PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

Remote Monitoring of Channel Geomorphology and In-Channel Vegetation of the Central Platte River

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I. INTRODUCTION

This Geomorphology and Vegetation Remote Monitoring Protocol supersedes the previous field-based monitoring protocol [Platte River Recovery Implementation Program (Program), 2010]. Initial data to help develop this updated protocol were collected in 2017, and the protocol will be implemented in 2018 to assess the revised methodology. The previous protocol focused on ground measurements of a wide range of geomorphic- and vegetation-related variables in the approximately 95-mile Associated Habitat Reach (AHR) that extends from Lexington to Chapman (**Figure 1**) over the 8-year period from 2009 through 2016. The variables included in the monitoring were hypothesized as important in meeting Program objectives to (1) improve survival of whooping cranes during migration, (2) improve least tern and piping plover production, and (3) avoid adverse impacts on pallid sturgeon in the Lower Platte River. This updated protocol is based on a thorough evaluation of the data and lessons-learned from the field-based protocol, current understanding of the habitat needs of the species and the Program's ability to influence the habitat, and recent advances in remote sensing technology. This updated protocol represents a streamlined approach that focuses on remote sensing, supplemented with a limited amount of field validation data.

The Program's decision to transition to a remote-sensing-based protocol stems from limitations and concerns associated with the field-based protocol and recent advances in remote-sensing technology that will facilitate more efficient measurement of a smaller set of key variables over a larger portion of the AHR than was previously feasible. Major factors in the decision included:

1. Spatial Coverage – The pure panel anchor points (APs)[1] that were measured every year in the previous protocol were spaced at approximately 5-mile intervals along the AHR, and one rotating AP, measured only once every four years, was located between each of the pure panel APs. The total channel length occupied by the individual APs averaged about 1,000 feet; thus, the pure panel APs occupied only about 4 percent of the overall length of the AHR (Tetra Tech, 2017). The limited spatial coverage, coupled with high interannual variability at the individual APs, led to concerns that uncertainty in results from the AP-based monitoring were too large to identify reach and system-scale trends.
2. Anchor Point Access – The majority of the APs were located on private lands. Loss of access through time at some locations further limited the spatial and temporal coverage of the monitoring data.
3. Advances in Remote Sensing – Since 2009, it has become technically and financially feasible for the Program to collect bathymetric LiDAR data annually for the entire AHR. As a result, much, if not all, of the spatial coverage issue with the AP-based protocol will be eliminated because measurements will not be restricted to the APs.
4. Streamlined Monitoring Variables – An extensive suite of variables was measured during the field-based protocol. Detailed evaluation of the data and ongoing improvement in the Program's understanding of the needs of the target species indicate that, while potentially useful for assessing general river and vegetation processes, many of the variables could be eliminated from the monitoring without compromising the Program's ability to meet their objectives. This is particularly true for the vegetation data, where all vegetation down to the species level was documented under the previous protocol. Current understanding of the habitat needs of the target species indicates that the primary factor related to vegetation is unvegetated channel width, a variable that can be directly measured from the remote sensing data without detailed documentation of the individual species.
5. Cost and Uncertainties – Based on the more complete spatial coverage, the resulting lower uncertainty, and the lower cost, remote sensing will provide a more cost-effective means of obtaining the data necessary to meet Program objectives.

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[1] The individual study sites at which the detailed field data were collected for the PRRIP (2010) protocol were referred to as "anchor points".

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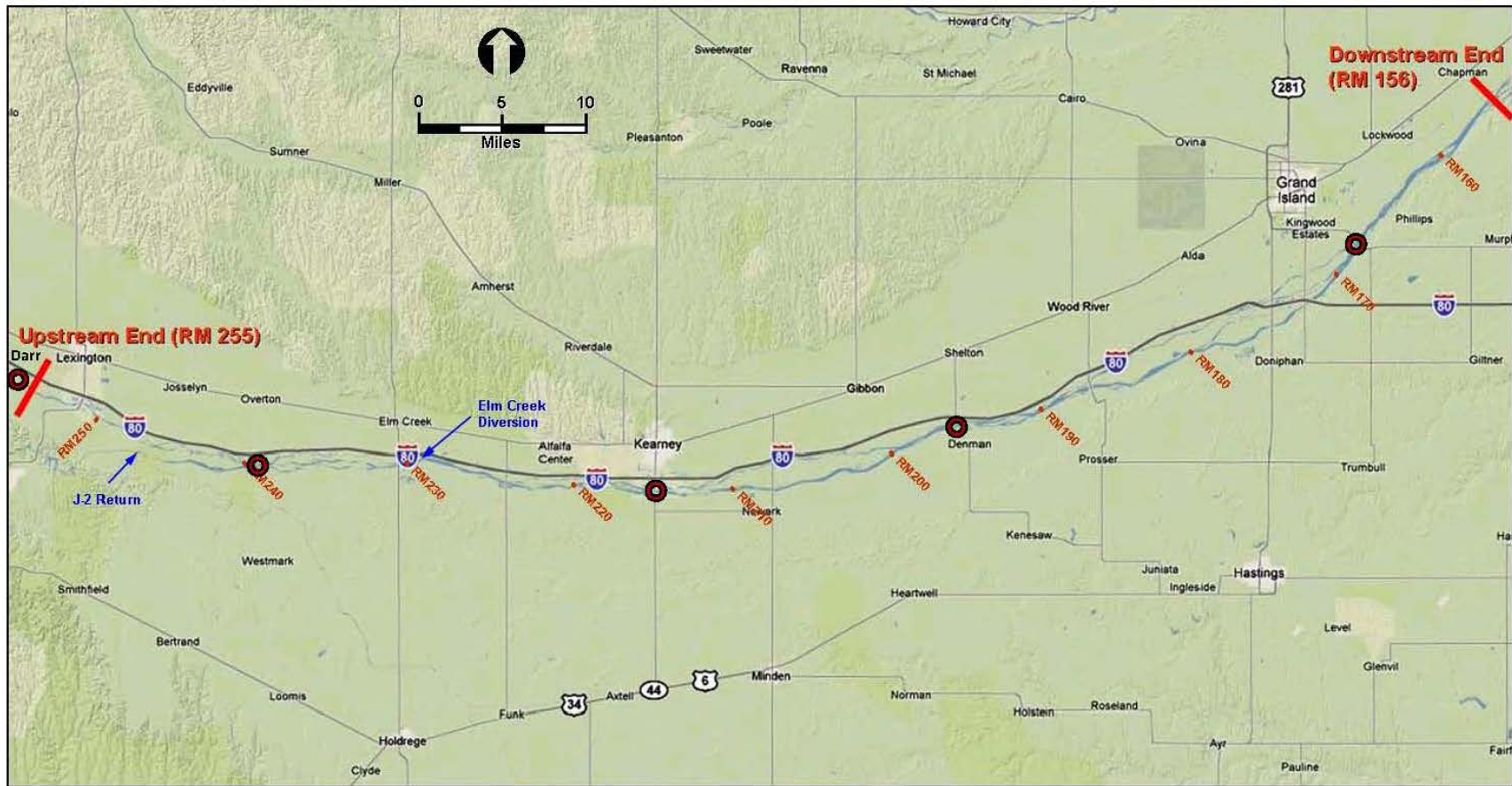
Figure 1. Location map of the associated habitat reach (AHR).

II. PURPOSE

The purposes of the geomorphology and in-channel vegetation monitoring under this protocol are to 1) document spatial and temporal trends in channel morphology and in-channel vegetation, 2) evaluate relationships between the documented changes and natural drivers (primarily hydrology) and management actions by the Program and other entities throughout the Associated Habitat Reach (AHR). Several priority hypotheses identified in the Program's Adaptive Management Plan (AMP) are directly linked to river morphology and are also influenced by in-channel vegetation. This protocol will serve as effectiveness monitoring for Program management actions implemented under the AMP, and it will also serve as a resource for evaluating existing and future Program hypotheses. Information gained from the monitoring will be summarized for inclusion in planning documents related to implementation of the AMP and the Environmental Account Annual Operating Plan (AOP).

III. BACKGROUND

In 2009, the Program developed and implemented a field-based interim draft geomorphology and vegetation monitoring protocol. The protocol was revised in 2010 based on lessons learned from the 2009 effort (Program, 2010), and the revised protocol was implemented for seven (7) more years from 2010 through 2016 (Tetra Tech, 2017). The geomorphology portion of the protocol was designed to document trends in channel geomorphology parameters, including channel width, planform, aggradation/degradation, bed material grain sizes, and sediment loads in the AHR during the 13-year first increment of the Program that was originally scheduled to conclude in 2019. Similarly, the in-channel vegetation monitoring provided system-wide status in areal coverage and elevation range of in-channel seedlings and invasive vegetation. This information was designed for use in the annual and long-term planning for implementation of the Program's Adaptive Management Plan (AMP) and use of water in the Environmental Account (EA) to evaluate the extent of existing native and non-native invasive species infestations, and to serve as a mechanism for identification of new invasive species populations before infestations become widespread.

