata	valley oak	Tree
Quercus wislizeni	interior live oak	Tree
Sambucus Mexicana	blue elderberry	Tree/shrub
Toxicodendron diversilobum	poison oak	Shrub

North Fork Elk Creek provides a good example of a model site that can inform revegetation design. This model site is approximately 7,500 ft long and extends from just upstream of Whiskey Creek Road, downstream to the confluence with Elk Creek at Reference Reach/CMR 17 (Figure 7). The riparian corridor at this model site is relatively undisturbed and supports a multi-layered riparian canopy, dominated by a diversity of native trees and shrubs. The above table provides a native riparian plant species list from this model site based on our field reconnaissance.

Watershed-specific Plant Material. Plant material refers to container stock, acorns/buckeye seed, or willow/cottonwood cuttings that are installed at planting sites. Plant material should be ideally derived from the same watershed as the subject foothill stream or from nearby watersheds within the larger Colusa Basin Watershed. Plant material should be derived from reaches with similar physical conditions as the planting sites. Such genetic specificity increases the potential for survival, because the plant material tends to be better adapted to the physical conditions of the planting sites. Appropriate restoration container stock (deepots and treepots) should be contract grown by a native plant nursery and the nursery should be given 1-2 years lead time (depending on container sizes) to propagate watershed-specific material.

Flash Grazing and Active Revegetation. Patches of active revegetation within Riparian Pasture Management areas should be left ungrazed for the first 5-10 years following plant installation to facilitate establishment of the plantings. The flash grazing regime can then be resumed in actively revegetated areas once the plantings become large enough to coexist with this regime.

Weed Control and Active Revegetation. In the absence of grazing in Riparian Pasture Management areas or in reaches adjacent to croplands, weeds should be monitored and controlled (via manual removal or herbicides) as needed to facilitate establishment of the plantings. The level of effort for weed control will depend on site-specific weed establishment conditions and available funding. Effort should first be expended to apply wood chip or rice straw mulch (~3 inch thick layer) in a ~3-4 ft diameter area around each planting and to maintain this area free of weeds. Next, as funding allows, weeds should be controlled in the space beyond the mulched areas.

Irrigation. Plantings should be irrigated in the dry seasons during the initial plant establishment period (i.e. the first 3 growing seasons after installation). The frequency and duration of watering should be tailored to facilitate rooting deep into the soil profile and thereby support the establishment of native plants that will not require long-term watering. Therefore, plants should be irrigated with 5-10 gallons of water per event and the frequency of irrigation should be gradually reduced during the 3-year plant establishment period.

The irrigation methods with the greatest likelihood of success will be those that fit the land use practices of the landowners in the respective planting reaches and those methods that may provide dual benefits to landowners and riparian vegetation. For example, in ranchland reaches, wells could be installed that provide both a water source for riparian plantings and livestock. Drip irrigation systems can be installed from new or existing wells to riparian plantings. The use of water trucks could also be considered where adequate funding is available. Plantings could be hose-watered from a water truck, or water trucks could be used to fill water storage tanks that gravity feed a drip irrigation system.

Many of the potential planting sites will be adjacent to orchards such as the downstream reach of Reference Reach/CMR 16 on Cortina Creek (Figure 6) and the entirety of Reference Reach/CMR 17 on Elk Creek (Figure 7). Drip irrigation systems are already installed in the orchards providing an opportunity, where landowners are amenable, to extend drip irrigation from the orchard systems to plantings in the riparian zone.

Riparian Habitat Restoration Constraints

First of all it should be recognized that it is not appropriate to restore or establish new riparian vegetation, especially woody riparian vegetation, everywhere where it is lacking along the foothill streams of the Colusa Basin Watershed. For example, establishing woody riparian vegetation on the banks of flood-prone channels may increase their susceptibility to overbank flooding which may be damaging to adjacent croplands. And it may not be feasible to establish woody riparian vegetation on the banks of channelized streams which are used as deep-water conveyance channels for irrigation water. Non-shrub and tree riparian vegetation may be feasible to establish in these instances as a means to reduce bank erosion potential and reduce channel maintenance.

The following is a list of general constraints to riparian habitat revegetation that should be evaluated during site selection and restoration plan preparation. A number of these constraints are touched upon in the revegetation approaches discussed above:

- cost
- water availability-both natural sources/soil moisture regimes and artificial sources for irrigation
- topography
- establishing vegetation on near-vertical banks
- establishing vegetation on actively retreating banks or where there is direct bank erosion pressure
- access
- soil conditions
- woody riparian vegetation may need to be routinely removed from flood conveyance capacity limited channels
- weed competition with native natural recruits and plantings
- browse damage to native natural recruits and plantings
- the agricultural footprint limits the available restoration area

Arundo and Tamarisk Control Opportunities

The future Integrated Watershed Management Plan should include a plan for the control of arundo and tamarisk, which would identify priority locations for control and a suite of control methods. Preparing such a plan is beyond this scope of work. However, the following is a summary of the general opportunities for arundo and tamarisk control based upon our field reconnaissance and mapping results.

Relatively low abundance and extent of Arundo and Tamarisk infestations provides an opportunity for substantial control at relatively low cost. As noted in the results section, the abundance and spatial extent of arundo and tamarisk is relatively low throughout the survey area, with the exception of a few hot spots. The current spatial extent of these species is much less than the area of suitable habitat. Therefore, there is a window of opportunity now to substantially control the spread of these species at less cost than that for more heavily infested watersheds.

Begin control efforts at the upstream extent of the invasion. Vegetative reproduction is the primary mode of regeneration for arundo (EIP Associates 2002). Arundo stem fragments and/or rhizomes are dispersed downstream via flood flows. Tamarisk reproduces both via wind-blown or water-born seed as well as via stem fragments. Therefore, efforts to control these species should begin at the upstream extent of their distribution within a given stream to minimize the potential for colonization of downstream control areas from upstream populations. The inner valley reach of Cortina Creek in the upstream end of Reference Reach/CMR 16 (Figure 6) is believed to comprise the upstream end of low abundance Tamarisk infestation which should be controlled first as part of a comprehensive management plan for that Reference Reach and the larger Cortina Creek corridor.

As noted in the Methods Section, our mapping effort was accomplished primarily from aerial photograph interpretation and small patches of arundo and tamarisk were likely missed especially in the upstream/remote reaches of the survey area. Therefore, the distribution of arundo and tamarisk should be mapped via ground reconnaissance along streams that are selected for treatment.

Prioritize control efforts on streams where relatively short reaches are infested upstream of high to moderate quality habitat. This approach will help to achieve the greatest benefit to riparian habitat quality per unit of control effort.

Prioritize control efforts on streams where a low severity infestation occurs within high quality riparian habitat. Arundo and tamarisk seedlings can compete with native riparian tree and shrub seedlings (e.g. with willow/cottonwood seedlings recruiting onto active floodplains) and thereby potentially inhibit the regeneration of native riparian habitat. Therefore, low severity infestations within high quality habitat should be controlled as another means of achieving the greatest benefit to riparian habitat quality per unit of control effort. The low severity infestation of arundo within high quality willow/cottonwood dominated habitat on Walker Creek is a good example of this particular opportunity.

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