December 08, 2017

Claire DeLeo and David Hirt
Boulder County Parks and Open Space
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Longmont, Colorado 80503

RE: Final Report: Influence of Crack Willow on Stream Geomorphology, Wildlife, and Native Plant Community Composition.

Hello Claire and David,

This report provides results and analyses of our BCPOS-funded research project to study the influence of crack willow on stream geomorphology, bank erodibility, understory native plant communities, and the avian community. The original research proposal proposed to study the influence of crack willow trees on stream banks, native wildlife and plant communities, and to provide a summary of integrated pest management methods for crack willow. David Hirt and other Boulder County staff have been invaluable to the completion of this project, and we thank you deeply for your support of this project.

Because our matching grant (though it was awarded) has not yet been provided by CWCB, we were unable to provide the depth of research on these sites as we had originally intended. However, we believe we have addressed well the majority of the scope items in the original grant with BCPOS, and we will invoice BCPOS for only those research items actually conducted for the project. As we continue to do research on this topic, we will be happy to provide supplemental reports to you.

I would like to also take a moment to thank Denise Wilson, Heather Manier, and Matt Norville for their field and GIS contributions to this project. If after evaluating this report you should have further questions, don't hesitate to call or email.

Kind regards,

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ABSTRACT

This research project was designed to examine the influence of crack willow (*Salix fragilis and related S. alba*, and hybrids between these species) on the geomorphology and bank erodibility of Colorado Front Range rivers (Boulder Creek and Cache la Poudre River), and the relationship of these exotic trees on native flora and avian species. This study further evaluates the variety of integrated pest management options for crack willow, including the costs of various treatment methods.

Crack willow, which can reach 8 feet in diameter and 70 feet high, occurs in several streams in Boulder County, often times dominating the upper canopy strata of the riparian area. Dense stands of crack willow, we have hypothesized, results in the suppression of native species diversity, chokes stream channels, and armors banks to an unnatural degree, thus reducing flood capacity and increasing risk of stream incision. Further, we hypothesize crack willow is regenerating naturally in Front Range streams. To address these hypotheses (detailed below), we evaluated reaches of Coal Creek (Boulder OSMP property), Boulder Creek (Alexander-Dawson) and Lefthand Creek (Peck and Jorgensen). Results indicate no significant differences in understory herbaceous cover, a significant difference in understory shrub cover, high evidence of re-sprouting, armoring of banks, and a (to be determined) influence on raptor and heron nesting activity.

BACKGROUND

According to observations of the principal investigator, and as revealed by the literature (Anon 2000, Weber 2003), crack willow has the potential to completely dominate the canopy strata of Front Range plains and foothills riparian systems, suppress native species diversity, and choke stream channels, thus reducing flood capacity and increasing risk of incision. Crack willow was introduced into eastern portion of the United States in colonial times (Newsholme 1992). *Salix fragilis* is an invader of river corridors, lakesides and wetlands (Weber, 2003), causing changes to stream hydrology, higher erosion and sedimentation rates, impacts to flooding patterns, and possibly increased water use compared to indigenous plant species (Anon 2000). Negative consequences for biodiversity where *S. fragilis* has become invasive have also been documented, as the thick canopy of *S. fragilis* is sufficient to shade out other plants and reduce invertebrate abundance (Weber 2003).

METHODS

The following hypotheses were evaluated by this research project:

1) Dense crack willow stands along streambanks provide higher bank stability scores (Streambank Stability Assessment Protocol method) than cottonwood- and/or peachleaf willow-dominated stands.
2) Plant species diversity, plant species richness, and plant structural diversity is lower beneath dense crack willow stands compared to cottonwood- and/or peachleaf willow-dominated stands.
3) There is an inverse relationship between crack willow stand density and cottonwood regeneration beneath the crack willow canopy.
4) Crack willow stands harbor lower nesting habitat for cavity-nesting birds, raptors, and rockery species such as Great blue heron, as compared to cottonwood- and/or peachleaf willow-dominated stands.

To address these hypotheses, and with respect to the general approach in section 2, the following methods were utilized.

Site Selection: With the guidance of David Hirt, who reviewed pre- and post-flood aerial imagery (2011 and 2014 BCPOS aerial imagery), John Giordanengo and David visited several potential reference sites (i.e., dominated by cottonwoods and associated native species) and crack willow sites (i.e., upper canopy consisting of at least 50% cover of crack willows, with crack willows the dominant overstory species). Study reaches were dominated by either crack willow or native trees/shrubs for at least 200 meters of their length, with a width of at least 50 meters on river right and river left. Several potential reference sites were rejected due to lack of uniformity in the upper canopy layer (i.e., mixture of Siberian elm, cottonwood, and crack willow at Braly, Western Mobile, and Heatherwood), geomorphic confounding variables (i.e., road construction in the overbank zone and low-flow crossings at Parrish Ranch), and for other reason. The only crack willow infested reaches that met our site selection criteria, and which we had access to, occurred on Lefthand Creek (Peck, BCPOS; and Jorgensen, private, below Brewbaker-Sorensson). Additional research and requests for access permission may result in additional crack willow infested sites in the future. Locating adequate (i.e., pristine) reference sites is highly difficult on the Front Range of Colorado, as the overwhelming majority of our plains and foothills streams have been heavily impacted biologically and geomorphically by centuries of agricultural, timber, and development pressure, and impacted hydrologically by upstream diversions. With these confounding variables in mind, we selected reference sites on Coal Creek (OSMP property upstream of Hwy 93) and on Boulder Creek (Alexander-Dawson, BCPOS property).

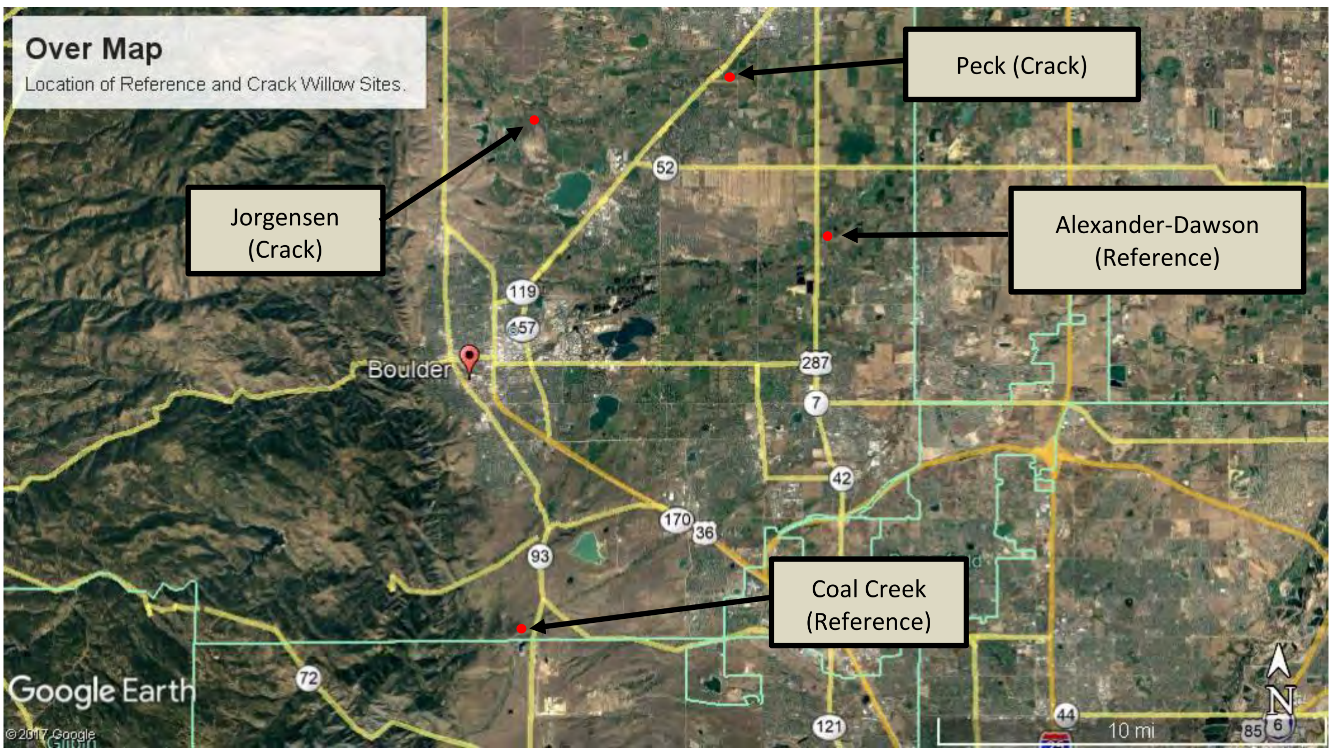

Figure 1. location of study reaches. Individual property maps with monitoring transect locations are located in **Appendix D**.

