

# Roles of Critical Uncertainties Research in Large-Scale Restoration: Examples from the Columbia Estuary Ecosystem Restoration Program

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National Conference on Ecosystem Restoration, Coral Springs, Florida  
April 19, 2016

# NCER History for Lower Columbia R. & Estuary Study: Development of Evidence-Based Evaluation of Large-Scale Ecosystem Restoration

- ▶ **NCER 2004, Orlando, FL. Talk:** Restoration in a Changing World: Addressing Natural Variability in Tidal Marsh & Seagrass Restoration Project Planning & Performance Assessment
- ▶ **NCER 2007, Kansas City, MO. Talk:** Evaluating Cumulative Ecosystem Response to Salmon Habitat Restoration Projects in the Columbia River Estuary
- ▶ **NCER 2009, Los Angeles, CA. Session:** Assessing Cumulative Effects of Multiple Restoration Projects on an Ecosystem
- ▶ **NCER 2011, Baltimore, MD. Pre-Conference Workshop:** Assessing Cumulative Ecosystem Effects of Multiple Restoration Projects
- ▶ **CEER (Conference on Ecological and Ecosystem Restoration), 2014, New Orleans, LA. Session:** Application of Evidence-Based Evaluations (EBE) for Large-Scale Ecosystem Restoration Programs

