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Water Typing Model Field Performance Assessment Approach and Procedures

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Water Typing Model
Field Performance Assessment
Approach and Procedures

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Washington State
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Submitted by:

Terrapin Environmental
988 Twisp River Road
Twisp, Washington 98856

In association with

BioAnalysts, Inc.
Eagle, Idaho 83616

and

EarthRes.i
Tacoma, WA 98402

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1 Introduction

For more than 20 years the water typing system used in Washington's forest practices rules to establish riparian protection measures has been based on beneficial uses, one of which is fish use. The maps originally generated to implement the water typing system were based on limited field knowledge of the upper limits of fish distribution. Surveys conducted by a variety of sponsors suggested that boundaries between fish-bearing and non fish-bearing streams were incorrectly identified, with nearly all the errors resulting in significant underestimation (placement too far downstream) of the actual upper extent of fish-bearing streams. Due to the prevalence of fish-bearing waters being incorrectly classified, water type maps and default physical criteria presuming fish presence were adjusted periodically as more reliable information became available.

To immediately address the well-documented and widespread under-classification problem, the Forest Practices Board adopted a temporary Emergency Rule for water typing in 1996 (FPB 1996). The rule calls for a presumption of fish presence on streams greater than two feet wide and less than a 20% gradient in the absence of field verification. The Emergency Rule also adds a section to the Forest Practices Board Manual that includes a uniform stream survey protocol so that affected landowners and other interests can provide data to disprove the presumption of fish presence in a manner that provides credible data to support proof of absence. Water type map updates have largely been associated with individual Forest Practice Application and Hydraulic Project Approvals in preparation for timber harvest and road building activities. As with the original water type map generation, the default criteria were based on limited field data collected at the upper limit of fish distribution, and land managers have continued to conduct extensive field surveys to determine fish presence/absence for regulatory purposes.

New Forest Practices regulations were enacted as a result of a series of stakeholder negotiations which led to the Forest and Fish Report in 1999. Changes to the Forest Practices regulations that were outlined in the Forest and Fish Report included direction to develop a model to classify fish-bearing waters using data available on a geographical information system (GIS). The Forest Practices Board and Forest and Fish policy group instructed the Instream Scientific Advisory Group (ISAG) to develop the model as rapidly as possible so that continued electro-fishing effort and extensive field surveys could be reduced or eliminated. Guidance provided to ISAG was to generate the model using existing survey data to facilitate rapid model implementation. Streams are to be classified with an equal likelihood of over and under-classification of fish habitat and a performance target for model accuracy was adopted.

1.1 Model Development

Building upon previous studies illustrating the relationships among fish distribution and geomorphic stream characteristics, the ISAG Statistical Team used existing field surveys collected by a variety of sources to develop a multiple parameter logistic regression model (Conrad et al. 2003). The model has been developed in a GIS framework, whereby the measuring and recording of geomorphic stream characteristics are done by GIS at grid-center points along a 10-meter digital elevation model (DEM) generated stream network. Use of the model assumes that the 10-meter DEM can be used to identify the physical location of the stream and describe its geomorphic characteristics. There are five physical attributes associated with each point on the DEM network: basin size, elevation, upstream gradient, downstream gradient, and mean annual precipitation. Only one field verified parameter was required to develop the model, the upstream end of fish location, referred to herein as field-surveyed or observed end of fish point (EOFP). All DEM-generated stream network points are classified as fish present (or fish habitat) downstream of the observed EOFP, whereas upstream points are classified as fish absent (or non-fish habitat).

In total, 4,052 field surveyed EOFPs were used to generate 1,443,471 fish absent | fish present (FAFP) data points in the western Washington DEM stream network. Because the data set that was available for model building was extremely large, a split sample validation method was used to develop the logistic regression models and evaluate their performance.

The current model is comprised of two parts: the logistic regression model (LRM) and a stopping rule procedure. The LRM describes the relationship between the binary dependent variable, fish presence (or fish habitat present), and map derived geomorphic parameters. This model predicts the probability of fish use at grid center points along a string of 10-meter DEM-generated stream network. However, classifying DEM network points with the final logistic regression model does not result in a prediction of an end-of-fish point on the stream system, as fish absent points may be interspersed among fish present points, especially in the upper reaches of watersheds. A "stopping rule" procedure was developed that processed the strings of FAFP data representing streams and placed a predicted EOFP in each string. The procedure processed a string of FAFP data from the downstream end and progressed upstream until a set of conditions was met at which point it "stopped" and placed a predicted end-of-fish point in the string.

