A Geospatial Tool for Wetland Prioritization at the Watershed Scale

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Abstract

There is an increasing demand for assessing ecosystem functions for freshwater wetlands, especially when comparing or prioritizing among wetlands at the watershed scale. We estimated the relative potential of selected ecosystem functions for freshwater wetlands within a watershed using widely available geospatial data. We developed four functions to estimate 1) flood storage, 2) late season flow, 3) sediment retention and 4) temperature control in four pilot watersheds in Oregon (Tualatin, Coquille, Upper Grande Ronde and Sprague). These watersheds are geographically separated from each other representing diverse ecoregion environments. Spatial analysis and geographic information system (GIS) were designed for maximum re-use, based on publicly-available data, commonly-used software, semi-automated techniques and wetland characterizations that attempt to capture fundamental wetland processes. Our data sources include 30-meter digital elevation models, NRCS soil survey extracts, USGS National Land Cover Data, USGS HUC8 boundaries (polygons) and statewide wetland delineations (polygons) processed within ArcGIS 10.2 and Python 2.7.5 software. Model parameters were compiled using multiple proxy values for size, slope, aspect, proximity, flow path distance, hydrologic gradient, shade, and soil characteristics. WPT characterizations emphasize the multi-faceted value of freshwater wetlands, relating potential within a watershed as well as providing model-based characterizations between watersheds. Our wetland prioritization tool (WPT) provides useful information to estimate and compare the relative potential for selected wetland functions, thereby improving success in wetland conservation, restoration, and mitigation efforts.

Keywords: wetland, freshwater, watershed, ecosystem function, GIS, Oregon, conservation.

Contents

Introduction

This report details a subset of research for the 2013 EPA Wetland Program Development Grant, to the Institute of Natural Resources and Portland State University or "INR-PSU", a two-year effort ending September 2015. The overall project objective is to "improve success in wetland conservation, restoration, and mitigation efforts in Oregon", which is divided into four components. The scope of this report is "Component 1. Add hydrological modeling to attribute services and functions to individual wetlands in the state wetlands geodatabase".

Component 1, a.k.a. the Wetland Prioritization Tool (WPT) provides a technique to estimate the potential for specific wetland functions: 1) flood storage, 2) late season flow, 3) sediment retention and 4) temperature control, with relative comparisons within a watershed.

Wetlands in Oregon

Wetland environments vary significantly within Oregon, occurring within nine (9) distinct Level III ecoregions (Figure 1), areas where environmental resources are of similar type, quality and quantity (Wiken, Nava & Griffith, 2011). Across the State, approximately 206,000 individual wetlands have been identified (ONHIC/TWC 2009), with 71% classified as "palustrine" (Table 1) plus special categories for palustrine environments such as playa, vernal pool and wet prairie.

The current Oregon Wetlands Geodatabase attributes wetlands for water provisioning services based on small-scale, watershed-level characteristics. It is desirable to classify wetland functions on a more detailed level; however, with over 205,000 wetlands in Oregon, it is not feasible to perform field observations for all of these sites. GIS-based hydrological analysis and modeling for individual wetlands could "significantly improve the quality and usability of wetland information in the geodatabase" (INR-PSU 2013). Toward that goal, the wetlands were organized into wetland complexes based primarily on proximity but with manual adjustments, that is, wetlands within 100 meters of one another are identified as a unique “wetland complex” (Kagan et al. 2013, INR 2013). Approximately 118,000 wetland *complexes* were created using this aggregation method, a.k.a “Project Data”.

Study Area

Oregon hydrologic drainage patterns are dominated by discharge into the Pacific Ocean, with additional flows as part of the Great Basin and California Hydrologic Regions (USGS and USDA 2012). Project data identifies eighty (80) subbasins at the 8-digit hydrologic unit classification (HUC8) contained in whole or in part within state boundaries (Bauer 2013). Of these, four were chosen to represent a variety of Oregon wetlands: Coquille, Sprague, Tualatin, and Upper Grande Ronde. Criteria for the selections included whether the basins: 1) are representative of multiple Level III ecoregions; 2) are wetland-rich relative to total HUC8 basin area; 3) are expected to have overall high ecosystem function value and have “understandable” watershed hydrology, based on expert opinion; 4) have a mix of human population densities (urban vs. rural) and human modifications (natural vs. man-made environments); and 5) are of interest to the project team and beyond, based on known research and publications.

Pilot subbasins were selected to represent multiple ecoregions with emphasis given to HUC8 basins which are: a) rich with wetlands of high overall ecosystem service value, b) have straightforward watershed hydrology, and c) have a mix of natural and human populated or modified lands. The project team selected four (4) HUC8 basins for pilot analysis (Figure 2). Relevant characteristics are summarized in Figure 3.

Coquille

Profile: area, drainage, environment, etc. (Figure 4)

Tualatin

Profile: area, drainage, environment, etc. (Figure 5)

Sprague

Profile: area, drainage, environment, etc. (Figure 6)

Upper Grande Ronde

Profile: area, drainage, environment, etc. (Figure 7)

Data

Data sources and scale are shown in Table 2. Project data defines the basic analysis element (wetland complex) and landscape scale (modified HUC8 boundaries) for the WPT. Additional data were acquired from public sources to maximize re-use of the techniques presented. Standard 30-meter digital elevation model (DEM) can be substituted for the 10-meter DEM used in this study, although lower resolution elevation data will result in coarser calculations and more highly aggregated wetland function estimates.

Methods

Summary

Four Tasks were defined in the INR-PSU grant (Task A, B, C and D, described below). Hydrologic modeling was indicated in the original grant. However, two significant challenges were encountered in preparing for statewide analysis. First, hydrologic models such as InVEST and SWAT often require flow and discharge information from gaging stations. The number and spatial distribution of USGS hydrologic gaging stations in Oregon is small, 232, (USGS 2015) compared to the number, scale and distribution of the wetland complexes being studied. Second, hydrologic models are optimized to approximate characteristics of streams and rivers, with no or severely limited ability to process sinks such as wetlands (often referred to as "reservoirs" in documentation). It was deemed more productive to use spatial analysis techniques to model the potential wetland functions.

As a result, the *modified* goal of Component 1 is to rank the relative potential for four wetland complex functions within a HUC8 watershed using spatial analysis of attributes for size, elevation, landscape position (relative to streams), land cover, and selected soil properties (Figure 8). For each study area (HUC8), data is prepared and clipped to the HUC8 boundary, then attributes are derived from source data, area-weighted averages are calculated for each attribute for each wetland complex then normalized by wetland complex within the HUC8, wetland functions are calculated for each "model" or set of equations under investigation (in this case two models were developed, as described below), and finally the modeled wetland function values by wetland complex are normalized within the HUC8.

Software

We performed spatial analysis mainly in ESRI's ArcGIS 10.2 with cost path analysis calculated using Python 2.7.5, for performance reasons. Calculations and statistical graphics were generated using IBM SPSS Statistics 19 and 21 and Microsoft Excel 2010.

Task A: Identify the three to five target watersheds for the analysis

(See description of Study Area, above.)

Task B: Identify and gather the critical datasets and evaluate their utility for modeling

Data sources which provided coverage for the entire State of Oregon were preferred. Ideally, data with consistent, moderate resolution (10-meter) would also be preferred, but was difficult to obtain. For example, NRCS data is provided in high-resolution rasters (1-meter), but coverage does not include all of Oregon lands. Where NRCS soil data is unavailable, permeability values were substituted for soil values, especially Sprague. Note: The high resolution of NRCS data contributes to long processing times. The decision was made to maintain 1-meter resolution for soil data to assure that small wetland complexes (smaller than a 10-meter pixel) would still generate values for soil attributes.

While NHD flowline data provides extensive stream and river networks for statewide analysis, a challenge in using NHD vector files is that they may not match the elevation data, i.e., the location of stream segments may not follow the surface contours. This may occur because of the manner in which the NHD data was created, where data capture occurred at multiple scales. For this study, proximity and distance attribute calculations relied on a NHD feature which was “burned” into the DEM, rather than creating a synthetic stream network.

The INR-PSU grant directed use of Lidar elevation data. In fact, study areas were chosen which had moderate-to-high lidar coverage of wetland complex areas of interest. The contrast of high-resolution lidar data versus the moderately coarse DEM data presented problems in blending results for attribute calculations for wetland complexes where a mix of elevation source data was required. The experience with use of mixed-resolution soil data contributed to a preference to the WPT elevation calculations. Therefore, the 10-meter DEM was used for elevation data, which provided a consistent resolution across the entire state.

Task C: Test methods and attribute wetland functions

Assumptions

Discussions with the project team resulted in modeling of the wetland functions listed in Task D below. After review of relevant literature, project data and further discussion, the following attributes were selected to support the chosen models. Due to the landscape scale of the WPT analysis, preference was given to data types and sources which allowed for analysis without on-site visits.

Much data extraction and analysis was performed using raster layers. Two common exceptions arose in calculating zonal statistics, which resulted in NULL attributes being assigned for specific wetland complexes: 1) the wetland complex was smaller than the raster cell, e.g., values from 30-meter land cover dataset were not assigned to small wetland complexes, and 2) wetland complex polygons were contained within one another. Both cases have workarounds but in this study, wetland complexes with NULL attributes due to these cases were excluded from analysis (Table 3).

Attributes

For each HUC8 watershed, for each attribute, a table of all wetland complexes was created. Within each HUC8, the attribute values are normalized from 0 – 1, where the wetland complex with the largest attribute value is assigned a value of 1 and the wetland complex with the smallest attribute value is assigned a value of 0. An overview of how attributes were extracted and derived is shown in Figure 9.

The design of the attribute table is simple to understand and modify if, for example, expert data was available for selected attribute tables. To demonstrate, the attribute table for slope contains a wetland complex identifier (OBJECTID), the slope average for the wetland complex and the normalized, relative ranking for each wetland complex within the HUC8:

OBJECTID	MEAN	SLOPE_NML
1	10.1152539	0.4013831
2	0.795939477	0.0315837
3	1.345424365	0.0533877
4	1.369849	0.0543569
5	0.68432096	0.0271545

Size For each wetland complex, size = total acres provided in the project geodatabase (INR-PSU 2013). Normalize.

Slope Calculate slope using the 10-meter DEM provided for the project (INR 2013). Buffer each wetland complex by 30 meters to include the area adjacent to the wetland complex, given the 10-meter pixel size of the DEM data. For each wetland complex, calculate weighted-area average slope using zonal statistics for each wetland complex. Normalize.

Shade To approximate the amount of shade for a wetland complex, select land cover data values for forest , specifically deciduous (41), evergreen (42) and mixed (43) (Chang and Psaris 2013). Buffer each wetland complex by 30 meters to include the area adjacent to the wetland complex, given the 30-meter pixel size of the land cover data. Determine the proportion of forested areas within the 30-meter-buffered wetland complex, i.e., the sum of type 41, 42 and 43, using zonal statistics. Normalize.

Aspect Generally speaking, south-facing slopes receive more sunlight and are therefore likely to experience more evaporation than north-facing slopes (Johnson and Wilby 2014). Create an aspect raster from the 10-meter DEM, then create a new raster with value = 1 wherever aspect is south, southeast or southwest (i.e., aspect = 90 - 270 where 0 = due north). Determine the proportion of area facing south within each wetland complex, i.e., aspect_south = 1. Normalize.

Elevation Calculate area-weighted average elevation for each wetland complex using zonal statistics. Normalize.

Proximity For each wetland complex, general landscape position is categorized as it relates to the nearest water feature (NHD flowline) and the 100-year floodplain. Values are assigned from “far” to “close”, then normalized from 0 – 1, with the highest proximity value (farthest from the river) = 1 and the lowest proximity value (closest to the river) = 0.

PROXIMITY	
1	River, within 100 feet
5	Floodplain, 100-year
10	Other

Other. For each wetland complex, the default is assigned, i.e., proximity = 10.

Floodplain. For each wetland complex, determine if the wetland complex intersects the 100-year floodplain boundary. If yes, proximity = 5.

River. The river feature is buffered to 100 feet (NHD flowline). For each wetland complex, a spatial intersection is performed against the buffered river feature to determine if the wetland complex is coincident with the river. If yes, proximity = 1.

Distance Distance represents the length of a hypothetical, computer-generated flow path following the likely surface flow between the pour point of the wetland complex and the nearest water body. For each wetland complex, if proximity = 1, hydrologic interaction is assumed to be likely and therefore distance = 1. If the wetland complex lies beyond the immediate riparian area, i.e., proximity > 1, calculate distance to the water feature. Normalize.

Pour Point. For each wetland complex, locate the pour point. First, condition the DEM in order to calculate flow direction. Generate flow accumulation values and determine the maximum flow accumulation within each wetland complex polygon using zonal statistics. In many cases, multiple pour points are identified by the spatial analysis tool, especially in areas which are flat, i.e., having little variation in elevation. In the case of multiple pour points, if the wetland complex size (total acres) is less than 1.5 acres, it is possible to use the wetland complex centroid as the pour point (force the centroid to be located within the wetland complex polygon). For larger complexes, the pour point must be selected manually given the multiple locations highlighted by flow accumulation comparisons.

Flow Path Length. For each wetland complex, determine if the wetland complex pour point is coincident with the water feature (NHD flowline). If yes, assign distance = 1 foot (to reduce errors in calculations of hydrologic gradient, described below). For remaining wetland complexes, calculate a least cost path from the pour point to the nearest water body (nearest NHD river segment) and calculate the length. Normalized values range from 0 – 1 with the wetland complex with the shortest flow path length = 0, e.g., the 1-foot distances identified when the pour point is coincident with the water feature.

An automated process was developed in Python 2.7.5 to calculate Flow Path because original efforts to use ArcGIS 10.2 Model Builder resulted in extremely slow processes.

Hydrologic Gradient Hydrologic gradient, similar to stream gradient, measures the change in elevation between pour point of wetland complex and intersection with nearest water body (NHD stream segment) divided by length of flow path. End-point elevations (start and end) are extracted for each flow path line from the distance calculations (above). Hydrologic gradients range from 0-1 so no further normalization is required. This index was developed to consider not only the speed but also the travel time of flow.

$$\text{HYDROLOGIC GRADIENT} = \frac{\Delta\,\text{elevation}}{\text{flow path length}}$$

Soil Properties

Where NRCS data is available for the entire HUC8 watershed, rasterize values for each attribute then calculate zonal statistics for each wetland complex. Calculate soil values and wetland functions in attribute tables.

Where NRCS data is not available, first rasterize NRCS attributes and then non-NRCS attributes ("R6", provided for this study by INR), then merge into a single raster. For each pixel, give priority to NRCS. In other words, if NRCS data is available, use it, otherwise, use non-NRCS values. Calculate soil values for each wetland function in a raster layer then perform zonal statistics for these intermediate soil values for each wetland function, i.e., flood storage. Calculate wetland function estimates in attribute tables.

Percent Clay. For each HUC8 watershed, identify which Oregon counties which lie within the HUC8 boundary. Using the online Web Soil Survey tool (USDA-NRCS WSS 2013), download the soil survey data for each county which is wholly or in part within the HUC8 boundary. Using the Soil Viewer in ArcGIS, for each soil within the HUC8 boundary, map percent clay as a weighted average of all vertical horizons. Clip and merge the soil surveys by HUC8.

For each wetland complex, using the rasterized polygon, perform zonal statistics to identify the average percent clay within the wetland complex boundaries. Normalize.

Available Water Supply (AWS). Repeat the process for Percent Clay, substituting the property AWS when mapping in the Soil Viewer. The wetland complex with the highest average AWS will result in a normalized AWS = 1.

Hydrologic Soil Group (HSG). Repeat the process for Percent Clay for each of three HSG types when mapping in the Soil Viewer: C poorly drained, D for very poorly drained and C/D for HSG type C and D together. These types are often associated with hydric soils in wetland environments. Determine the proportion of HSG soils within the wetland complex, i.e., the sum of type C, D and C/D. Note: HSG types are recorded as text, therefore each of the three downloads will need to be reclassified to a number to support further processing. These numbers do not represent a natural ordering, i.e., they are nominal classifications. As a result, the normalizations are based on the average proportion of each HSG type within the wetland complex, i.e., the wetland complex with the highest proportion of C, D, and C/D soils respectively will result in a normalized HSG value = 1 for that HSG type.