# Restoration Design Uncertainties in Tidal Freshwater and Estuarine Wetlands



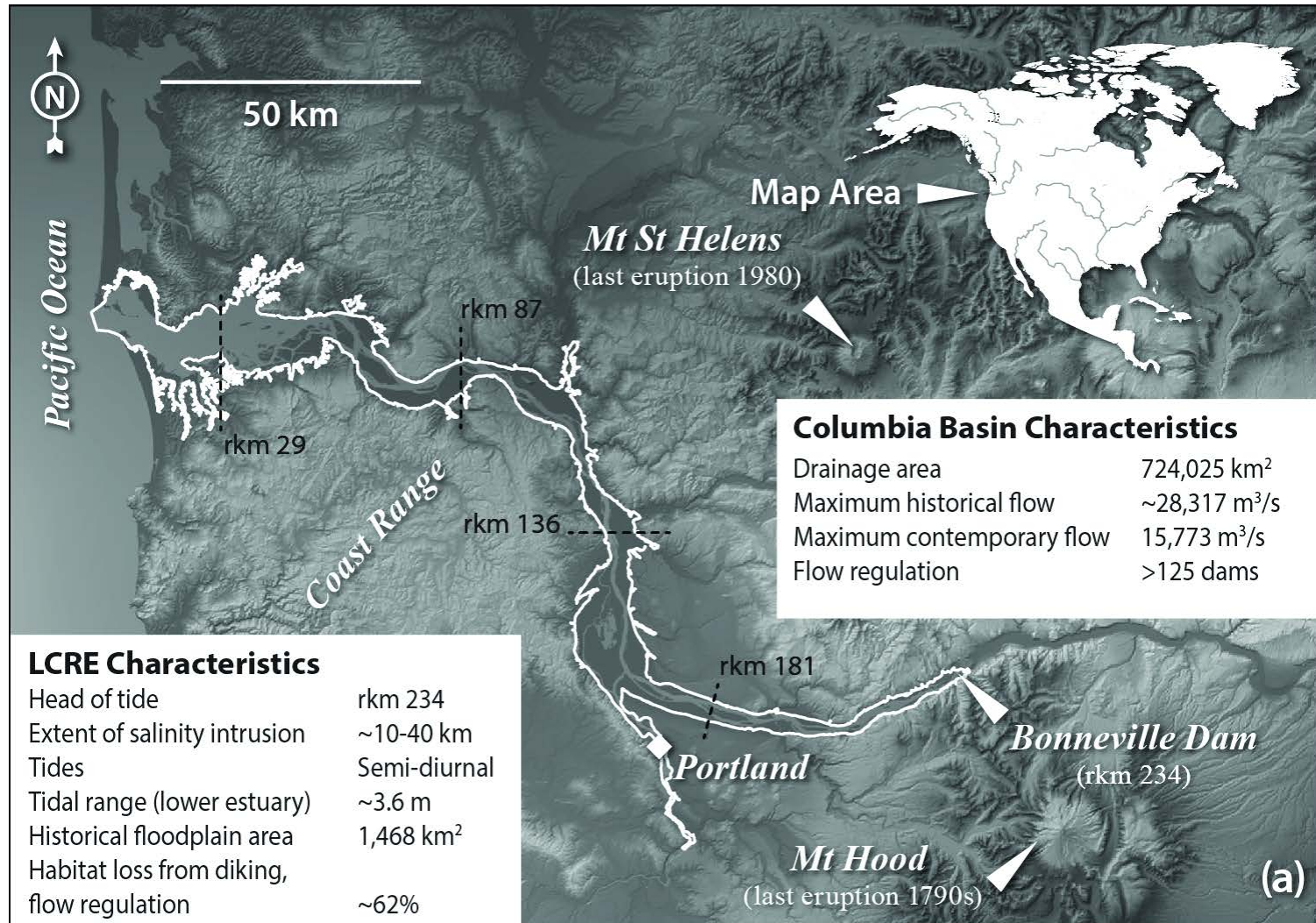
Pacific Northwest  
NATIONAL LABORATORY

Proudly Operated by **Battelle** Since 1965

Primary Restoration Method: Hydrologic Reconnection by Breaching Dikes



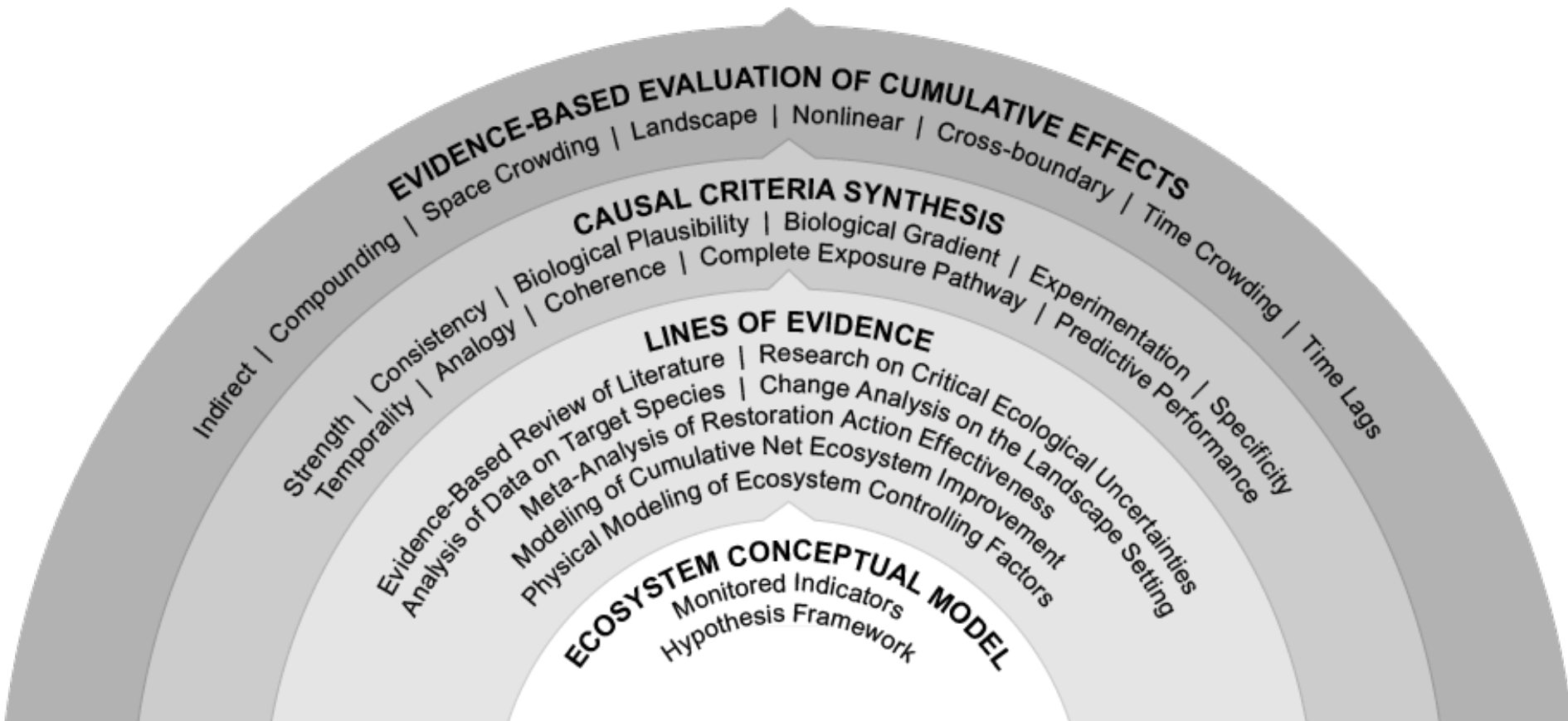
# Study Area: ~1500 km<sup>2</sup> Floodplain of the Lower Columbia River & Estuary



River reaches are defined in Jay et al. 2016 in press, *Estuaries and Coasts*

# Evidence-Based Evaluation: Backbone of the Columbia Estuary Restoration Program

Q: How do we evaluate the cumulative effects of large-scale ecosystem restoration?



A trans-disciplinary method melds evidence-based medicine, cumulative effects assessment, and critical thinking.

Diefenderfer et al.  
*Ecosphere* Article e01242 *in press*

# FY 15: 3 Challenge Modules

- ▶ Mounds
- ▶ Reed canarygrass
- ▶ Channel networks





# Methods



## 10 PNW Field Sites for Mounds and Reed Canarygrass

### Module-specific Methods

#### ▶ *Mounds*

- Insufficient data for planting success
- Focused field data collection on physical parameters

#### ▶ *Reed Canarygrass*

- Analysis of dataset for vegetation and elevation

- Site surveys

#### ▶ *Channel Outlets*

- Examined GIS datasets
- Analyzed channel outlet counts, perimeter, channel area, wetland area, and island area for > 300 REFERENCE wetlands
- Linear regressions as a function of wetland area



### General Methods

- ▶ Initial Scoping: Features, Environmental Effects, Relevant Site Conditions for Planning, Practical Considerations (e.g., regulatory constraints, cost, constructability, local infrastructure)
- ▶ Outreach to Project Sponsors in the Lower Columbia River and Estuary, funded through the Program
- ▶ Outreach to Practitioners in Adjacent Regions (Puget Sound, Outer Coast) Regarding Lessons Learned and Historical Restoration Sites Suitable for Research
- ▶ Systematic Literature Review