The channel geomorphology and vegetation data collected under the field-based protocol occurred at a series of 40 sites [referred to as anchor points (APs)] spaced at approximately 5-mile intervals along the AHR (**Table 1**). Data were collected at 25 of the sites each year, with 20 of the sites (the "pure panel" APs) measured every year and the remaining 20 "rotating" APs measured once every four years. The individual APs consisted of 3 primary transects that spanned the channel between the high banks, spaced at approximately 500-foot intervals, along which detailed bed profiles were surveyed using survey-grade RTK GPS (**Figure 2**). Vegetation data were collected at a series of individual 1 m^2 quadrats spaced at 15 m intervals (in most years) along the primary transects and 2 or 4 additional transects approximately equally spaced between the primary transects[2]. All plant species within each quadrat frame and present at greater than trace densities (i.e., >~2% of the quadrat area) were identified, and their cover was documented using Daubenmire (1959) cover classes. The vegetation sampling included 3,000 to 5,700 individual quadrats each

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[2] During the first four years (2009-2012), vegetation data were collected at a total of 7 transects at each AP. Analysis of the data from this sampling indicated that two of the transects could be eliminated without sacrificing the sampling objectives while significantly improving the efficiency with which the sampling could be conducted. As a result, only 5 transects were sampled during the last 4 years (2013-2016).

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year, with 26 (2009) to nearly 180 (2013) individual species present at the sites. In addition to the geomorphic survey and vegetation data, up to 10 bed material samples and one composite bar material sample were collected at each AP during each of the annual data collection efforts.

The monitoring protocol also called for collection of up to six bed and suspended load transport measurements at pre-defined discharge ranges at the following five bridges in the AHR:

- Lexington (SH-L24A/Rd 755)

- Overton (SH-L24B/Rd 444)

- Kearney (SH-44/S. 2nd Ave.)

- Shelton (SH-L10D/Shelton Road)

- Near Grand Island (US-34/Schimmer Drive)

A total of 85 bed load and 92 suspended load samples were ultimately collected over the 8-year period.

The draft data analysis protocol (Program, 2012) called for evaluation of 38 individual metrics at a range of scales from individual transects to the nine geomorphic reaches identified in Fotherby (2008). The metrics fell into one of six general categories: Hydrologic, Hydraulic, Geomorphic, Vegetation, Sediment, and Whooping Crane. The initial attempt to evaluate the data for the 2012 annual report consisted of statistical comparisons of the 2009 through 2012 data sets to identify trends across a broad range of the geomorphic, vegetation and sediment variables at each of the identified scales (Tetra Tech, 2017). This resulted in a large number of analyses that are difficult to interpret in the context of Program priorities. Beginning with the 2013 annual report and culminating with the draft final data analysis report (Tetra Tech 2017), the Program directed that the trend analysis be restricted to the following priority hypotheses to provide a more focused analysis:

1. <u>Flow 1</u> –A detailed analysis of changes in bed sediment volume within the main channel was conducted for each of the eight (8) years of available data, and the results were evaluated to assess the sediment transport balance along the overall study reach. In presenting the analysis, the variability in sediment loads (and the resulting sediment balance) and the implications of this variability to conclusions about the aggradation/degradation status of each portion of the reach, including the magnitude of any identified sediment transport imbalance, were evaluated.

2. Flow 3 –The correlation between flow, green line elevation (GLE) and unvegetated width was evaluated. As specified in the Data Analysis Plan, the edges of unvegetated segments along each transect were identified by the GLE points. The total unvegetated width was then defined as the cumulative length of all unvegetated segments between GLE points within the main channel at each transect. To remove the effects of river slope in the correlations, the difference between the GLE and the local 1,200 cfs water surface was used rather than the actual elevation. The following specific correlations were evaluated using the metrics defined in this manner:

    a. GLE versus annual peak discharge (Q_p, Monitoring Plan Section 5.1.1), defined as the maximum mean daily discharge between January 1 and the date of the survey in each year.

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b. GLE versus germination season discharge (Q_{Ger}, Monitoring Plan Section 5.1.2), defined as the representative mean daily discharge between June 1 and July 15 (the primary season for establishment of cottonwood seedlings). For this analysis, both the mean and median discharge during the period were evaluated to assess which one provides the best correlation.

c. Total unvegetated width (W_{unveg}) versus annual peak discharge (Q_p).

d. Total unvegetated width (W_{unveg}) versus germination season discharge (Q_{Ger}).

e. GLE versus total unvegetated width (W_{unveg}).

3. <u>Flow 5</u> –The influence of spraying versus peak flows on phragmites distribution and frequency were evaluated using vegetation plot data in conjunction with Geodata Interoperability Specification (GIS)-formatted records of annual spraying.

4. <u>Mechanical 2</u> –The correlation between total unvegetated width (W_{unveg}), braiding index (BI) and percent consolidation at bankfull discharge was evaluated.

The field-based protocol resulted in extensive sets of both geomorphic and vegetation data that provide valuable information to the Program related to the above priority hypotheses (documented in Tetra Tech 2017). Despite the extensive data sets, several issues were identified with the field-based approach that led to the development of this remote sensing-based protocol:

1. Uncertainty in the key data related to a combination of the representativeness of the individual transects and APs to the remainder of the AHR and scatter in the measured data (particularly sediment loads) resulted in substantial uncertainty in the Program's ability to draw firm conclusions about the effects of natural and manmade drivers of change in the system, particularly on the sediment transport balance.

2. Collection and analysis of the extensive data sets required large annual expenditure.

3. A large portion of the data (particularly, species-level vegetation data) were determined to be of only limited value in helping the Program meet their objectives.

Table 1. Anchor point locations for Program (2010) field-based protocol

Anchor Point No.	River Miles and Channel Designation	Pure (P) or Rotating (R) Panel	Location
40	254.4	R1	Lexington
39	250.8	P	Lexington Bridge (Hwy 283)
38	249	R2	
37	246.5 N, S	P	J2 Return – Jeffreys Island
36	244.0 N, S	R3	
35	241.5 N, S	P	
34	239.1	R4	D/S Overton Bridge (Rd 444)
33	236.4	P	Cottonwood Ranch transects
32	234.1 M, N, S	R1	
31	231.5	P	U/S Elm Creek Bridge
30	228.6	R2	D/S Kearney Diversion
29	226.4	P	
28	224.3	R3	Odessa Rd. Bridge
27	221.9	P	
26	219	R4	
25	216.5	P	
24	214	R1	D/S Kearney Bridge (Hwy 44)
23	211.5 M, N1, N2	P	
22	208.4 M, N1	R2	U/S 32 Rd. Bridge (Hwy 10)
21	206.7 M, N1	P	
20	204.0 M, N1	R3	
19	201.1 M, N1	P	D/S Lowell Rd Bridge
18	199.5	R4	
17	196.4	P	U/S Shelton Rd. Bridge
16	193.8	R1	
15	190.7	P	
14	189.3	R2	
13	186.7 M, N1	P	D/S Hwy 11 Bridge
12	184.0 M, N1	R3	
11	181.8 M, N1	P	D/S S Alda Rd. Bridge
10	179.0 M, N1, N2, N3	R4	
9	176.5 M, N1, N2, N3	P	U/S SR 34/281 Bridge
8	174 M, N1, N2, N3	R1	Grand Island
7	171.5 M, N1, N2, N3	P	D/S I-80 Bridge
6	169.1 M, N1	R2	
5	166.9	P	D/S SR 34/Hwy 2 Bridge
4	164	R3	
3	161.8	P	Phillips
2	158.7	R4	
1	156.6	P	D/S Bader Park Rd. Bridge

Table 2. Summary of Vegetation Survey Sites (2009-2016)

Year	Anchor Points	Sites	No. of Transects		No. of Quadrats		No. of Individual Species
			Pure Panel	Total	Pure Panel	Total	
2009[†]	27	41	154	308	2,817	4,285	26
2010	26	29	154	210	3,936	5,224	125
2011	27	29	147	189	4,310	5,694	102
2012	25	27	140	189	3,085	4,134	125
2013[†‡]	25	41	105	220	2,189	3,304	179
2014[‡]	24	28	120	140	2,259	2,973	149
2015[‡]	25	29	105	125	2,366	2,984	135
2016[‡]	25	29	105	145	2,341	3,099	147

[†] Includes Secondary channels surveyed once every four years
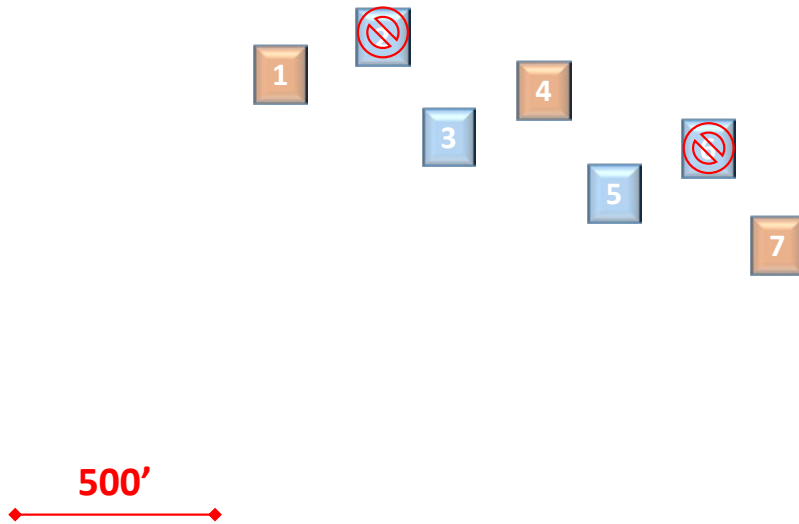[‡] Only 5 transects sampled at each AP

Figure 2. Anchor Point 29 (RM 226.5) showing the typical layout of the geomorphology and vegetation monitoring transects. Detailed geomorphology data are collected and analyzed at Transects 1, 4 and 7. Prior to 2013, vegetation monitoring was conducted.