Task D: Model hydrological attributes across the watershed

For each HUC8, a master attribute table was compiled with all wetland complexes and all project attributes (Table 4). For each wetland complex, four potential wetland complex functions were calculated: 1) flood storage, 2) contribution to late-season flow, 3) sediment retention and 4) temperature control or regulation. Values for each model were added to the master attribute table (Table 5). Each attribute was deemed to enhance or diminish the potential for the wetland function, thereby resulting in a "+" or "-" rating for each functional calculation (Tables 6 and 7).

Variations of these "+" and "-" ratings, individual formulas, and attribute combinations were tested in iterations, and modified based on modeling results, literature review, and consultation with the project team.

Multiple attributes were generated to represent landscape gradient (slope and hydrologic gradient) and to represent landscape position relative to the river feature (proximity and distance). The initial suite of wetland function calculations used the simpler attributes for landscape gradient (slope) and landscape position (proximity). After discussion with the project team, multiple models were suggested and trials executed. Eventually, a second suite of wetland function calculations was selected to represent the use of more complex versions of these landscape attributes (hydrologic gradient and distance). A comparison is shown in Figure 10, formulas in Tables 8 and 9. Visual representations of the model equations are shown in Figures 11, 12 and 13.

Results

Correlations between functions

Analysis began with bivariate correlations between wetland functions within each model, using a simple Pearson correlation coefficient, “r”. (Figures 14, 15, 16 and 17 for Model 1, Figures 18, 19, 20 and 21 for Model 2). Consistent positive correlations were identified between flood storage and temperature control for all four watersheds regardless of the models used in the study, while consistent negative correlations were found between flood storage and sediment retention and sediment retention and temperature control across the four watersheds.

Model 1 functions for flood storage, late season flow, and sediment retention rely on proximity, which is a highly abstracted attribute with only three values, 1, 5 or 10. While negative correlations are shown for comparisons between “proximity” functions (e.g., flood storage and late season flow), it is likely that a more accurate correlation would be created if each proximity class was analyzed separately.

Correlations between models

Evaluation continued with correlations between Model 1 and Model 2 for each watershed for each of four wetland functions (Figures 22, 23, 24 and 25). In general, the two models are in good agreement, as shown by higher significant r values for all functions. A one-to-one relationship indicates a redundant model. Case in point, temperature control does not vary from Model 1 to Model 2 (since measures of slope and distance are not part of the temperature control formula). This duplicative relationship results in an “r” value of 1.0. Excluding temperature control function, flood storage has the highest correlation coefficient, followed by sediment retention and late season flow (except Upper Grande Ronde where late season flow has a higher r value than sediment retention).

Clustering of the scatterplots is evident, perhaps from the influence of "proximity" classifications. In the case of Sprague, which contains large areas without NRCS data, it might be valuable to analyze the NRCS areas separately from those without NRCS data to determine whether formula modifications or alternate soil data would improve the results.

Results by watershed

This study did not attempt to create comparisons between watersheds. Rather, estimates of wetland function were normalized *within* each of the four pilot watersheds. As a summary, relative results for each watershed are displayed in boxplots by wetland function, by watershed for each of two Models (Figures 26 and 27). As shown the thickness of box-whisker plots, for the middle 50% of wetland functions, model 1 estimate are more widespread compared to the model 2 estimates. Across the four study watersheds, flood storage has the highest value compared to the other three functions. Temperature control function exhibits the lowest in both Coquille and Tualatin where mean elevations are the lower compared to the other two inland watersheds. Individual attributes are also presented for reference (Figures 28, 29 and 30). Note that Sprague soil values for AWS, % clay and HSG were not available as input attributes due to the merging of NRCS and non-NRCS data.

Discussion

Assumptions about wetland Functions

Formulas and assumptions made in this study have been carefully documented to encourage discussion. Most important is the potential to improve management of wetlands: Can the WPT shed light on previously unknown wetland functions and their relationship to the landscape and soil. Modifications of the formulas and assumptions used in the current study might improve wetland function estimates. For example, would base flow data improve calculations of the potential for late season flow? What if flexible riparian zones were used rather than 100 year floodplain for proximity estimates?

Data sources and processing

Data sources have also been selected to encourage experimentation and dialog. Decisions to use publicly-available data to derive landscape attributes and to create simple, editable attribute tables, were designed to make the WPT more understandable, more accessible and more reusable. As with function formulas, there is room for modification. For example, our use of USGS NLCD data to estimate forest land covers could be replaced by percent canopy, which might provide a better estimate of shading. Our analysis relies on data organized at different spatial resolutions. For example, we used 1m soils, 10m DEM, and 30m land cover data. While using 1-meter resolution soil data provided accurate estimates of soil information for each wetland complex, it was computationally demanding for processing the data.

Automation

If the WPT is to be reused for statewide analysis, many processes can be automated. ArcGIS provides Model Builder for simple techniques and is somewhat self-documenting. It is recommended that Python be used for faster processing.

Conclusions

This study seeks to estimate the potential for selected wetland functions in the State of Oregon at the wetland complex level. The Wetland Prioritization Tool (WPT) was designed to be straightforward and easy-to-replicate, using tools and techniques which approximate basic wetland processes. Resulting can complement field observations and measurements if available and enhance decision-making capabilities where field data does not exist.

The primary benefit of estimating the potential for wetland functions at a watershed-scale is to improve the ability to prioritize wetlands in the State of Oregon for conservation, restoration and mitigation. Use of the WPT may: 1) reduce the time and resources required to evaluate and compare wetland complexes, 2) enhance existing field data which has been collected by people with varying degrees of subject matter expertise, 3) provide information about timing and site selection, thereby improving the efficiency of field work, and 4) offer potential guides for wetland conservation and management.

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Tables

Table 1. Oregon Wetlands by wetland type

wetland type	count	%
1-palustrine (freshwater)	129,924	71.1%
2-pond	44,279	24.2%
7-tidal mud flat	1,072	0.6%
8-salt marsh/swamp	1,473	0.8%
9-playa	3,317	1.8%
10-vernal pool	173	0.1%
12-wet prairie	2,606	1.4%
total	182,844	100.0%

Table 1. *Oregon wetlands by wetland type, provided in Project Data for the Wetland Prioritization Tool (WPT).* Source: *ONHIC/TWC 2009*

Table 2. Project Data

Category	Source(s)	Scale
"PROJECT DATA"		
ORWAP wetlands GDB	ODSL/TWC	to 0.008 acres (31 sq meters)
HUC 8 (modified)	TWC	misc
ENVIRONMENT		
DEM	TWC	10-meter
Land Cover (2011)	USGS	30-meter
Precipitation and Temperature	PRISM/OSU	~ 800-meter
SOILS		
Web Soil Survey (primary)	NRCS/USDA	to 1-meter
Soil Permeability (secondary)	INR	30-meter
WATER FEATURES		
Streams, Rivers	NHD/USGS	1:24,000 – 1:100,000

Table 2. Project Data. *Data and sources used to estimate wetland functions using the Wetland Prioritization Tool (WPT).*

Table 3. Exceptions

	Coquille	Sprague	Tualatin	Upper Grande Ronde
Wetland Complexes				
number	**1,114**	**2,924**	**1,682**	**2,589**
number for analysis	**1,085**	**2,661**	**1,573**	**2,474**
% for analysis	**97%**	**91%**	**94%**	**96%**

Table 3. Exceptions. *Number of wetland complexes in original project database compared to number which were piloted for the Wetland Prioritization Tool.*

Table 4. Master Attribute Table

IDENTITY				
				V1
OBJECTID	RegionID_ComplexID	HUC_8	SIZE_ACRES	SIZE_NML

DISTANCE & GRADIENT							
	V2		**V3**		**V4**		**V5**
SLOPE	SLOPE_NML	PROXIMITY	PROX_NML	DISTANCE	DIST_NML	HYDRO_GRAD	HG_NML

TEMPERATURE CONTROL			
V12		**V13**	**V14**
NLCD4X_NML	ELEV	ELEV_NML	ASP_NML

SOIL - NRCS						
	V6		**V7**	**V8**	**V9**	**V10**
AWS	AWS_NML	CLAY	CLAY_NML	HSG_C	HSG_CD	HSG_D

SOIL - nonNRCS									
	V6a		**V6b**		**V6c**		**V6d**		**V11**
SOILFmrg	SOILF_NML	SOILLmrg	SOILL_NML	SOILSmrg	SOILS_NML	SOILTmrg	SOILT_NML	PERM	PERM_NML

Table 4. Master Attribute Table*. Sample of compiled weighted-area averages and normalized values for wetland complexes within a HUC8 subbasin, for the Wetland Prioritization Tool (WPT).*

Table 5. Model Results

IDENTITY		MODEL 1					MODEL 2			
OBJECTID		FLOOD_M1	LATE_M1	SED_M1	TEMP_M1		FLOOD_M2	LATE_M2	SED_M2	TEMP_M2

Table 5. Model Results*. Potential wetland functions calculated for 1) FLOOD_Mx flood storage, 2) LATE_Mx contribution to late-season flow, 3) SED_Mx sediment retention and 4) TEMP_Mx temperature control.*

Table 6. Wetland Functions (with NRCS)

	Flood storage	Late season flow	Sediment retention	Temp control
Size	+	+	+	
Slope	-	-	-	
Hydrologic Gradient	-	-	-	
Proximity to stream	-	+	+	
Distance to stream	-	+	+	
Soil - NRCS				
% clay	-	-	+	-
AWS	+	+	-	+
HSG (C, D, C/D)	-	+/-	+	-
Temperature				
Shade, % forested				+
Elevation				+
Aspect, % south-facing				-

Table 6. Wetland Functions (with NRCS). *Project attributes, with NRCS soil values, and their relationship to potential wetland functions for the Wetland Prioritization Tool (WPT).*

Table 7. Wetland Functions (<u>without</u> NRCS)

	Flood storage	Late season flow	Sediment retention	Temp control
Size	+	+	+	
Slope	-	-	-	
Hydrologic Gradient	-	-	-	
Proximity to stream	-	+	+	
Distance to stream	-	+	+	
Soil - without NRCS				
L_SOIL_PER	+	+	-	+
Temperature				
Shade, % forested				+
Elevation				+
Aspect, % south-facing				-

Table 7. Wetland Functions (<u>without</u> NRCS). *Project attributes, <u>without</u> NRCS soil values, and their relationship to potential wetland functions for the Wetland Prioritization Tool (WPT).*

Table 8. Model Formulas, NRCS

	Flood storage	Late season flow
Model 1		
soil	[[1 - [(Clay + HSG) / 2]] + AWS] / 2	[[1 - Clay] + AWS] / 2
function	[size + (1-slope) + (1-proximity) + soil] / 4	[size + (1-slope) + proximity + soil] / 4
Model 2		
soil	same	same
function	[size + (1-hydro grad) + (1-distance) + soil] / 4	[size + (1-hydro grad) + distance + soil] / 4

	Sediment retention	Temp control
Model 1		
soil	[[(Clay + HSG) / 2] + AWS] / 2	[[1 - [(Clay + HSG) / 2]] + AWS] / 2
function	[size + (1-slope) + proximity + soil] / 4	[shade + elevation + (1-aspect) + soil] / 4
Model 2		
soil	same	same
function	[size + (1-hydro grad) + distance + soil] / 4	same

Table 8. Model Formulas, NRCS. *Equations for both Model scenarios in developing the Wetland Prioritization Tool showing how attributes added to or reduced the potential for specific wetland functions.*

Table 9. Model Formulas, non-NRCS

	Flood storage	Late season flow
Model 1		
soil	soil permeability	soil permeability
function	[size + (1-slope) + (1-proximity) + soil] / 4	[size + (1-slope) + proximity + soil] / 4
Model 2		
soil	same	same
function	[size + (1-hydro grad) + (1-distance) + soil] / 4	[size + (1-hydro grad) + distance + soil] / 4

	Sediment retention	Temp control
Model 1		
soil	(1 - soil permeability)	soil permeability
function	[size + (1-slope) + proximity + soil] / 4	[shade + elevation + (1-aspect) + soil] / 4
Model 2		
soil	same	same
function	[size + (1-hydro grad) + distance + soil] / 4	same

Table 9. Model Formulas, non-NRCS. *Equations for both Model scenarios in developing the Wetland Prioritization Tool showing how attributes added to or reduced the potential for specific wetland functions. Use when NRCS soil survey data is not available for entire watershed under investigation.*

Figures

Figure 1. Ecoregions.

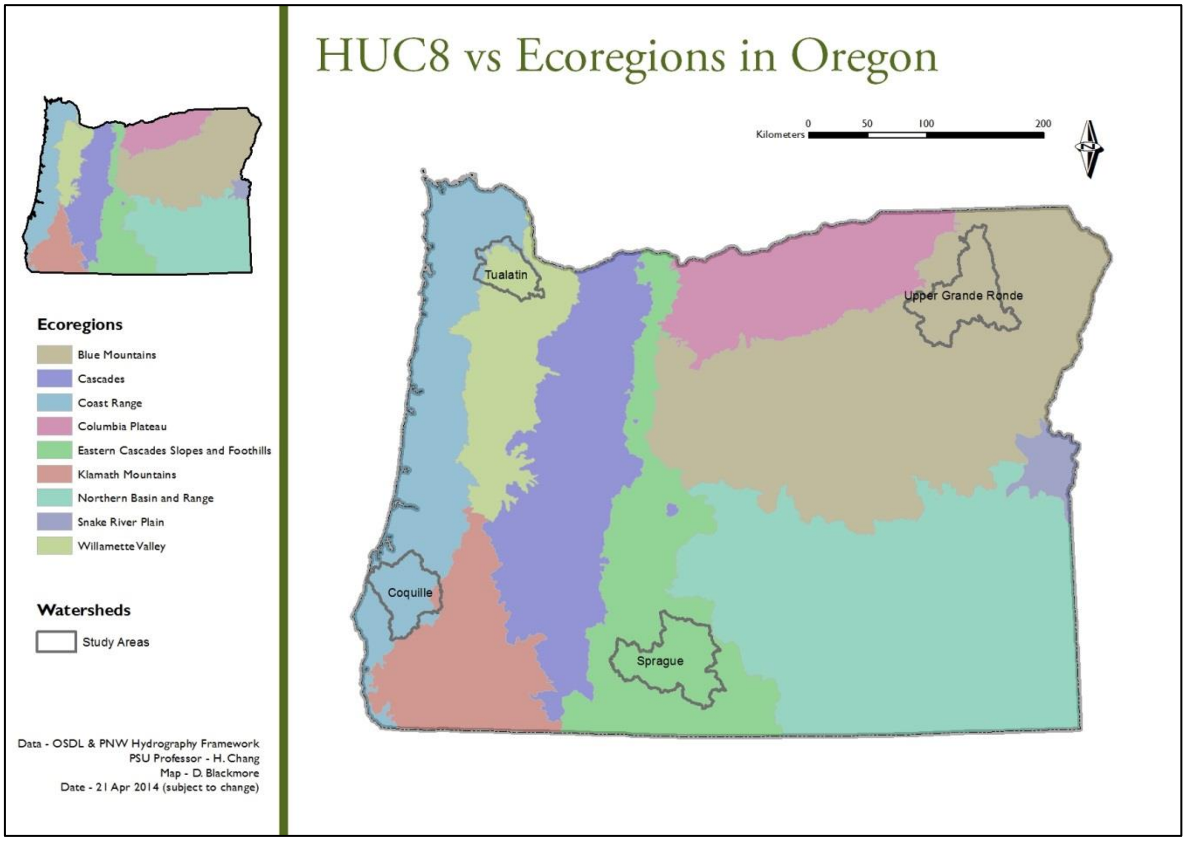

Figure 1. Ecoregions. *Level III ecoregions in the State of Oregon showing study areas for the INR-PSU Wetland Prioritization Tool, including subbasins Coquille, Sprague, Tualatin & Upper Grande Ronde.*

Figure 2. Study Areas.