The logistic regression model output values together with heuristic stopping rules predicts the point representing the likely upper extent of fish habitat, referred to hereafter as predicted EOFP. The use of the term "current model" in this study plan refers to the combination of both the LRM and stopping rules. All measures of accuracy, precision, and balance will be made on the outcome of the LRM and stopping rules combined.

1.2 Model Assessment Conducted to Date

Conrad et al (2003) made several assessments of the current model with the existing data set. Prediction error of each point was calculated as the mapped distance between the field surveyed EOFP and the predicted EOFP. Application of the current model to the existing withheld validation data set revealed that the mean and median absolute error distance was 762 feet and 327 feet per predicted point, respectively, with over 25% of the points predicted perfectly (zero error distance). However, the distribution of errors was skewed, with more large error distances associated with overestimation of fish use (the predicted EOFP is situated upstream of the observed EOFP) . The current model, on average, overestimated upstream fish use by 140 feet, although the median net error distance was 0. Very large overestimations of fish use were more common than very large underestimations.

The assessment results described above are based upon error measured in feet per string of cells along the DEM generated stream network. The string form of the stream network data is convenient for assessing error on an error per predicted point basis, but suffers major drawbacks for characterizing performance throughout the stream network due to duplication in prediction error measurement and disproportionate representations of EOFP types (both further described in this document).

Recognizing that the use of these numbers directly to compute total error for a basin or any other section of the stream network would result in an overestimate of error, a fourth order sub-basin (FOSB) error assessment procedure was conducted to account for structure of the stream network using the existing data set. This procedure also remedied the problem of duplicate error counts by developing error processing rules. The FOSB error assessment process estimated an average absolute error for the model of 445 feet / mile or about a 92% correct classification of fish presence for FOSBs. However, unlike the string data assessment, the FOSB procedure suggest the current model tends to underestimate (the predicted EOFP is situated downstream of the observed EOFP) fish use by 62 feet per point on average.

Characterizing model performance by classification accuracy has its own set of problems, including the ability of the DEM procedures to accurately identify the stream network. In addition, the FOSB error assessment methods used to estimate prediction error were not ideal because entire basins were not covered by field surveys.

1.3 Need for Further Model Assessment

Recognizing proper model assessment requires evaluating predictive performance on data that were not used as part of the original model development, the ISAG Statistical Team used only a fraction of the previously surveyed points for model building purposes. Thousands of previously surveyed points were withheld as independent model testing data. While the withheld data played an important role in evaluating model performance, it unfortunately suffers several drawbacks with regards to model assessment.

First, it is acknowledged that the field survey data collection included in the dataset was not specifically intended for model development and assessment purposes. There was no deliberate sampling design which resulted in a non-random geographic distribution of EOFP and the Fish Absence / Fish Presence data available for model building and assessment purposes. Streams chosen for fish presence surveys included in the withheld data were not randomly selected from the population of streams managed under the Forests and Fish Agreement. Much of the data is geographically concentrated, and many areas under Forests and Fish Rules are underrepresented or not included in the withheld database.

Secondly, the total number of field observed EOFP are not proportionally allocated among the three recognized EOFP boundary types. Model assessment results indicate that variation in prediction error can in part be explained by the location of the predicted EOFP within the stream network. Prediction error is smaller and much less variable where the model projects small non-fish bearing streams join larger, fish-habitat streams (these points are referred to as lateral confluence EOFPs). These EOFP types represent the vast majority of the model predictions, yet are greatly under-represented in the existing dataset. Use of the existing dataset to directly compute model performance throughout the entire stream network may overestimate model error. The methods used to estimate precision and balance at the stream network scale were not ideal because entire basins were not covered by field surveys.

A third concern of the existing model assessment includes the uncertainty behind the accuracy of the DEM generated stream network. Basin wide FAFP classification accuracy rates are sensitive to how you define your stream network. For instance, if all DEM generated streams and attendant predicted EOFP are included in the assessment, regardless of whether a defined channel exists in the field, correct classification rates based on ft / mile of stream network may not accurately characterize model performance.

And perhaps most importantly, the observed end of fish points (EOFP) within the withheld training data were established using at least four different field survey protocols. In fact, nearly 70 percent of observed EOFPs within the training data set represent the perceived upstream extent of accessible fish habitat (last habitat point) rather than the most upstream point in which fish were encountered by electrofishing or visual observations (last fish point). Moreover, at least three different protocols were used among survey organizations to locate and map the last habitat point.