IV. DESIGN CONSIDERATIONS

A.   Area of Interest

The area of interest for the geomorphology and vegetation monitoring consists of Platte River channels within the AHR that extends from Lexington, NE (U.S. Highway 283) (RM 239.5) downstream to Chapman, NE (RM 156.5) (Figure 1). The analysis area will be confined to active main, side channels and approximately 50 feet to 100 feet from the top of the channel bank into the overbank on each side of the channel. Analysis area shapefiles (subsequently referred to as the *analysis hull*) will be developed for all active channels based on channel conditions at inception of this monitoring protocol. To ensure spatial consistency in the comparative analyses, the shapefiles will be altered only to the extent necessary to account for migration of active channels beyond the analysis hull polygon boundary.

B.   Habitat Metrics for Target Species

The Program has identified the following as key metrics for evaluating changes in habitat quality for the target species:

1.   Whooping Cranes

Based on a synthesis of data collected in the AHR between 2001 and 2013 (Program, 2017), the Program has determined that habitat selection for whooping cranes is maximized at unvegetated channel widths of 650 feet and unforested widths of 1,100 feet. The Program has informally accepted maximum unobstructed channel widths of at least 650 feet and unforested corridor widths of at least 1,100 feet as highly favorable whooping crane riverine roosting habitat and as management objectives for whooping cranes. The Biological Opinion for the PRRIP (BiOp) (USFWS, 2006) also indicated that whooping cranes require a suitable amount of shallow water, with relatively stable depth in the range of 0.7 feet, for roosting habitat.

Based on these findings, the monitoring will include systematic measurements of maximum unvegetated channel width and unforested channel width throughout the AHR based on remotely-sensed vegetation heights and characteristics. The amount of shallow water habitat (defined for purposes of this protocol as depths less than 0.7 foot) will be quantified using results from two-dimensional hydraulic models developed using the bathymetric LiDAR data (see Section VI.B.).

2.   Least Terns and Piping Plovers

Synthesis of the data collected in the AHR under the previous protocol indicates that implementation of the Program's Flow-Sediment-Mechanical (FSM) management strategy may not achieve the stated management objective for least terns and piping plovers (Program, 2015).

As a result, monitoring targeted at least tern and plover habitat is not explicitly included in the protocol.

C.   Channel Geomorphology and Vegetation Monitoring

The geomorphology and vegetation monitoring program is designed to meet the following specific objectives to document spatial and temporal trends in channel morphology, in-channel vegetation and key habitat metrics for the target species within the AHR:

- Identify spatial and temporal changes/trends in channel morphology across a range of discharges, including (1) aggradation and degradation, (2) channel width, and (3) channel depth.
- Identify spatial and temporal changes in the occurrence and distribution of in-channel vegetation height classes with heavy focus on vegetation-related channel width metrics that are important predictors of whooping crane roosting habitat.
- Evaluate relationships between geomorphic drivers such as hydrology and changes in channel morphology and in-channel vegetation.
- Identify spatial and temporal availability and changes in whooping crane habitat metrics, specifically the proportion (or area) of channel suitably wide and shallow for whooping crane roosting.

D.   Reporting Scale

Monitoring results will be evaluated and reported by geomorphic reach on an annual basis, based on the nine (9) reaches identified in Fotherby (2008) (**Table 3**). A detailed description of the reporting requirements is presented in Section VII.

Table 3. Geomorphic Reaches within the AHR, as defined by Fotherby (2008)

Reach	Description	River Miles	Length (mi)
1	Lexington Bridge to Overton Bridge (including north channel of Jeffery Island)	254.5 - 239.5	15
2	South channel of Jeffery Island from J2 Return to Overton Bridge	247 - 239.5	7.5
3	Overton Bridge to Elm Creek Bridge	239.5 - 231	8.5
4	Elm Creek Bridge to Odessa Bridge	231 - 224	7
5	Odessa Bridge to Minden Bridge	224 - 208	16
6	Minden Bridge to Gibbon Bridge	208 - 202	6
7	Gibbon Bridge to Wood River Bridge	202 - 187.5	14.5
8	Wood River Bridge to Grand Island (Hwy 34)	187.5 - 173	14.5
9	Grand Island (Hwy 34) to Chapman Bridge	173 – 156.5	16.5

E. Definitions

1. Accretion Zone – area encompassed by existing former channels of the river.
2. Active Channel – portion of the channel where inundation and movement of bed sediment occurs sufficiently often to maintain the area devoid of permanent woody vegetation.
3. Associated Habitat Reach (AHR) – Active channels of the 95-mile reach of the central Platte River between Lexington, NE (U.S. Highway 283) (RM 251.5) and Chapman, NE (RM 156.5).
4. Area of Interest – Active river channels (main and side-channels) and approximately 50 feet to 100 feet of overbank beyond the tops of the banks on either side of the channels.
5. Ground Sample Distance (GSD) – For remote sensing data, the distance between pixel centers as measured on the ground.
6. Digital Surface Model (DSM) –Surface model of vegetation heights derived from "highest hit" LiDAR data.
7. Digital Terrain Model (DTM) – Terrain model representing bare earth elevations derived from LiDAR "first return" data.
8. Hydroflattened DTM – Terrain model representing bare earth elevations in non-wetted areas and water-surface elevation in inundated areas.
9. Topobathymetric DTM – Terrain model representing bare earth elevations in both wetted and non-wetted areas derived from the green LiDAR returns.
10. Total Unvegetated Channel Width (TUVCW) – Sum of individual segments meeting the criteria for MUVCW across each transect.
11. Maximum Unobstructed Channel Width (MUOCW) – Maximum continuous distance of water, bare sand, and short vegetation (both sparse and dense, <2 feet tall), calculated based on individual transects spaced at approximately 1,000-foot intervals.
12. Area Suitably Shallow for Roosting – Total channel area less than or equal to 0.7-feet deep at specified discharges.

V. Data Collection and Processing

Four general categories of data will be collected and processed under this protocol: 1) hydrologic data, 2) management action data, 3) remote sensing data, and 4) training and validation data. The following sections describe the sources, collection methods and specific metrics for each category.

A. Hydrologic Data

Platte River discharge and river stage data (and associated rating curves) will be obtained from the records for the U.S. Geological Survey (USGS) gaging stations located at Overton (06768000), Kearney, (06770200) and Grand Island (06770500). Approved instantaneous (15-minute) and mean daily stage and discharge data will be uploaded to a Program Database for use in the hydrologic and hydraulic analyses. The following metrics will be calculated every year to summarize river conditions during periods of interest such as the spring and fall whooping crane migration seasons:

- Q_{Max} –maximum mean daily discharge for the time-period between successive surveys.

- Q_{40Avg} – maximum 40-day duration average discharge for the time-period between successive surveys.
- $Q_{Germination}$ – average discharge during germination period (6/1 to 7/15).
- $Q_{SpringWC}$ – average discharge during spring whooping crane migration (3/6 to 4/29).
- Q_{FallWC} - average discharge during fall whooping crane migration (10/09 to 11/15).
- $FDC_{water-year}$ – annual flow duration curve, including a table of median, 10-, 25-, 75- and 90-percent exceedance flows.
- $FDC_{Germination}$ – flow duration curve during germination period (6/1 to 7/15), including a table of median, 10-, 25-, 75- and 90-percent exceedance flows.
- $FDC_{SpringWC}$ – flow duration curve for spring whooping crane migration period (3/6 to 4/29), including a table of median, 10-, 25-, 75- and 90-percent exceedance flows.
- FDC_{FallWC} – flow duration curve for fall whooping crane migration season (10/9 to 11/15), including a table of median, 10-, 25-, 75- and 90-percent exceedance flows.

