LOOKING FOR A BETTER WAY TO FIND WETLANDS: COMPARING MAPPING MODELS ON THE QUINAULT INDIAN RESERVATION

by

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ABSTRACT

Looking for a better way to find wetlands: comparing mapping models on the Quinault Indian Reservation

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An improved wetland database is consistent with the management goals of the Quinault Indian Reservation and other land managers in the Pacific Northwest. Wetland screening tools are used in land use planning and are important to protect the habitat of valuable species that utilize wetlands. This project compared to the National Wetland Inventory and a proprietary wetland map known as the AECOM wetland suitability index. The two wetland mapping databases were compared as part of a larger effort to assess the extent of certain wetland classifications. Predicted wetland area polygons (65) were sampled and the field verified classification was used to compare with predicted from both wetland screening tools. This study determined the accuracy of each database based on the success rate of correctly predicted Cowardin (1979) classifications. Both databases were compared to field observations using a kappa statistic method. Results showed a statistically insignificant difference between each database, although AECOM approaches a better level of reliability than NWI. Both screening tools were rated as "fair" overall in predicting wetland system and class, with an average success rate of about 52%.

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Contents

Introduction

Finding wetlands

Reliable information on the extent of wetlands is critical to understanding their resource value and plan for their management. To date, often the only source of wetland mapping has been through the National Wetland Inventory (NWI) (United States Fish and Wildlife Service, 2016). The NWI provides landowners and resource managers a consistent format, based on established nomenclature and methods. NWI information is based on aerial photo interpretation in combination with limited field verification. The NWI approach provides rough estimates of how many acres and what type of wetlands occur in an area of interest. The accuracy of NWI wetland identification and classification is highly dependent on forest cover and is generally believed to underestimate forested wetlands in particular, and subsequently, total wetland area by approximately 45% (Werner 2004).

Defining wetlands

There are several definitions in the wetland literature that are based on legal and ecological characteristics (Ramsar 2013). This study uses the U.S. Army Corps of Engineers definition which is the nationwide standard and is used in implementing the Clean Water Act. This definition is recognized in planning efforts to protect water quality, providing wildlife habitat and flood storage. The manual states that wetlands are:

“*those areas that are inundated or saturated by surface or ground water at a frequency and duration sufficient to support, and that under normal circumstances do support, a prevalence of vegetation typically adapted for life in saturated soil conditions. Wetlands generally include swamps, marshes, bogs, and similar areas*.”

Wetland types or classes in this study follow the characterization method developed by Cowardin (1979) which is also used by NWI. The Cowardin system can be used to classify all types of wetlands in the United States. This study focuses on are freshwater Forest/scrub shrub (wetlands with a canopy cover of >30%, also known as Palustrine forested/scrub shrub or PFO/SS), Emergent (Wetlands with less than 30% cover of trees or shrubs and covered by herbaceous plants, also known as Palustrine emergent or PEM), and Estuarine (Tidally influenced, brackish water wetlands).

Quinault wetland management

The Quinault Indian Reservation (QIR) is located in a very remote and undeveloped region of Washington State with the primary land use being industrial forestry. Past management of QIR wetlands has resulted in degradation of habitat structure, hydrologic regimen, and water quality. In some cases failing culverts have created additional wetland areas effectively turning roads into berms. Declining water quality in the QIR and surrounding basins has been documented over the last several years (Quinault Indian Nation, 2016). Logging has been proven to permanently alter hydrologic processes in similar forested habitats (Perry and Jones, 2017) which is likely contributing to this degradation. Further, Beckett et al. (2016) studied the effectiveness of the Forest Practices Act (Title 222 of the Washington Administrative Code) and found that harvesting in and upslope of forested wetlands results in a higher water table and increased water runoff in watersheds. Compared to residential and other industrial land uses however, timber production causes less degradation overall due to minimal increases in impervious surface. As long as haul routes are directed around instead of through wetlands, and adequate measures are taken to preserve the hydrology of adjacent wetlands to timber sale units (such as buffers and strategically placed culverts) the worst impacts from harvest activity is loss of wildlife habitat, altered hydrologic regime, such as reduced water quality and increased runoff. An improved wetland inventory could aid foresters in laying out timber sales so that landowners can have both an income as well as habitat for culturally important plant and animal species since Cowardin classifications represent specific habitat types.

Forested ecosystems are notoriously difficult for mapping wetlands using remote sensing because canopy cover obscures photo interpretation of forested wetlands (Werner, 2004; Tiner, 2015). The QIR has low laying topography and receives up to 120 inches of annual rainfall (PRISM, 2004). Forested wetlands on the QIR are composed of primarily Sitka Spruce (*Picea sitchensis*) and Western Hemlock (*Tsuga heterophylla*) but plantations have included a higher ratio of Douglas fir (*Pseudotsuga menziesii*). The vast majority of forested wetlands and riparian zones were logged at some point over the last century. Non-forested wetlands count for at least 1/3 of the total wetland area on the QIR. This type of wetland provides habitat for many culturally important species such as *Camassia quamash, Ledum groenlandicum, Cervus Canadensis, Odocoileus hemionus.*

Harvest management priorities now include buffers for wetlands and vary depending on the associated stream.