Avian Study: The avian research was not conducted at the same level of detail as originally intended due to lack of funding by CWCB. Alternatively, with the funding available, we overlaid 2014 raptor and Great Blue Heron nesting data with the 2014 BCPOS aerial imagery, which is at a high enough resolution to determine if nests occurred in cottonwoods, peach leaf willows, crack willow, or unknown species of trees. The study included all raptor data points between Hwy 287 and the foothills, north of baseline road and south of Hwy 66.

Vegetation Surveys: We conducted line-point intercept monitoring (Herrick et al. 2005) using lasers (ground cover) and periscopes (canopy cover) in 100-meter transects to measure vegetation cover (species cover, diversity, structure). The original research design aimed to collect a minimum of 10 randomly located transects in each study reach, within a 25-foot buffer of the canopy edge to reduce influence of non-target conditions on the desired understory measurements. However, due to the geometry of selected study reaches (i.e., crack willow and cottonwood stands were narrow and long rather than long and wide), we instead used four 200-meter long transects at each site, two in each overbank zone (**Figure 2**). Presence absence data was also recorded within a 2m wide belt along the 100m long transect. Vegetation was recorded in the following categories:

Line-point Intercept Survey Tool: periscope (for canopy cover) mounted on arm with laser (for ground cover)

- Species: unknowns recorded to the genus if known, or grass-like, shrub, tree, forb.
- Life history trait: Native, Introduced, Perennial, Annual, Biennial, Forb, Grass, Tree, Shrub.
- Height (i.e., for structural diversity): Upper Canopy = greater than 30 feet high, Mid Canopy = 5-15 feet, Ground Cover = everything below 5'.

Raw data is provided in a separate excel spreadsheet. Photos of vegetation transects are provided in **Appendix B**.

Stream Stability Assessment and Cross Section Survey: Utilizing the Streambank Stability Assessment Protocol (Sholtes and Giordanengo 2016), we measured streambank conditions via ocular estimates along 100 meters of each study reach, bordered by either crack willow stands, or cottonwoods and native shrub communities. The percentage of a bank study reach exhibiting specific elements (i.e., dense surface roots, bank composition, herbaceous and woody vegetation, bank angle, degree of active bank erosion, etc.) was recorded on bank right and left bank. The bank was defined as the area between the toe (i.e., outer edge of the inner berm) and the elevation of the ordinary high water mark. Three cross-sections were surveyed at 25 meter intervals within each 100 meter study reach. Survey points included transect origin (overbank or upland zone), overbank bench, top of bank, ordinary high water mark (i.e., bankfull), toe of slope (i.e., edge of inner berm), edge of water at low flow, and thalweg. Refer to **Appendix C** for photos, and a full list of elements surveyed. Raw data is provided in a separate excel spreadsheet.

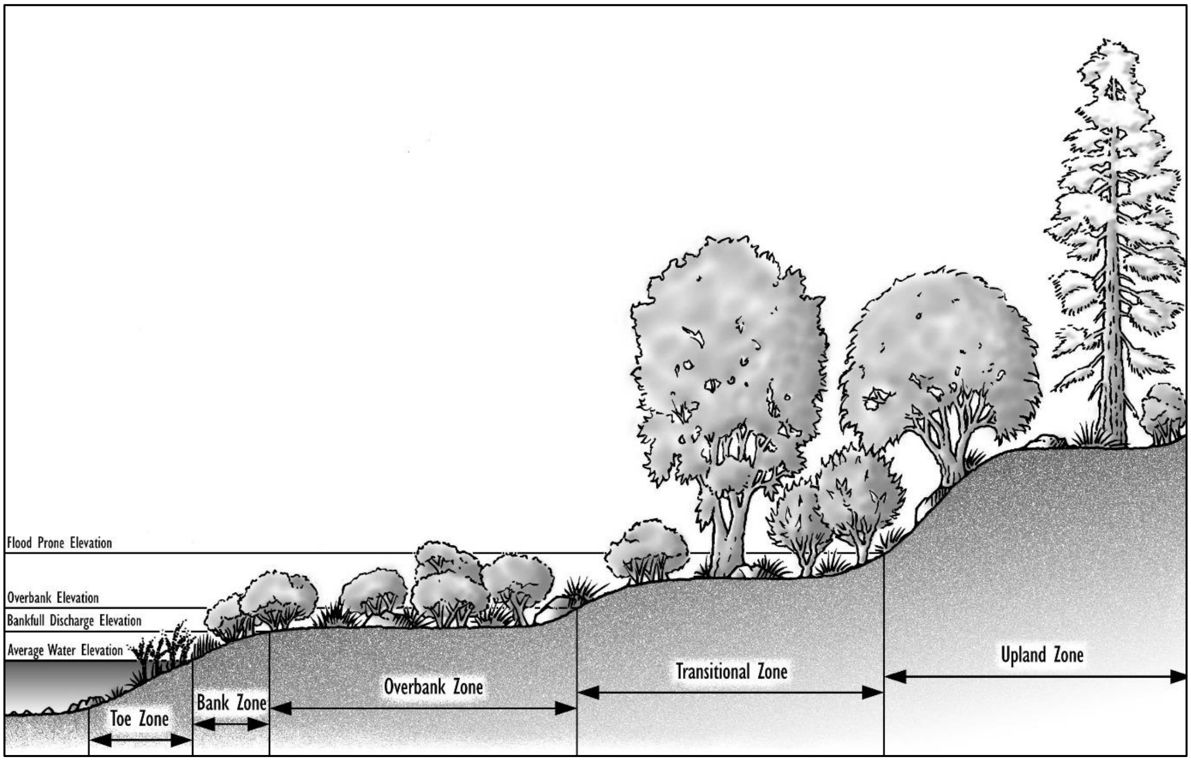

Figure 2. Riparian zonation (Hoag and Fripp, 2005).

Avian Survey: Due to lack of funding from a partner grant, the avian survey was reduced to include an assessment of existing BCPOS nesting records for raptors and great blue herons. We have also received raptor nest data from the City of Longmont (presented below), and we have requested raptor data (by tree species) from the City of Fort Collins. For the Longmont data, species of raptor is record by vegetation type where nests occur.

For the Boulder County desktop analysis (to be completed and supplied in a supplemental report), the survey area will include a review of all known raptor nests and heron rookeries occurring south of Hwy 66, east of Hwy 36 (the foothills), north of Baseline Road, and west of Hwy 287. Using high resolution aerial imagery provided by BCPOS, nesting data will be projected atop aerial imagery according to three vegetation signatures: a) crack willow canopy, b) cottonwood canopy, and c) other vegetation.