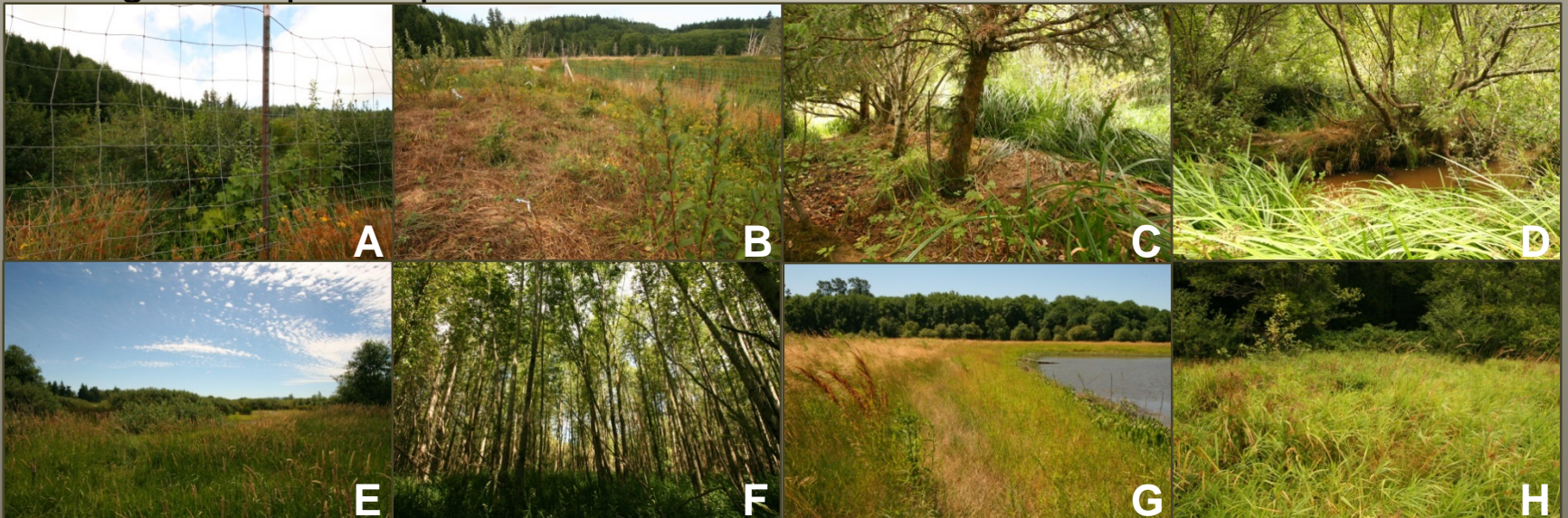
# Challenge Module: Mounds



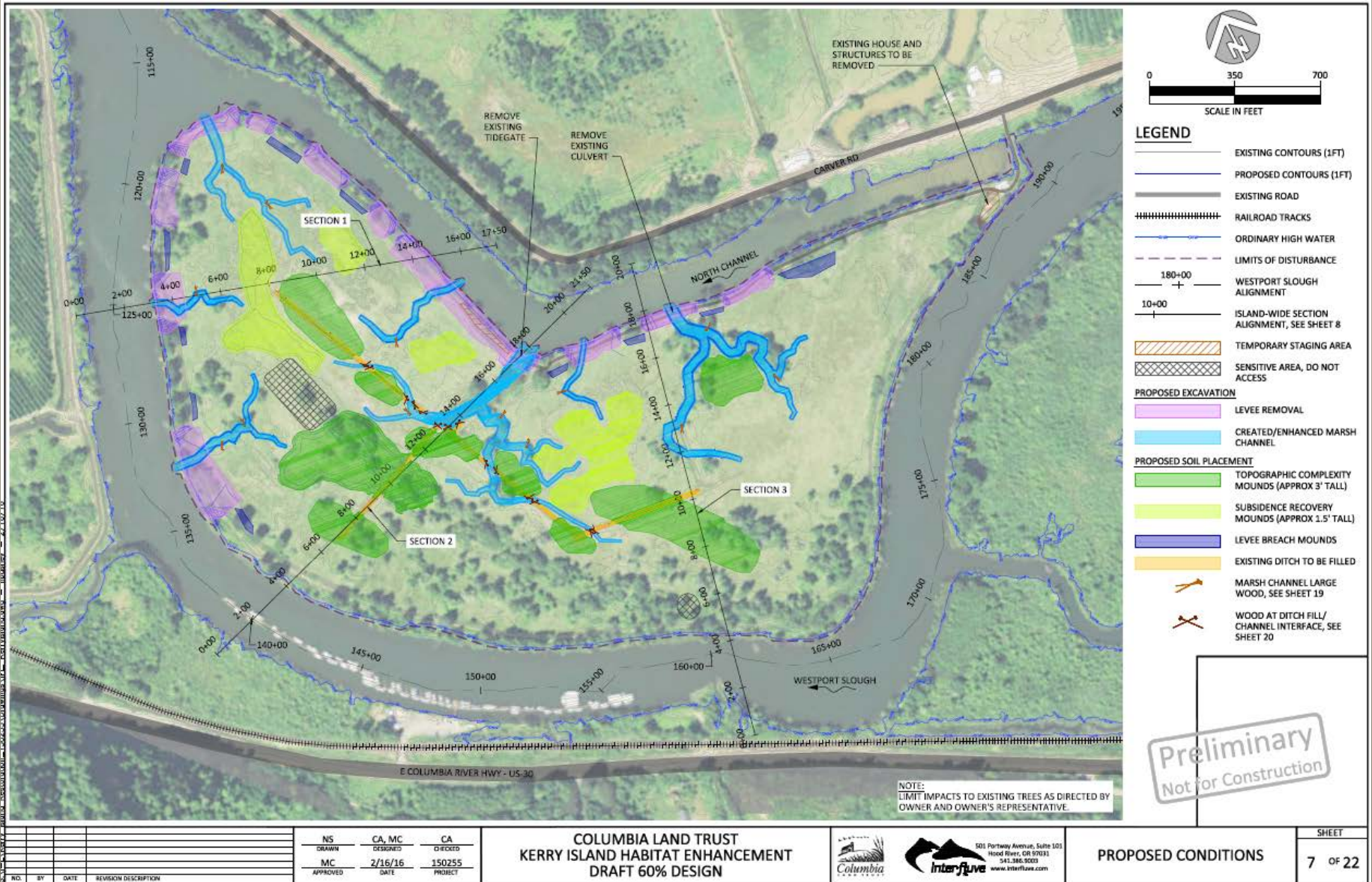


# Challenge Module: Mounds

- ▶ *Mounds* – Mounds or hummocks help defray costs of moving excavated material offsite and have been proposed in CEERP projects to provide topographic diversity with the potential to reduce the impacts of subsidence, accelerate the development of woody plant communities, control reed canarygrass, produce a plant community mosaic, and generally increase habitat complexity at the restoration site.
- ▶ *The design challenge is that science-based construction specifications for mounds (e.g., height, width, aspect, slope) are not well-established regionally.*
- ▶ *What is the right balance between practical concerns and ecological function?*
- ▶ Therefore, research focused on design parameters, and physical and biological response parameters.