Current wetland screening tools

The current mapping effort is part of the Quinault Indian Nation (QIN) Wetland Program Plan (Bingaman and Ravenel, 2016). Prior to the implantation of this plan, NWI maps provided the most comprehensive wetland inventory on the QIR. These maps were produced using photointerpretation of aerial imagery from 1985 (Bill Kirschner, USFWS, Personal Communication 2016). Although there have been field verification sites off reservation, no field verification sites were visited on the QIR (Tony Hartrich, Personal communication, 2016). The current effort is part of the 2nd phase of an Environmental Protection Agency Wetland Program Development grant. The first phase of the grant funded mapping of reservation wetlands using a predictive model (known as the AECOM Wetland Suitability Index, or WSI), as opposed to photo interpretation (AECOM, 2015). In association with the AECOM wetland mapping project a there was a field verification effort consisting of 53 sites of the predicted 1,353 QIR wetland polygons. This field verification was restricted to wetlands along or near roads and Cowardin class and total area were not verified. The AECOM verification effort found an error rate of approximately 40%, suggesting that this model database is only 60% accurate in predicting wetland presence and class. This current study, is more comprehensive in that it looks at the difference in predicted vs. observed Cowardin classes in addition to determining jurisdictional wetland presence. For example, PFO/SS wetlands may have an even higher ratio of predicted wetlands to actual wetlands (errors of commission), whereas PEM or PSS classes have a lower ratio due to less canopy cover and a more distinct signature in ancillary data sets. This study does not identify errors of omission, or rather unmapped wetlands in areas predicted by the model to be uplands. The time and resources for this project limited the scope. Each wetland sample site was also rated using the Washington State Department of Ecology's 2014 Wetland Rating System for Western Washington (Hruby, 2014) to aid in documenting Cowardin class, but the results of these ratings are not reported. Riverine, Marine and Lacustrine wetlands make up a large percentage of the total wetland acreage on the QIR, but because these are more easily mapped using remotely sensed data than the types selected for this study, they are not included.

The aim of this project

The information obtained from remote sensing and field investigation is useful for managing oftentimes conflicting natural resource uses. This is true for wetland management throughout the United States as much as on the QIR. For example, Forested wetlands that have little value as timber could be conserved for wildlife use. With better wetland maps, foresters could exclude forested wetlands with economically marginal timber from the harvest units to prioritize wildlife habitat and other ecological functions. To better understand wetland ecosystems and subsequently inform a compromise between management priorities on the QIR I ask the question: How accurate are two predicted wetland presence and classification models that are based on primarily remotely sensed data? This study adopts modified methods from several previous wetland verification studies to compare modern wetland mapping models to inform the reader of the utility of the each model.

Literature Review

A review of the literature shows that many studies have been done to map wetlands that combine remotely sensed data with field investigations. The methods used for the current research follow those outlined in the literature review. The results of this study reflect the findings of studies done in areas of similar forested landscape and hydrologic complexity. Ways of improving the model and database are discussed in terms of past verification studies, as well as suggestions for future research based observations.

Quinault Indian Nation project area

Little has been published on wetlands specifically on the QIR. However, QIN (The governing body of the QIR and its people) is aware of the value wetlands have as a natural resource and is interested in understanding reservation wetlands in the context of research conducted in similar landscapes. QIN also recognizes that identifying and classifying wetlands on the QIR is of critical importance in the current climatic situation. Several studies that focus on the wetland prairies of the western Olympic Peninsula are helpful in setting the stage for this study (Anderson, 2009; Rocchio et al. 2015; Gavin et al. 2013; Bach and Conca, 2004) which characterize most of the bog and fen wetland types found on the QIR. Decadal to century scale changes in floodplain wetlands have also been studied on and around the QIR (O'Connor etal. 2003).

The most important regulatory document relevant to this study is the QIN Forest Management Plan (FMP). This document is the regulatory framework for all natural resource management decisions on the QIR. It contains a regulatory definition of wetland areas and how they are treated under various types of resource activities. The other primary wetland document produced for the QIN is the Models and Methods report for the WSI. This index was created for QIN by a contractor (AECOM 2015) and is based on a GIS model that includes several sources of information including National Wetland Inventory (USFWS, 2016), LIDAR, and soil data (See Appendix 1). The appropriate regional supplement to the U.S. Army Corps of Engineers 1987 wetland delineation manual for the QIR is the Western Mountains Valleys and Coast (USACOE 2010).

Wetland classification

The Wetland Determination Form for this manual was used to determine wetland presence. This determination by itself, however only provides information in a very small area (<10m) for classifying various wetlands (see Methods section for classification schema). One classification method utilized in this study to determine the Cowardin class is the Hydrogeomorhic (HGM) approach (Brinson 1993). The HGM approach to classifying wetlands provides more information on the types of ecological functions provided. It categorizes the wetland into classes that describe how the water moves through the wetland as opposed to relying on vegetation cover in the Cowardin method.

Examples of HGM types include slope, depressional, lake-fringe, tidal fringe, and riverine wetlands. HGM class is notoriously difficult to predict using remote sensing technology (Dvorett et al. 2012). Both NWI and WSI use the Cowardin code classification method, but special modifiers at the subclass level of classification are similar to the HGM approach.