RESULTS

<u>Vegetation Cover</u>

Tables 1-2 provide a summary of vegetation survey data in crack willow and reference sites in absolute cover, which is used for the purposes of understanding the influence of vegetation on bank stability. **Table 3-4** provide relative cover of vegetation by site, transect, and life history trait. From the data collected and analyzed, there was little to no significant difference in vegetation cover between crack willow and cottonwood dominated (i.e., reference) sites. It should be noted, however, that the best reference site available in Boulder County POS property did show a significant diversity of native shrubs, and high levels of structure between Upper Canopy (30-50% absolute cover), mid canopy (7-36% absolute cover) and herbaceous ground cover (21-34% absolute cover). Further, the Coal Creek site harbored several species of native shrubs (*Crataegus erythropoda, Rhus trilobata, Ribes aureum, and Amorpha fruticose*) that were not found in the crack willow sites.

Abslolute Cover by Transect				Upper Canopy			Mid Canopy	Total Herbaceous		Herbaceous Groundcover by Life History										Tree GC		Shrub GC	
Reach Type	Site	Transect	Total # Spp	salfra	popdel	popacu		Intr.	Native	IPG	IAG	IPF	IBF	IAF	NPF	NBF	NAF	NAG	NPG-L	IT	NT	IS	NS
crack	Peck	T-1	26	75%	0%	0%	30%	34%	3%	30%	0%	4%	0%	0%	1%	0%	0%	0%	2%	0%	0%	0%	3%
crack	Peck	T-2	24	75%	2%	0%	7%	40%	9%	33%	0%	7%	0%	0%	0%	0%	2%	0%	7%	0%	0%	0%	0%
crack	Peck	T-3	18	81%	0%	0%	12%	11%	3%	6%	0%	3%	0%	1%	0%	0%	0%	0%	3%	0%	0%	0%	7%
crack	Peck	T-4	29	74%	0%	0%	1%	18%	1%	9%	0%	4%	4%	0%	0%	0%	0%	0%	1%	0%	0%	0%	7%
reference	Alex-Daw	T-5	20	0%	49%	0%	0%	24%	4%	20%	0%	2%	0%	2%	0%	0%	0%	0%	4%	0%	0%	0%	2%
reference	Alex-Daw	T-6	18	0%	41%	0%	0%	11%	0%	10%	0%	0%	1%	0%	0%	0%	0%	0%	0%	0%	0%	0%	2%
reference	Alex-Daw	T-7	17	0%	48%	0%	0%	8%	16%	5%	0%	3%	0%	0%	0%	0%	1%	0%	15%	0%	0%	0%	0%
reference	Alex-Daw	T-8	9	0%	63%	0%	0%	10%	6%	9%	0%	1%	0%	0%	0%	0%	0%	0%	6%	0%	0%	0%	0%
crack	Jorgensen	T-9	41	73%	12%	0%	14%	7%	6%	6%	0%	0%	1%	0%	1%	0%	0%	0%	5%	3%	0%	0%	1%
crack	Jorgensen	T-10	27	92%	0%	0%	0%	6%	1%	6%	0%	0%	0%	0%	0%	0%	0%	0%	1%	0%	0%	0%	0%
reference	CoalCreek	T-11	39	0%	11%	20%	36%	20%	3%	19%	0%	1%	0%	0%	0%	0%	0%	0%	3%	0%	0%	0%	15%
reference	CoalCreek	T-12	28	0%	33%	8%	7%	34%	3%	32%	0%	1%	1%	0%	0%	0%	0%	0%	3%	0%	0%	0%	13%
reference	CoalCreek	T-13	30	0%	16%	37%	28%	30%	1%	24%	0%	6%	0%	0%	0%	0%	0%	0%	1%	0%	1%	0%	26%
reference	CoalCreek	T-14	30	0%	20%	22%	21%	19%	2%	15%	0%	4%	0%	0%	2%	0%	0%	0%	0%	0%	0%	0%	26%

Note: Tree GC and Shrub GC = trees and shrubs occurring in the groundcover level (less than 5' high)

Table 1. Absolute cover (%) of upper canopy, mid canopy, herbaceous (i.e., understory) cover, and species richness (raw # species) by transect. I = introduced, N = native, P = perennial, B = biennial, A = annual, F = forb, G-L = grass-lie (grasses, sedges, rushes), S = shrub, T = tree.

Absolute Cover by Site			Upper Canopy			Mid Canopy	Total Herbaceous		Herbaceous Groundcover by Life History										Tree GC		Shrub GC	
	Type	Total # Spp	salfra	popdel	popacu		Intr.	Native	IPG	IAG	IPF	IBF	IAF	NPF	NBF	NAF	NAG	NPG-L	IT	NT	IS	NS
AVERAGE:	Crack	27.50	78.3%	2.3%	0.0%	10.7%	19.2%	3.9%	15.0%	0.0%	3.1%	0.9%	0.2%	0.3%	0.0%	0.3%	0.0%	3.2%	0.5%	0.0%	0.0%	3.0%
AVERAGE:	Reference	23.88	0.0%	35.1%	10.9%	11.5%	19.7%	4.4%	16.9%	0.0%	2.3%	0.3%	0.2%	0.3%	0.0%	0.1%	0.0%	4.0%	0.0%	0.1%	0.0%	10.6%
STDEV:	Crack	7.61	0.07	0.05	0.00	0.11	0.15	0.03	0.13	0.00	0.03	0.02	0.00	0.01	0.00	0.01	0.00	0.02	0.01	0.00	0.00	0.03
STDEV:	Reference	9.55	0.00	0.18	0.14	0.15	0.10	0.05	0.09	0.00	0.02	0.00	0.01	0.01	0.00	0.00	0.00	0.05	0.00	0.00	0.00	0.11

Table 2. Average absolute cover and standard deviation, by site type (crack willow or reference).

Relative Cover by Transect				Upper Canopy			Total Herbaceous		Herbaceous Groundcover by Life History										Tree GC		Shrub GC	
Reach Type	Site	Transect	Total # Spp	salfra	popdel	popacu	Intr.	Native	IPG	IAG	IPF	IBF	IAF	NPF	NBF	NAF	NAG	NPG-L	IT	NT	IS	NS
crack	Peck	T-1	26	100%	0%	0%	92%	8%	82.0%	0.0%	10%	0%	0%	3%	0%	0%	0%	5%	100%	0%	0%	100%
crack	Peck	T-2	24	97%	3%	0%	82%	18%	67.3%	0.0%	14%	0%	0%	0%	0%	4%	0%	14%	97%	3%	0%	0%
crack	Peck	T-3	18	100%	0%	0%	77%	23%	46.1%	0.0%	23%	0%	8%	0%	0%	0%	0%	23%	100%	0%	0%	100%
crack	Peck	T-4	29	100%	0%	0%	94%	6%	46.9%	0.0%	24%	24%	0%	0%	0%	0%	0%	6%	100%	0%	0%	100%
reference	Alex-Daw	T-5	20	0%	100%	0%	86%	14%	72.3%	0.0%	7%	0%	7%	0%	0%	0%	0%	14%	0%	100%	0%	100%
reference	Alex-Daw	T-6	18	0%	100%	0%	100%	0%	90.7%	0.0%	0%	9%	0%	0%	0%	0%	0%	0%	0%	100%	0%	100%
reference	Alex-Daw	T-7	17	0%	100%	0%	33%	67%	20.8%	0.0%	13%	0%	0%	0%	0%	4%	0%	62%	0%	100%	0%	0%
reference	Alex-Daw	T-8	9	0%	100%	0%	63%	38%	56.3%	0.0%	6%	0%	0%	0%	0%	0%	0%	38%	0%	100%	0%	0%
crack	Jorgensen	T-9	41	86%	14%	0%	54%	46%	45.7%	0.0%	0%	8%	0%	8%	0%	0%	0%	38%	86%	14%	0%	100%
crack	Jorgensen	T-10	27	100%	0%	0%	86%	14%	84.5%	0.0%	0%	0%	1%	0%	0%	0%	0%	14%	100%	0%	0%	100%
reference	CoalCreek	T-11	39	0%	35%	65%	87%	13%	82.2%	0.0%	4%	0%	0%	0%	0%	0%	0%	13%	0%	100%	0%	100%
reference	CoalCreek	T-12	28	0%	80%	20%	92%	8%	86.4%	0.0%	3%	3%	0%	0%	0%	0%	0%	8%	0%	100%	0%	100%
reference	CoalCreek	T-13	30	0%	30%	70%	97%	3%	77.3%	0.0%	19%	0%	0%	0%	0%	0%	0%	3%	0%	100%	0%	100%
reference	CoalCreek	T-14	30	0%	48%	52%	90%	10%	71.3%	0.0%	19%	0%	0%	10%	0%	0%	0%	0%	0%	100%	0%	100%