# Example Design: Kerry Island



NO.	BY	DATE	REVISION DESCRIPTION

NS	CA, MC	CA
DRAWN	DESIGNED	DIRECTED
MC	2/16/16	150255
APPROVED	DATE	PROJECT

**COLUMBIA LAND TRUST**  
**KERRY ISLAND HABITAT ENHANCEMENT**  
**DRAFT 60% DESIGN**

501 Portway Avenue, Suite 103  
 Hood River, OR 97031  
 541.386.9000  
 www.interfluvio.com

**PROPOSED CONDITIONS**

## Key Findings: Mounds

*All findings from field work in this study must be interpreted in light of the fact that sampling occurred in Summer 2015 at or near mid-day and that ambient air temperatures were very high relative to historical averages and trends.*

- ▶ Soil moisture stratified with elevation
- ▶ Planting success has been variable; often requires multiple years of planting for establishment
- ▶ The tree species develop variable shading properties with mature canopies, which are important for reed canarygrass control
- ▶ Stratification of soil temperature was less conclusive but temperature appeared to positively vary with elevation
- ▶ Mound aspect appeared to be less important to temperature and moisture than hypothesized
- ▶ Qualitatively observed differences in plant mortality and the vigor of plantings appeared to correspond to differences in soil organic matter and moisture
- ▶ Variable effects of size and configuration
- ▶ Corresponding recommendations for restoration design and planning are presented in the report along with remaining uncertainties

# Challenge Module: Reed Canarygrass



## Challenge Module: Reed Canarygrass

- ▶ Reducing the extent of invasive reed canarygrass in the extensive tidal freshwater region of the LCRE is thought to facilitate establishment of native plant communities, improve food web dynamics, prevent floodplain armoring, allow passive channel formation, and avoid barriers to establishment of natural benthic communities. Concurrent research into reed canarygrass function is ongoing through BPA's Ecosystem Monitoring Program.
- ▶ *The design challenge is that science-based construction specifications for topography (e.g., elevation, slope) and specific biological control methods to prevent or eliminate reed canarygrass are not well established in **tidal** freshwater ecosystems.*
- ▶ *What is the best way to achieve practical results and biological control in context of a tidal-fluvial system?*
- ▶ Therefore, research focused on environmental conditions for establishment, and control methods through site design or treatment.

# Outreach Summary: Reed Canarygrass

- ▶ Control using inundation (impounded water) is not feasible in tidally reconnected restoration sites
- ▶ Control by scrape down has uncertainties (long-term accretion) and produces material requiring disposal
- ▶ Control using woody plants is a core strategy; mounds are a key method of establishing them
- ▶ Shading does not maintain a diverse understory
- ▶ With a strong understanding of the site and multiple years of management, reed canarygrass can be controlled with a multi-factor approach, but this has not been adequately demonstrated in tidal areas
- ▶ **Planners are either scraping down or building mounds; mid-elevations (high-marsh) are trending to reed canarygrass**



# Reed canarygrass Elevations: Design for Low Marsh, High Marsh, or Shrub

## Wetland Elevation Ranges by River Mile

<b>River Mile</b>	<b>5</b>	<b>10</b>	<b>15</b>	<b>20</b>	<b>25</b>	<b>30</b>	<b>35</b>	<b>40</b>	<b>45</b>	<b>50</b>	<b>55</b>	<b>60</b>	<b>65</b>	<b>70</b>	<b>75</b>	<b>80</b>
<b>River Kilometer</b>	<b>3</b>	<b>6</b>	<b>9</b>	<b>12</b>	<b>16</b>	<b>19</b>	<b>22</b>	<b>25</b>	<b>28</b>	<b>31</b>	<b>34</b>	<b>37</b>	<b>40</b>	<b>43</b>	<b>47</b>	<b>50</b>
Lower Marsh Elevation	5.0	5.0	4.1	3.2		3.2	3.1	3.6			2.9			4.2	3.8	4.4
Lower RCG Elevation	NA	NA	NA	8.1	8.0	6.8	6.8	5.4	5.7	5.8	5.8	6.0	6.2	6.3	6.4	6.6
Lower Shrub Elevation		10		9.2			9.1	7.4			7.8	8.1		8.3	8.4	8.9
<b>River Mile</b>	<b>85</b>	<b>90</b>	<b>95</b>	<b>100</b>	<b>105</b>	<b>110</b>	<b>115</b>	<b>120</b>	<b>125</b>	<b>130</b>	<b>135</b>	<b>140</b>	<b>145</b>	<b>150</b>	<b>155</b>	<b>160</b>
<b>River Kilometer</b>	<b>53</b>	<b>56</b>	<b>59</b>	<b>62</b>	<b>65</b>	<b>68</b>	<b>71</b>	<b>75</b>	<b>78</b>	<b>81</b>	<b>84</b>	<b>87</b>	<b>90</b>	<b>93</b>	<b>96</b>	<b>99</b>
Lower Marsh Elevation		5.6		5.9	5.8		5.6	6.2		6.6			7.4	8.0	7.7	
Lower RCG Elevation	6.9	6.9	7.1	7.2	7.4	7.7	8.0	8.1	8.2	8.4	8.7	8.7	8.8	8.9	9.0	9.2
Lower Shrub Elevation		9.2		8.6	8.6			10.0		10.9		14.0	9.8	13.1	10.8	
<b>River Mile</b>	<b>165</b>	<b>170</b>	<b>175</b>	<b>180</b>	<b>185</b>	<b>190</b>	<b>195</b>	<b>200</b>	<b>205</b>	<b>210</b>	<b>215</b>	<b>220</b>	<b>225</b>	<b>230</b>		
<b>River Kilometer</b>	<b>103</b>	<b>106</b>	<b>109</b>	<b>112</b>	<b>115</b>	<b>118</b>	<b>121</b>	<b>124</b>	<b>127</b>	<b>130</b>	<b>134</b>	<b>137</b>	<b>140</b>	<b>143</b>		
Lower Marsh Elevation						9.6	10.7	10.2		10.4		12.7		12.0		
Lower RCG Elevation	9.4	9.7	10.2	10.5	10.8	11.2	11.6	12.5	13.0	13.5	13.9	14.2	14.3	15.1		
Lower Shrub Elevation						14		13	15			16		17		