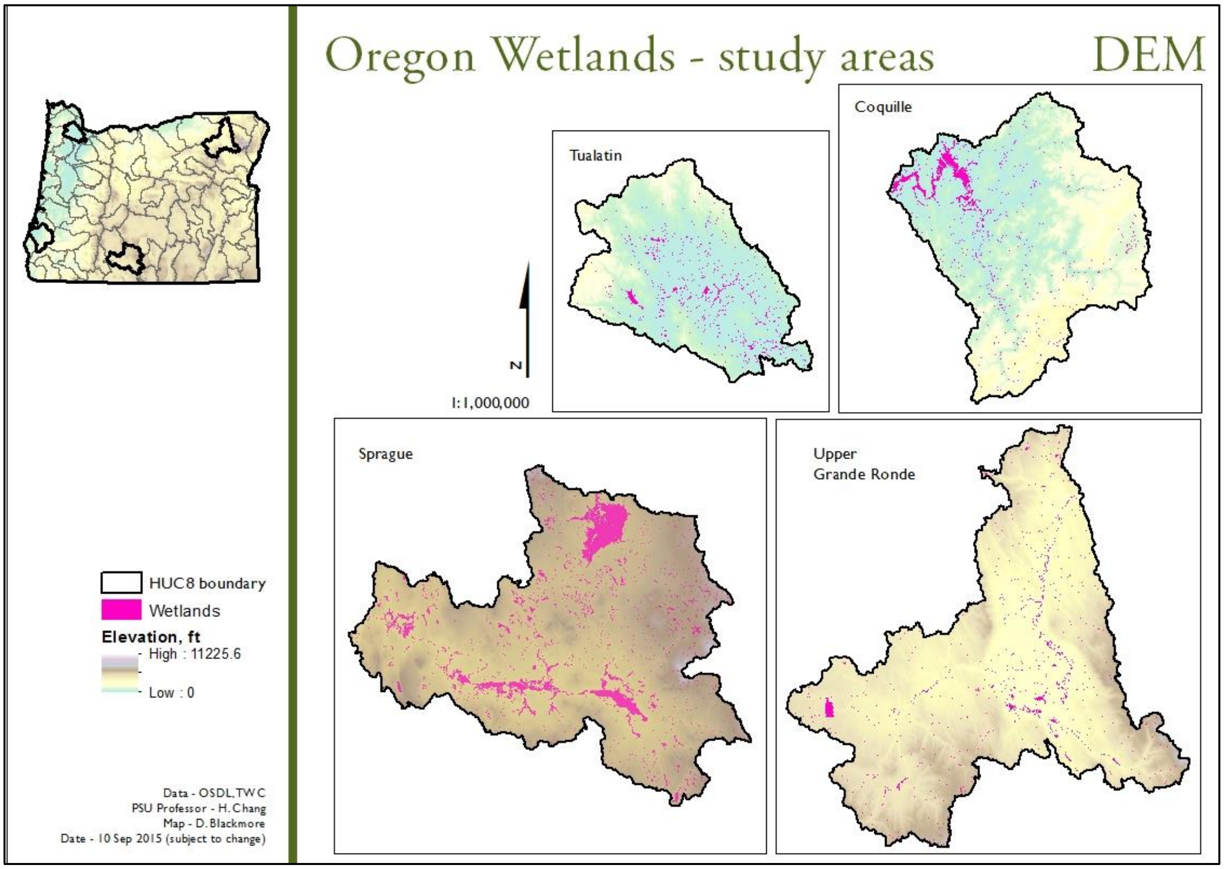

Figure 2. Study Areas. *HUC8 subbasins in the State of Oregon with elevation, pilot study areas for the INR-PSU Wetland Prioritization Tool.*

Figure 3. Study Area Profiles

	Coquille	Sprague	Tualatin	Upper Grande Ronde
HUC8 Watershed				
size, km^2	2,737	4,171	1,836	4,238
annual precipitation, mm	1,709	580	1,293	695
annual temperature, C	11.4	6.7	10.9	7.0
elevation, ft	1,186	5,243	636	4,159
slope, degrees	17.8	5.5	8.3	10.8
Wetland Complexes				
number	1,114	2,924	1,682	2,589
density (number/km^2)	0	1	1	1
size, acres (mean)	23	36	16	6

Figure 3. Study Area Profiles. *HUC8 subbasins in the State of Oregon with elevation, pilot study areas for the INR-PSU Wetland Prioritization Tool.*

Figure 4. Coquille

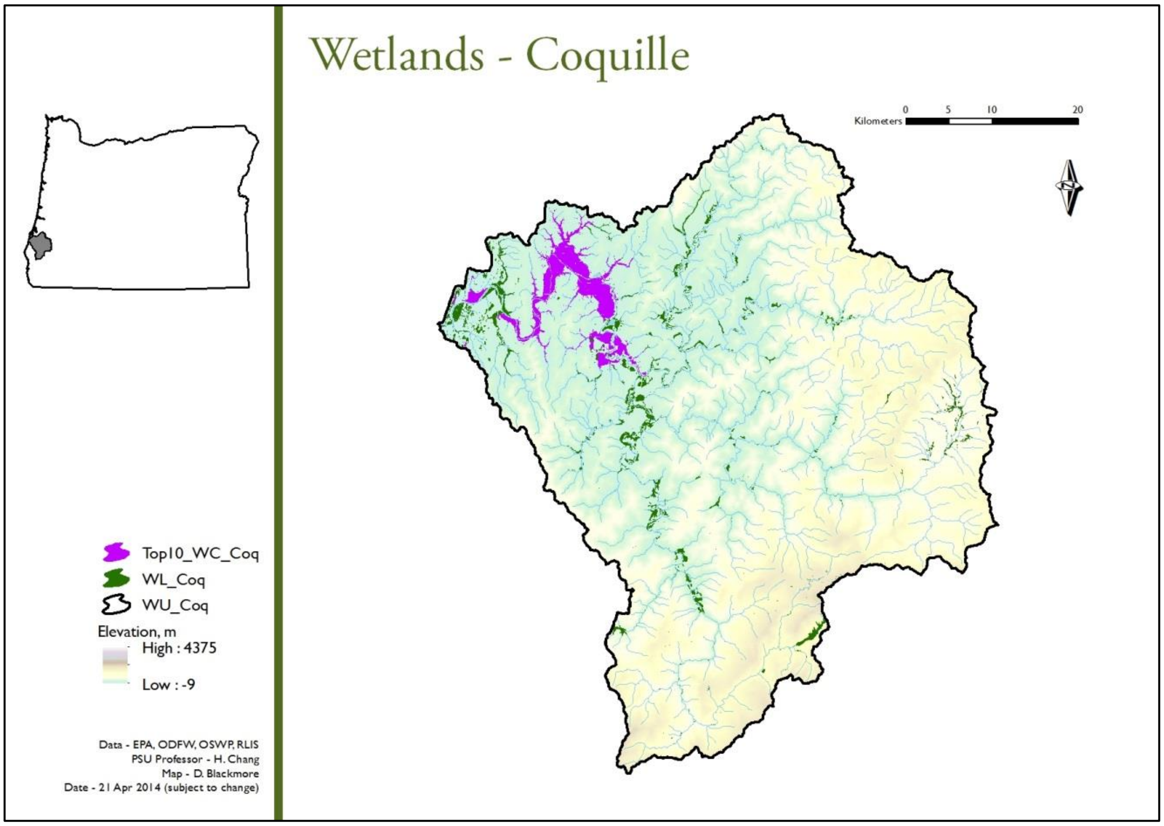

Figure 4. Coquille. *One of four pilot study areas (HUC8) for the INR-PSU Wetland Prioritization Tool.*

Figure 5. Sprague

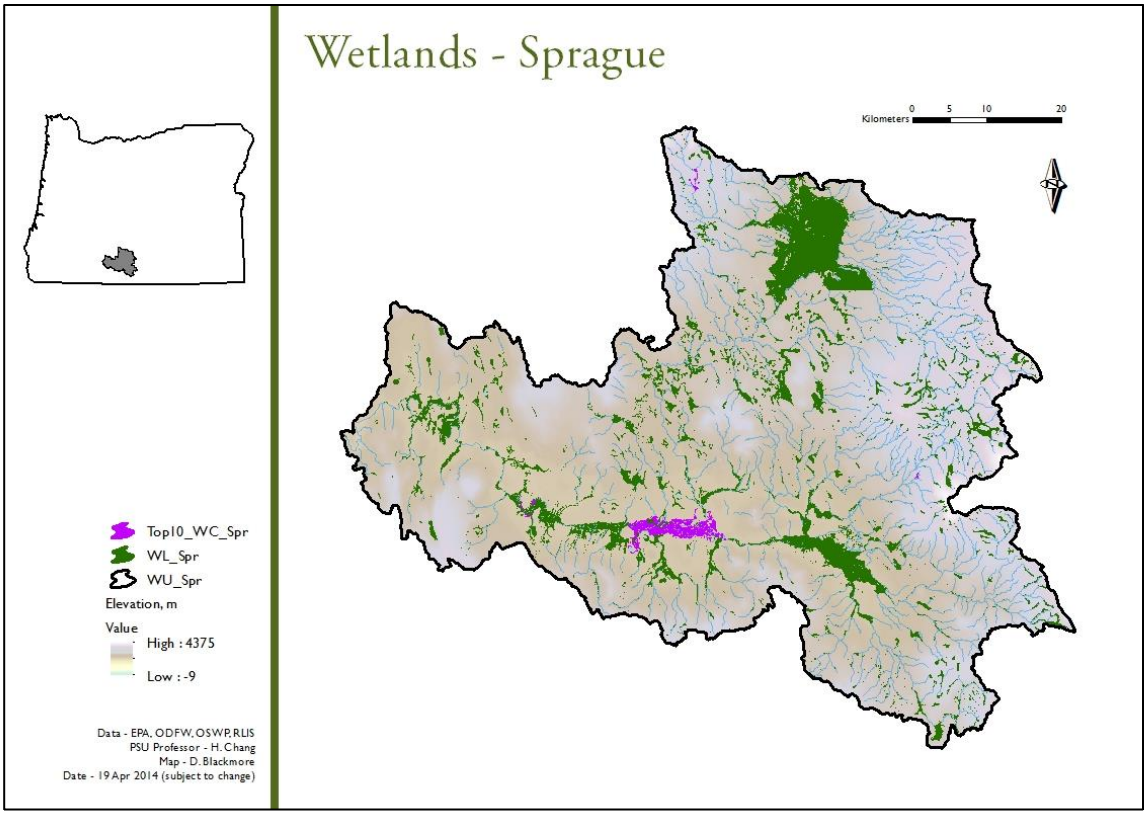

Figure 5. Sprague. *One of four pilot study areas (HUC8) for the INR-PSU Wetland Prioritization Tool.*

Figure 6. Tualatin

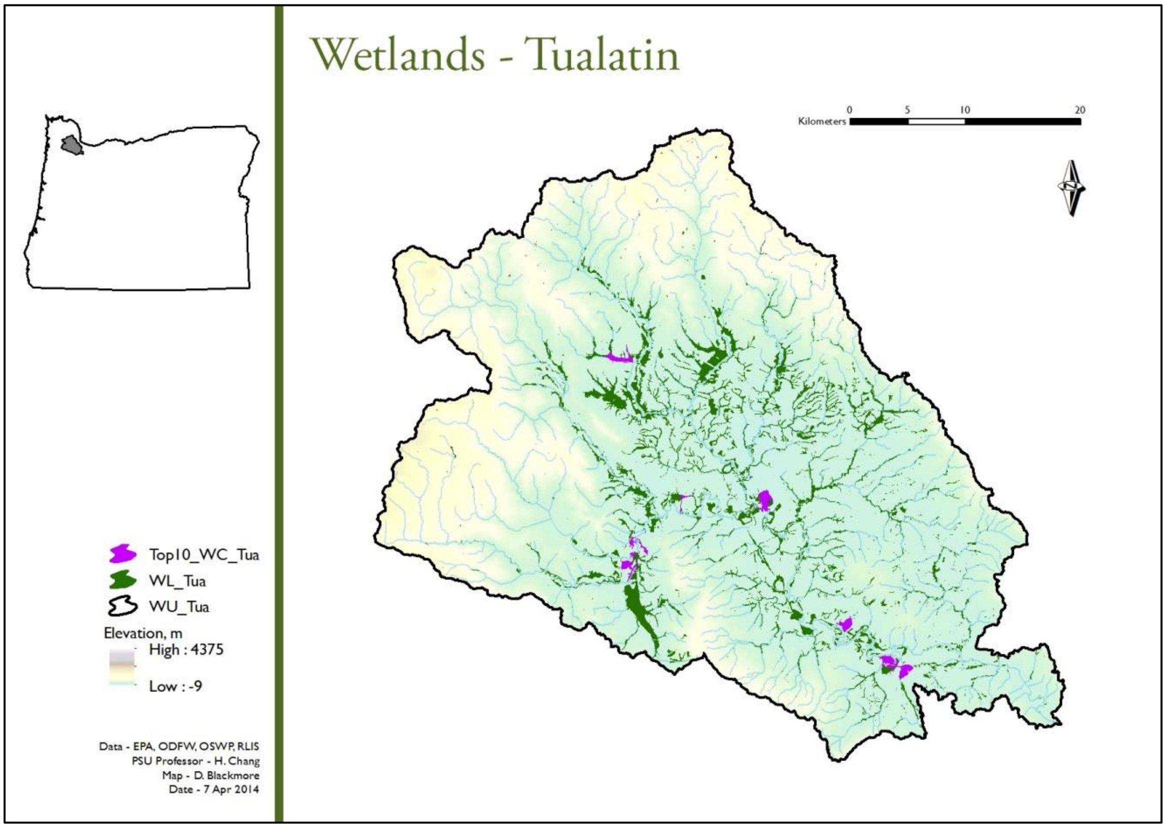

Figure 6. Tualatin. *One of four pilot study areas (HUC8) for the INR-PSU Wetland Prioritization Tool.*

Figure 7. Upper Grande Ronde

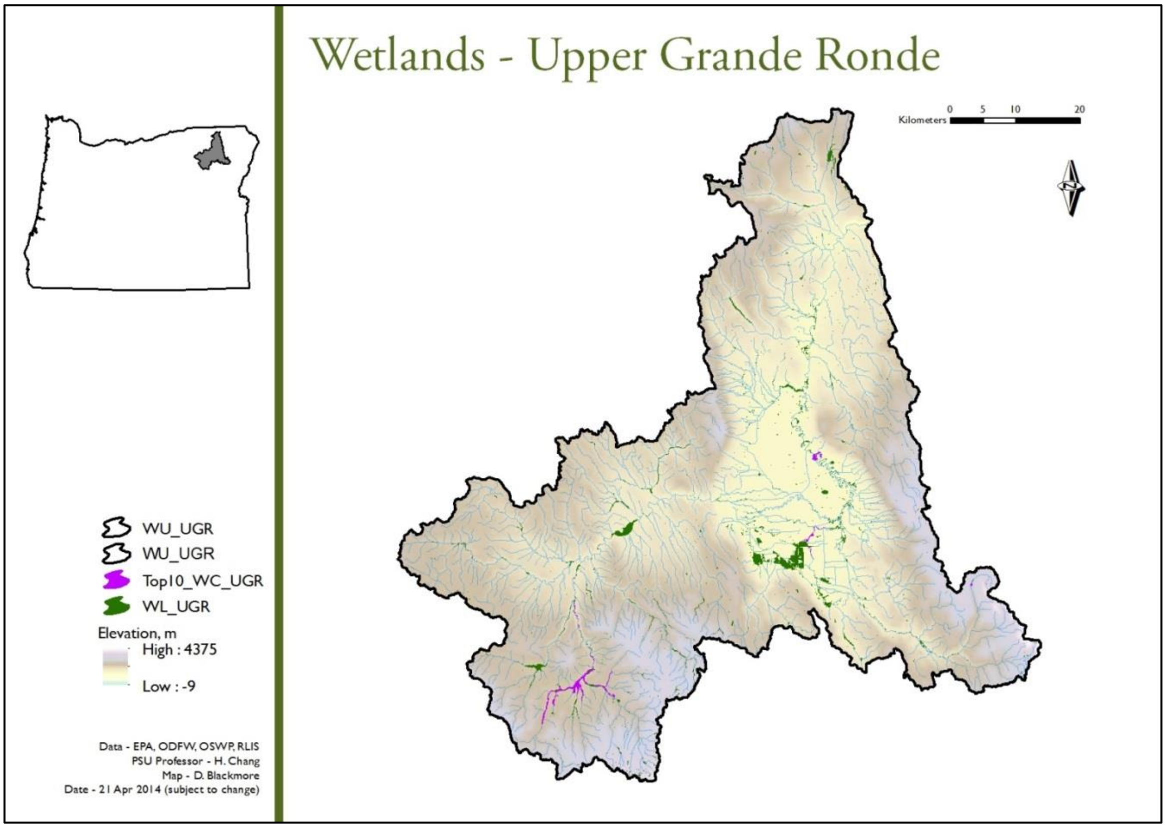

Figure 7. Upper Grande Ronde. *One of four pilot study areas (HUC8) for the INR-PSU Wetland Prioritization Tool.*