Note: Tree GC and Shrub GC = trees and shrubs occurring in the groundcover level (less than 5' high)

Table 3. Relative cover by transect. I = introduced, N = native, P = perennial, B = biennial, A = annual, F = forb, G-L = grass-lie (grasses, sedges, rushes), S = shrub, T = tree.

Relative Cover by Site

			Upper Canopy			Total Herbaceous		Herbaceous Groundcover by Life History										Tree GC		Shrub GC	
		Total # Spp	salfra	popdel	popacu	Intr.	Native	IPG	IAG	IPF	IBF	IAF	NPF	NBF	NAF	NAG	NPG-L	IT	NT	IS	NS
AVERAGE:	Crack	27.50	97.2%	2.8%	0.0%	80.7%	19.3%	62%	0%	12%	5%	1%	2%	0%	1%	0%	17%	97%	3%	0%	83%
AVERAGE:	Reference	23.88	0.0%	74.2%	25.8%	81.0%	19.0%	70%	0%	9%	2%	1%	1%	0%	1%	0%	17%	0%	100%	0%	75%
STDEV:	Crack	7.61	0.06	0.06	0.00	0.15	0.15	0.18	0.00	0.10	0.10	0.03	0.03	0.00	0.02	0.00	0.12	0.06	0.06	0.00	0.41
STDEV:	Reference	9.55	0.00	0.31	0.31	0.22	0.22	0.22	0.00	0.07	0.03	0.02	0.03	0.00	0.01	0.00	0.22	0.00	0.00	0.00	0.46

Table 4. Average relative cover and standard deviation by treatment type.

Crack willow and cottonwood regeneration

Based on informal conversations with a variety of practitioners over the past decade, the principal investigator has concluded there are many weed management and other natural resource professionals who believe crack willow does not regenerate naturally, but is an artifact of historical plantings. Further, many weed management specialists are not aware of how to properly identify crack willow, or they are not aware of its existence. Like many willow species, however, individuals of *Salix* fragilis are highly adapted to flooding and burial, their stems producing abundant adventitious and dormant later buds, capable of producing functional roots and leaf shoots when buried along stream corridors.

During the SSA and Vegetation surveys, observers documented the occurrence of crack willow (**Image 2**) and cottonwood saplings/seedlings via photographs and presence/absence data. Additionally, the principal investigator has observed numerous reaches on the Big Thompson River, Little Thompson River, Poudre River, and other Font Range streams where crack willow is growing from cuttings following the 2013 flood. These results are corroborated in at least one paper by Budde et. al. (2011), who documented high rates of asexual reproduction of *Salix fragilis* in Argentina.

Image 2. Crack Willow Regeneration Photos (<u>upper left</u> = re-sprout from fallen branch, Peck; <u>lower left</u> = re-sprout from fallen branch, Jorgensen; <u>upper right</u> = re-sprout from branch, Peck; <u>lower right</u> = apparent re-sprout from seed, Jorgensen)

No cottonwood seedlings, saplings, or young adults were observed in the understory of the crack willow survey reaches. However, a moderate density (i.e., greater than 10 individuals per study reach) were of crack willow saplings were observed in each crack willow study site. While most of these re-sprouts were the result of asexual reproduction, there were two samples removed from Peck that appeared to be actual seedlings.

A high density (i.e., over 50 individuals per study reach) of cottonwood seedlings and saplings were observed in the Alexander-Dawson reference site during the sampling period. A low density (i.e., less than 10 individuals) of young adult cottonwoods were observed at the Coal Creek reference site. The absence of cottonwood seedlings at Coal Creek may be the result of increased overstory shading of this site, as cottonwood seedlings require high sun and high ground disturbance conditions, under the correct soil moisture regimes, to successfully establish from seed.

Raptor and Heron Nesting Preferences

The data in **Table 5** is a summary of 78 nesting sites for 7 raptor species, and a single recording of a Great blue heron rookery provided by the City of Longmont. Of the seven raptor species reported, 94% of the nesting occurrences occurred in the native *Populus deltoides* (plains cottonwood). 100% of bald eagle nests occurred in *P. deltoides*, while at least 94% of nesting for Great-horned owls and Red-tailed hawks occurred in *P. deltoides*. The one species with an equal preference for native and non-native trees was Cooper's hawk, which occurred in one *P deltoides* and one *Fraxinus pennsylvanica* (non-native to Boulder County). However, with just 2 total nesting records in the City of Longmont data set, additional sampling is recommended to draw robust conclusions about this species. Of all raptor nesting sites, just one record (Great-horned owl) was from a crack willow tree.

	Basic Statistics (all species)						# of occurrances by substrate (raw data)						
Key and species	**# total nests**	**% of nests in *P. deltoides***	**% of nests in non-native**	**% of nests on platform**	**% of nests on cliff**	**% of nests on Pole**	**Artificial Platform**	**Powerline Pole**	**Cliff**	***Populus Deltoides***	***Salix Fragilis***	***Ulmus Pumila***	***Fraxinus pensylvanica***
OSP = Osprey	7	0%	0%	86%	0%	14%	6	1					
GHO = Great-horned owl	16	94%	6%	0%	0%	0%				15	1		
RTH = Red-tailed hawk	41	98%	2%	0%	0%	0%				40		1	
BE = Bald eagle	5	100%	0%	0%	0%	0%				5			
BRNO = Barn owl	4	0%	0%	0%	100%	0%			4				
SWH = Swainson's hawk	3	67%	33%	0%	0%	0%				2		1	
CH = Cooper's hawk	2	50%	50%	0%	0%	0%				1			1
GBH = Great blue heron	1	100%	0%	0%	0%	0%				1			

Table 5. Raptor and Heron Nesting Preferences, City of Longmont data.

Stream Stability Assessment

Table 6 provides a summary of the streambank stability assessment (SSA) data for all sites. For each transect and site, the reference sites have a higher composite bank erosion hazard score, as compared to the crack willow sites. The higher scores were in part a result primarily of a high density of surficial crack willow roots, which in effect armor the banks. These areas of very high surficial roots also exhibited a low cover of herbaceous vegetation (**Image 3**). The dense surficial roots occurred primarily between the toe of the bank and the ordinary high water mark elevation, the zone of a streambank which undergoes some of the most significant erosion on an annual basis. With such armoring, it is possible to expect an increased risk of streambed incision (i.e., downcutting), thus disconnecting the overbank zone from annual floodwaters. Refer to the cross-section data for additional regarding evidence of incision in the reference and crack willow sites. The crack willow sites also exhibited higher overbank cover, lower active bank erosion, a more stable bank composition, and lower vegetation cover on banks, as compared to the reference sites.