Comparing wetland screening approaches

Several similar studies involving the field verification of NWI maps have been conducted throughout the country. Wu et al. (2014) compared the ACOE method (used for regulatory purposes) to the NWI method (used for inventory/planning purposes) in New York and found that the data agreed 78% of the time with field investigations. Dvorett et al. (2012) used existing NWI data to predict HGM classification in Oklahoma. The authors conducted field verification at 149 sites and found that NWI predicted HGM class at 60% of sites. Werner (2004) found that NWI maps predicted wetland areas relatively accurately (293 out of 294) in California, but missed 50% of additional wetlands (errors of omission). Dahl et al. (2015) discusses additional major drawbacks of remotely sensed wetland data. They point out that wetland substrate, salinity, and certain vegetation communities are impossible to measure via satellite. Rampi et al. (2014) assessed the accuracy of the recently updated NWI maps for the state of Minnesota. They found that an object based image analysis method had a much higher accuracy than NWI (a 9% to 20% improvement depending on the area of interest) at predicting actual wetland boundaries. At least one of their study sites was in a similarly forested landscape like that found on the QIR. Another study by Fuller et al. (2006) used an “early spring

IKONOS pan-sharpened satellite image." They found that any amount of automated classification and delineation did not result in significantly improved predictions.

All of these studies highlight the limitations of remotely sensed wetland data in predicting Cowardin/HGM class and regulatory wetland presence. This study recreates portions of the previously discussed types of validation on a new area that is extremely hydrologically complex and uses the resulting data to analyze the NWI map and the WSI.

Methods

Environmental setting

The project area for this study (the QIR) is approximately 200,000 acres of low laying, gentle topography, in the hyper-marine, Sitka spruce forest zone of the Olympic Peninsula. The maritime climate with abundant moisture throughout the year, relatively mild winters, and cool summers. Annual precipitation varies within the range of Sitka spruce and is influenced greatly by local topography. Most of the annual precipitation falls in the winter and early spring and summer precipitation is limited but persistent coastal fog maintains healthy epiphyte communities.

Experimental Design

Data collection for this study took place December, 2016 thru February, 2017. Although not an ideal time to make wetland determinations, scheduling and funding constraints necessitated winter field work. Typical wetland field verification methods for planning purposes (EPA Level 1 Rapid assessment method, U.S. EPA, 2006) were used to locate and estimate Cowardin cover class. Standard wetland determination and classification methods were used to identify wetland presence and class (See *Introduction*). Observed Cowardin Class was determined by looking at the dominant cover class in the predicted NWI or WSI predicted wetland polygon area. Mixed classes were recorded as specified by Dahl et al. (2015), but the dominant class surrounding the sample point took precedence over the total extent of the wetland polygon.

In order to reduce sampling bias, a Generalized Random Tessellation Stratified survey design was constructed for WRIA 21 (Olsen, 2016). From this set of randomly selected points, a subsample 65 sites were selected out of the three most abundant Cowardin classes (20 Estuarine, 21 PEM and 24 PFO/SS) with the exception of Riverine. The NWI predicted Cowardin class of wetland polygons in which these points are located were then overlaid on the WSI GIS layer. This sample size and classes were selected based on the availability of one wetland scientist to conduct field research in the area of interest. These methods are designed to be scaled up for verification of more wetland polygons as time or resources become available. This level of effort was dictated by the Wetland Program Development grant.

Specific Cowardin classifications that were field investigated for this study included Estuarine, Intertidal, with the classes unconsolidated shore, emergent, scrub shrub, forested, Palustrine Emergent, and Palustrine scrub/shrub and Forested (referred to as PEM, PFO/SS in *Figure 1*). The correct classifications was recorded in order to compare to the predicted classifications to the field verified classifications.

Study Approach

This study only identifies errors of commission. Distance to the actual wetland edge from the predicted wetland polygon was estimated using a GPS to measure the distance between two points along the access route and as needed elsewhere. None of the sample plots was >10 meters from the edge of the wetland unit being investigated/classified. Several sample locations were flooded at the time of inspection, in which case the sampling location was offset to the nearest point to gain access to the soil profile. It will be assumed that if hydric soil characteristics are present on slight rises, there wetland soil characteristics are also present in the flooded areas. Wetland plant species were identified with twig characteristics and collected as a reference, the remnants of herbaceous species were identified and photographed as reference. Although determinations were done in the winter, enough remnants of plants (or a lack of plants for unconsolidated areas) were present at each of the sample sites to positively identify the correct Cowardin class. Hydrogeomorphic position, Cowardin water regime and other special modifiers were recorded when obvious but as stated before, these data are not used in the analysis of each wetland map.

Data Analysis

The Kappa statistic is used to determine the significance of categorical data by comparing observed to predicted classification (Fleiss etal. 2013). This method is standard in the analysis of remotely sensed data (Congalton, 2008). Kappa matrices were calculated for NWI and WSI for both the system and class level of Cowardin classification, similar to Rampi et al. (2014). The resulting statistic indicates the level of accuracy of each map. The Kappa statistic takes into account the number of classes that would be correctly predicted if they were just randomly assigned to wetland polygons. These results are reported along with the percent correct because they provide more of an explanation rather than just indicating an incorrect classification. Each dataset was entered into an online kappa statistic calculator (Graphpad, 2017). The ratio of correct Cowardin classes versus the incorrect classes are reported (although many wetlands have multiple Cowardin classes, the dominant Cowardin class observed in the polygon in which the sample point is located was used for the purposes of this study). This determines the likelihood that a Cowardin system or class is likely to be dominant at an unsampled wetland within the QIR. This analysis is similar to Kudray and Gale's (2000) methods in that they take into account different Cowardin classes.

Results

Observed Cowardin classes and jurisdictional determinations

Of the 65 wetland sampling locations, 60 met all three indicators of the Army Corps of Engineer wetland determination form (90%). This result does not say much because there was always a wetland nearby and the point just happened to be within the adjacent upland.