B. Management Action Data

Program management actions are designed and implemented to create and/or maintain highly suitable habitat for Program target species. These actions include herbicide application, disking, burning, tree clearing, channel widening and sediment augmentation. All activities will be documented by the Executive Director's Office (EDO) and stored in a spatial database (GDB format) which can be used in ArcGIS. Data will be organized by year, and will include Program management activity type, polygons of affected areas, and date of implementation, and any other available information relevant to the trend and habitat status analyses. Specific data collection methods are described below:

- Aerial in-channel herbicide application – Extent of aerial application of herbicide captured using helicopter-mounted sub-meter accuracy GPS that generates polygons of area sprayed in real time. Channel widening – Extent and dimensions of earthwork, recorded using as-built survey utilizing survey-grade accuracy GPS and/or annual LiDAR surveys.
- Disking – Extent of disking, captured using hand-held, sub-meter accuracy GPS to delineate disking polygons after disking operations have been completed.
- Ground and airboat herbicide application – Extent of application, captured using sub-meter accuracy GPS.
- Prescribed burning – Extent of prescribed burns on tract vegetation that is conducted on a 4-year rotating schedule.
- Sediment Augmentation – Extent, dimensions, and volume of augmentation, recorded using as-built survey utilizing survey-grade GPS and annual LiDAR surveys.
- Tree clearing – Extent of removed trees, delineated prior to removal using the most currently available aerial photography, and ground-truthed after removal.

C. Remote Sensing Data Collection and Processing

Four band (red, green, blue, and near infrared) aerial photography and bathymetric LiDAR will be collected concurrently, twice annually in accordance with the Program's remote sensing data collection protocol (PRRIP 2011). A late-spring data collection will occur between mid-June and

early-July; and a fall collection will occur between mid-October and mid-November. In both cases, data collection will occur during periods of low river discharge and low river turbidity. The late-spring collection effort will include aerial photography for the entire AHR and bathymetric LiDAR from Lexington to Elm Creek.[3] The fall effort will include aerial photography and bathymetric LiDAR data for the entire AHR. Aerial imagery will be collected and processed to a 6 inch digital pixel resolution, processed and orthorectified by the remote sensing contractor and delivered to the Program as four-band GeoTIFF images and seamless true color and Color-Infrared (CIR) mosaics.

LiDAR data will be collected at a mean resolution of no greater than 2.3 feet GSD or better with a relative vertical accuracy of ±0.3 feet or less. The LiDAR data will be processed by the contractor and delivered to the Program as LAS point files and digital elevation models (DEMs) in ERDAS Imagine File (.img) format. LiDAR-related deliverables will specifically include the following:

- Hydroflattened digital terrain model (DTM), which provides bare earth elevations in non-wetted areas and water surface in inundated areas.
- Highest hit digital surface model (DSM), which provides highest hit (vegetation canopy) in non-wetted areas and water surface in inundated areas.
- Topobathymetric DTM, which provides bare earth ground elevations in all wetted and non-wetted areas.

D.   Field Collection of Training and Validation Data

1.   Channel Morphology Data

To validate the accuracy of LiDAR-derived Topobathymetric DTMs, approximately 1,000 linear feet of river channel will be surveyed within 24 hours of each LiDAR flight. Surveys will be performed using RTK GPS, tied-in to appropriate survey control points. The data will consist of a minimum of 400 randomly-selected points throughout a pre-selected validation area at each of five Program properties: the Plum Creek Complex in the Lexington to Overton segment, the Elm Creek Complex in the Elm Creek to Odessa segment, the Ft Kearney Complex in the Kearney to Minden segment, the Clark Island Complex in the Gibbon to Shelton segment and the Shoemaker Island Complex in the Alda to Grand Island segment. Survey points shall be taken on the channel bed, avoiding grade breaks, steep slopes, and actively eroding surfaces. Data collection will be focused on active and recently inundated areas of the channel with minimum point spacing of 6 feet. Point coverage will also include a range of wadable channel depths and bar heights relative to the water-surface with equal "wet" and "dry" coverage. Point attributes shall include the following:

1. X, Y, Z coordinates in NAD83 NE State Plane, in US Survey Ft & NAVD 88 Geoid 03

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[3] The late-spring bathymetric LiDAR data is used as implementation and effectiveness monitoring for Program sediment augmentation operations.

2. Point Code/Description

    a. WSEL – Water Surface Elevation

3. CW – Channel Wet (Subaqueous Points)
4. CD – Channel Dry (Dry Channel Points)

    a. Time/Date

2. Vegetation and Land Cover Data

In-channel vegetation assessments will be made based on general vegetation characteristics, differentiated by height and percent vegetative cover that appear to be key to whooping crane roost-site selection. Training and validation data for use in the eCognition software will be collected in the field by placing the vegetation at each of a series of patches (training data) or points (validation data) approximately uniformly distributed throughout the AHR into one of the following six general vegetation classes:

1. Forest / Mature Trees: All vegetation exceeding 15 feet in height.
2. Shrub / Tall Invasive: All vegetation between 6 feet and 15 feet in height. This class will typically include immature woody vegetation and phragmites.
3. Tall Herbaceous: Areas of vegetation between 2 feet and 6 feet in height.
4. Short Dense Herbaceous: Areas of dense vegetation (>75% vegetative cover) less than 2 feet in height.
5. Short Sparse Herbaceous: Areas of sparse vegetation (<75% and >25% vegetative cover) less than 2 feet in height.
6. Bare Sand: (<25% vegetative cover).

The data will be collected during September (prior to first frost and before whooping crane migration) via airboat survey, and as close in time as practical to the collection of the aerial imagery and LiDAR data. The training and validation data will be collected independently by two different staff members/crews (as appropriate), with the locations identified using handheld GeoXT or GeoXH GPS units.

a) Training Data

Training Data will be collected by tracing polygons with the handheld GPS around a minimum of 20 uniformly distributed patches of short, dense vegetation (Vegetation Class 4) and 20 uniformly distributed patches of short, sparse vegetation (Vegetation Class 5) within each geomorphic reach each year. In preparation for the field sampling, the approximate locations of the patches should be identified from the imagery, and the final locations adjusted in the field to ensure that the mapped areas contain sufficiently homogeneous stands of the relevant vegetation class. All vegetation patches will be a minimum of 100 yd^2 in size, and to the extent possible, will be located on Program or other conservation organization-owned lands. Training data will not be collected within the tree, shrub and willow, and tall dense vegetation classes (Vegetation Classes 1, 2 and 3), as these classifications will be incorporated into the analysis based only on vegetation height. Training data will also not be collected within water, wet sand, and dry sand areas as these classes change based on flow, and thus, will inherently be different during field and imagery data collection efforts. Documentation at each of the sampled patches will include patch identification,

notes on the characteristics and general types of vegetation present within the patch, ground photographs, and the GPS coordinate file containing the polygons or waypoints that delineate the patch boundary.

b) Validation Data

Validation data collection procedures and documentation will be identical to the above-described training data collection procedures at the individual patches; however, the sample patch size will be reduced to a minimum of 20 yd^2 and considerably more patches will be sampled. The data collection will include a minimum of 50 samples each in uniformly distributed patches of short, dense vegetation and short, sparse vegetation (Vegetation Classes 4 and 5) within each bridge segment each year (total of 100 samples). Data will also be collected at a minimum of 20 uniformly distributed patches each of trees, shrubs and willows, tall dense vegetation, dry sand, wet sand and water (Vegetation Classes 1, 2, 3 and 6; total of 120 samples). The validation data collection locations will not overlap with the training data patches.

VI. Data Analysis

A.   Preliminary Processing of Aerial Imagery and LiDAR

- The aerial imagery and LiDAR products delivered from the aerial mapping contractor will be processed prior to analyzing the data to reduce file size to a manageable level using the following procedure:
- The imagery and LiDAR surfaces will be degraded to 3-foot pixel resolution, clipped to the channel shapefile discussed in Section IV. A., snapped to a common raster grid system, and merged to facilitate vegetation classification using the Trimble eCognition software. Through this process, care must be taken to ensure that all 4 bands in the aerial imagery are maintained in the processed aerial imagery files.
- A vegetation-height raster file will be created by subtracting the Hydroflattened DTM raster from the highest hit DSM raster.
- A topographic DEM of differences (DOD) will be created by subtracting the processed topobathymetric DTM for the current year from the DTM from the previous year. The DTM will provide base elevation data for cross sections and two-dimensional (2-D) model nodes for the habitat-related analyses, and the DOD will be used to quantify aggradation/degradation changes for purposes of monitoring the system-wide sediment transport balance.