Elevations are in feet, NAVD88

# Reed Canarygrass Conceptual Diagram

Shrub



High Marsh

500-1200 g/m<sup>2</sup>/yr



Low Marsh

100-500 g/m<sup>2</sup>/yr



(Hanson et al., 2015)

RCG (vs Carex):

- More standing stock remains in winter
- Lower Nitrogen content
- Decomposes more slowly
- Differences in prey community

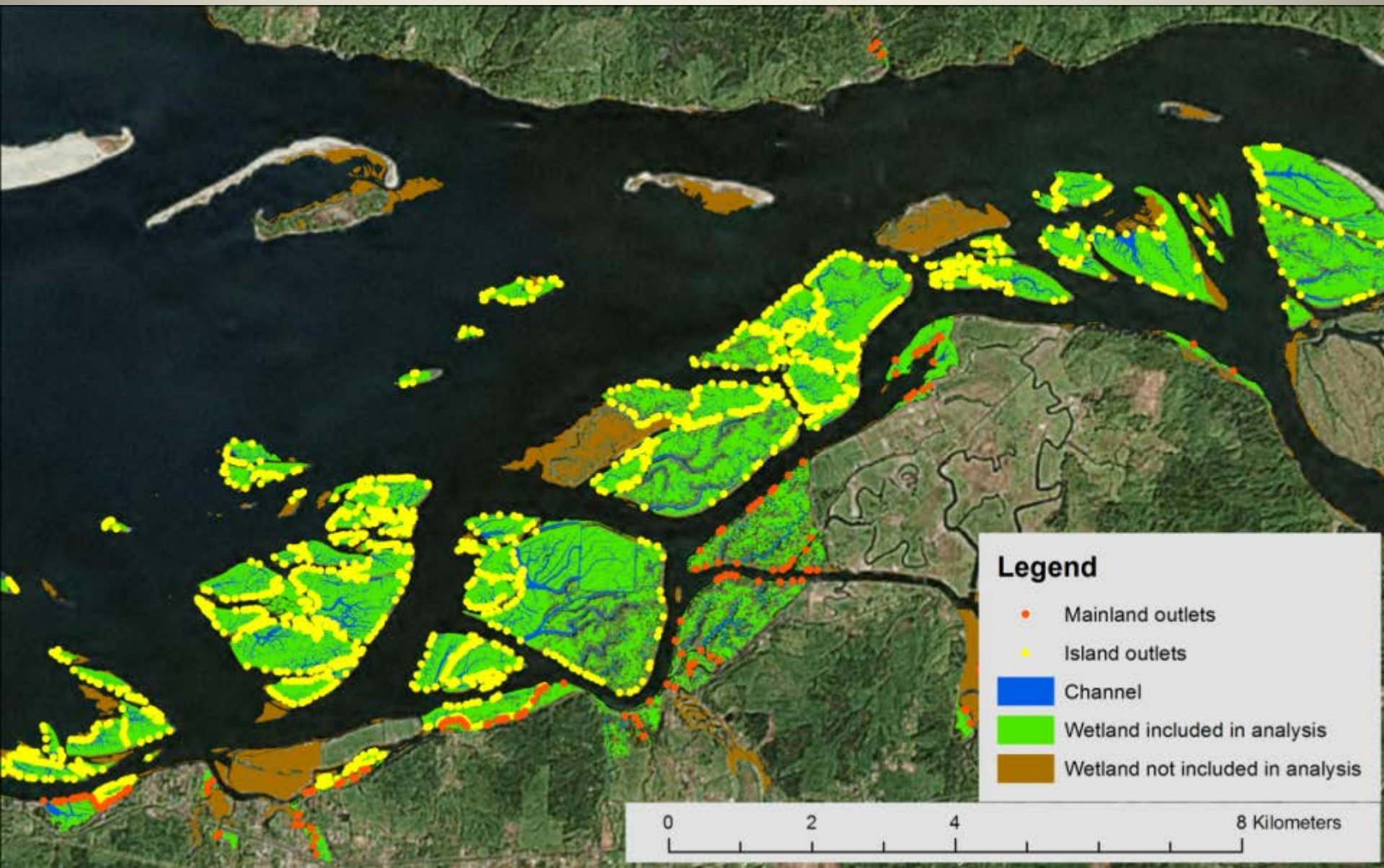
(Hanson et al., 2016)



# Findings of Literature Review and Field Data Analysis Led to Implications for Practice

- ▶ Consider the potential loss of high marsh resulting from control methods focused on establishing high and low elevations.
- ▶ Combine multiple methods for multiple years to achieve control effects.
- ▶ Comprehensive site preparation prior to restoration may be more effective and cost efficient than post-restoration control.
- ▶ Consider control at the largest possible scale, at minimum, the site.
- ▶ Plant or seed strong competitors to fill aboveground and belowground niches.
- ▶ Planting designs should consider the fact that effects of woody species on light change as they mature (e.g., *Salix lucida* and *Fraxinus latifolia* do not shade the understory at maturity).
- ▶ Policy context: (1) the majority of projects/sponsors do not have funding for post-restoration stewardship or maintenance. Thus, it is practical and less expensive in the long run to control reed canarygrass to the greatest extent possible during the restoration project; (2) experimental study of control methods in unconstricted tidal regions is recommended.