The two models agreed at the system level at 54 sites (83%) and at 34 sites at the class level (52%). NWI correctly predicted Cowardin system and class at 33 sites (51%). WSI correctly predicted Cowardin system and class at 35 sites (54%). Both models were best at predicting a Palustrine Forested or Scrub/shrub (PFO/SS) wetland with a 75% success rate. NWI did poorest with Palustrine Emergent (PEM) wetlands, only getting those right 25% of the time. Both mapping resources correctly guessed Estuarine wetlands correctly about half the time. Out of the observed sample sites, both models agreed with each other more often for all Cowardin classes than with field conditions. See Table 1 for a comparison of predicted and observed wetland classifications andTable 2 for a compasrison of observed class to predicted class using the kappa statisticTable 3 displays the predicted wetland area for each Cowardin class for both NWI and WSI.

NWI class prediction agreed with observations approximately 17.89% more often than was expected by chance (Kappa=0.225) and NWI system prediction agreed with observations 31.39% more often than was expected by chance (Kappa=0.671). Higher Kappa scores indicate strong agreement between data sets. WSI class prediction agreed with observations 26.58% more often than was expected by chance (Kappa=0.344) and WSI system prediction 42.11% more often than was expected by chance (Kappa=.846). Even though WSI system prediction is considered to be very good, the 95% confidence interval (0.725 to 0.966) overlaps with NWI's (0.509 to 0.833) which indicates that WSI is not significantly different than NWI. The Kappa analysis is better than just reporting percent correct because in addition to ruling out agreements expected by chance, it accounts for the bias each map has towards one class or another. In other words, predictions for both maps tended to favor one classification over the other (i.e. EM, which were observed to be SS, see Table 2). It is important to note that kappa just compares two datasets, not an unknown and known (e.g. estimate vs guess), necessarily.

It is a measure of concordance between datasets, and does not assume or mean that one dataset is "right" and another is a hypothesis.

Table 1: Comparison of predicted and observed wetland classifications in terms of percentage correct

Cowardin Class	# of correct NWI Classifications (% correct)	# of correct WSI classifications (% correct)	# of correct ACOE jurisdictional wetlands (% correct)	# of WSI and NWI agreed (% agreement)	
				System	Class
PFO/SS	21 (91%)	25 (89%)	20 (83%)	22 (92%)	15 (63%)
PEM	5 (22%)	2 (15%)	20 (95%)	20 (95%)	10 (48%)
Estuarine	12 (67%)	8 (40%)	20 (100%)	12(60%)	6 (30%)
Total # correct (%correct)	33 (51%)	35 (54%)	60 (92%)	54 (83%)	34 (52%)

Table 2: NWI and WSI classification error matrix for QIR study area

	Observed System				
NWI	Estuarine	Marine	Riverine	Palustrine	Total
Estuarine	**10**	0	3	1	14
Marine	2	**2**	0	0	4
Riverine	0	1	**0**	0	1
Palustrine	3	0	0	**43**	46
Total	15	3	3	44	65
Overall Kappa Statistic: 0.671 (good)					

	Observed System				
WSI	Estuarine	Marine	Riverine	Palustrine	Total
Estuarine	**15**	1	1	0	17
Marine	0	**1**	0	0	1
Riverine	0	1	**2**	2	5
Palustrine	0	0	0	**42**	42
Total	15	3	3	44	65
Overall Kappa Statistic: 0.846 (very good)					

	Observed Class				
NWI	U	EM	FO	SS	Total
U	**6**	1	1	5	13
EM	5	**7**	2	15	29
FO	1	1	**9**	5	16
SS	0	0	4	**3**	7
Total	12	9	16	28	65
Overall Kappa Statistic: 0.225 (fair)					

	Observed Class				
WSI	U	EM	FO	SS	Total
U	**9**	2	2	0	13
EM	3	**4**	0	18	25
FO	0	0	**12**	3	15
SS	0	3	2	**7**	12
Total	12	9	16	28	65
Overall Kappa Statistic: 0.344 (fair)					

(U= Unconsolidated shore, EM=Emergent, FO=Forested, SS=Scrub/shrub)

Discussion

Mapping and classifying wetlands is difficult, especially on the low topographic relief and the hydrologic complexity of the QIR. The WSI wetlands screening tool provided little improvement in wetland classification over existing NWI. The area of wetland screening tool development is rapidly developing, Rampi et al. (2014) found a 22% increase in accuracy using an object based image analysis approach which utilized high resolution leaf off orthorectified imagery taken in a forested landscape. Object based image analysis could with existing data on the QIR if resources were available Field verification is the most reliable way to tell the extent of wetlands on the QIR but, it is not feasible given the extent and remoteness of the QIR. The combination of remote sensing data in tandem with field verification data would be to develop program that uses the Tracking Analyst extension in ArcGIS to track changes apparent in aerial imagery of wetland areas over time (such as forested wetlands that are logged and go through successional stages to become forested again). Inputs into this program would consist of field verified spectroscopic readings to provide characteristic spectral signatures for automated computer recognition.

One of the data sources for the WSI was the NWI (weighted 16%). Since over 90% of the sample sites were within a jurisdictional wetland, an improved map should just incorporate 100% of the predicted NWI maps. Any additional wetland areas should be predicted using the other data sources, with the majority of NWI's 16% weight going towards the GAP land cover database (See Appendix 1). GAP imagery is the most comprehensive land cover inventory in the United States (Gergely and McKerrow 2016) and could have been better utilized in my opinion.