B.   Volume Change Analysis

Channel bed-sediment volume change (aggradation/degradation) for each geomorphic reach will be calculated from the topobathymetric DOD by developing a histogram of volume change with bins in 0.1 foot increments, multiplying the number of points in each bin by the square of the pixel resolution (i.e., 9 ft^2) and the magnitude of the corresponding elevation change, and summing the resulting volumes. A consistent sign convention will be used for the analysis, with negative (-) values indicating degradation and positive (+) values indicating aggradation. Consistent with

recommendations in Lane, et al., (2000), all pixel values, regardless of their magnitude, will be used in computing the best-estimate magnitude of the volume change. Uncertainty in the estimate will then be computed based on the reported uncertainty for the subaerial and subaqueous portions of the surfaces using the following formula (Lane, et al., 2000):

$$\sigma_v = \pm t * d^2 \left(\sum_{i=1}^{4} N_i \sigma_i^2 \right)^{\frac{1}{2}} \quad (1)$$

Where σ_v is the uncertainty in the estimate volume change, t is the t-statistic associated with the desired level of confidence (e.g., t-1.96 for the 90% confidence bands), d is the pixel resolution, N_i is the number of pixels in each error category (i), and σ_i is the propagated error between the two comparative surfaces, computed by the following formula:

$$\sigma_i = \left(\sigma_j^2 + \sigma_k^2 \right)^{1/2} \quad (2)$$

where σ_j and σ_k are the Root Mean Square Errors (RMSE) of the relevant zones for the current and previous-year surfaces, respectively. Since the mapping error for the LiDAR is different for subaerial and subaqeous areas, there will be two values for σ_j and σ_k for each year of data, and there are, therefore, four possible combinations (i) of j and k for each pixel:

1. Subaerial in both surfaces
2. Subaerial in the prior-year surface and subaqueous in the current-year surface
3. Subaqeous in the prior-year surface and subaerial in the current-year surface
4. Subaqeous in both surfaces

Degradational areas (negative elevation change) will also be differentiated into lateral and general bed erosion components by assuming degradational values of greater than 3 feet represent lateral bank erosion. The 3-foot value is based on EDO observations of average bank height in the AHR and may be adjusted in the future as more data becomes available. Areas initially identified as bank erosion will be manually checked, and those that occur in the middle of the channel reclassified back into bed erosion, because scour holes and erosion into the sides of mid-channel bars can also exceed 3 feet.

Volume change will be reported in cubic yards (CY) as well as tons using a conversion factor of 1.5 tons per CY.

C. Channel Morphology and Hydraulics Assessment and Analysis

Two-dimensional (2-D) hydrodynamic models will be developed internally and updated annually to identify changes in width, depth, and channel depth/height distribution over a range of discharges. Nine hydraulic models will be constructed, one for each geomorphic reach. The model geometries will be bound longitudinally by the adjoining bridges in the bridge segments and laterally by the eCognition analysis hulls. The model will be calibrated for the recorded discharges at the time of the LiDAR flights and ground surveys, and to water-surface profiles from the remote sensing data, surveyed water surface elevations, and stage loggers located throughout the analysis area. Manning's roughness values will be specified for the vegetation polygons from the

eCognition analysis, and adjusted, as appropriate, to achieve calibration. A range of flows from 500 cfs to 5,000 cfs will then be run with the calibrated models. It is tentatively assumed that the following 5 discharges within this range will be sufficient to quantify the relationships: 500 cfs, 1,200 cfs, 2,000 cfs, 3,000 cfs and 5,000 cfs. The difference between the predicted water surface elevations and the corresponding channel bed elevation will be computed to quantify the following analysis metrics, by discharge, for each geomorphic reach:

- Total inundated area
- Water volume – Total volume of water within the reach at the indicated water-surface elevation
- Average depth – Ratio of water volume to total inundated area
- Average Top width –Ratio of total inundated area to channel length
- Width-Depth (W/D) ratio – Ratio of average top width to average depth
- Area of inundation of 0.7 foot or less

D.   In-Channel Vegetation and Land Cover Classification and Analyses

Trimble eCognition software will be used, along with the training and validation data, to evaluate in-channel vegetation and land cover, primarily to assess the whooping crane metrics. For the basic vegetation and landcover analysis, annual vegetation classifications within the area of interest that include the active channel and approximately 50 feet to 100 feet of the overbanks, will be delineated from the annual aerial imagery using eCognition (Appendix A). To accommodate software limitations, the processed 3-foot pixel resolution fall aerial imagery and vegetation height DEMs developed under Section VII. A. will then be segmented into shorter reaches of river (generally Lexington – Odessa, Odessa – Shelton, Shelton – HWY 281, and HWY 281 – Chapman) prior to initiating the supervised classification to provide more manageable file size. The imagery and vegetation height DEM files will then be imported into eCognition and used to classify imagery into the vegetation and land cover classes defined in Section IV. D. 2. The final vegetation classification file will be exported as a shapefile and evaluated for accuracy in ArcGIS using the field-collected validation data. During the accuracy assessment, wet sand, dry sand, and water will be combined into a single class as these classes are highly variable depending on discharge.

Vegetation classifications will be validated annually to determine the accuracy of the remote-sensing results. For each remote survey, the accuracy for each vegetation classification will be calculated by dividing the number of correct classifications by the total number of field-based classifications collected in each class using the validation data set. In addition, a geodatabase will be developed with an attribute table that will detail the coverage of each vegetation class.

Maximum unvegetated channel width (MUVCW), to be used in evaluating drivers of vegetation change, will be computed by dividing the total unvegetated area (water, bare sand, and sparse short vegetation) by the reach length for each geomorphic reach. This metric will be reported in acres by geomorphic reach.

Final vegetation and land cover class areas and MUVCW will be compared to the corresponding areas from previous years to quantify yearly changes. The results will be reported in acres of change by geomorphic reach for both main and side channels.

E.   Whooping Crane Analyses

1.   Maximum Unobstructed Channel Width

Maximum unobstructed channel width (MUOCW) is an important metric for habitat selection by whooping cranes (PRRIP 2017, Chapter 2). The magnitude and annual change in MUOCW will be quantified using the vegetation/land cover classification to complete a transect-based analysis consistent with the methodology presented in PRRIP 2017, Chapter 4. A set of valley-wide transects spaced at approximately 1,000-foot intervals will be developed during the first analysis year, and this set will be used for the analysis in each subsequent year to provide a consistent baseline for comparison of the annual changes. Adjustments may be made to the transect lengths if the channel migrates beyond the end of the original transects. Transects will be generally oriented perpendicular to flow at main channel discharges at or above 4,000 cfs (approximate bankfull discharge). In performing the analysis, the vegetation/land cover shapefile will be intersected with the transects to identify areas of water, sand (Vegetation Class 6), and short vegetation (< 2 ft; Vegetation Classes 4 and 5) considered to be unobstructed. MUOCW will be calculated as the maximum continuous unobstructed length at each transect. The average value, standard deviation, minimum and maximum values for each geomorphic reach will be reported.

2.   Area of Channel Suitably Shallow for Roosting

Results from the annual 2-D hydraulic modeling will be used to identify the proportion of channel area less than or equal to 12 inches deep across a range of flows from 500 cfs to 5,000 cfs, as discussed in Section VI. C. Areas with depth less than or equal to 12 inches will be overlaid onto the MUOCW transects, and the total overlapping area with MUOCW greater than or equal to 650 feet will be computed to quantify the current area of suitable whooping crane roosting habitat.

F.   Analysis of in-channel vegetation drivers

In 2017, the Program evaluated a total of 11 primary hydrologic, geomorphic, and management variables in a robust regression analysis framework to assess their influence on total unvegetated channel width (TUCW) and MUOCW during the period from 2007 through 2015 (PRRIP 2017, Chapter 4). The evaluation concluded that TUCW was most highly correlated with 40-day duration maximum discharge, disking, herbicide application, and wetted width of the channel at bankfull discharge. The evaluation also concluded that MUOCW was most highly correlated with the above four factors, plus median bed material grain size. The data collected through this monitoring protocol will be used to update the robust regression analysis every other year.

VII.   Annual Reporting and Deliverables

Annual monitoring deliverables will include draft and final reports (in Microsoft Word) that document the activities completed during each monitoring season, any difficulties encountered,

and recommendations, if any, for revising the protocol methodologies. The draft report shall be submitted for review at the beginning of each January to the Program who will have 30 days to review the draft report. A final report that addresses any review comments will be submitted within 30 days after receipt of review comments. Other deliverables to be included with the final annual report will include raw survey and mapping data, coordinates of training and validation sites, ground photographs and field documentation of project activities, and other documents or materials collected and/or developed as a part of annual monitoring activities. Where appropriate, all data will be compiled in Excel spreadsheet format and incorporated into the Program database. Data will be reported in accordance with guidelines outlined in the Program's AMP and the Program's Management System.

VIII.   Field Safety

Since this protocol defines a significant field data collection effort for collection of the training and validation data, the safety of field personnel should be a priority when conducting the field work. There are inherent risks and hazards associated with field work, especially when working around water, so every effort should be made to minimize those hazards and risks. If a corporate or agency safety manual is not available for use by field personnel, it is highly recommended that a safety plan be developed prior to conducting the tasks defined in this protocol. The safety plan should address issues related to working around and on water, boating safety, traffic safety, severe weather, and wildlife.

All federal and state guidelines should be adhered to when conducting field work using boats and other watercraft. Field personnel should wear a U.S. Coast Guard approved personal flotation device (PFD) at all times while working on or over water. Safe boating procedures should be followed at all times and standard emergency equipment such as fire extinguishers and first aid kits should be included on all manned watercraft.

When working in or traversing the river by foot, quicksand can be a potential threat. Although drowning in quicksand is impossible, becoming temporarily trapped in quicksand is possible. Therefore, field personnel working in or traversing the river by foot should wear a PFD and be familiar with the procedures to remove themselves from quicksand, should that be necessary.