For the reasons stated above, an entirely new end of fish point data base will be developed in order to collect field data using a consistent, standardized protocol to conduct an unbiased evaluation of model performance. This approach provides an opportunity to assess the transferability or generalization of the water type model(s) across western Washington for management and regulatory purposes.

1.4 Study Purpose

The ISAG Statistical Team acknowledges the limitations of the existing dataset and the transferability of the assessment results to all of western Washington. The team recommended more field surveys be conducted to provide a more reliable assessment of model performance. This study design combines an examination of overall model performance with supporting components aimed at identifying potential sources of error in model predictions.

The purpose of this study plan is to:

- Examine the performance of the model to predict the upstream end of fish habitat throughout forested lands in western Washington managed under the Forests and Fish Rules.
- Determine the magnitude and balance of errors in predicting the upstream end of fish habitat.
- Identify and quantify factors that contribute to errors in model prediction.
- Establish a network of monumented survey locations to allow for characterization of seasonal and annual variability in the upstream extent of fish use.

The study plan includes the sampling design, field methods, data compilation/processing, and data analysis and interpretation procedures. Standard protocols for verifying the upstream distribution of fish in the field (end of fish points, EOFP), measuring stream morphology and habitat characteristics, locating model predicted EOFPs on the ground, and mapping field verified EOFP are included in this plan to ensure consistent data collection techniques.

2 Sample Design

The basic challenge of sampling is to estimate some characteristic of a population by observing only part of the population. The population being sampled is the collection of all the items that are of interest, which in this case are measures of the distance between predicted EOFPs and observed EOFPs (referred to as ΔEOFP) on streams flowing through forested lands in western Washington under the jurisdiction of the Washington State Forest Practice Rules. All the possible sampling units available within the population constitute the sampling frame. In this case, we have an accurate accounting of the total number of predicted EOFPs, and as such the entire network of predicted EOFPs constitutes our sampling frame.

Selection of a sample is a crucial step in an unbiased evaluation of model performance across western Washington forest lands managed under the Washington Forest Practice rules. The "goodness" of the sample determines the generalizability of the results. It is important to select a sampling method that increases the degree to which the selected sample represents the population.

2.1 Random Sampling

One way to ensure an unbiased estimation of model performance is to select sample units by drawing a simple random sample from all of the predicted EOFPs within the study population. A simple random sample is one that is obtained in such a way that all units in the defined sampling frame have an equal and independent chance of being selected. Random sampling is the best single way to obtain a representative sample. If samples are not randomly selected, then one of the major assumptions of inferential statistics is violated, and inferences are correspondingly tenuous. Simple random sampling is easy to accomplish within the GIS framework. Because simple random sampling is a fair way to select a sample, it is reasonable to generalize the results from the sample back to the population.

2.2 Survey Efficiency Considerations - Cluster Sampling

One drawback to the simple random sampling approach, however, is that it is likely that the sample of individual predicted EOFPs will be dispersed across a wide geographic region requiring extensive travel between sample points, thus resulting in very costly field surveys. For instance, each sample EOFP may be selected from an equal number of separate basins or sub-basins. In such a situation, travel between individual points could result in inefficient use of crew time and cost per sample would be quite high. In addition, such an approach would result in incomplete surveys of sample basins, which would increase the difficulty in evaluating model performance at larger spatial scales.

It may be more practical and desirable to assess model performance in a number of streams within a given area in order to maximize crew efficiency. Cluster sampling is sampling in which groups of items (e.g., predicted EOFPs), not individual items, are randomly selected. Thus, cluster sampling involves sampling clusters of items rather than single items. Generally, cluster sampling cannot be expected to give the same precision as a simple random sample with the same total number of items, since close items tend to be more similar than items in general. Therefore, a cluster sample is equivalent to a random sample of independent units with a somewhat smaller size.

However, cost savings may allow a cluster sample to be considerably larger than a simple random sample can be. Hence a cluster sample may give better precision than a simple random sample for the same sampling cost.

Critical to this approach is a method of defining the sample clusters so that all EOFP predictions within the lands administered under the Forest and Fish Rules are included in the sampling frame. We propose to use natural drainage basins to define cluster samples. Conrad et al. (2003) adopted 4th order sub-basins (FOSB) as the primary unit of interest to assess model performance at a basin scale. FOSBs are defined based on the change in stream order from 4 to 5 in a string of points on the 10m DEM network and typically contain several lateral and terminal EOFP predictions. While the FOSB accounts for the structure of the stream network and generally provides a good representation of EOFP boundary types, a number of lower order basins do not drain into a 4th order basin, but rather drain directly to 5th order or larger channels. Using only the FOSB as the sampling units, these lower order basins would not be identified as part of a defined sample unit and subsequently would not be included in the sampling frame (Figure 1). Moreover, by using only FOSBs, we ignore those parts of the stream network that occur in higher order channels where the model may perform very well.