# Challenge Module: Channel Connections

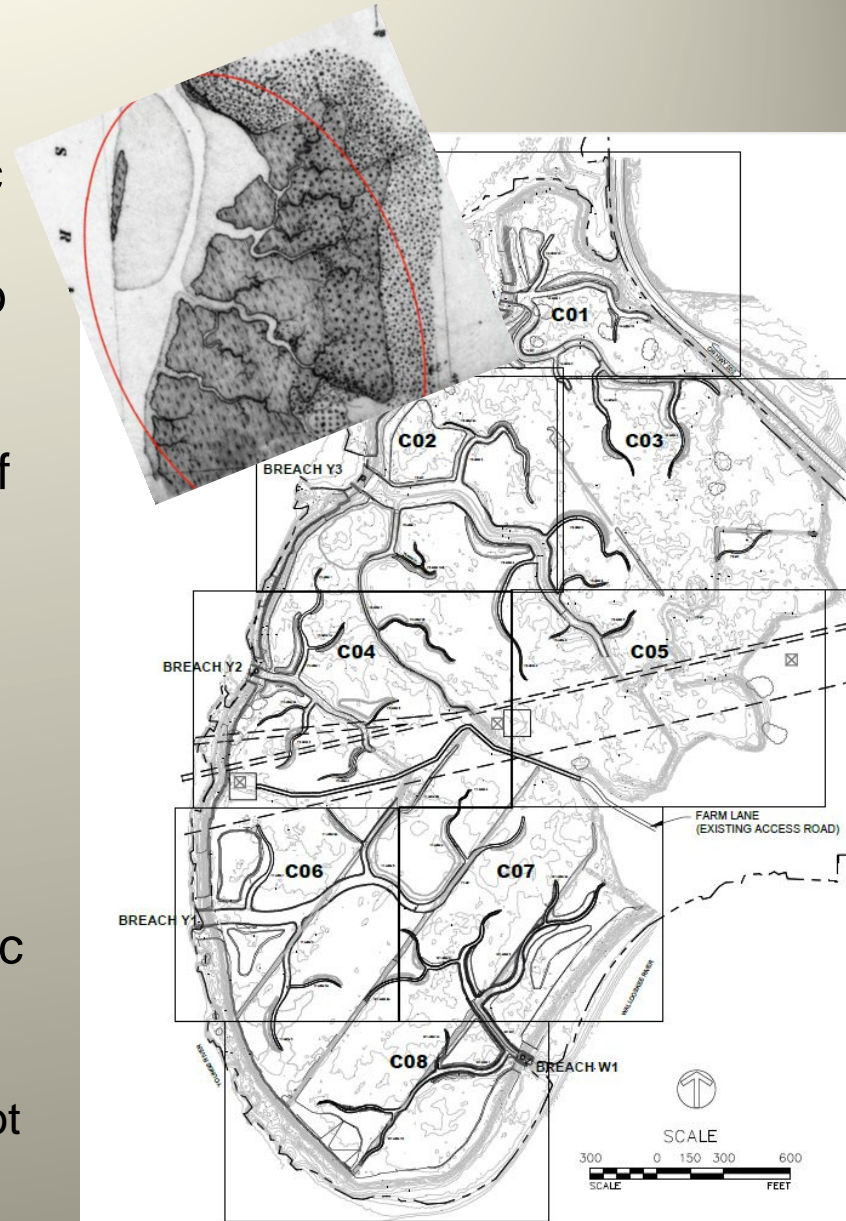


## Challenge Module: Channel Networks

- ▶ Optimal channel network design (e.g., density, number of outlets) results in establishment of natural channel-forming processes, increased fish access, improved hydrologic connectivity and associated fluxes of nutrients and materials into and out of restored wetlands.
- ▶ *The design challenge is that science-based construction specifications for channel networks (e.g., number of outlets, extent and dimensions of excavation, passive versus active channel formation) are not well established for the tidal-fluvial system.*
- ▶ *What are the considerations to optimize channel network design to achieve an unimpeded hydrologic regime for a given site and position in the LCRE?*
- ▶ A large number of metrics for morphometry and morphology, and through practitioner outreach we prioritized number of channel outlets (also called channel confluences), an area of high uncertainty

# LCRE Outreach & Literature Review Summary: Channel Networks

- ▶ Practitioners seek to restore site-specific historical channel networks
- ▶ Many practical considerations weigh into design (infrastructure, land use, stakeholders, cost benefit analysis)
- ▶ Level of caution regarding applicability of findings from other tidal environments
- ▶ Concerned about rules of thumb for channel outlets derived from tidal areas being applied to fluvial portions of LCRE (upriver or tributary)
- ▶ Few papers directly relevant to the engineering of channel-outlet density
- ▶ The most relevant papers used allometric approaches as basis of design recommendations
  - Typical focus on channel morphology, not channel network morphometry, for dependent variables



## Findings: Channels – Variability

- ▶ High variability of channel network properties within reaches.
- ▶ Using reach-mean or median values as a guide for restoration project design is not recommended (no “lookup table”)