Figure 8. Approach

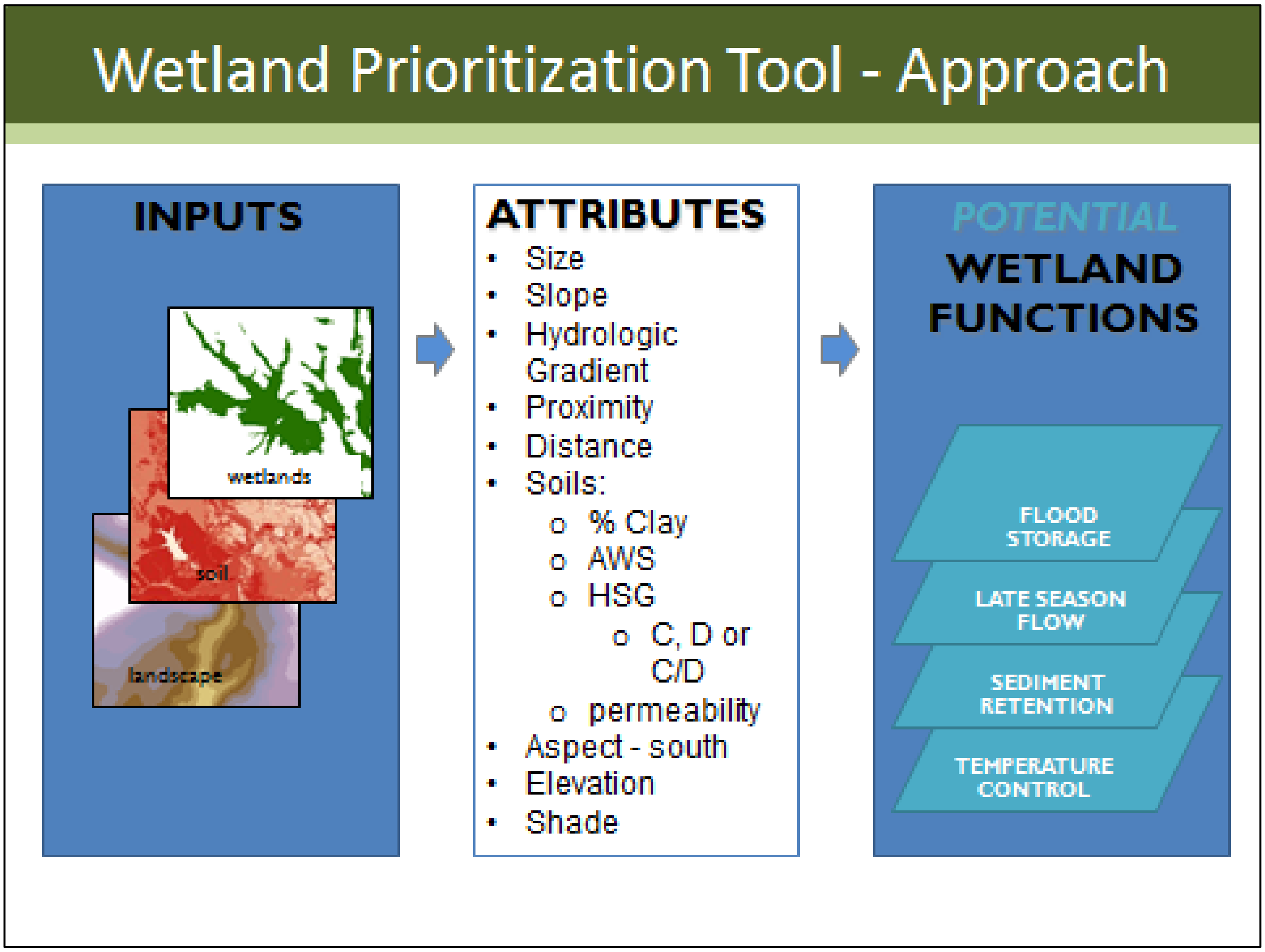

Figure 8. Approach. *Approach for ranking wetland complexes within a HUC8 subbasin for the INR-PSU Wetland Prioritization Tool.*

Figure 9. Attributes

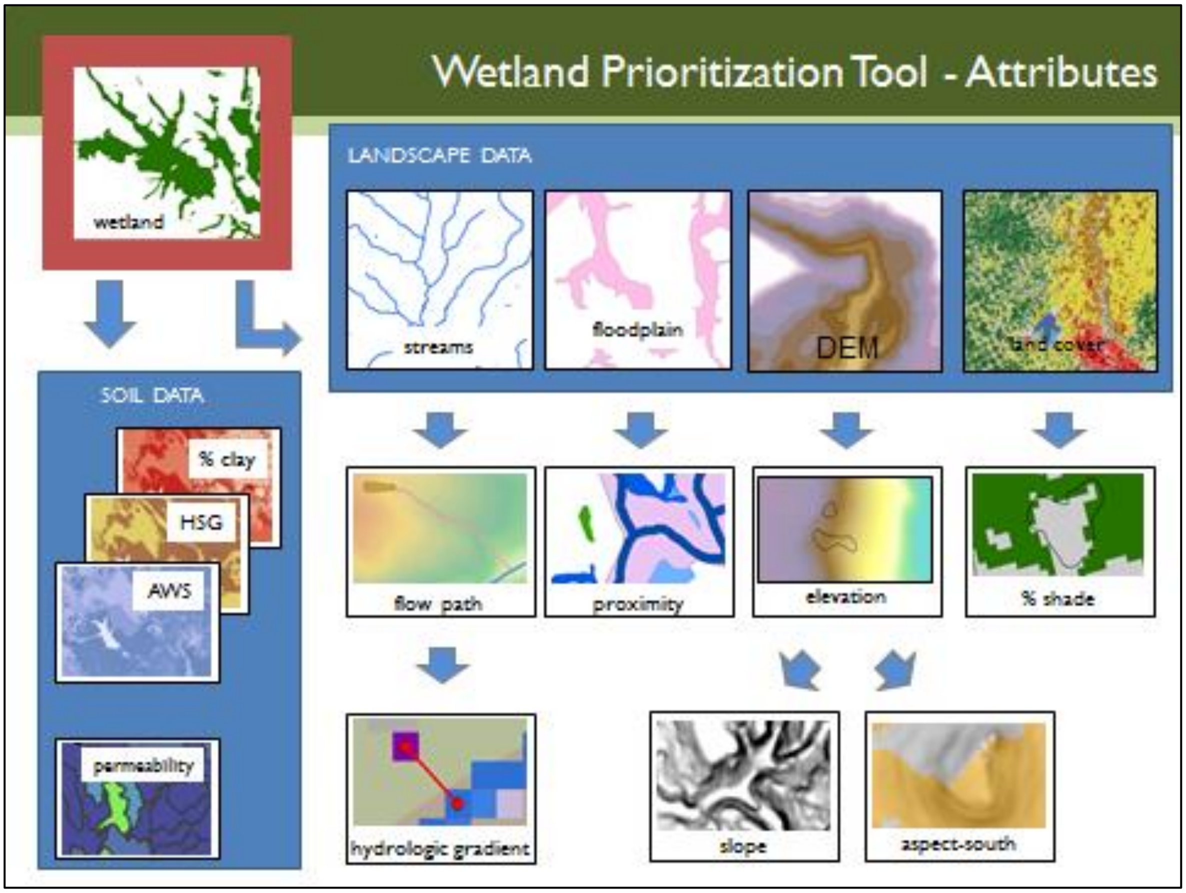

Figure 9. Attributes. *Overview of how attributes were extracted and derived for the INR-PSU Wetland Prioritization Tool.*

Figure 10. Model Variables

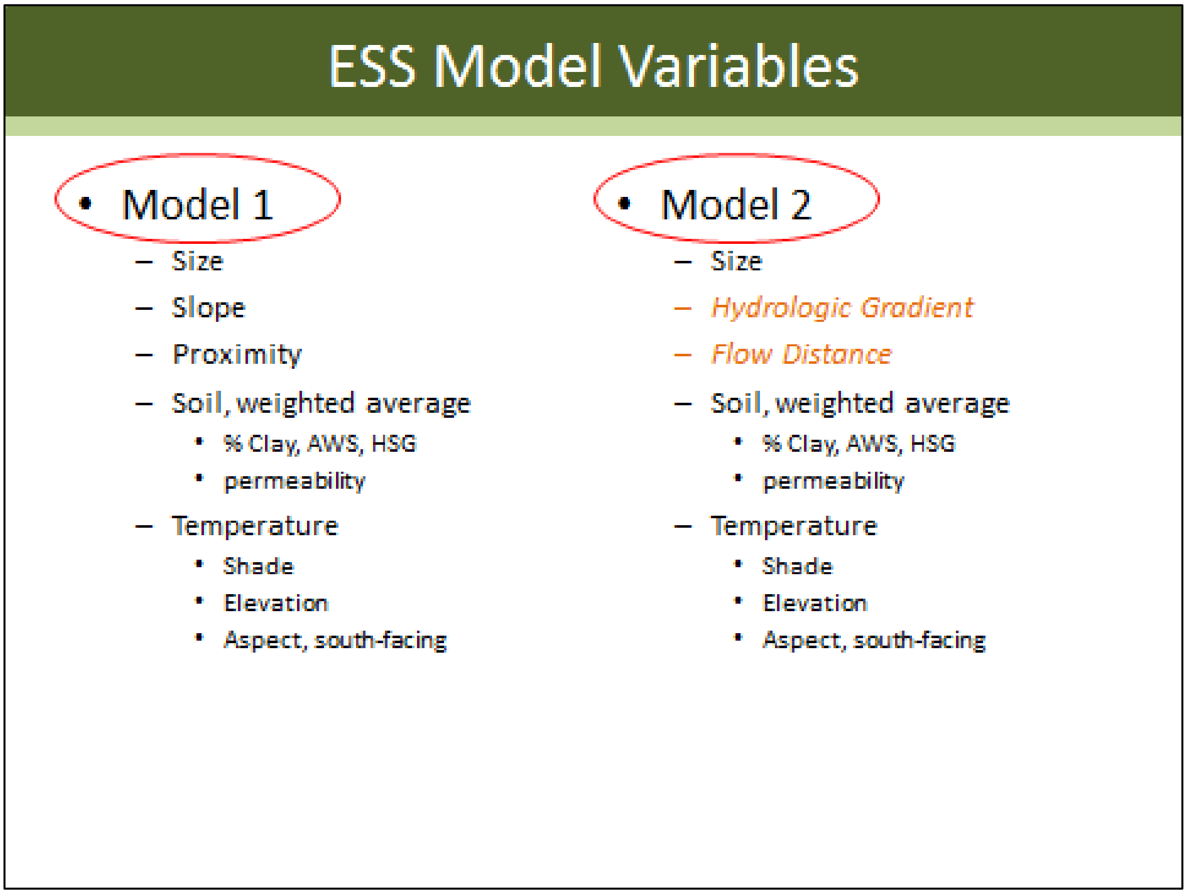

Figure 10. Model Variables. *Variables used in modeling of potential wetland functions for the INR-PSU Wetland Prioritization Tool.*

Figure 11. Equations for Model 1

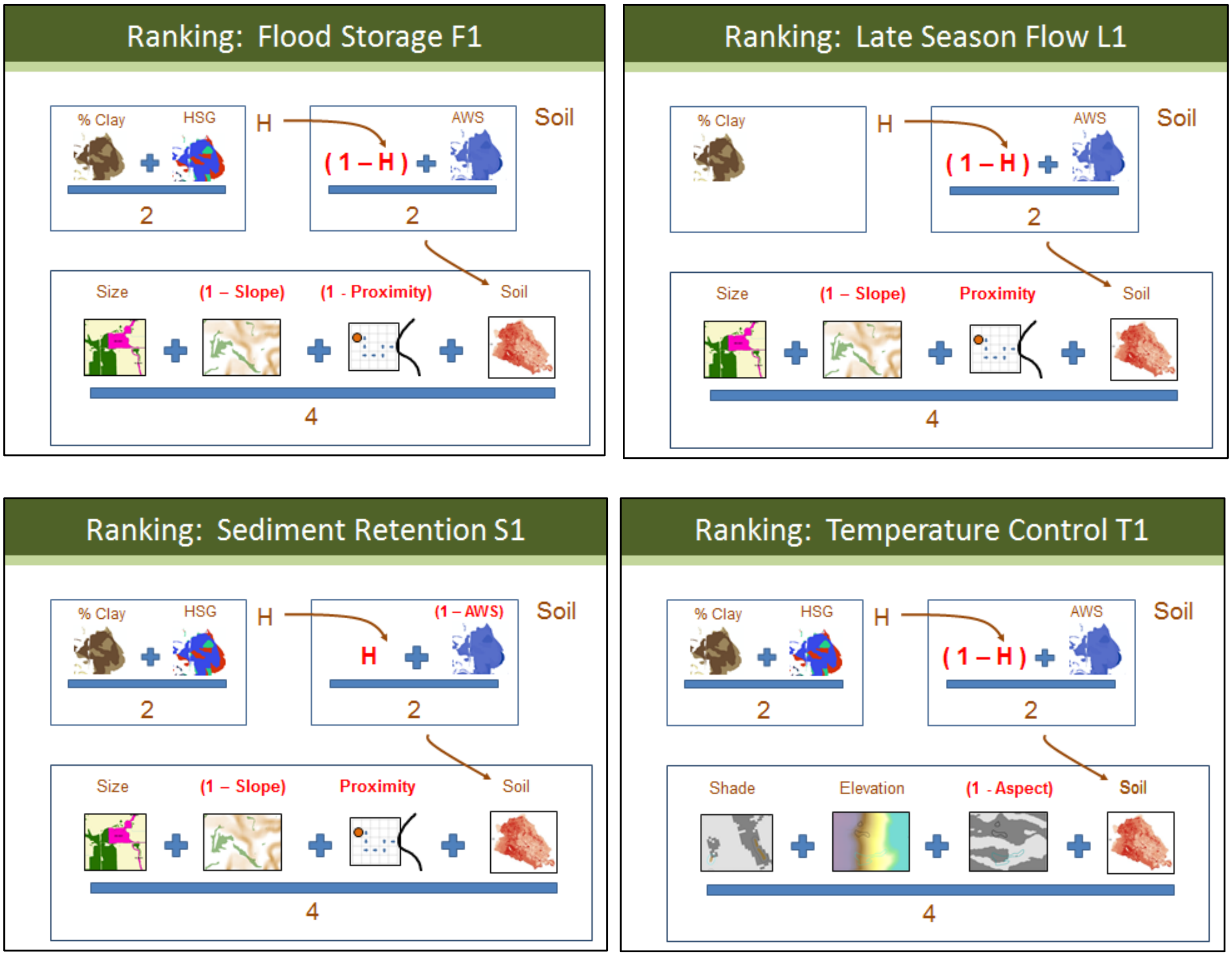

Figure 11. Equations for Model 1. *Visual depictions of wetland function calculations for Model 1 for the INR-PSU Wetland Prioritization Tool.*