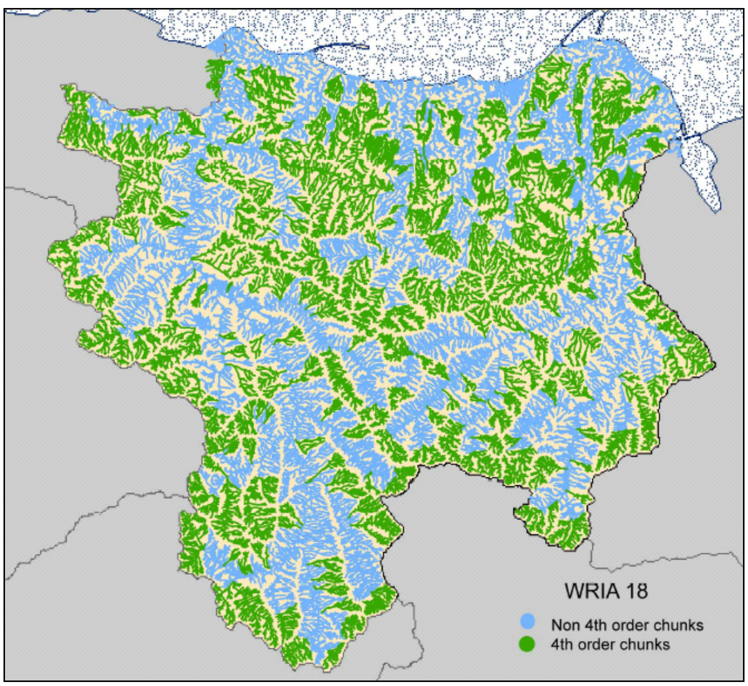

Figure 1. Schematic illustrating the distribution of 4th order sub basins in the Dungeness River watershed.

These problems will be circumvented by defining EOFP clusters as follows. The entire stream network under Forest and Fish Rules will first be delineated into 4^{th} basins. Then the remaining streams (streams not included in the first cut of fourth order basins, such as 3^{rd} order or lower basins that flow directly to 5^{th} order or higher channels) will be delineated into progressively lower order basins. Just like the 4^{th} order basins identified in the first cut, all of the predictions within the 3^{rd} order basins will be considered a cluster for sampling purposes. Likewise, the remaining 1^{st} and 2^{nd} order basins situated between individual 3^{rd} and 4^{th} order basins will form separate EOFP clusters (Figure 2).