It is recommended that weather forecasts for the study area be checked frequently for severe storms. Severe thunderstorms that can include lightning, hail, high winds, and even tornadoes pose a significant hazard to field crews in isolated areas where shelter may not be readily available. Field crews should be prepared for and be able to deal with severe weather at all times.

Field personnel should be familiar with basic first aid and should know the locations of all local emergency medical facilities and hospitals within the study area. In the case of a severe or life threatening injury, field personnel should rely on emergency 911 services. For non-life threatening and non-severe injuries, injured field personnel should be transported as soon as possible to a local medical facility such as an urgent care facility or hospital.

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APPENDIX A

PLATTE RIVER RECOVERY IMPLEMENTATION PROGRAM

REMOTE MONITORING OF IN-CHANNEL VEGETATION

VEGETATION CLASSIFICATION TUTORIAL

1. Open ArcGIS on <u>Your Computer</u>
    a. Load a copy of the DEFAULT_IMAGE_ANALYSIS_HULL within the "N:\Projects\PRRIP\eCognition Files\Default Hull and DAX Files" folder.
    b. Export a copy of the DEFAULT_IMAGE_ANALYSIS_HULL within the "N:\Projects\PRRIP\eCognition Files\Default Hull and DAX Files" folder to a new year-specific folder in the "P:\PRRIP\Imagery Classification\'YEAR' HULL and DAX" folder as FALL_'YEAR'_IMAGE_ANALYSIS_HULL.
    c. Load the fall imagery file located in a folder within the "P:\PRRIP\Imagery\'YEAR'_'MONTH'_4band" folder.
    d. Make adjustments to the new FALL_'YEAR'_IMAGE_ANALYSIS_HULL within the "P:\PRRIP\Imagery Classification\'YEAR' HULL and DAX" folder for areas where channel widths change. Try to avoid including highways, gravel roads, 2-track roads, houses, development, etc. within the HULL.

DO NOT MAKE ADJUSTMENTS TO THE "DEFAULT_IMAGE_ANALYSIS_HULL" FILE!!!

2. Create a new folder structure on the <u>Image Analysis Computer</u>
    a. Create a new, year-specific folder on the <u>Image Analysis Computer</u> within the "C:\Users\farnsworthj\Desktop\Imagery Classification" folder called "'YEAR'"
    b. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'" folder called "Fall 'YEAR' LiDAR and Imagery"
        i. Create a new folder on the <u>Image Analysis Computer</u> within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' LiDAR and Imagery" folder called "Fall 'YEAR' TIFFs"
        ii. Create a new folder on the <u>Image Analysis Computer</u> within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' LiDAR and Imagery" folder called "Fall 'YEAR' LiDAR"
    c. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\ 'YEAR'" folder called "Fall 'YEAR' HULL and DAX"

i. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\ 'YEAR'\Fall 'YEAR' HULL and DAX" folder called "Fall 'YEAR' HULL"

ii. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\ 'YEAR'\Fall 'YEAR' HULL and DAX" folder called "Fall 'YEAR' DAX"

d. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\ 'YEAR'" folder called "Clipped Fall 'YEAR' LiDAR and Imagery"

i. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Clipped Fall 'YEAR' LiDAR and Imagery" folder called "Fall 'YEAR' Clipped Imagery"

ii. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Clipped Fall 'YEAR' LiDAR and Imagery" folder called "Fall 'YEAR' Clipped LiDAR"

e. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'" folder called "Fall 'YEAR' eCognition"

i. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' eCognition" folder called "Fall_2017_'Year'_Lexington_Odessa"

ii. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' eCognition" folder called "Fall_2017_'Year'_Odessa_Shelton"

iii. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' eCognition" folder called "Fall_2017_'Year'_Shelton_HWY 281"

iv. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' eCognition" folder called "Fall_2017_'Year'_HWY 281_Chapman"

f. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'" folder called "Fall 'YEAR' Results"

i. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' Results" folder called "Fall_'Year'_Lexington_Odessa"

ii. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' Results" folder called "Fall_'Year'_Odessa_Shelton"

        iii. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' Results" folder called "Fall_'Year'_Shelton_HWY 281"

        iv. Create a new folder on the Image Analysis Computer within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' Results" folder called "Fall_'Year'_HWY 281_Chapman"

3. Create a copy of the files used in the classification process

    a. Create a copy of all annual, fall 4-band TIFF imagery files from the "P:\PRRIP\Imagery\'YEAR'\PHOTOS\TILES" folder and place it within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\"Fall 'YEAR' LiDAR and Imagery\Fall 'YEAR' TIFFs" folder on the <u>Image Analysis Computer</u>.

    b. Create a copy of the Hydro_Flattened_Water_Surface LiDAR folder from the "P:\PRRIP\'YEAR'\Elevation\'YEAR'_PRRIP_LiDAR_'MONTH'" folder and place them within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\"Fall 'YEAR' LiDAR and Imagery\Fall 'YEAR' LiDAR" folder on the <u>Image Analysis Computer</u>.

    c. Create a copy of the Highest Hit LiDAR folder from the "P:\PRRIP\'YEAR'\Elevation\'YEAR'_PRRIP_LiDAR_'MONTH'" folder and place them within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\"Fall 'YEAR' LiDAR and Imagery\Fall 'YEAR' LiDAR" folder on the <u>Image Analysis Computer</u>.

    d. Create a copy of the 'YEAR'_IMAGE_ANALYSIS_HULL within the "P:\PRRIP\Imagery Classification\'YEAR' HULL and DAX" folder and place it within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' HULL and DAX" folder on the <u>Image Analysis Computer</u>.

4. Open Global Mapper on the <u>Image Analysis Computer.</u>

    a. Load the FALL_'YEAR'_IMAGE_ANALYSIS_HULL by clicking on the Folder icon and navigating to the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' HULL and DAX\Fall 'YEAR' HULL" folder on the <u>Image Analysis Computer </u>and load the "Fall_'YEAR'_IMAGE_ANALYSIS_HULLS.shp" file

    b. Click on the Wrench (Configure) and then set the Projection to:

     i. State Plane Coordinate System

     ii. Nebraska (FIPS 2600)

     iii. NAD83

     iv. Feet (U.S. Survey)

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c. Load all TIFF imagery files within the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\"'YEAR' LiDAR and Imagery\'YEAR' Fall TIFFs" folder on the Image Analysis Computer into Global Mapper by clicking on the Folder icon and navigating to the TIFF files.
d. Click on 'No to All'
e. Merge, clip and degrade the 4-band imagery TIFFs to a 2-foot resolution and title the imagery "FALL_'YEAR'_CLIPPED_IMAGERY"

i. Use the "pencil" icon to select the HULLS that you want to clip and merge the imagery by. Perform these steps 4 times: Lexington-Odessa, Odessa-Shelton, Shelton-HWY 281, and HWY 281-Chapman.
   1. Select only the channel segments within 1 of the 4 areas of interest (i.e., do not select all polygons as that will include the areas between large channel splits).
   2. Within the File menu under 'Export' select 'Raster/Image Format'
      a. Select 'GeoTIFF' and click OK
      b. Within the 'Geo TIFF Options' tab
         i. Set the Multi-band options to 8 and 4 bands
         ii. Set the Sample Spacing/Scale to 2 feet for both the 'X-axis' and 'Y-axis'
         iii. Check the box for 'Always Generate Square Pxls'
         iv. Check the box for 'Generate TFW (World) File' and 'Generate PRJ File' only, the other boxes on the right should not be checked.
      c. Within the 'Tiling' tab
         i. Select 'No Tiling – Just One Export File'
      d. Within the 'Export Bounds' tab
         i. Select 'Crop to Selected Area Feature(s)'
ii. Click 'OK' at the bottom of the Erdas Imagine Export Options window
   1. Set Band 1 to 'Band 1 [Red Color Band]'
   2. Set Band 2 to 'Band 2 [Green Color Band]'
   3. Set Band 3 to 'Band 3 [Blue Color Band]'
   4. Set Band 4 to 'Band 4'
iii. Click 'OK' at the bottom of the Set up Bands for Export window
   1. Set the output folder to "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Clipped Fall 'YEAR' LiDAR and Imagery\Fall 'YEAR' Clipped Imagery"
   2. Name the file by the Bridge Segments included in the output (i.e., Lexington-Odessa, Odessa-Shelton, Shelton-HWY 281, or HWY 281-Chapman).
   3. Example name: Lexington_Odessa_Fall_'YEAR'
   4. Select "Geo TIFF Files (*.tif, *.tiff)"
iv. Click 'Save'

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f. Load the WSTM LiDAR data into Global Mapper by clicking on the Folder icon and navigating to the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\"'YEAR' LiDAR and Imagery\Fall 'YEAR' LiDAR\Rasters\Hydro_Flattened_Water_Surface" folder on the <u>Image Analysis Computer</u> and selecting 'ws_Platte_1', 'ws_Platte_2', 'ws_Platte_3', and 'ws_Platte_4' and click 'Open'.