Figure 12. Equations for Model 2

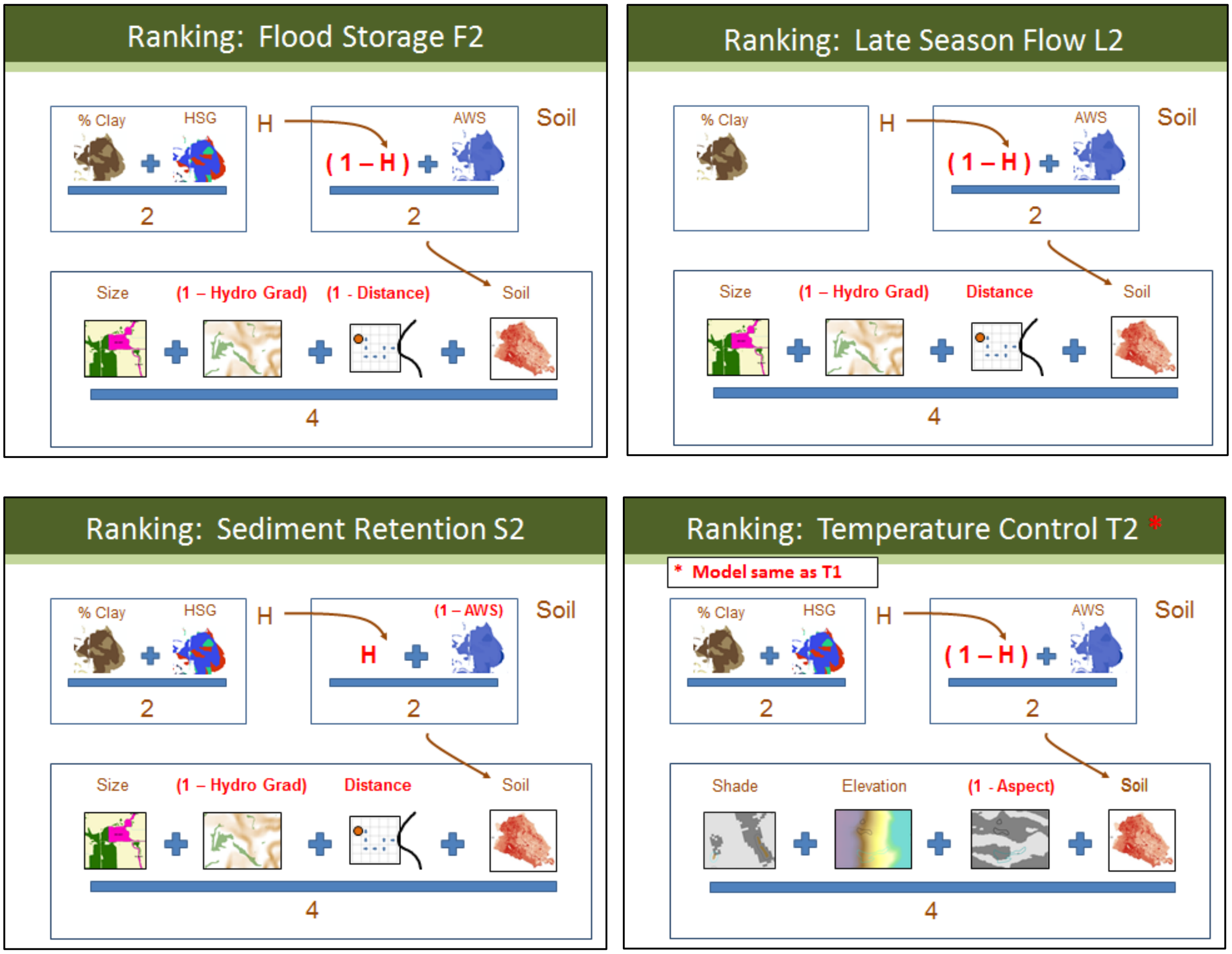

Figure 12. Equations for Model 2. *Visual depictions of wetland function calculations for Model 2 for the INR-PSU Wetland Prioritization Tool.*

Figure 13. Equations for non-NRCS

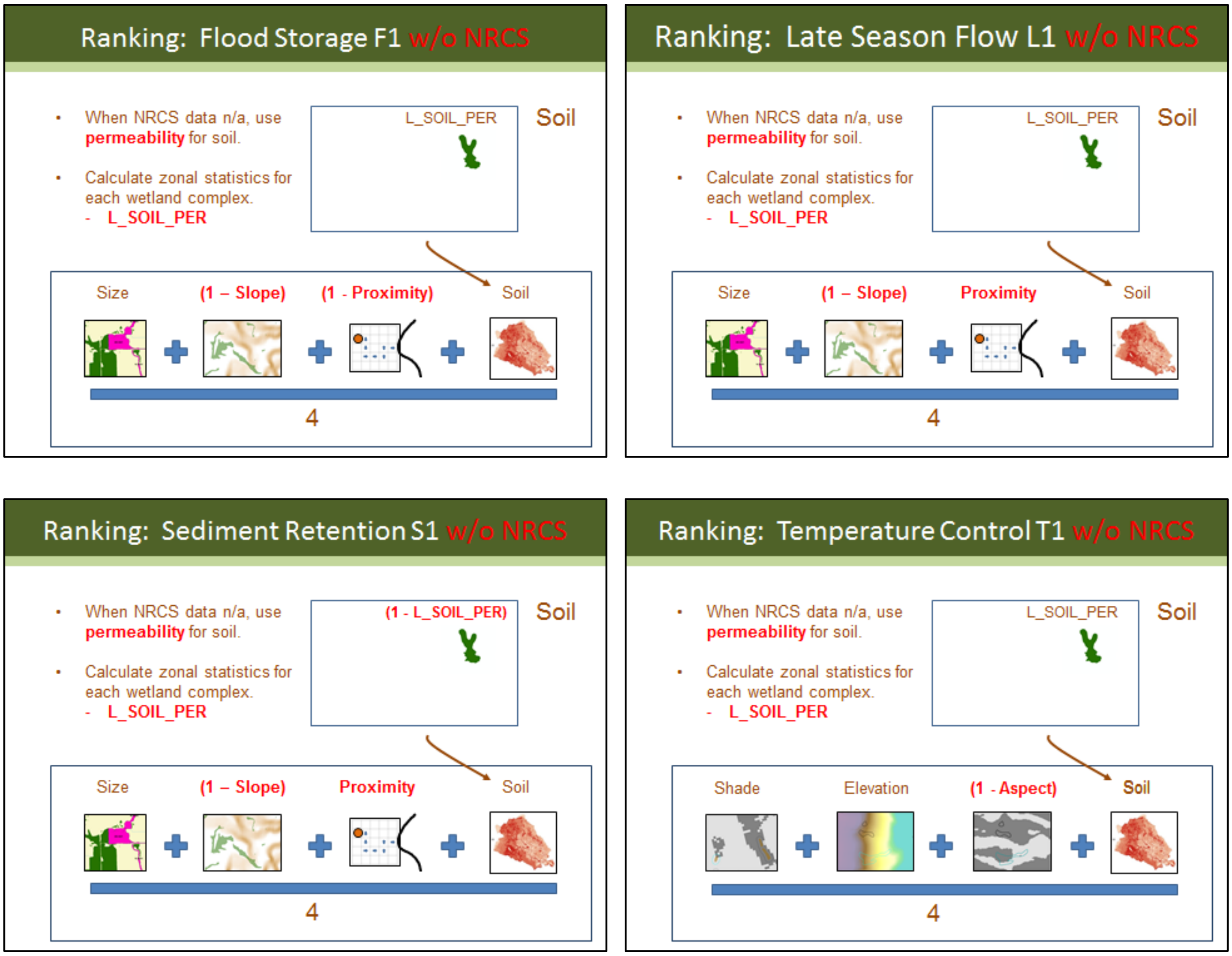

Figure 13. Equations for non-NRCS. *Visual depictions of wetland function calculations in the INR-PSU Wetland Prioritization Tool, highlighting the exchange of soil permeability data in areas where NRCS soil survey data is unavailable. Similar substitutions can be made for Model 2.*

Figure 14. Correlations, Model 1, Coquille

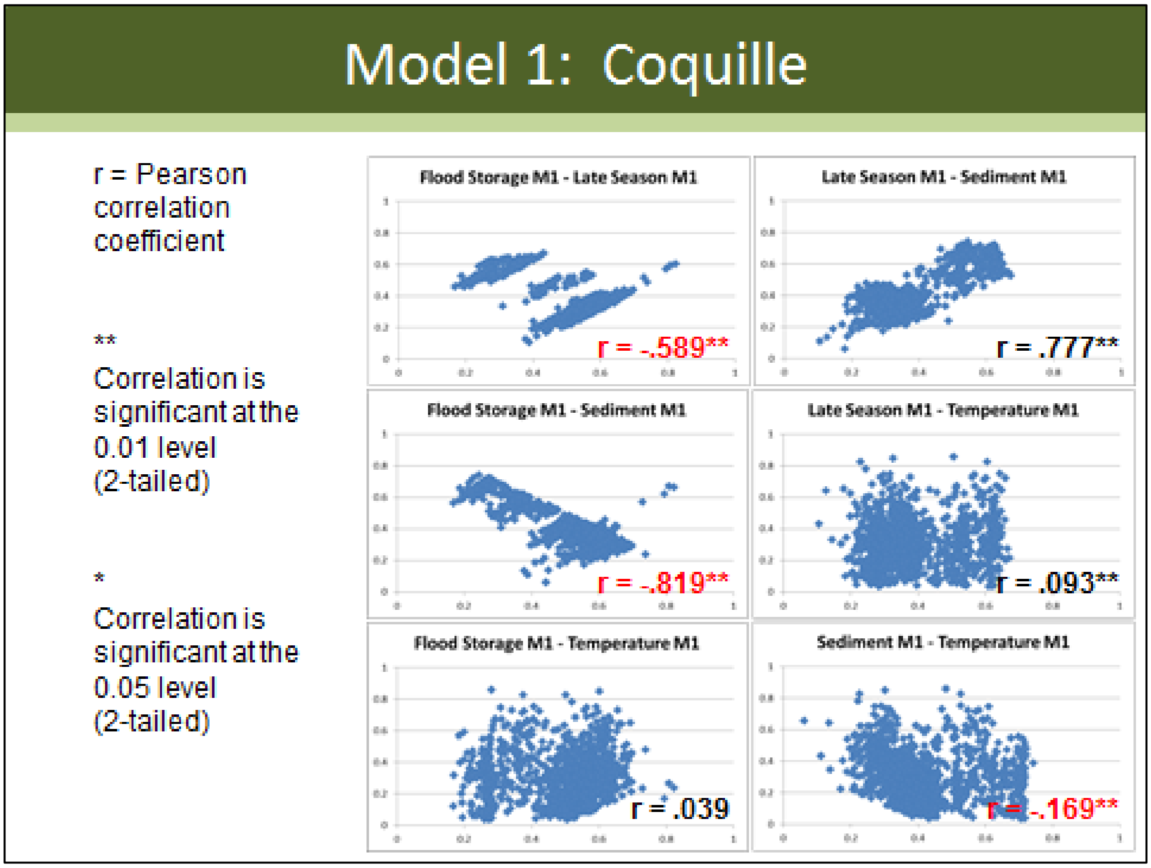

Figure 14. Correlations, Model 1, Coquille. *Bivariate correlations between estimates of wetland functions for Model 1 in the Wetland Prioritization Tool.*

Figure 15. Correlations, Model 1, Sprague

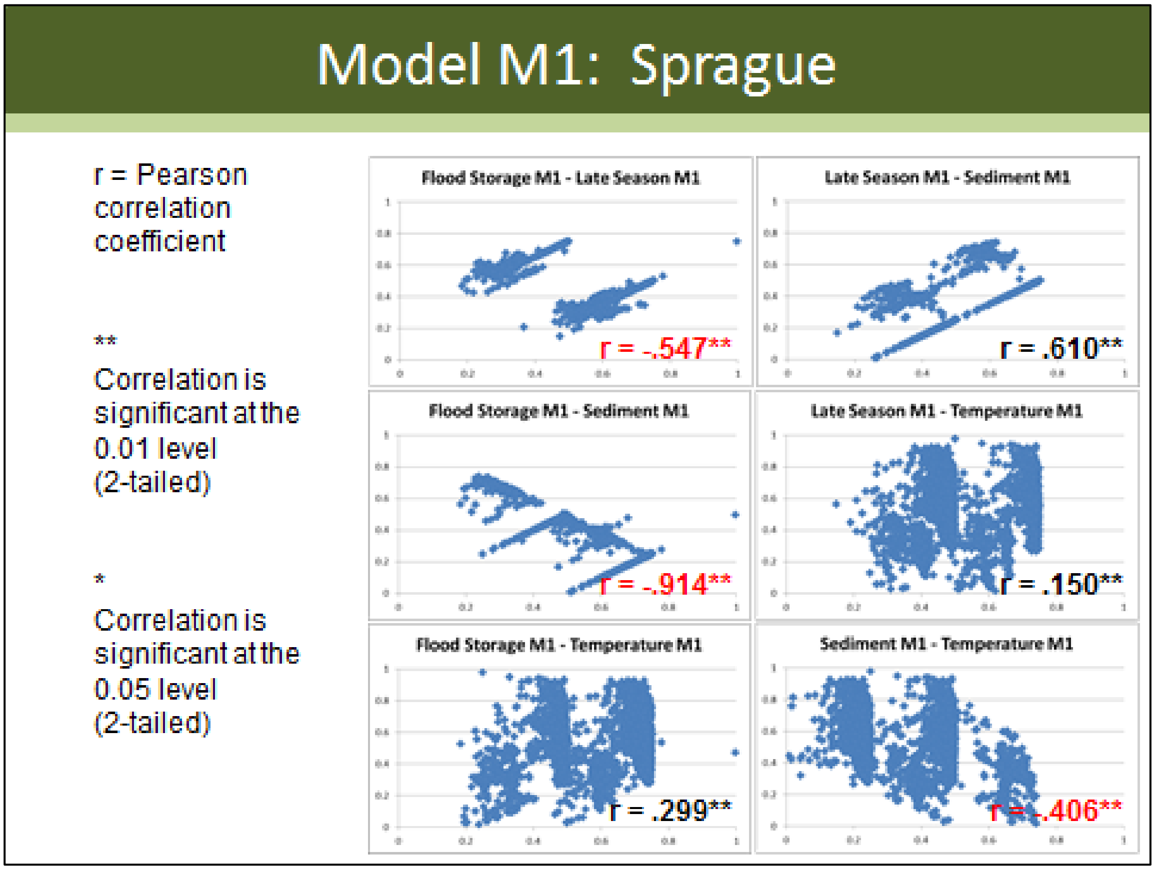

Figure 15. Correlations, Model 1, Sprague. *Bivariate correlations between estimates of wetland functions for Model 1 in the Wetland Prioritization Tool.*

Figure 16. Correlations, Model 1, Tualatin

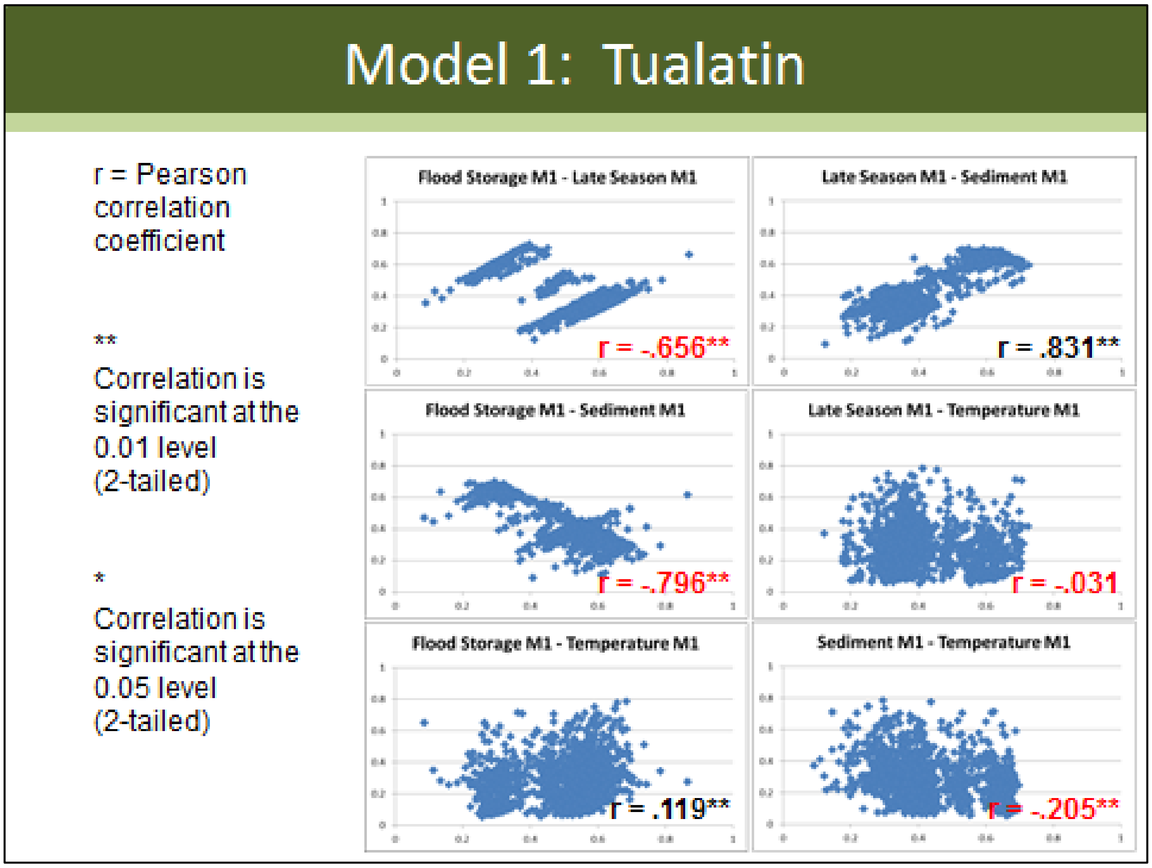

Figure 16. Correlations, Model 1, Tualatin. *Bivariate correlations between estimates of wetland functions for Model 1 in the Wetland Prioritization Tool.*