### Number of Outlets per Wetland, for Mainland Wetlands:

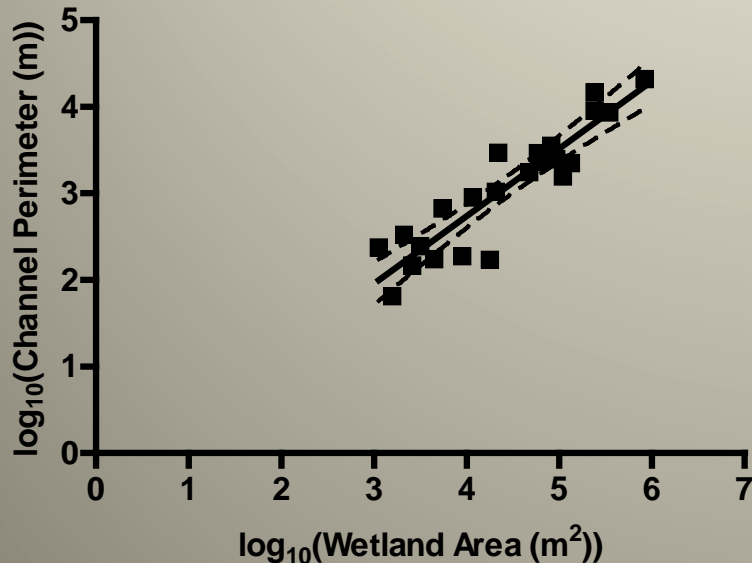
Reach	N	Mean	SD	Min.	Q1	Med.	Q3	Max.	CV (%)
A	24	6.46	9.75	1.00	1.00	2.50	7.75	41.00	151
B	60	5.58	7.44	1.00	1.00	2.00	6.75	33.00	133
C	22	2.91	2.67	1.00	1.00	1.50	5.00	9.00	92
D	5	1.20	0.45	1.00	1.00	1.00	1.50	2.00	37
E	19	1.21	0.71	1.00	1.00	1.00	1.00	4.00	59
F	28	2.36	3.76	0.00	1.00	1.00	2.00	20.00	160
G	2	1.50	0.71	1.00	*	1.50	*	2.00	47
H	4	1.50	1.00	1.00	1.00	1.00	2.50	3.00	67

- Variability among channel networks on wetland islands was also high: e.g., range from 1 to 69 channel outlets

# Best Fit Linear Models For Mainland Reaches

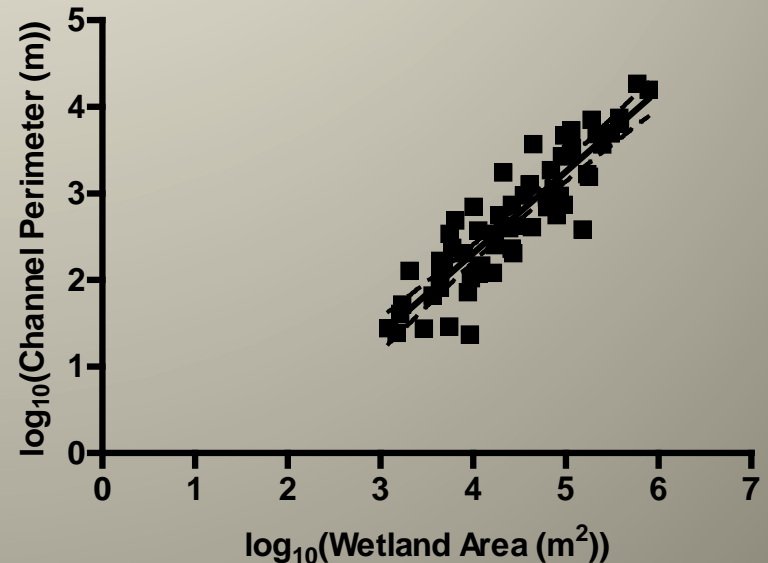
Greater than 80% of the variance explained for Channel Perimeter as a function of wetland area in individual models for reach A and reach B wetlands on the mainland only

$$y = -0.38 + 0.78 (\log_{10} \text{wetland area})$$



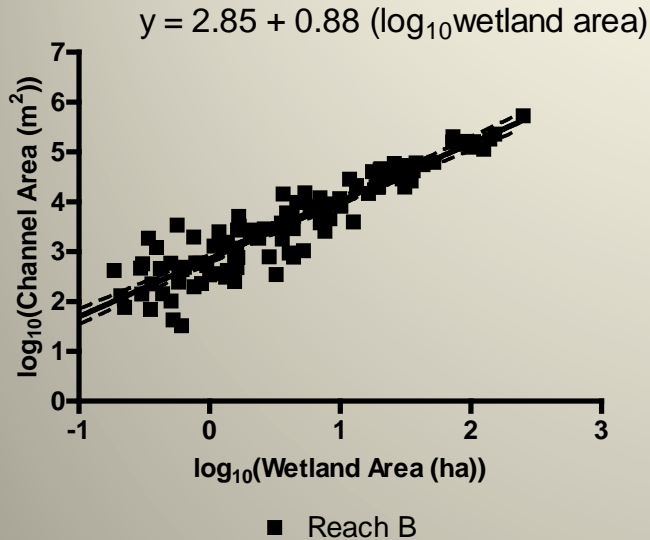
■ Reach A

$$y = -1.46 + 0.94 (\log_{10} \text{wetland area})$$

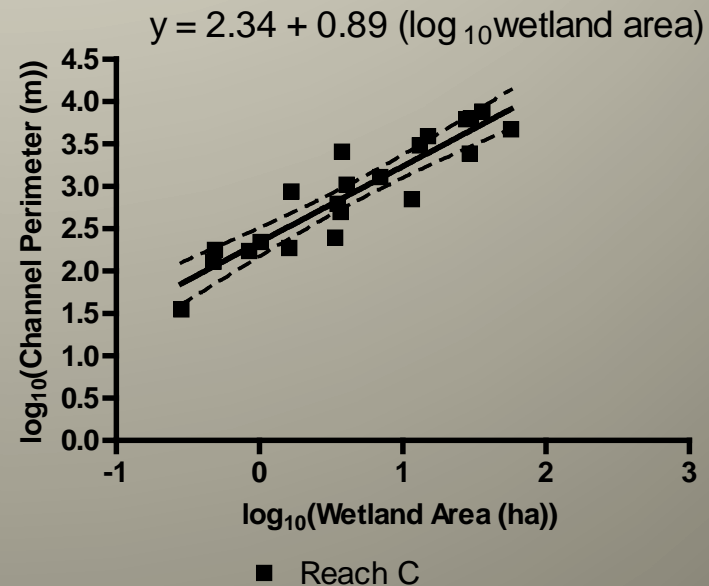
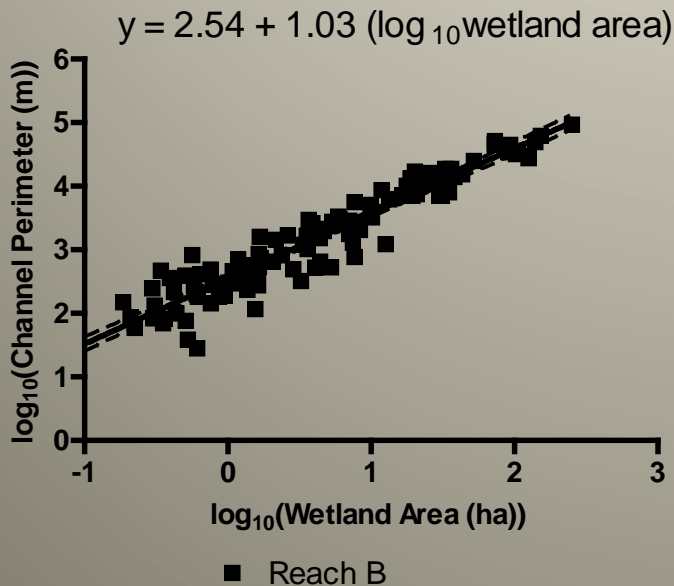