			REACH ID: Peck		REACH ID: Alex-Daws		REACH ID: Jorgen		REACH ID: CoalCr	
Bank Stability										
Weights			*Percent of Length*		*Percent of Length*		*Percent of Length*		*Percent of Length*	
1	**Bank Composition**	**subweight**	**Left Bank**	**Right Bank**	**Left Bank**	**Right Bank**	**Left Bank**	**Right Bank**	**Left Bank**	**Right Bank**
	Cohesive (Silt/Clay)	4	2	2					30	30
	Sand	5	5	5	98	85	30	40	30	30
	Gravel/Cobble	2				10	40	20	25	25
	Dense or large roots/ECB	3	93	93			5	10	5	10
	Boulder/Bedrock	1			2	5	25	20	10	5
			3.1	3.1	4.9	4.5	2.7	2.9	3.5	3.6
3	**Bank Angle - Degrees**									
	Mild - 0-30	1	30	30	80	20	20	10		
	Moderate - 30-60	2	65	60	10	30	80	80	75	72
	Steep - 60-90	3	5	9	10	20		10	25	28
	Overhang - > 90	4		1		30				
			1.8	1.8	1.3	2.6	1.8	2.0	2.3	2.3
2	**Bank Cover**									
	Ground (soil + rock + litter)	5	10	8	38	60	55	40	75	75
	Dense or large roots/ECB	3	50	40	2	5	25	30	5	5
	Herbaceous	3	40	35	60	35	20	30	20	20
	Shrubs/Trees (seedlings)	4	0	0	1	1	1	1	0	0
	Shrubs/Trees (< 5 ft tall)	3	7	6	1	4	1	1	2	2
	Shrubs/Tres (5-15 ft tall)	2	5	7	2	2	1	2	23	23
	Shrubs/Trees (> 15 ft tall)	1	52	53	1	5	50	40	55	50
			2.5	2.3	3.7	4.0	3.1	3.0	3.1	3.2
		Total Cover:	164	149	105	112	153	144	180	175
4	**Overbank Cover**									
	Ground (soil + rock + litter)	5	49	64	79	80	93	86	48	56
	Dense or large roots/ECB	3								
	Herbaceous	3	43	33	20	19	7	13	26	30
	Shrubs/Trees (seedlings)	4	1	1	1	1				
	Shrubs/Trees (< 5 ft tall)	3	7	2				1	26	14
	Shrubs/Trees (5-15 ft tall)	2	19	7		2		14	22	25
	Trees/Shrubs (> 15 ft tall)	1	76	78	56	45	92	85	18	24
			2.2	2.4	2.9	3.2	2.5	2.5	3.1	3.1
		Total Cover:	195	185	156	147	192	199	140	149
2	**Active Bank Erosion**									
	Low: 0 - 25%	1	100	100	100	70	100	100	80	80
	Moderate: 25 - 50%	3								
	High: 50 - 75%	5								
	Severe: 75 - 100%	7				30			20	20
			1	1	1	2.8	1	1	2.2	2.2
Composite Bank Erosion Hazard Score:			29%	29%	35%	45%	31%	32%	39%	39%

Table 6. Summary data for Stream Stability Assessment. A higher score indicates an increased risk of bank erosion.

Image 3. High Cover of Surficial Crack Willow Roots (<u>upper left</u> = ditch on Jorgensen, roots reaching over 30 ft from source tree; <u>lower left</u> = woody and fibrous roots, Jorgensen; <u>upper right</u> = toe and inner berm hardened by roots, Jorgensen; <u>lower right</u> = 1’ high mass of fibrous roots, Jorgensen)

Width : Depth Ratios

The bankfull width is a measure of how wide the stream is when it is carrying the channel-forming flows. These are the flows that occur on a regular (annual or semiannual) basis and maintain the channel shape. Bankfull width is a function of flood frequency, sediment regime, and the bed and bank materials of the channel (Rosgen, 1996). Changes in any of these factors may result in a change in width, which in turn changes the hydraulics of the channel and may lead directly to vertical channel adjustments (aggradation or degradation).

Cross-section data was used to generate width:depth rations, which are one form of understanding the streams ability to carry sediment, and possible evidence of incision or aggradation zones within a river system. Width:depth rations are presented in **Table 7**. The highest bankfull width occurred at Alexander-Dawson, and may be a result of this being a high deposition zone. The lowest width:depth ratio occurred at Coal Creek reference site. Both the Peck and Jorgensen sites had similar width:depth ratios. Complete survey data is available as a separate excel spreadsheet.

Site	Type	OHWM W:D	TOB W:D
Coal Creek	Reference	8.4	6.0
Alexander-Dawson	Reference	23.6	21.6
Peck	Crack willow	12.0	10.9
Jorgensen	Crack willow	10.1	8.6

Table 7. Average Width to Depth Ratios by Stream Type and Transect

Management Implications

Vegetation

Due to the high degree of historical disturbance to riparian systems in the study area, the lack of an acceptable reference site was a significant confounding variable for this project. The timing of the survey (one survey period in late summer) resulted in the observers not recording many of the early spring flowers that may be on each site but not persistent in late summer. Further, the lack of the number of crack willow and reference sites available for the study, and the small spatial extent of the study sites, resulted in fewer sample transects in each sample site than originally anticipated. As a result, we provide the following summary with the caveat that reference sites were not in a high state of functioning, and the data is not statistically robust:

1) Crack willow sites have a lower percent cover and diversity of understory shrubs than the reference sites. The native shrub cover that did exist for the crack willow sites was largely influenced by a single transect on the Peck property, in which there was a large stand of chokecherry. Alternatively, the Coal Creek reference site had a great diversity and cover of native shrubs in all four transects. The influence of shade on understory shrub recruitment varies by the species, and additional research is needed before drawing significant conclusions.
2) Absolute crack willow upper canopy cover is much higher than the cottonwood upper canopy cover of the reference sites. Increased aerial cover reduces light penetration to the ground, which, when combined with lower scour potential on bank and overbank areas in crack willow sites, may have impacts to recruitment of native shrubs.
3) Crack willow is regenerating asexually throughout Boulder and Larimer county. While the data in this study shows clear evidence of crack willow regeneration in two streams in Boulder County, the

principal investigator and others have documented asexual reproduction of crack willow in St. Vrain Creek, the Cache la Poudre River, the Big Thompson River, and many other CO Front Range streams.

Bank Erosion and Geomorphology

The results of the SSA show that the crack willow dominated reaches exhibit higher bank stability, to the extent of being armored. When such armoring occurs on streams, one result can be stream incision and reduced connectivity to the floodplain. However, this hypothesis was not supported by the simple analysis of width:depth ratios provided in this study. Possible reasons for the lack of clarity as to the influence of crack willow and reference site vegetation on width:depth ratios include: a) lack of an adequate number of research sites, 2) all streams are in a period of recovery following the 2013 flood, and as such indicators of bank-full width are poor and/or the bankfull width is still undergoing post-flood adjustment, and c) all study reaches are heavily altered by upstream diversions. Additional geomorphic analysis is required, and possible hydraulic modelling, to shed more light on the influence of bank armoring (by crack willow roots) on of stream incision. Additional analyses might include incision ratios, entrenchment ratios, and other analyses which would require more detailed surveying.

Raptor Nests and Great Blue Heron Rookeries

Bald eagles and Great blue herons are among Boulder's most iconic images of healthy riparian areas, wetlands, and lakes. Given the data provided by this study, it is apparent Bald eagles and Great blue herons are obligate nesters in plains cottonwood. Further, the vast majority of other raptors surveyed have a very high preference for the native plains cottonwood, as compared to crack willow or other non-native trees. While additional avifauna studies may reveal other species may be impacted by the invasive crack willow, the impact of crack willow on our top bird predators, as shown in this study, provides some insight into the potential broader impacts of crack willow on wildlife and food webs dependent upon healthy riparian corridors.