Figure 17. Correlations, Model 1, Upper Grande Ronde

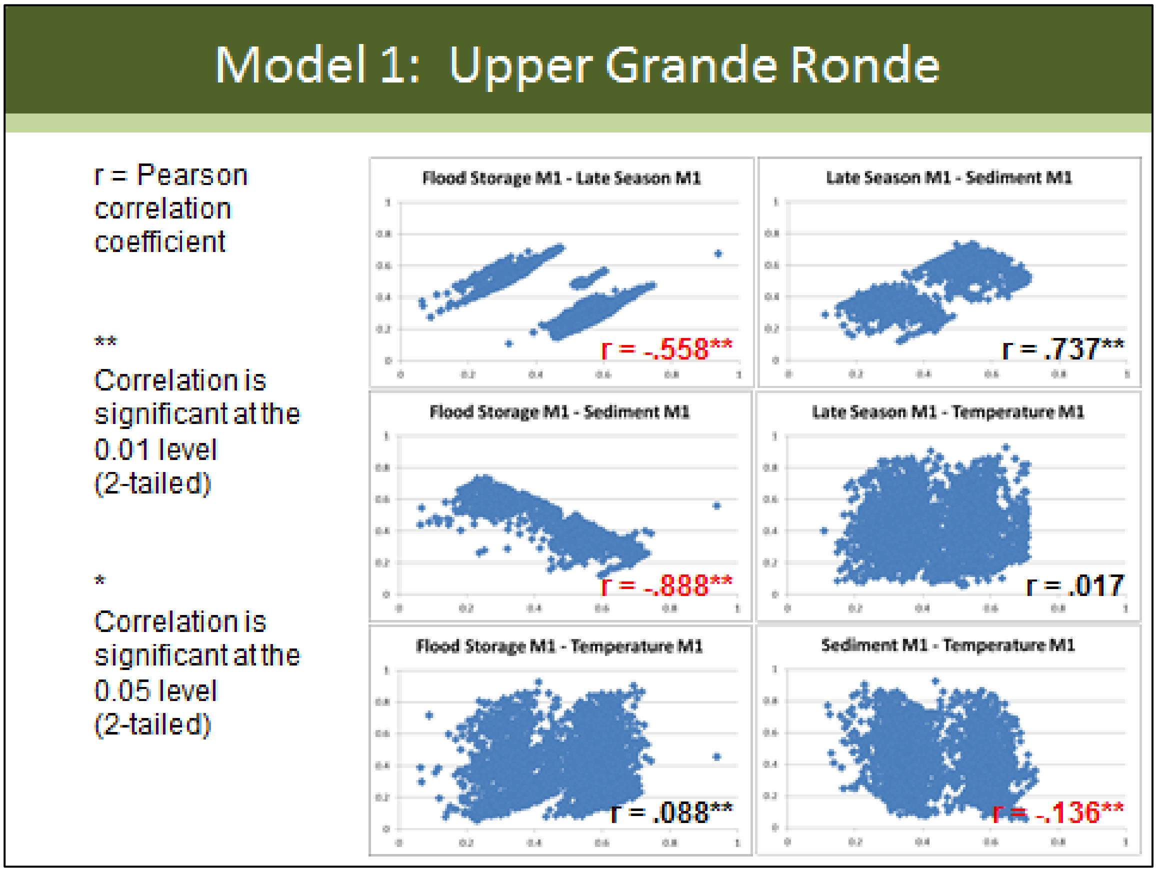

Figure 17. Correlations, Model 1, Upper Grande Ronde. *Bivariate correlations between estimates of wetland functions for Model 1 in the Wetland Prioritization Tool.*

Figure 18. Correlations, Model 2, Coquille

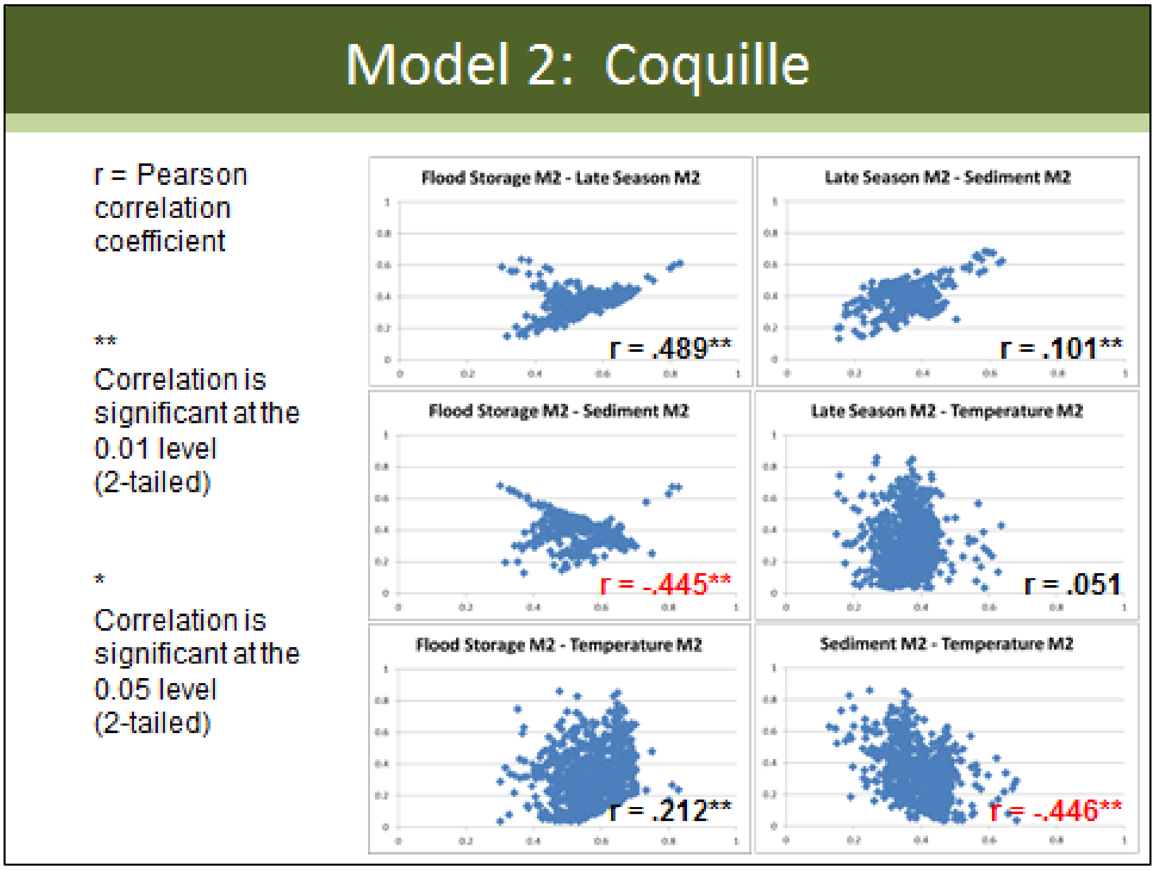

Figure 18. Correlations, Model 2, Coquille. *Bivariate correlations between estimates of wetland functions for Model 2 in the Wetland Prioritization Tool.*

Figure 19. Correlations, Model 2, Sprague

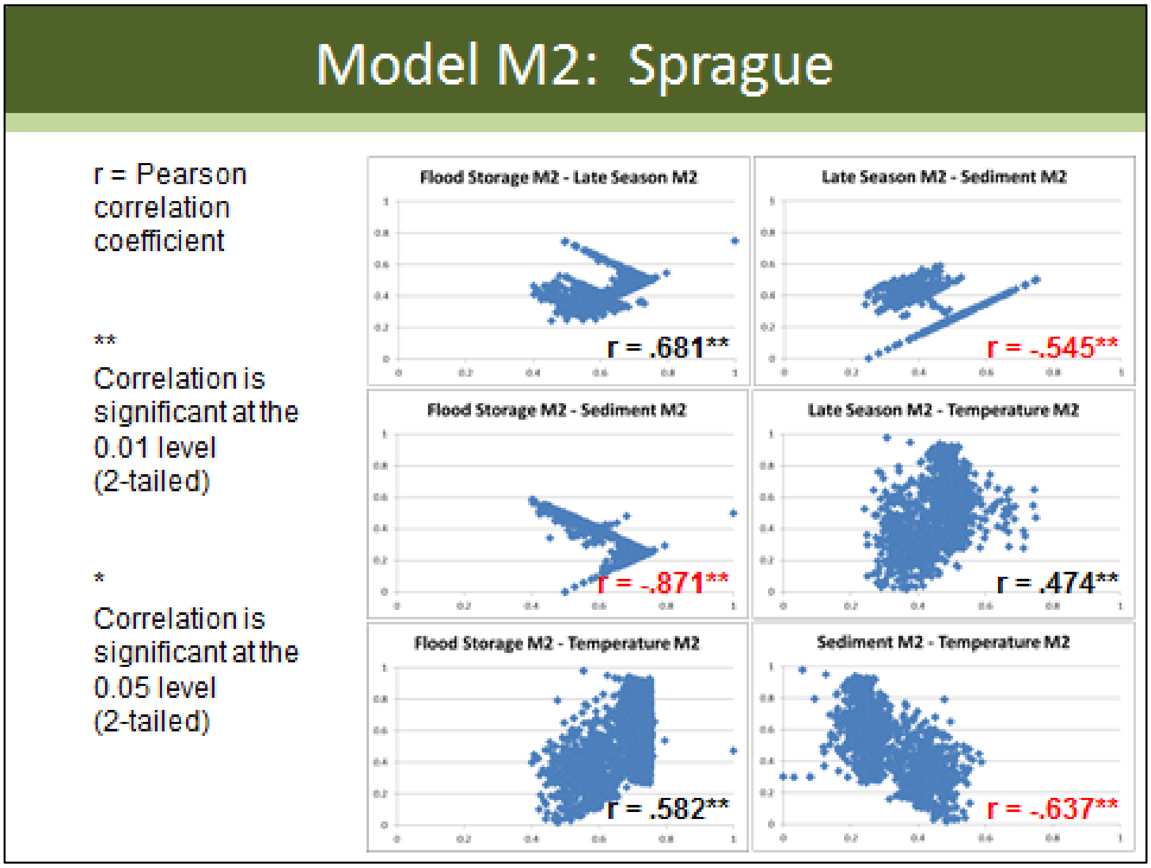

Figure 19. Correlations, Model 2, Sprague. *Bivariate correlations between estimates of wetland functions for Model 2 in the Wetland Prioritization Tool.*

Figure 20. Correlations, Model 2, Tualatin

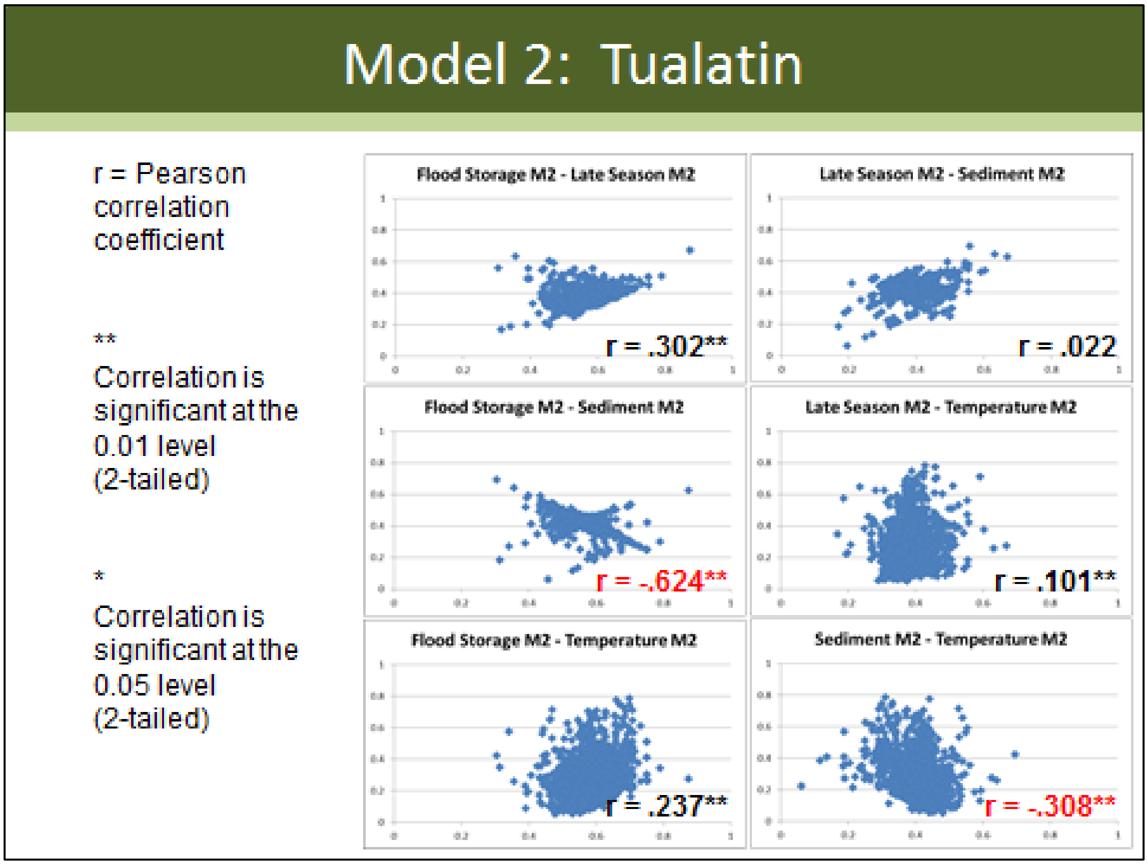

Figure 20. Correlations, Model 2, Tualatin. *Bivariate correlations between estimates of wetland functions for Model 2 in the Wetland Prioritization Tool.*

Figure 21. Correlations, Model 2, Upper Grande Ronde

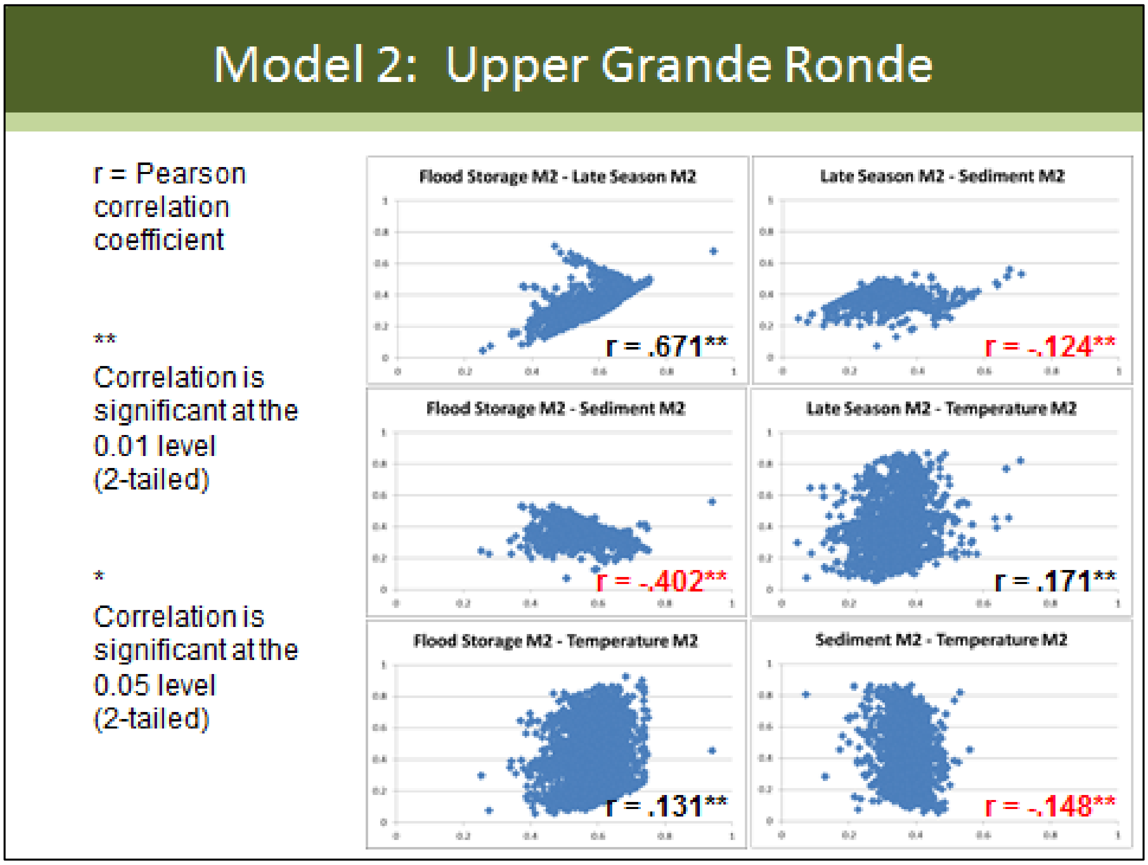

Figure 21. Correlations, Model 2, Upper Grande Ronde. *Bivariate correlations between estimates of wetland functions for Model 2 in the Wetland Prioritization Tool.*