   i. WSTM = Hydro-flattened Bare Earth Surface
   ii. Select the 4 WSTM files within Global Mapper, right click, and group them into a single layer called 'WSTM'
   iii. Use the "pencil" icon to select the HULLS you want to clip and merge the imagery by. Perform these steps 4 times: Lexington-Odessa, Odessa-Shelton, Shelton-HWY 281, and HWY 281-Chapman.
      1. Select only the channel segments within 1 of the 4 areas of interest (i.e., do not select all polygons as that will include the areas between large channel splits).
   iv. Go to 'File' and under the 'Export' menu select 'Export Elevation Grid Format'
      1. Select ErDas Imagine File
      2. Within the 'Erdas Imagine Export' tab
         a. Select File Type to Elevation (32 Bit floating point samples)
         b. Select 'Vertical Units' of FEET
         c. Change the X-axis to 2 feet and the Y-axis to 2 feet
         d. Check the 'Always Generate Square Pxls'
         e. Only select the 'Create Compressed File' (i.e., deselect all of the others)
         f. Set 'Block Size' to 64
      3. Within the 'Tiling' tab
         a. Select 'No Tiling – Just One Export File'
      4. Within the 'Export Bounds' tab
         a. Select 'Crop to Selected Area Feature(s)'
   v. Click 'OK' at the bottom of the Erdas Imagine Export Options window
      1. Set the output folder to "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Clipped Fall 'YEAR' LiDAR and Imagery\Fall 'YEAR' Clipped LiDAR"
      2. Name the file by the Bridge Segments included in the output (i.e., Lexington-Odessa, Odessa-Shelton, Shelton-HWY 281, or HWY 281-Chapman).
      3. Example name: WSTM_Lexington_Odessa_Fall_'YEAR'
      4. Select Erdas Imagine Files (*.img)
   vi. Click 'Save'
      g. Load the DSM LiDAR data into Global Mapper by clicking on the Folder icon and navigating to the

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"C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\'"'YEAR' LiDAR and Imagery\Fall 'YEAR' LiDAR\Rasters\Highest_Hit" folder on the <u>Image Analysis Computer</u> and selecting 'hh_Platte_1', 'hh_Platte_2', 'hh_Platte_3', and 'hh_Platte_4' and click 'Open'.

- i. DSM = Surface Including Vegetation
- ii. Select the 4 DSM files within Global Mapper, right click, and group them into a single layer called 'DSM'
- iii. Use the "pencil" icon to select the HULLS you want to clip and merge the LiDAR data by. Perform these steps 4 times: Lexington-Odessa, Odessa-Shelton, Shelton-HWY 281, and HWY 281-Chapman.
    1. Select only the channel segments within 1 of the 4 areas of interest (i.e., do not select all polygons as that will include the areas between large channel splits).
- iv. Go to 'File' and under the 'Export' menu select 'Export Elevation Grid Format'
    1. Select ErDas Imagine File
    2. Within the 'Erdas Imagine Export' tab
        a. Change File Type to Elevation 32 Bit
        b. Select 'Vertical Units' of FEET
        c. Change the x-axis to 2 feet and the y-axis to 2 feet
        d. Check the 'Always Generate Square Pxls'
        e. Only select the 'Create Compressed File' (i.e., deselect all of the others)
        f. Set 'Block Size' to 64
    3. Within the 'Tiling' tab
        a. Select 'No Tiling – Just One Export File'
    4. Within the 'Export Bounds' tab
        a. Select 'Crop to Selected Area Feature(s)'
- v. Click 'OK' at the bottom of the Erdas Imagine Export Options window
    1. Set the output folder to "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Clipped Fall 'YEAR' LiDAR and Imagery\Fall 'YEAR' Clipped LiDAR"
    2. Name the file by the Bridge Segments included in the output (i.e., Lexington-Odessa, Odessa-Shelton, Shelton-HWY 281, or HWY 281-Chapman).
    3. Example name: DSM_Lexington_Odessa_Fall_'YEAR'
    4. Select Erdas Imagine Files (*.img)
- vi. Click 'Save'
    h. Load the clipped WSTM and DSM and calculate the differences in elevations
- i. Navigate to the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Clipped Fall 'YEAR' LiDAR and Imagery\Fall

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‘YEAR’ Clipped LiDAR” folder and load the WSTM and DSM files (NOT the .ige files)

1. Within the Analysis drop-down menu select Combine/Compare Terrain Layers
2. Within the Combine Terrain Layers Options tab
    a. Under the Select First Elevation Layer(s) to Combine/Compare, select the ‘DSM’ file
    b. Under the Select Elevation Layer(s) to Combine the First Layer(s) with, select the ‘WSTM’ file
    c. Select Vertical Units ‘Feet’
    d. Change the x-axis to 2 feet and the y-axis to 2 feet
    e. Check the ‘Always Generate Square Pxls’
3. Within the ‘Export Bounds’ tab
    a. Select ‘Crop to Selected Area Feature(s)’

ii. Hit OK
iii. Use the “pencil” icon to select the HULLS you want to clip and merge the LiDAR data by. Perform these steps 4 times: Lexington-Odessa, Odessa-Shelton, Shelton-HWY 281, and HWY 281-Chapman.
1. Select only the channel segments within 1 of the 4 areas of interest (i.e., do not select all polygons as that will include the areas between large channel splits).
iv. Go to ‘File’ and under the ‘Export’ menu select ‘Export Elevation Grid Format’
1. Select ErDas Imagine File
2. Within the ‘Erdas Imagine Export’ tab
    a. Change File Type to Elevation 32 Bit
    b. Select ‘Vertical Units’ of FEET
    c. Change the x-axis to 2 feet and the y-axis to 2 feet
    d. Check the ‘Always Generate Square Pxls’
    e. Only select the ‘Create Compressed File’ (i.e., deselect all of the others)
    f. Set ‘Block Size’ to 64
3. Within the ‘Tiling’ tab
    a. Select ‘No Tiling – Just One Export File’
4. Within the ‘Export Bounds’ tab
    a. Select ‘Crop to Selected Area Feature(s)’
v. Click ‘OK’ at the bottom of the Erdas Imagine Export Options window
1. Set the output folder to “C:\Users\farnsworthj\Desktop\Imagery Classification\‘YEAR’\Clipped Fall ‘YEAR’ LiDAR and Imagery\Fall ‘YEAR’ Clipped LiDAR”
2. Name the file by the Bridge Segments included in the output (i.e., Lexington-Odessa, Odessa-Shelton, Shelton-HWY 281, or HWY 281-Chapman).

3. Example name: Fall_'YEAR'_WS_Vegetation_Height_Lexington_Odessa
4. Select Erdas Imagine Files (*.img)
vi. Click 'Save'
5. Open eCognition on the <u>Image Analysis Computer</u>.
    a. Click on 'OK' when the syntax error appears.
    b. NOTE: you can save the progress of a project <u>PRIOR TO THE SUPERVISED CLASSIFICATION STEP</u> by clicking on 'Create / Modify Project' at the top of the screen and then scrolling down and clicking on 'Save Project'. After that step DO NOT close the project until the last step is completed.
    c. Start a New Project by clicking on the 'New project' folder
    i. Navigate to the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Clipped Fall 'YEAR' LiDAR and Imagery\Fall 'YEAR' Clipped Imagery" folder on the <u>Image Analysis Computer</u> and load the .TIF file.
        1. Set the Spectral Bands
            a. Blue = 'Bridge Segments'_Fall_'Year'.tif [3]
            b. Green = 'Bridge Segments'_Fall_'Year'.tif [2]
            c. Red = 'Bridge Segments'_Fall_'Year'.tif [1]
            d. NIR = 'Bridge Segments'_Fall_'Year'.tif [4]
    ii. Under the Results folder set the folder to "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' Results\Fall_'Year'_'Bridge Segments'" by double clicking on the folder.
    iii. Click on 'Add Layer'
        1. Navigate to the "C:\Users\farnsworthj\Desktop\Imagery Classification\ 'YEAR'\Clipped Fall 'YEAR' LiDAR and Imagery" folder and add the "Fall_'Year'_WS_Vegetation_Height_'Bridge Segments'.img" file
            a. Click 'Yes' when Geomorph error pops up
            b. Assign the "Fall_'Year'_WS_Vegetation_Height_'Bridge Segments'.img" file as the DTM file
    iv. Click on the yellow and white folder under the Analysis Builder Toolbar
        1. Click on 'Yes' when the 'Your current results will be delete. Do you want to continue' pops up
        2. Navigate to "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' HULL and DAX\Fall 'YEAR' DAX" folder and load the Fall_'YEAR'_Classification.DAX file
        3. Click 'OK' when the warning pops up
    v. Scroll to the bottom and click on the 'Create layers' icon (will take a while to complete)
    vi. Scroll to the bottom and click on the 'Display RGB' icon