Several of the sample sites were within wetlands that were either highly modified or created by road building for logging operations. Most of these structures were installed over 40 years ago so the resulting wetlands have established highly functioning ecosystems. It would be almost impossible to parse these “artificial” wetlands out of the wetland database and doing so would be a disservice to the ecosystem services they are providing. Careful consideration should be given to each particular project that is likely to impact wetland or stream hydrology even if it is restoring a more natural hydrologic regime.

Figures 3 through 6 illustrate the boundary and classification discrepancies between NWI, WSI, and field observations. At this example site, WSI predicted much more wetland area than NWI, but field observations revealed even more. This was the most significant example out of the 65 sites, but it was a common theme. These situations would benefit from additional photo interpretation and field verification in order to produce a more realistic wetland boundary map.

The ecological implications of missing and misclassifying wetlands are significant. The more wetlands that are known, the better they will be managed for their ecological functions and designated uses based on water quality standards. Since having good water quality and habitat for fish and wildlife species is important to community members, land managers will be better able to keep conditions suitable and improve degraded sites with an improved wetland database. Using only remotely sensed wetland data to make natural resource management decisions does not account for the wetlands that were not correctly predicted and may lead to poorly managed wetlands that do not reach their full ecological potential.

Both the NWI and WSI correctly predicted fewer Cowardin classes than other field verification studies (Kudray and Gale, 2000; Werner, 2004; Wu et al. 2014). However, the rate of correctly predicting an ACOE jurisdictional wetlands (93%) were similar to Kudray and Gale's (95%), Wu's (83%) and Werner's (99%) findings which were conducted in similar forested landscapes. Although the rate of correctly predicted jurisdictional wetland areas was high, these data reveal significant discrepancies between both models and actual classifications on the QIR.

Predicted WSI wetland polygons appear to align with features made more apparent by the increased resolution of topography afforded by new remote sensing data. (Fig 3). The level of effort that the Minnesota Department of Natural Resources put into their 2016 NWI update (Macleod, Paige, & Smith 2013) is a good example for jurisdictions looking to improve the accuracy of their wetland inventories and compares the utility of two classification models against actual conditions.

Most of the wetland sites investigated for this study consisted of distinct plant community types but there were considerable gradations and interspersion of other communities. The community types observed are typical of those found in hydrologicly complex systems and especially for PFO wetlands, relatively frequent disturbance regime (most of this class of wetlands on the QIR are harvested every 40 years). Streamflow impoundment due to failed culverts was the primary anthropogenic influence for the current community at many sites. For example, many PUS and PSS wetlands were either PFO or upland before an access road was constructed, causing the water table to rise and in many cases, preserving the old growth stumps which were observed scattered throughout an otherwise non-forested wetland (See Appendix 3).

Many wetlands were in transitional states between different classes. For some sample wetlands near the river, but above the 100 year floodplain were old oxbows formed thousands of years ago that have slowly filled in with sediment or peat to become fens. Another blending of two classifications is the *Myrica gale* dominated wetlands which were always associated with *Sphagnum*. A few observed wetlands were artificial. Roads constructed over the years have significantly altered the water regime of many streams and wetlands. These impacts are particularly noticeable in areas with failing culverts. Neither model is designed to track the changing classifications over time as vegetation communities go through successional stages.

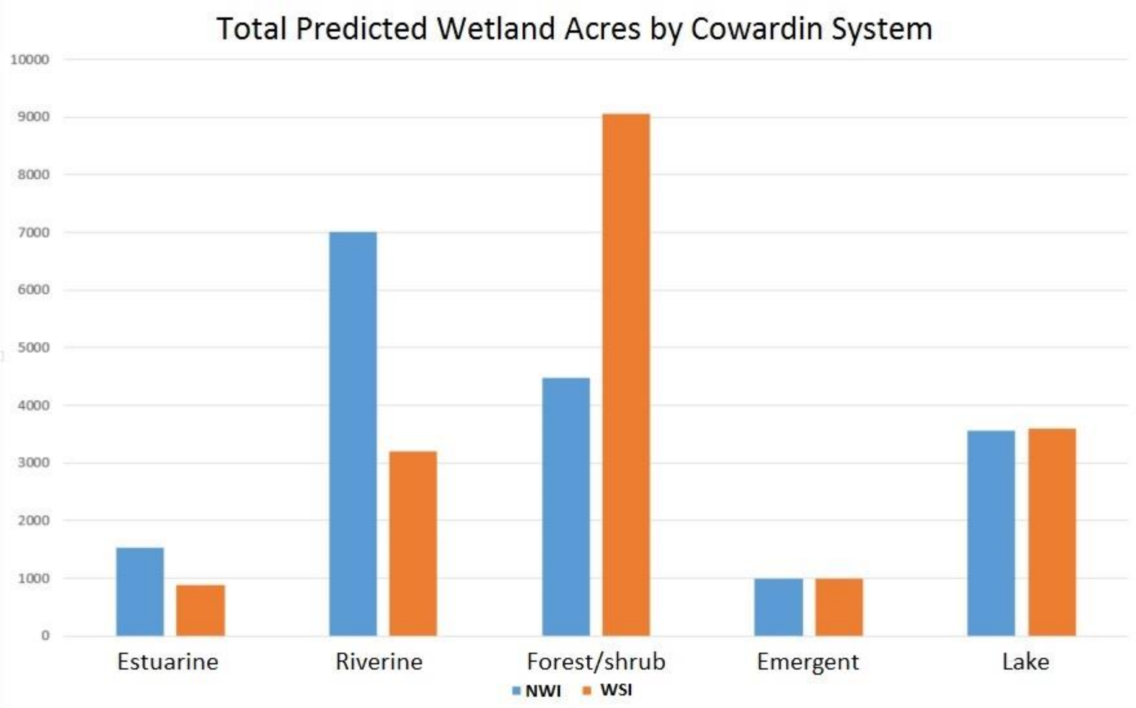
Most wetlands incorrectly classified as Emergent by both NWI and WSI were Scrub/Shrub due to the dominance of stunted *Myrica gale* (See Appendix 2: Example *in situ* photography of erroneously classified Emergent wetland). Most of the sample locations in these areas were likely predicted to be PEM because the *M. gale* was very low growing and difficult to distinguish as a dominant species from aerial imagery.