Figure 22. Model 1 vs. Model 2, Coquille

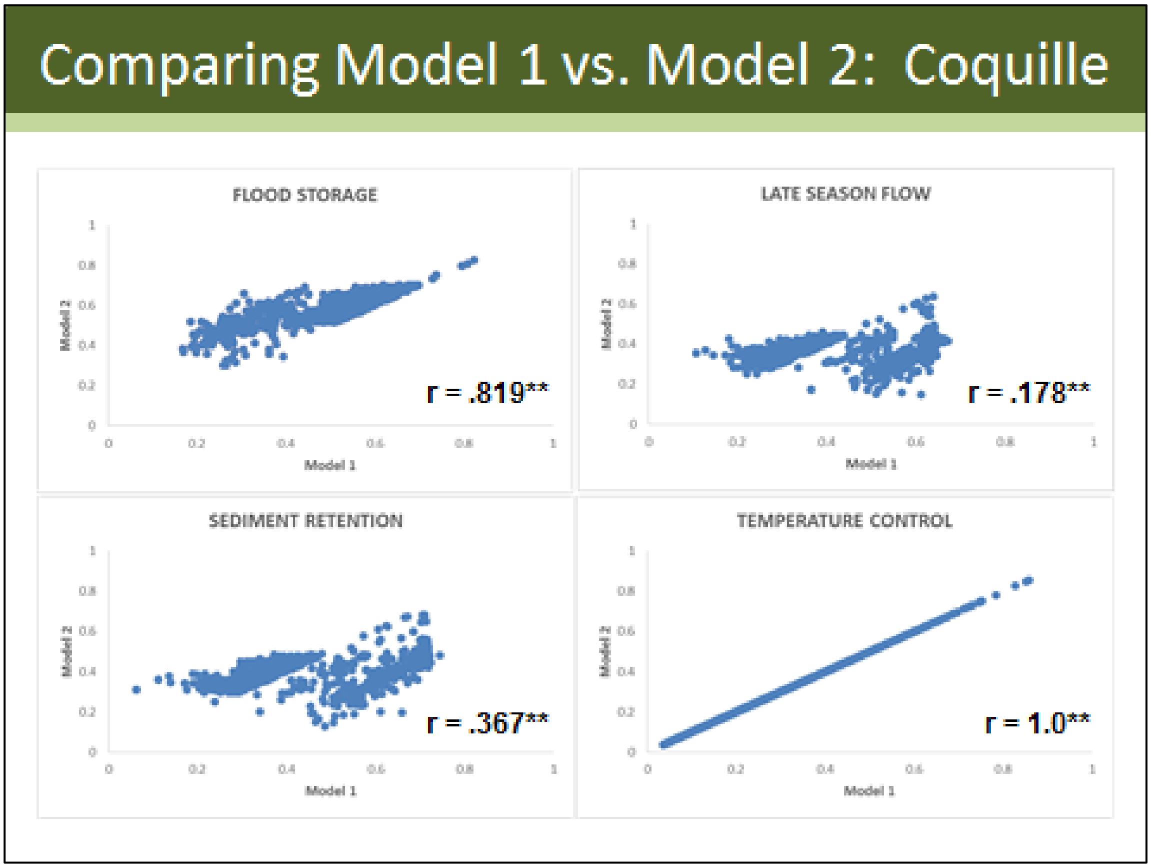

Figure 22. Model 1 vs. Model 2, Coquille. *Bivariate correlations between models for each of four wetland functions in the Wetland Prioritization Tool.*

Figure 23. Model 1 vs. Model 2, Sprague

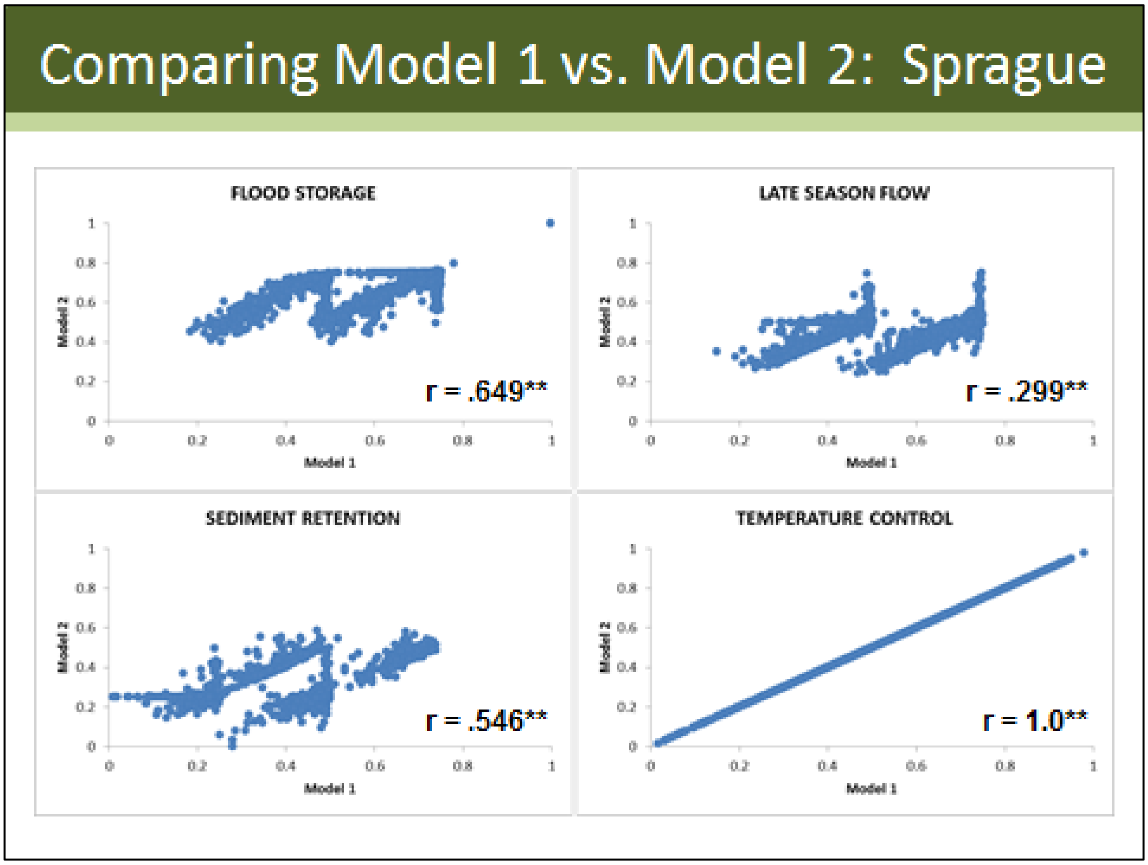

Figure 23. Model 1 vs. Model 2, Sprague. *Bivariate correlations between models for each of four wetland functions in the Wetland Prioritization Tool.*

Figure 24. Model 1 vs. Model 2, Tualatin

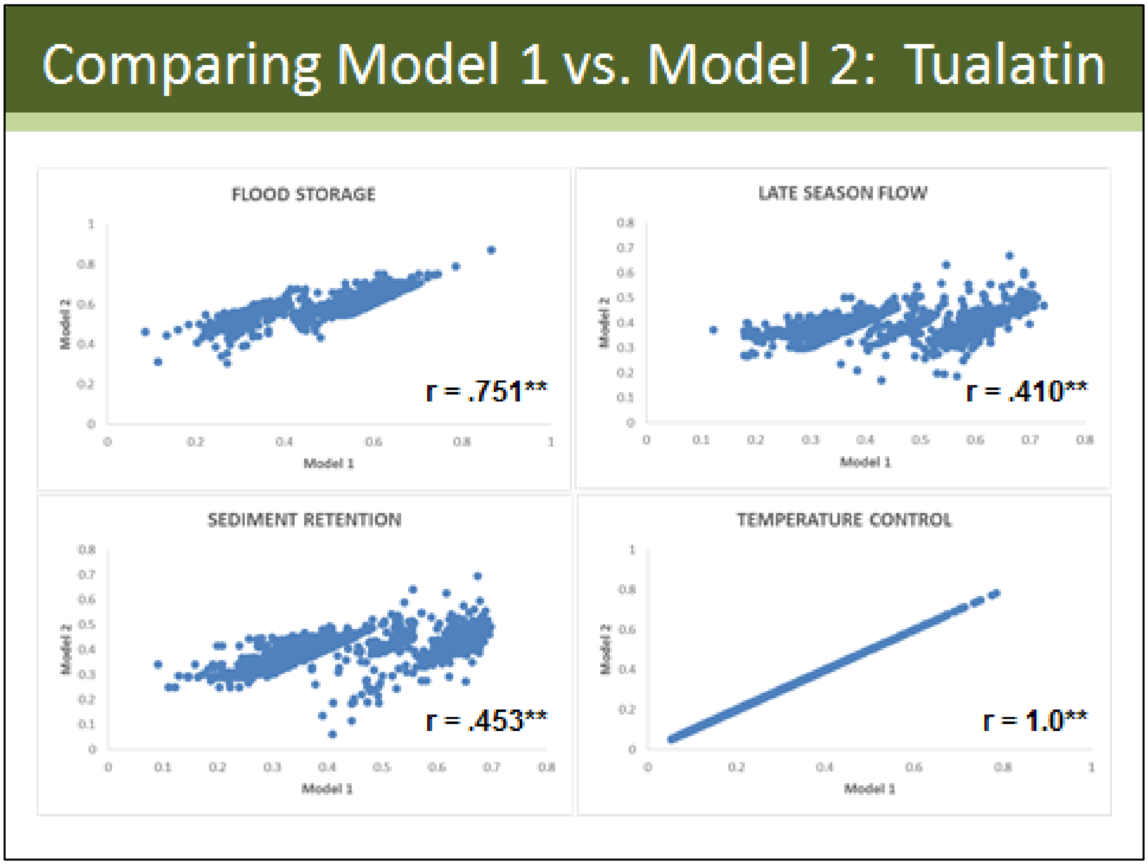

Figure 24. Model 1 vs. Model 2, Tualatin. *Bivariate correlations between models for each of four wetland functions in the Wetland Prioritization Tool.*

Figure 25. Model 1 vs. Model 2, Upper Grande Ronde

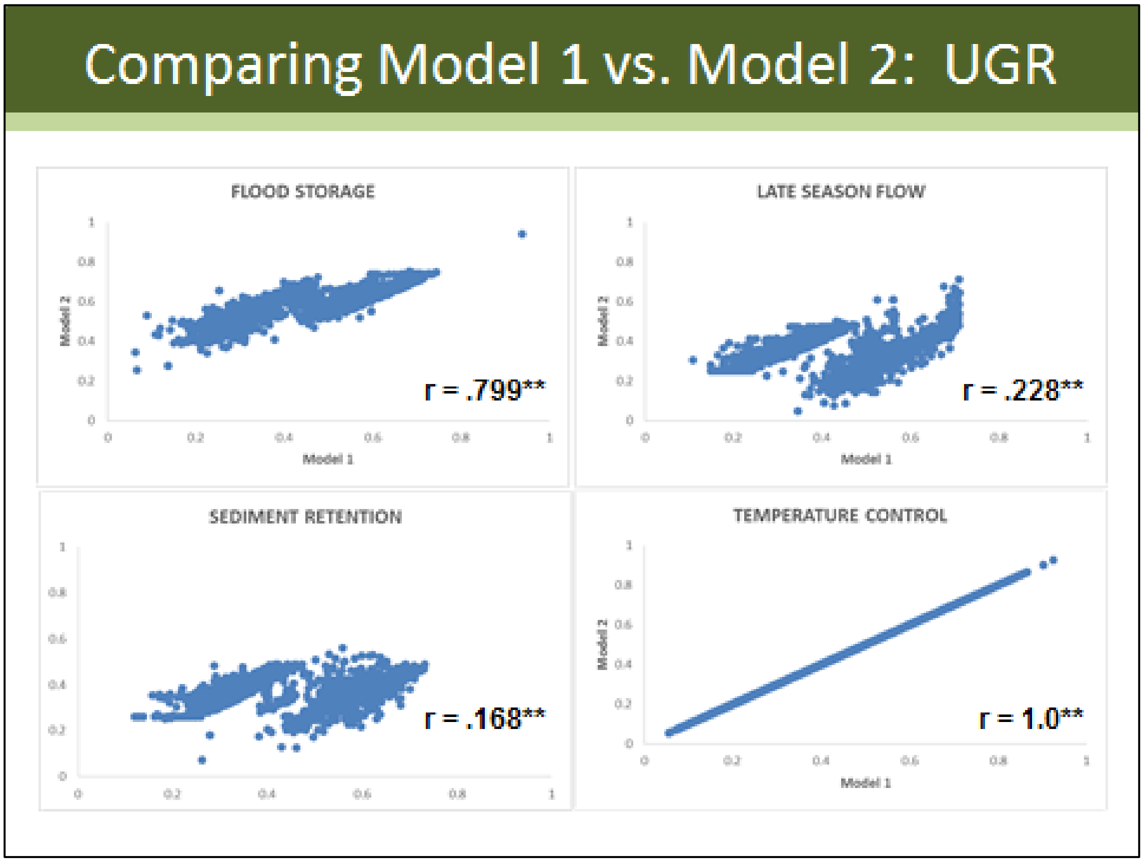

Figure 25. Model 1 vs. Model 2, Upper Grande Ronde. *Bivariate correlations between models for each of four wetland functions in the Wetland Prioritization Tool.*

Figure 26. Boxplots, Model 1

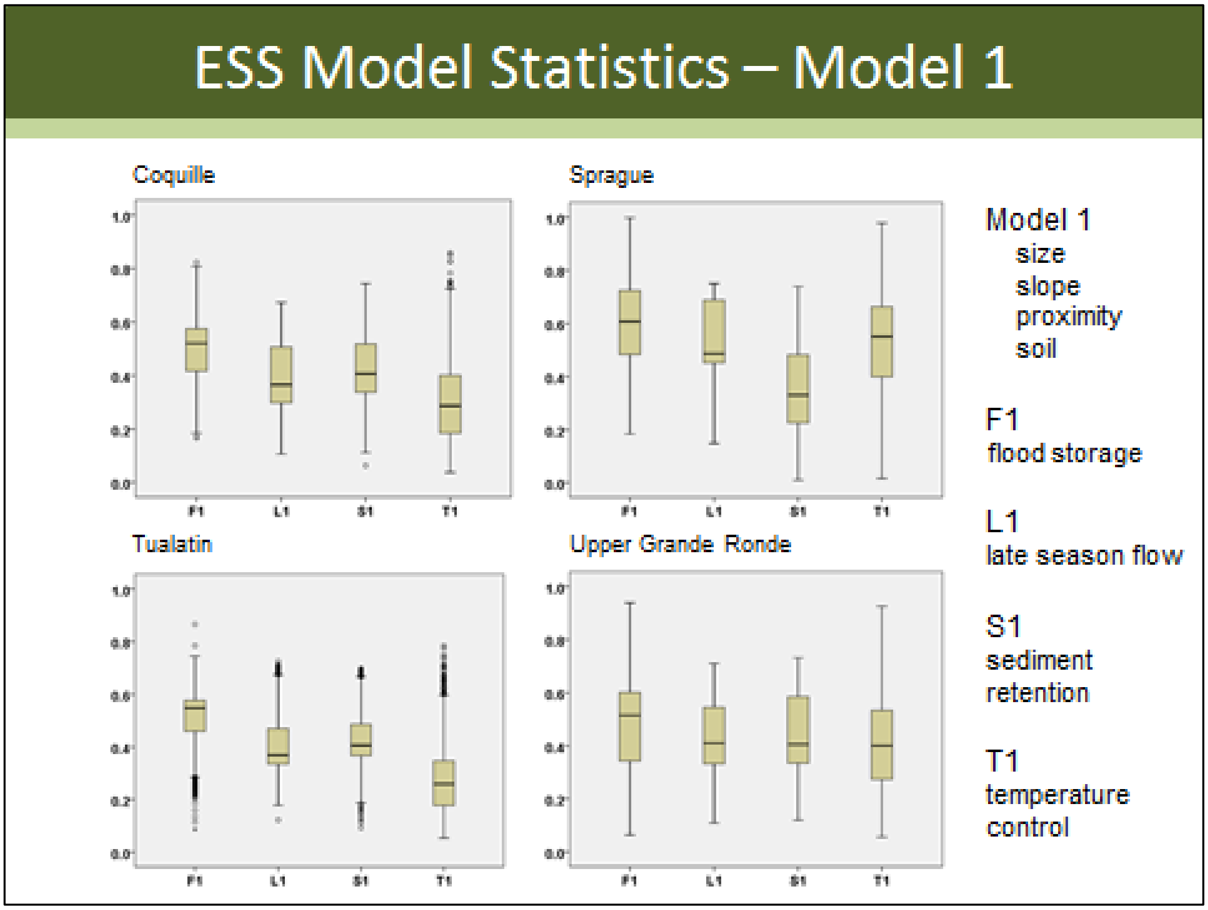

Figure 26. Boxplots, Model 1. *Box and whisker diagrams showing distribution of Model 1 estimates for wetland functions.*