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vii. Click on 'Add Layer'
1. Navigate to the "C:\Users\farnsworthj\Desktop\Imagery Classification\ 'YEAR'\Misc_Land_Use" folder and select the 'Misc_Land_Classes.shp' file

viii. Select the following layers in order from top to bottom
1. Threshold Segmentation | Classification
    a. Under Working domain set Select working domain to 'Pixel level, All objects'
    b. Under Threshold settings set Use layer to 'Bridge Segments'_Fall_'Year'.tif
    c. Under Threshold settings set Threshold to 254
    d. Under Class settings set the Class for dark as 'unclassified'
    e. Under Class settings set the Class for bright as 'HULL'
    f. Scroll to the bottom and click 'Execute'
2. Vector Based Segmentation
    a. Under Working domain set Select working domain to 'unclassified'
    b. Under Vector selection set Select vector layer to 'Misc_Land_Classes.shp'
    c. Under Vector selection set Select attribute to 'No, use all vectors'
    d. Under Vector selection set Select attribute values to '<no selection>'
    e. Under Classification set Classification mode to 'classify using attribute from attribute table'
    f. Under Classification set Select attribute to 'Class'
    g. Scroll to the bottom and click 'Execute'
3. Threshold Segmentation | Classification
    a. Under Working domain set Select working domain to 'unclassified'
    b. Under Threshold settings set Use layer to 'Fall_'Year'_WS_Vegetation_Height_'Bridge Segments'.img[1]'
    c. Under Threshold settings set Threshold to 2
    d. Under Threshold settings select 'Split objects'
    e. Under Class settings set the Class for dark as 'unclassified'
    f. Under Class settings set the Class for bright as 'Dense Vegetation'
    g. Scroll to the bottom and click 'Execute'
4. Minimum Mapping Unit
    a. Under Settings set Classes to 'Dense Vegetation'
    b. Under Settings set Minimum mapping unit (pxls): to 20
    c. Click on 'Apply'

5. Threshold Segmentation | Classification
   a. Under Working domain set Select working domain to 'Dense Vegetation'
   b. Under Threshold settings set Use layer to 'Fall_'Year'_WS_Vegetation_Height_'Bridge Segments'.img[1]'
   c. Under Threshold settings set Threshold to 6
   d. Under Threshold settings select 'Split objects'
   e. Under Class settings set the Class for dark as 'Dense Vegetation'
   f. Under Class settings set the Class for bright as 'Scrub-Shrub'
   g. Scroll to the bottom and click 'Execute'
6. Minimum Mapping Unit
   a. Under Settings set Classes to 'Scrub-Shrub'
   b. Under Settings set Minimum mapping unit (pxls): to 20
   c. Click on 'Apply'
7. Threshold Segmentation | Classification
   a. Under Working domain set Select working domain to 'Scrub-Shrub'
   b. Under Threshold settings set Use layer to 'Fall_'Year'_WS_Vegetation_Height_'Bridge Segments'.img[1]'
   c. Under Threshold settings set Threshold to 15
   d. Under Threshold settings select 'Split objects'
   e. Under Class settings set the Class for dark as 'Scrub-Shrub'
   f. Under Class settings set the Class for bright as 'Forest'
   g. Scroll to the bottom and click 'Execute'
8. Threshold Segmentation | Classification
   a. Under Working domain set Select working domain to 'unclassified'
   b. Under Threshold settings set Use layer to 'NDWI'
   c. For Threshold settings, hover over obvious water and set the Threshold to a number that appears to be representative of water (will need to adjust based on results of water classification)
   d. Under Threshold settings select 'Split objects'
   e. Under Class settings set the Class for dark as 'unclassified'
   f. Under Class settings set the Class for bright as 'water'
   g. Scroll to the bottom and click 'Execute'
   h. If the area identified as water is too inclusive (adjust up) or exclusive (adjust down) click on the Undo button, adjust the Threshold up or down accordingly, and click on Execute.

Repeat until the classification of water seems reasonable. Note, not all water will be correctly classified during this step…just make sure the classification seems reasonable and doesn't include too much area within the trees, etc. that clearly are shadows rather than water

9. Minimum Mapping Unit
   a. Under Settings set Classes to 'Water'
   b. Under Settings set Minimum mapping unit (pxls): to 20
   c. Click on 'Apply'
10. Multiresolution Segmentation
   a. Under the Analysis Builder Toolbar set the dropdown menu to the right of the down-arrow icon RGB
   b. Under Working domain set Select working domain to 'unclassified'
   c. Under Settings set Algorithm to 'region grow on object'
   d. Under Settings set Scale to '20'
   e. Click 'Execute' (will take a while to complete)
11. SAVE PROJECT. Navigate to the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' Results\Fall_'YEAR'_'Bridge Segments' folder and save the project as 'Fall_'YEAR'_'Bridge Segment'
12. Supervised Classification
   a. Once you reach step h, if manual classification or classification based on a statistics table are incomplete or wrong (e.g. mostly classified as water, etc.), undo and re-run the Multiresolution Segmentation step (step 10).
   b. Only perform steps b-g for the first bridge segments!!!
      i. For subsequent bridge segments scroll down to the Delete / Create samples and click on the 'Delete table' icon.
      ii. Within Load / Create samples under Sample selection mode select 'Add from statistics table'
ix. Within Load / Create samples under Select table (.csv) navigate to the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' Results\Fall_'Year'_'Bridge Segments'" folder that contains results of the bridge segments that were classified first and select the 'Supervised Classification.csv' file
      i. Click on the 'load statistic' icon
   b. Select 'CIR' for the background imagery in the Analysis Builder Toolbar dropdown menu

c. Click on 'Delete locals' and 'Delete table' if they are selectable options to remove any previously classified objects.
d. Select the class [i.e., water (bluer than pink), wet sand (pinker than blue), sand (light pink), sparse vegetation (light red), or short dense vegetation (red)] you want to classify by selecting the icon for that class.
e. Select a series of ≥100 polygons that are of the same class
f. Repeat until ≥100 of each class have been manually classified.
g. Within the Delete / Create samples click on the 'Export table' and save the supervised classifications as "Supervised Classification.csv" to be used to classify additional bridge segments within the same year.
h. Set the Classifier algorithm to 'Decision tree'
i. Set the Source to 'object based'
j. Scroll to the bottom and click on the 'Classify' icon
k. Update the .DAX file by clicking the 'Save' icon within the Analysis Builder Toolbar.

2. SAVE PROJECT. Click on Create | Modify Project, click on the 'Save Project' icon, navigate to the "C:\Users\farnsworthj\Desktop\Imagery Classification\'YEAR'\Fall 'YEAR' Results\Fall_'YEAR'_'Bridge Segments' folder and save the project as 'Fall_'Year'_'Bridge Segment'

3. Minimum Mapping Unit
   a. Under Settings set Classes to 'All Classes'
   b. Under Settings set Minimum mapping unit (pxls): to '20'
   c. Click on 'Apply'

4. Manual Editing
   a. Manually edit all polygons associated with powerlines that cross the channel and change them to Developed by selecting Developed and selecting the polygons within the boundaries of the powerline.
   b. If powerline polygons are merged with obvious forest or other polygons use the 'Cut Objects' button under Object Reshaping.
      i. Select the shape you want to edit, and click once on your starting point and double click the ending point at the part you want to cut

5. Object Merge
   a. Under Merge if same class set the dropdown to 'All Classes'
   b. Under Merge if same class click on the 'Apply' icon

6. Export
    a. Under Settings set Export type to 'Objects->vector'
    b. Under Settings set Class filter to 'All Classes'
    c. Under Settings set Attributes to '[Assigned class]'
    d. Under Settings set Export Name as 'Fall_'Year'_'Bridge Segments'_Classification'
    e. Under Export format set it as .shp
    f. Click on the 'Export' icon
7. Create a copy of the classification results within "P:\PRRIP\Imagery Classification\Fall 'YEAR' Imagery Classification Results" folder named "Fall_'YEAR'_'Bridge Segments'_Classification" and name the file "Final_Fall_'YEAR'_'Bridge Segments'_Classification"
8. When you close out of eCognition, click on 'Yes' when asked if you want to save the changes.

6. Manually edit all shadows that were classified as water within the trees in ArcGIS ON YOUR COMPUTER
    a. Under the selection menu, click on 'Select by Attributes', double click on 'Assigned_c', click the '=' sign, click on 'Get unique values', and double click on 'water'.
    b. Under the selection menu, click on 'Interactive Selection Method' and select 'Remove from Current Selection'
    c. Click on what you believe are truly 'water' areas to deselect the water areas that are classified as water. Channel areas should generally be fairly linear. If unsure whether it's water or not, scroll slightly or turn the layer off to confirm if it's water or a shadow.
    d. Start editing by clicking on the 'Editor' icon.
    e. Change the class of the remaining selected shadow/water areas to 'Short Dense Vegetation' by opening the attribute table; click on the first icon to open the drop down menu; select 'Find and Replace'; click on 'Replace'; beside Find what, type in 'water'; beside Replace with, type 'Short Dense Vegetation'; select 'Search Only Selected Field(s)'; and click on 'Replace all'. Note, 'water' and 'Short Dense Vegetation' are case sensitive without the ''.
    f. Click on the 'Editor' icon and 'Save Edits' then click on 'Stop Editing'.

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