Emergent plants were often co-dominant (>30% cover), but the prevailing Cowardin classification of PSS trumped the PEM determination in these cases.

The wetland upland gradient was difficult to determine in many areas because of the extremely subtle topography gradient. Some of the sample points that did not meet all three of the ACOE criteria for jurisdictional wetland presence did have 1 or even 2 of the 3 criteria. For delineation purposes, these wetland edges would be further scrutinized because there were likely special circumstances that would constitute the point being within a jurisdictional wetland.

Interspersion of the various Cowardin classes at most points was much higher than suggested by both WSI and NWI. Although this information is anecdotal, it is relevant to this study because any future wetland mapping effort must take this into account. Figures 1 through 4 illustrate this interspersion at one sampling location (WET0213).

Table 3. WSI and NWI Modeled Wetland Classifications by acres on the Quinault Indian Reservation



Conclusion

Which is the better model?

The WSI was 3% better than NWI at predicting Cowardin class. This is not statistically significant, but at least it is a step in the right direction. Since this study is part of a larger effort to improve the QIR wetland geodatabase, additional field verification and photointerpretation will have to be done before either WSI or NWI wetland maps are considered accurate. I propose that the WSI and NWI be used in tandem to create a more comprehensive map of the wetlands on the reservation. The results of this study should inform the reader that the reliability of remotely sensed wetland data in general depends heavily on the level of effort put into creating the model and the quality and types of inputs including field investigations and other ancillary datasets. The results indicate that both the NWI and the WSI have only a slightly better than 50% chance of correctly predicting Cowardin class. Some larger, more common wetland types may be correctly identified, but they day to day operations that impact wetlands on the QIR would benefit from having much more detailed information for all potential wetlands gained by conducting site visits by a wetland scientist. Given this rate, some apprehension should be expected when using either of these maps for planning purposes, let alone project level analyses.

How could we more definitively tell which map is better?

Navigating to sites revealed wetland areas likely extend beyond the boundaries suggested by both mapping resources. A study of errors of omission (i.e. unmapped wetlands) should be conducted to identify areas not mapped as wetlands by either NWI or the WSI, but have water tables within 1 m as predicted with a wet area index model such as White et al.'s (2012) method. Several edges of wetlands visited for this study extended well beyond the predicted edge for both mapping resources. A delineation study utilizing the Wet Area Index method as well as field verification should be conducted in order to determine how accurate each mapping approach is at predicting the total wetland area on the QIR.

Further wetland field investigations on the reservation would benefit to follow the framework described in this study. In order to keep the QIN wetland database up to date, the most recent available datasets should be input into the WSI algorithm or an equivalent such as the wet area index or the object based image analysis method (Rampi et al. 2014). Photointerpretation should be used to bring the WSI up to Federal Geodatabase standards (Dahl et al. 2015) so it can be incorporated into the official NWI database. Other Cowardin classifications should be investigated, especially Riverine and Palustrine Forested in order to reconcile the discrepancy between NWI and WSI predicted amount of riverine and Palustrine Forested wetlands. Additional investigations need to be done to quantify errors of omission, which I have observed to be up to 40% in similar forested ecosystems (BPA 2016). Field verification efforts should expand to include Riverine wetlands, which were not analyzed in this study, to come up with a better estimate for total Palustrine Forested and Riverine wetlands on the QIR. One reason NWI may estimate more Riverine than Palustrine wetlands is its incorporation of a buffered stream layer. This buffering essentially creates a polygon feature out of a line feature in GIS. The WSI doesn’t incorporate a buffered stream map. A buffered stream network would help bring the estimated riverine wetlands closer to reality.

Figure 1. 2015 aerial image of area surrounding wetland sampling 0213.