Restoration

A common concern among birding organizations, informal birding groups, and wildlife biologists, is the immediate impact that removing non-native trees can have on birds. Some bird species do use crack willow, Russian olive, tamarisk, and other non-native riparian trees and shrubs, at least during foraging, predator evasion, and other daily activities. In the case of crack willow, while the full impacts of this species on native bird communities is not known, the impact on one of our most important guilds (avian predators) is evident from this study.

In reality, land management agencies are not faced with a simple option to remove or not remove crack willow or other non-native trees and shrubs from our riparian areas. Rather, a phased approach to "remove and replace" invasive trees, whereby crack willows are removed in a systematic fashion (i.e., thinning in a phased approach), and replaced with native functional equivalents, can have several positive impacts, and provide opportunities to restore our riparian zones:

1) Increase light gaps and access to groundwater for cottonwood pole plantings and natural establishment of cottonwoods;
2) Increase light gaps and access to soil moisture for native shrub establishment;
3) Increase light gaps and ground disturbance that can be combined with herbaceous seeding of desired native grasses and forbs.

A phased approach to crack willow removal would not only allow for increased diversity and cover of desirable native shrubs and trees, but it would reduce the aesthetic impacts that can result from large scale removal of crack willow. A phased approach would also minimize possible adverse affects associated with clearing and grubbing, such as soil surface erosion and secondary weed invasion. Alternatives to the classic cut-stump method of treatment, such as hack-and-squirt, whereby the entire cambium and phloem are not interrupted, may be highly effective while reducing the incidence of re-sprouting. Treated trees can also be left as snags where appropriate, further reducing treatment costs and enhancing habitat for cavity nesting wildlife.

Boulder County POS is widely respected for their progressive management of natural resources amidst a community of nature enthusiasts, recreationists, and conservationists. It is our hope that this study provides some evidence that will help guide future management actions necessary to improve one of Colorado's most important wildlife habitats, our riparian areas.

APPENDIX A - LITERATURE CITED

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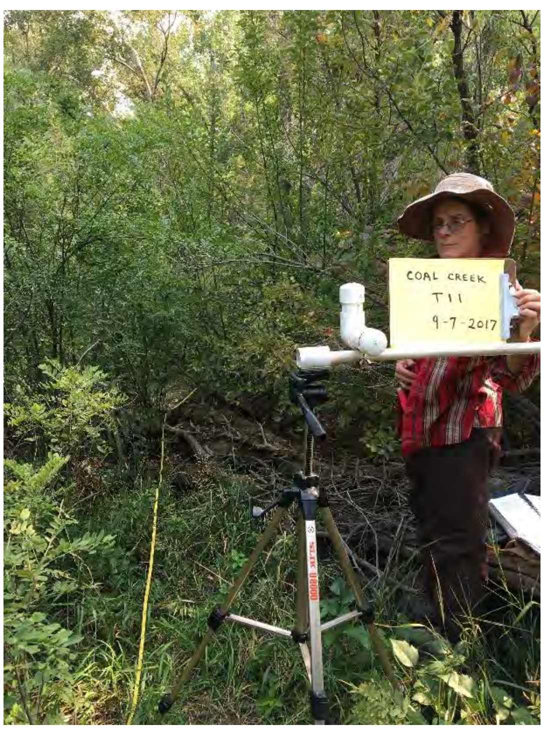
Appendix B – Vegetation Transect Photos

Note: a few transect photos are missing from this report. However, with the combination of overview photos and an abundant number of cross-section photos, we feel confident the reader will be provided with a solid understanding of the vegetation conditions where transects were recorded.

Coal Creek

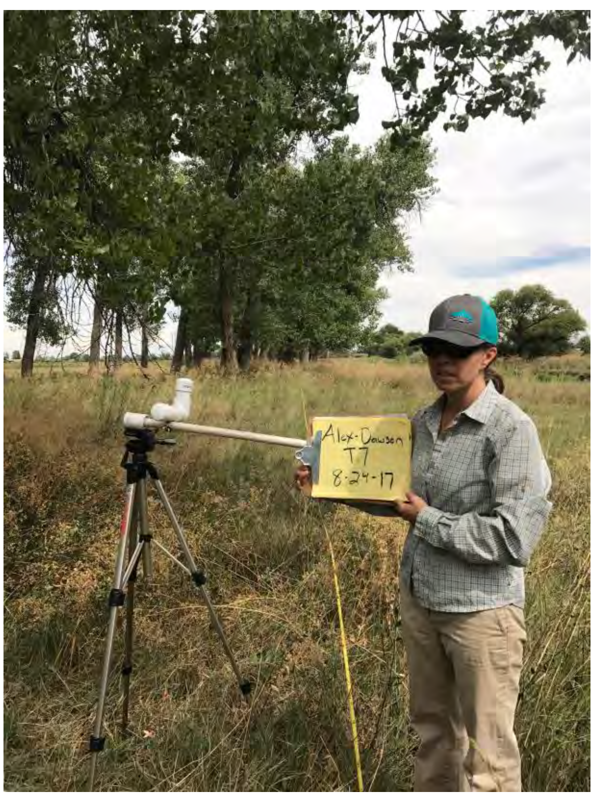
Overview of transect locations. Two transects on river left and two transects on river right.



Coal Creek Overview photo

Alexander-Dawson (Boulder Creek)

Overview of transect locations. Two transects on river right and two transects on river left.



Peck (Lefthand Creek)

Overview of transect locations at Peck property, T1, T2, and T3.


PECK
T1


Peck
T1
8-23-17

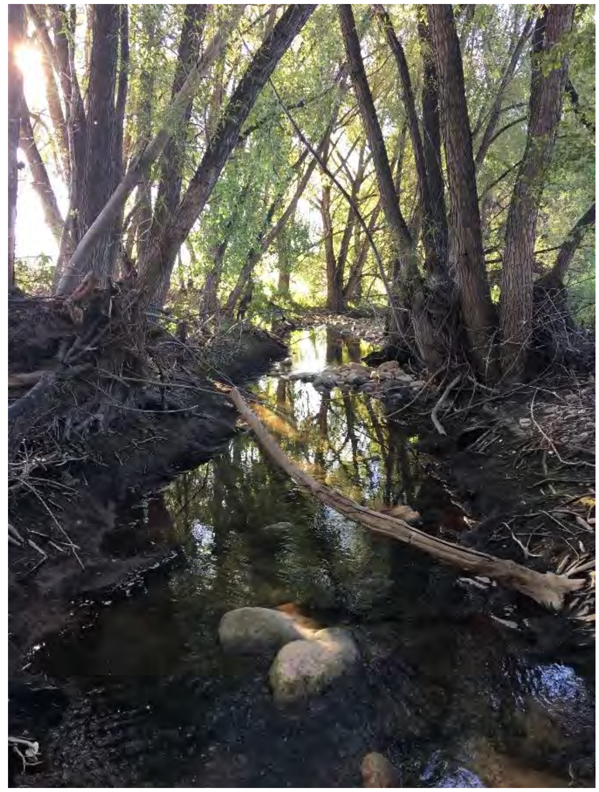

Peck
T3

Jorgensen (Lefthand Creek)

Overview of transect locations, and T10 and T9

APPENDIX C – STREAMBANK STABILITY ASSESSMENT AND X-S PHOTOS

Peck Overview: Crack Willow Site



Jorgensen Overview: Crack Willow Site

Coal Creek Overview: Reference Site

Alexander-Dawson Overview: Reference Site

Alexander-Dawson Cross-section 1 (up, down, across)