Figure 27. Boxplots, Model 2

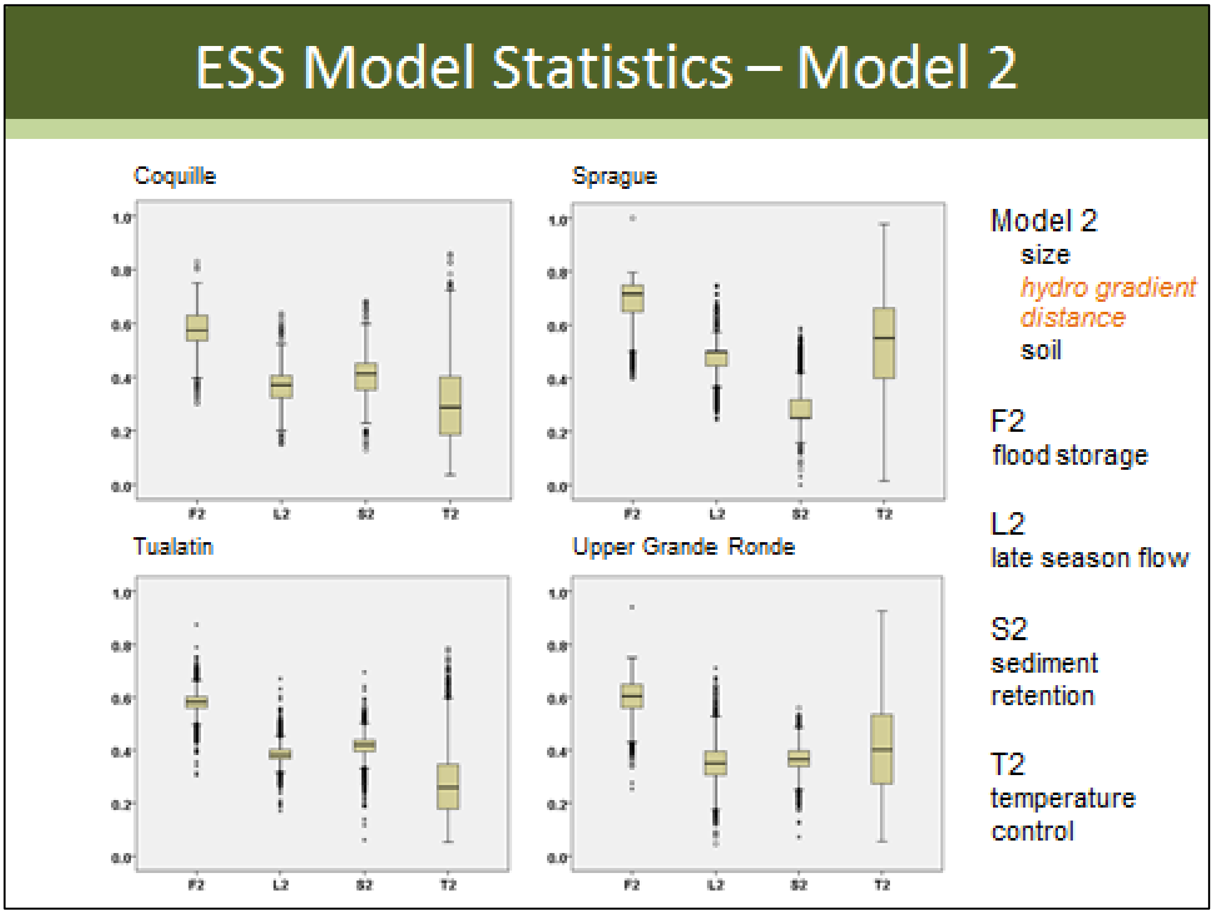

Figure 27. Boxplots, Model 2. *Box and whisker diagrams showing distribution of Model 2 estimates for wetland functions.*

Figure 28. Boxplots, Attributes 1 of 3

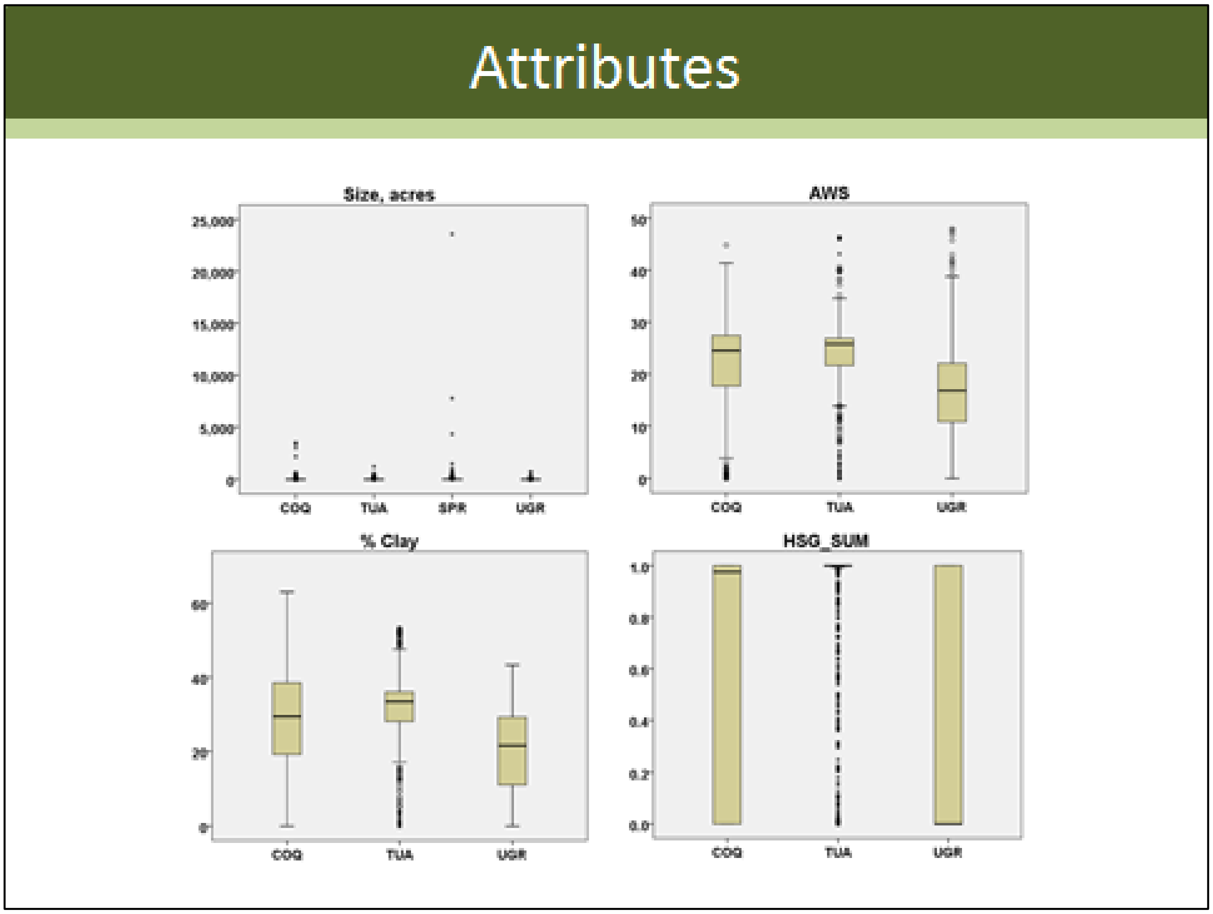

Figure 28. Boxplots, Attributes 1 of 3. *Box and whisker diagrams showing distribution of selected attribute values across study areas for the Wetland PrioritizationTool.*

Figure 29. Boxplots, Attributes 2 of 3

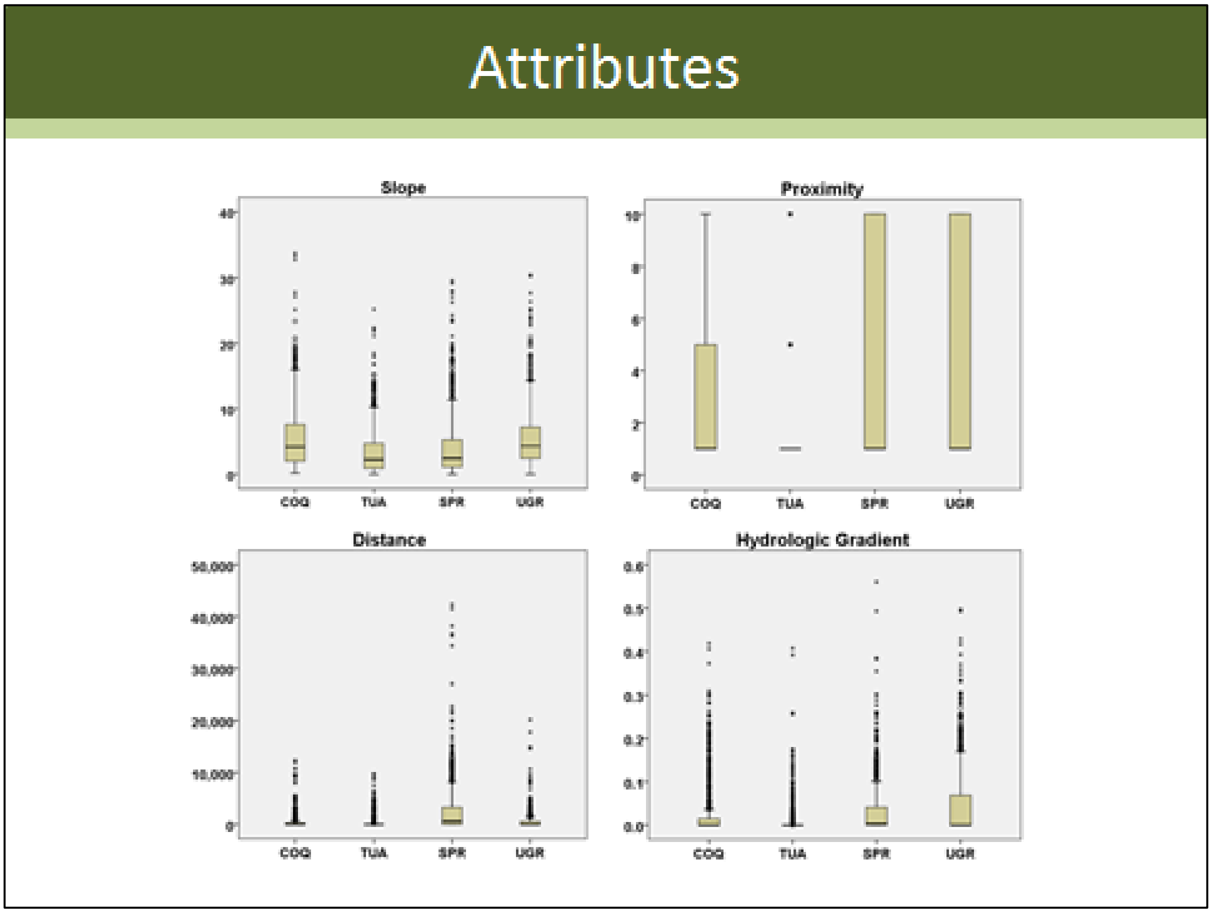

Figure 29. Boxplots, Attributes 2 of 3. *Box and whisker diagrams showing distribution of selected attribute values across study areas for the Wetland PrioritizationTool.*

Figure 30. Boxplots, Attributes 3 of 3

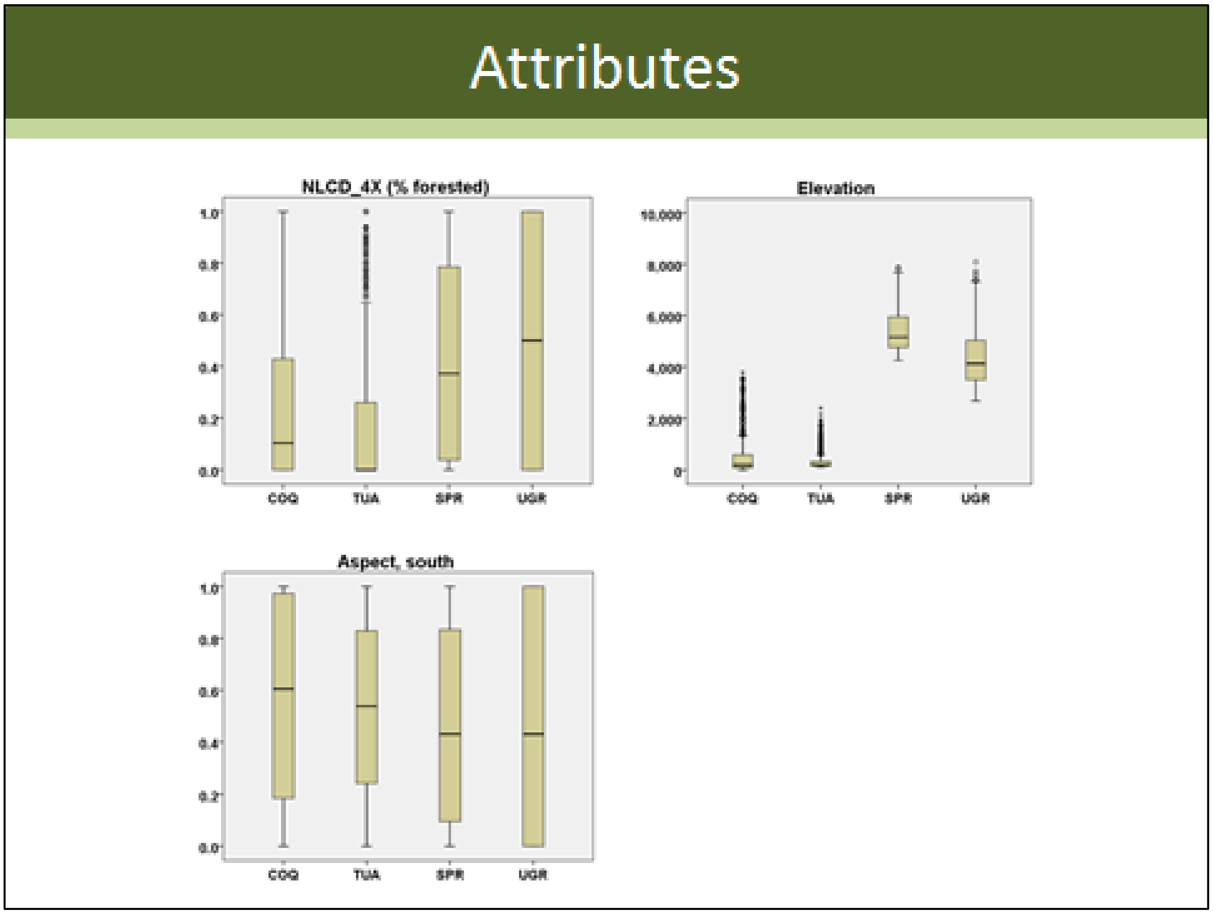

Figure 30. Boxplots, Attributes 3 of 3. *Box and whisker diagrams showing distribution of selected attribute values across study areas for the Wetland PrioritizationTool.*