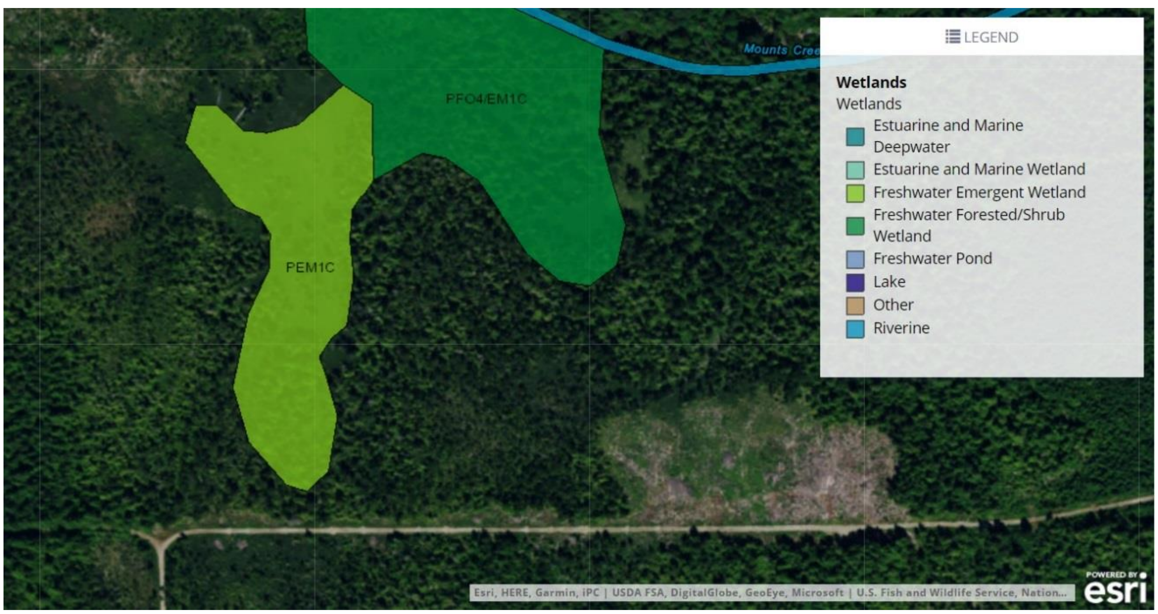


Figure 2. NWI map of predicted wetland extent and Cowardin class (Light green indicates Palustrine Emergent and Dark green indicates Palustrine Forested)

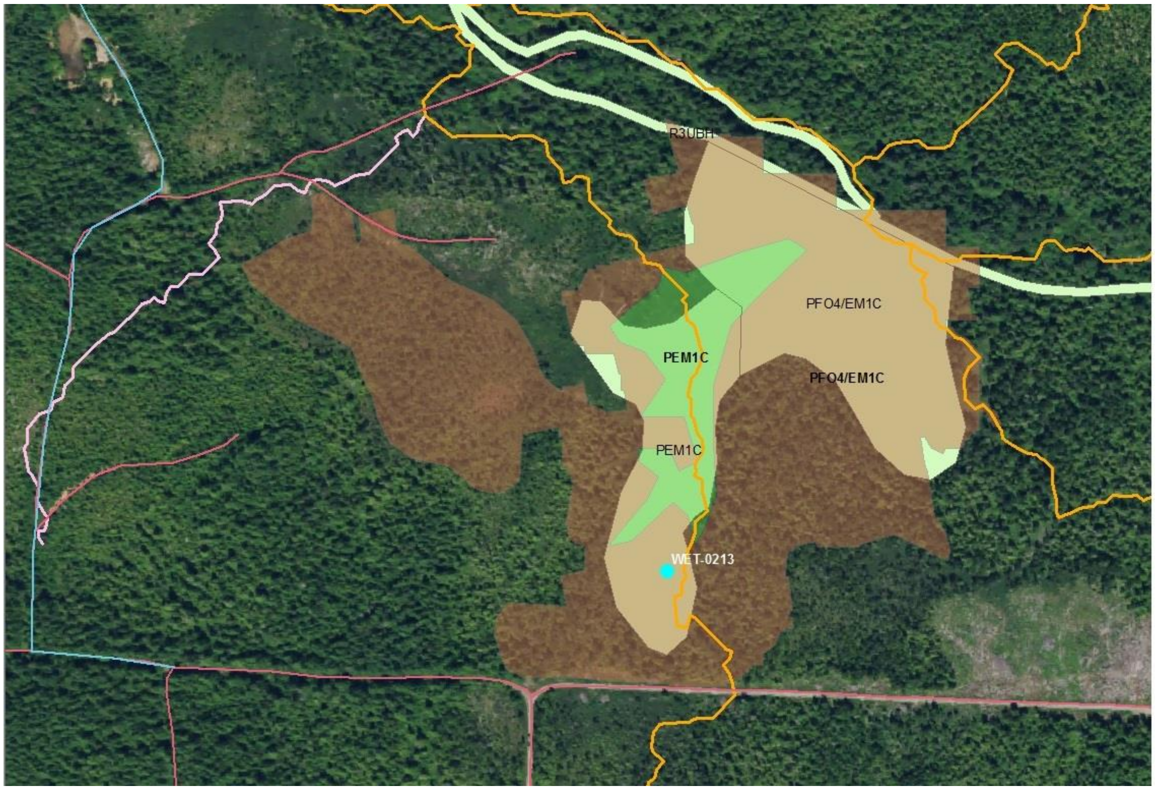


Figure 3. NWI and WSI predicted wetland area (Brown indicates Palustrine Forested, Green indicates Palustrine Emergent, and White is NWI)