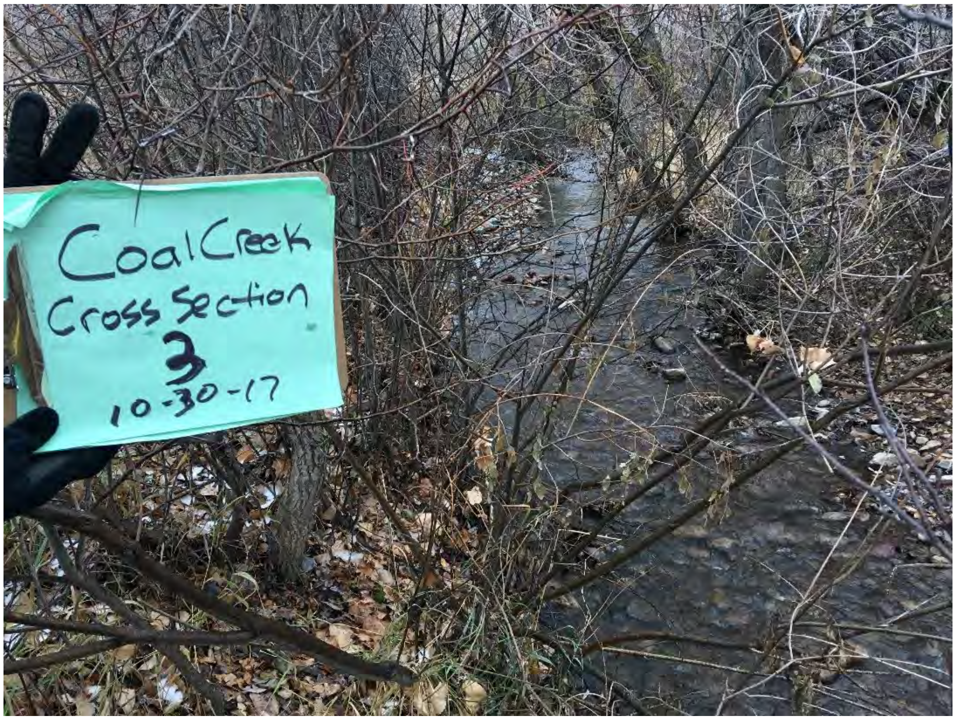
Alexander-Dawson Cross-section 2 (up, down, across)

Alexander-Dawson Cross-section 3 (up, down, across)

Coal Creek Cross-section 1 (up, down)

Coal Creek Cross-section 2 (up, down)

Coal Creek Cross-section 3 (up, down)



Peck Cross-section 1 (up, down, across)

Peck Cross-section 2 (up, down, across)

Peck Cross-section 3 (up, down, across)

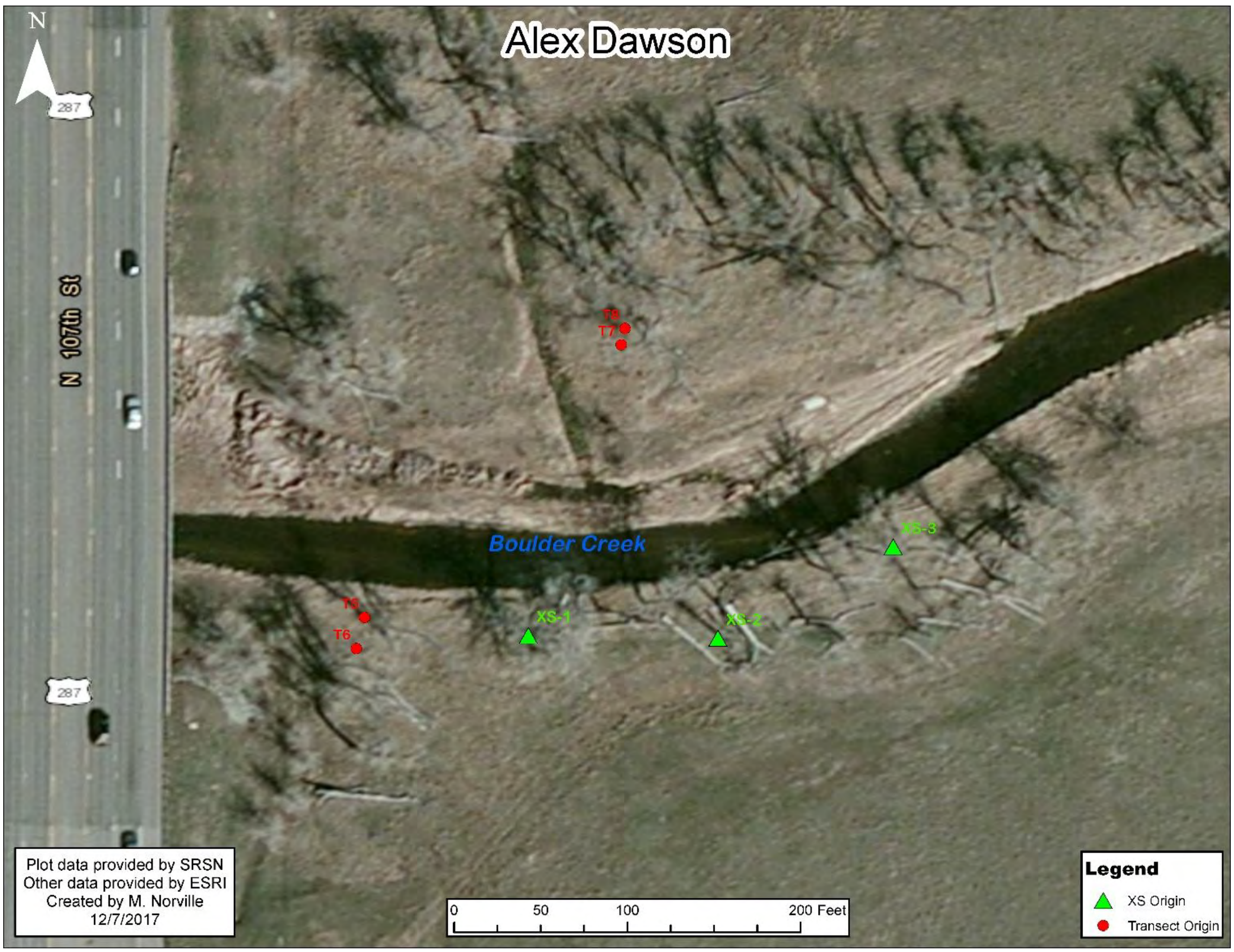
Jorgensen Cross-section 1 (up, down, across)