■ Reach B

# Best Fit Linear Models For Islands



Greater than 80% of the variance explained for Channel Perimeter as a function of wetland area in individual models for reach B and reach C island wetlands, and Channel Area for Reach B



## Implications for Practice: Channel Outlets (and Channel Perimeter and Channel Surface Area)

- ▶ Five models developed could be consulted in addition to routine methods, but none are for reaches with fluvial hydrology. In contrast to previously published research, we do not believe these models should be viewed as prescriptive given the variability in these metrics even between sites within reaches.
- ▶ The practitioners' approach based on historical channel network design, is not inferior to regression models.
- ▶ In many cases, island marsh geomorphology is inherently different than mainland sites, so reference information for one should only be applied to the other with care.
- ▶ The landscape setting is important to identifying the number of channel outlets, e.g., features such as proximity of upland slopes, and location of waterways relative to the wetland area of interest.



# Adaptive Management Cycle: It's not “magic” between monitoring and restoration



- ▶ Using monitoring data, the Restoration Design Challenges work performs **analysis, synthesis, and evaluation** as the basis of learning in the CEERP process
- ▶ 2016 marked the 5<sup>th</sup> complete Adaptive Management cycle in the Columbia Estuary Ecosystem Restoration Program

# Acknowledgements



We thank Bonneville Power Administration  
for sponsoring this research.

Questions?

Contact Information  
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# ANNEX: Initial Scoping: Key Elements of RDCs

## 1. Topographic Mounds

- a. Features (e.g., height, slope, material)
- b. Environmental Effects (e.g., soil temp, time to plant establishment)
- c. Relevant Site Conditions for Planning (e.g., historical and existing topo, sediment regime, plant community)
- d. Practical Considerations (e.g., regulatory constraints, cost, constructability)

## 2. Reed Canarygrass Control

- a. Features (e.g., inundation/salinity tolerance, reproductive strategies)
- b. Environmental Effects of Control (e.g., plant community, food web, channel formation)
- c. Relevant Site Conditions for Planning (e.g., elevation, hydrologic regime, growth form)
- d. Practical Considerations (e.g., regulatory constraints on control, cost)

## 3. Channel Network

- a. Features (e.g. channel density, sinuosity, number of hydrologic connections, confluences)
- b. Environmental Effects (e.g. salmon habitat opportunity, flux)
- c. Relevant Site Conditions for Planning (e.g., historical/current channel network, tidal prism, levees; plant community; landscape position)
- d. Practical Considerations (e.g., local infrastructure)

# LCRE Outreach and Literature Review

## Summary: Mounds

- ▶ *Outreach*: Cost of disposal is a primary driver
- ▶ Considerations include mimicking natural topography, but ultimately driven by quantity of material
- ▶ Considerations include providing habitats with trees and shrubs; possibility of shading other habitats
- ▶ Primary design guideline is elevation: below the 2-yr flood and/or regulatory limits on jurisdictional wetlands
- ▶ Biological components (eg affect of aspect and slope on moisture and radiation), soil type, and OM are not currently considered
- ▶ *Literature*: Planting success has been variable; often requires multiple years of planting for establishment
- ▶ Papers tended to focus on microtopography (height or elevation), soil and nutrients, and function
- ▶ Little evidence available for tidal or tidal-fluvial marshes
- ▶ Some findings indicate differences in environmental controls (moisture, temperature) based on aspect, elevation



## Implications for Practice: Channel Outlets (and Channel Perimeter and Channel Surface Area)

- ▶ Five models developed could be consulted in addition to routine methods, but in contrast to previously published research we do not believe these should be viewed as prescriptive given the variability in these metrics even between sites within reaches.
- ▶ No predictive models for response variables could be developed for 4 of 8 reaches; and none for channel outlets for any reach (highest  $R^2$  for outlets 73% for mainland and 69% for islands).
- ▶ Consequently, the practitioners' approach based on historical channel network design, is not inferior to regression models.
- ▶ In many cases, island marsh geomorphology is inherently different than mainland sites, so reference information for one should only be applied to the other with care.
- ▶ The landscape setting is important to identifying the number of channel outlets, e.g., features such as proximity of upland slopes, and location of waterways relative to the wetland area of interest.

## Findings: Channels - Linear Regressions

- ▶ Few good predictive models (defined as  $R^2 > 80\%$  for engineering purposes) for all specific combinations of reach, island or mainland position, and response variable
- ▶ The 5 predictive models were in the lowest three reaches of the river.
  - 4 for channel perimeter, 1 for channel area, and 0 for outlets
- ▶ Mainland: For each dependent variable, the slopes were significantly different among reaches. For all but one case, use of a *common slope for all reaches* in the model causes  $R^2$  to drop below 78%
- ▶ Island: For each dependent variable, the slopes were not significantly different among reaches A,B,C.  $R^2$  for the common slope models were  $R^2 = 84\%$  (area), 89% (perimeter), and 69% (outlets)