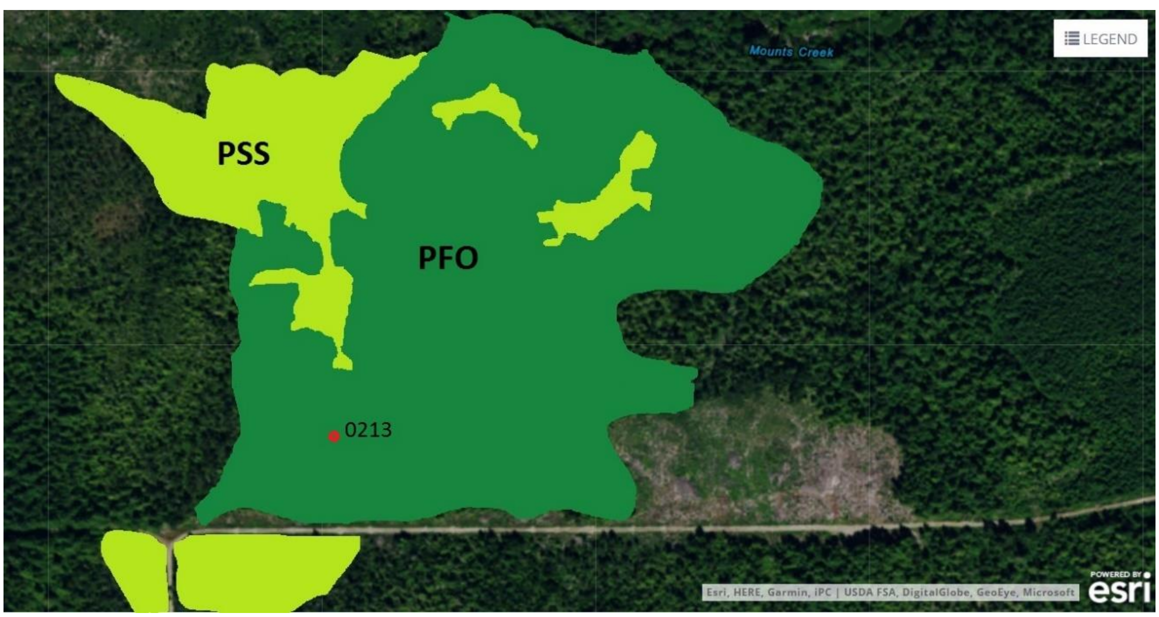


Figure 4. Estimated observed extent of wetland area around sampling point 0213**.**

If there were a chance to repeat this study, shrub and forested wetlands would be considered separately because although there were wetlands that were transitioning from PSS to PFO, most of the PSS wetlands consisted of the *Myrica gale* community type which are relatively permanent (Kunze, 1994) and were historically managed by Native Americans who burned them at certain intervals (Bach and Conca, 2004) for cultural use. A study to detect actual wetland boundaries should include some field verification in areas notoriously difficult to distinguish from uplands. It would also include a wet area index model as described by White et al. 2012.

Field investigations should be done to delineate a sample of wetlands in order to set more realistic weights to the various data inputs. Additional investigation should be directed towards riverine and PFO/SS in order to determine why there are so many more riverine wetlands predicted by NWI than WSI and why there are much more PFO/SS wetlands predicted by WSI than NWI. This difference is suspicious and actual conditions could be somewhere in between or much greater than either map predicts. Finally, besides wetland classification, wetland area should be investigated since both NWI and WSI tended to underestimate the size of wetlands.

There are many ways that wetland mapping could be improved on the Quinault Indian Reservation. Given the resources, a wetland scientist could choose one of or just the parts of the myriad of other wetland mapping studies used elsewhere in the U.S. The path forward is only possible with continued funding of the wetland program and sustained interest in managing the ecosystem more holistically rather than for a single resource.

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Appendices

Appendix 1. AECOM Wetland Suitability Index Data Sources and weighing schema

Layer	**Value**	**Score**	**Weight (% Influence)**
NRCS Hydric Soil	Blank field/NOT a Pond	0	15%
	Moderately/Somewhat Poorly Drained	15	
	Poorly Drained	20	
	Very Poorly Drained (Soil Complexes [MU 13, 20, 22, 37])	25	
	Very Poorly Drained (All other Soil Complexes)	35	
GAP Land Cover	North Pacific Hardwood-Conifer Swamp	20	22%
	North Pacific Lowland Riparian Forest and Shrubland	10	
	North Pacific Montane Riparian Woodland and Shrubland	10	
	North Pacific Shrub Swamp	20	
	Temperate Pacific Freshwater Emergent Marsh	20	
	Temperate Pacific Tidal Salt and Brackish Marsh	20	
	North Pacific Maritime Eelgrass Bed	20	
	Temperate Pacific Freshwater Aquatic Bed	20	
	Open Water (Brackish/Salt)	20	
	Open Water (Fresh)	20	
	Unlisted values in list (unconsolidated shore, pasture/hay, development high intensity, etc.)	0	
Stream Network	Any	40	16%
NWI Wetlands	Any	50	16%
Mapped Wetland Prairies	200 or >200 and Riparian_S not "1"	50	16%
	>200 and Riparian_S = "1"	20	
	<70 and in a hydric soil polygon	40	
Soils	Ds (Destruction)	20	15%
	Oo (O'Took)	20	
	Mu (Mukilteo Peat)	40	
	P (Pond)	40	
	Se (Sekiu)	30	

Appendix 2. Example *in situ* photography of erroneously classified Emergent wetland

The dark brown areas are dominated by *Myrica gale*, a shrub. This wetland was misclassified as Emergent by both NWI and WSI wetland maps. Photo Credit: Greg Eide, Quinault Indian Nation

Appendix 3: Example site of preserved old growth stumps in artificially impounded wetland (note soil shovel in lower right for scale)