<u>**Jorgensen Cross-section 2 (up, down, across)**</u>

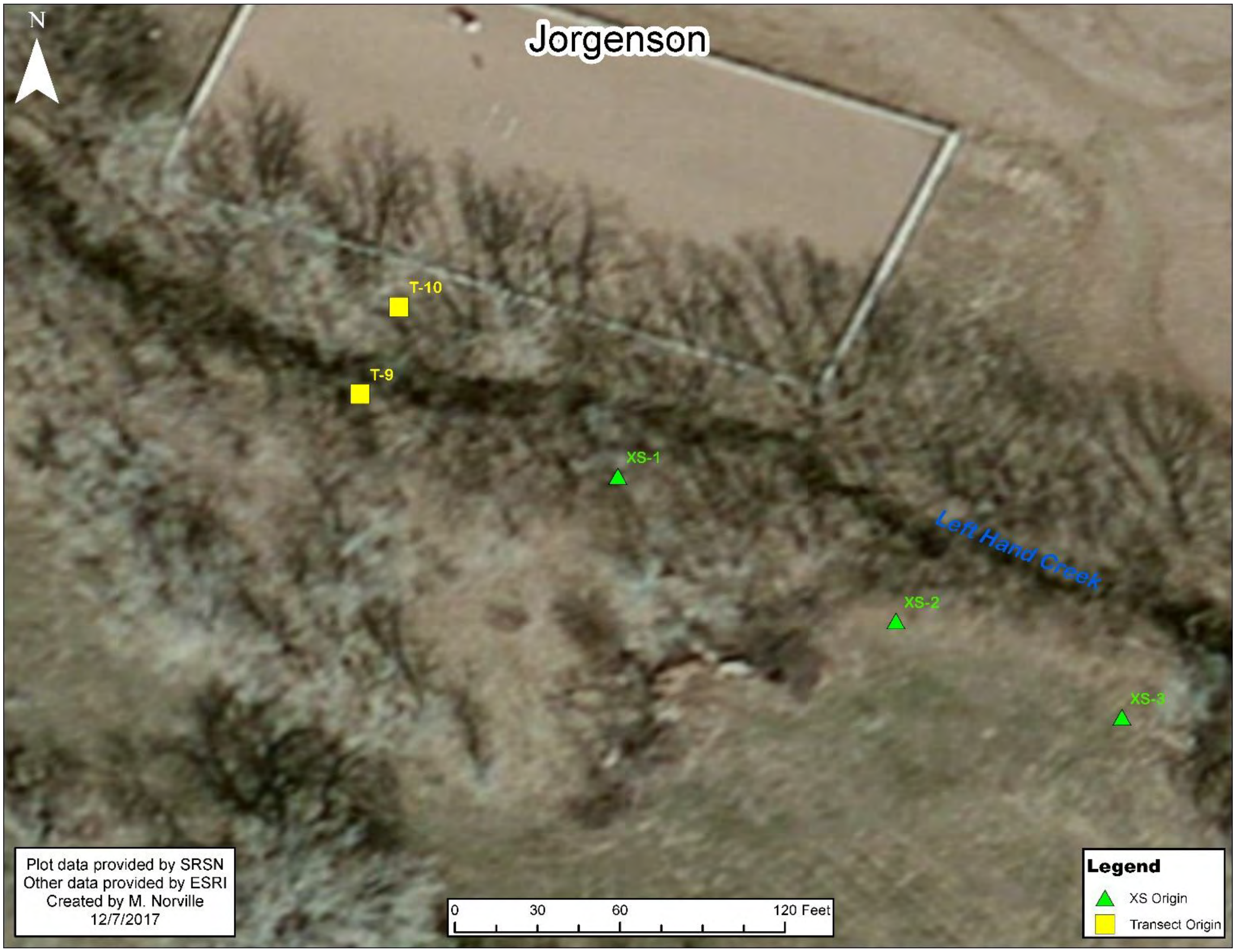
Jorgensen Cross-section 3 (up, down, across)

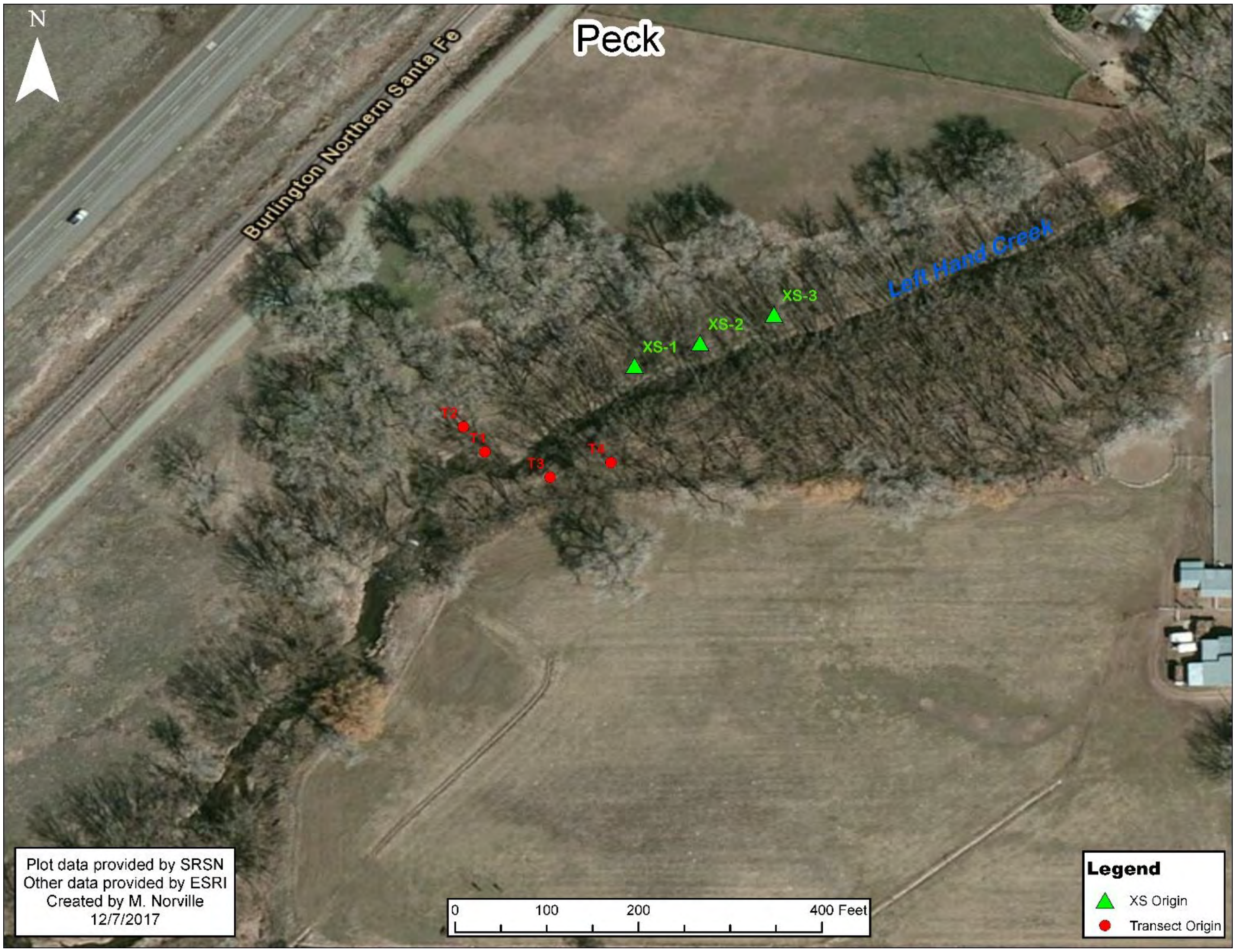
APPENDIX D – MONITORING MAPS

<u>Map Note:</u> Accuracy of GPS points are between 1 and 30 feet. In the case of the Coal Creek Map, Transect Origins were off enough that the points were moved manually to reflect a more accurate location in the field. Transect origins are all upstream, with a 100 meter transect running downstream of each point, parallel to the streambank. Cross section transects all ran perpendicular to the bank beginning at the origin of each cross section origin.




Coal Creek
N
Coal Creek
XS-3
XS-2
XS-1
CC-14
CC 13
CC 11
CC 12
Plot data provided by SRSN
Other data provided by ESRI
Created by M. Norville
12/7/2017
0
50
100
200 Feet
Legend
XS Origin
CC Origin


N
Jorgenson
T-10
T-9
XS-1
Left Hand Creek
XS-2
XS-3
Plot data provided by SRSN
Other data provided by ESRI
Created by M. Norville
12/7/2017
0
30
60
120 Feet
Legend
XS Origin
Transect Origin



N
Peck
Burlington Northern Santa Fe
Left Hand Creek
XS-3
XS-2
XS-1
T2
T1
T3
T4
Plot data provided by SRSN
Other data provided by ESRI
Created by M. Norville
12/7/2017
0
100
200
400 Feet
Legend
XS Origin
Transect Origin