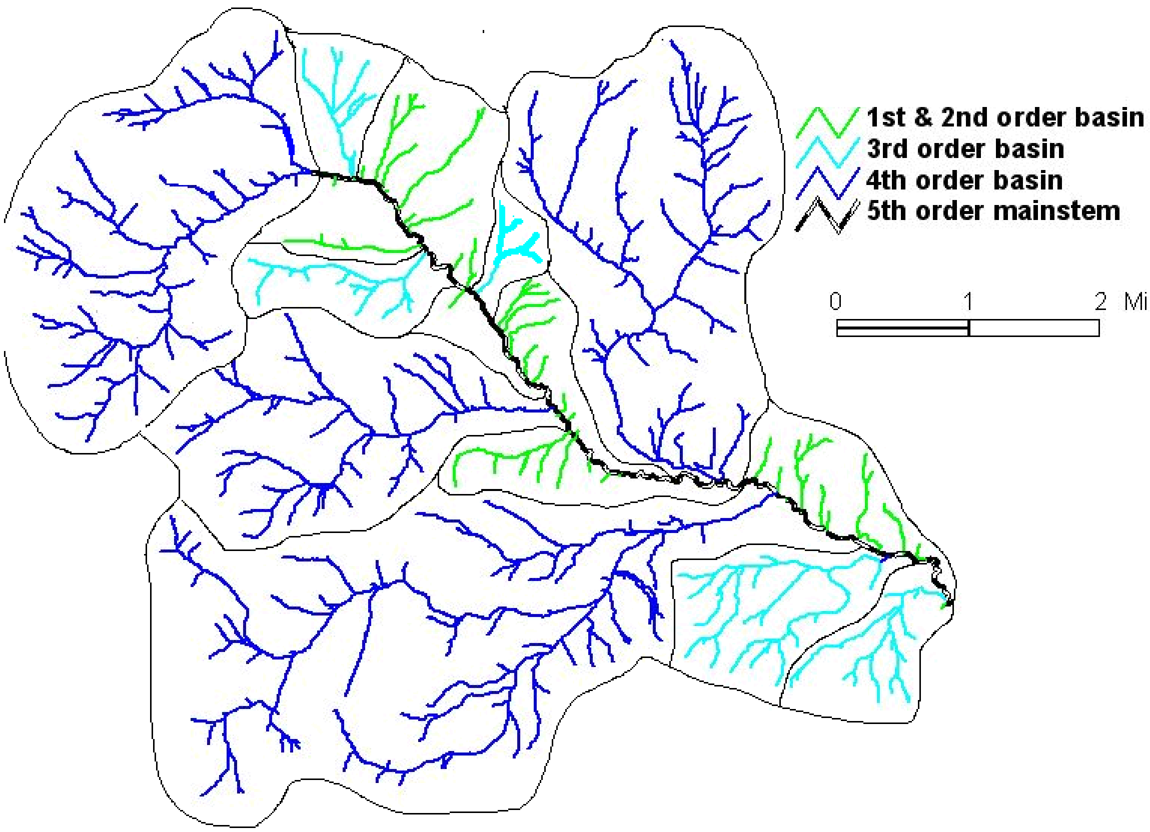

Figure 2. Schematic illustrating the delineation of natural drainage basins for defining clusters of EOFPs for sampling purposes.

2.3 Geographical Considerations - Stratified Sampling

A problem with both the simple random sampling and cluster sampling described thus far is that there is no control over how sampled items are spread through the population, and may, just because of the luck-of-the-draw, not get good representation of the variety of conditions (e.g., geologic-ecologic types) across all geographic regions that conspire to affect the model performance. Stratified sampling is a process of selecting a sample in such a way that identified strata in the sampling frame are represented in the sample.

This sampling method addresses the criticism that simple random sampling leaves too much to chance, so that the number of sampling units in different parts of the population may not match the distribution in the population. Stratified random sampling involves dividing the units in the sampling frame into non-overlapping strata, and selecting an independent random sample from each of the strata. This would ensure that each stratum is represented in the sample. There are a couple of advantages of stratified sampling: (1) if the sampling units within the strata are more similar than units in general, the estimate of the overall population mean will have a smaller standard error than a mean calculated with simple random sampling; and (2) there may be value in having separate estimates of population parameters for the different strata.

Because we are interested in ensuring that all ecoregions in the study population are included in the sample, we will divide the study population into geographic regions with relatively homogenous geologic and climatic conditions. We will use the ecoregion designations identified and described in the Washington Department of Fish and Wildlife GAP Data Products. An ecoregion is a contiguous geographic area of similar climate and geologic history. There are six distinct ecoregions mapped in western Washington. This stratification is intended to primarily control for the geographic spread of samples, but may also account for variability in model performance.

One way to ensure that all ecoregions of the study population are properly represented in the sample is to use a *proportional allocation* approach, which means that n_i, the sample size for stratum I, is made proportional to N_i, the number of items in that stratum. This method involves dividing the study population of sample units into non-overlapping geographical strata. Using this approach, a sample could be drawn by randomly selecting a targeted number of sampling units, where the samples are allocated among the regions proportional to the relative size of the region, where relative size is represented by the region's contribution of predicted EOFPs to the total number of predicted EOFPs in the entire study population. Therefore, more samples would be drawn from the region that contained the greatest number of EOFPs, but all regions would be represented in the sample.

2.4 Cluster Sampling Combined with Stratification

While employment of the cluster sampling scheme would optimize crew efficiency, ensure that EOFP boundary types are sampled in the proportion to which they occur on the landscape, and survey entire sub-basins, it does nothing to control the spread of samples across the study population. Therefore, to ensure that the entire population of EOFPs is well covered by the cluster sampling design, clusters will be nested within the geographic strata. That is, a samples will be drawn by randomly selecting a targeted number of clusters (sample basins) within each stratum.

2.5 Predicted EOFP Boundary Types

Boundary type designations describe the relationship of the EOFP to confluences with other streams (Figure 3). The EOFP boundary type designation has been shown to account for variation in model performance (Conrad et al. 2003). On average, prediction error is lower and less variable for lateral confluence EOFP predictions as compared to the mid-channel and tributary junction predictions (collectively referred to as terminal points). Lateral confluences are side tributaries entering a main channel and are frequently associated with a gradient break and/or a large change in basin area. Our sampling design allows us to estimate overall prediction error, and through a process of post-stratification, separate prediction errors for each boundary type.

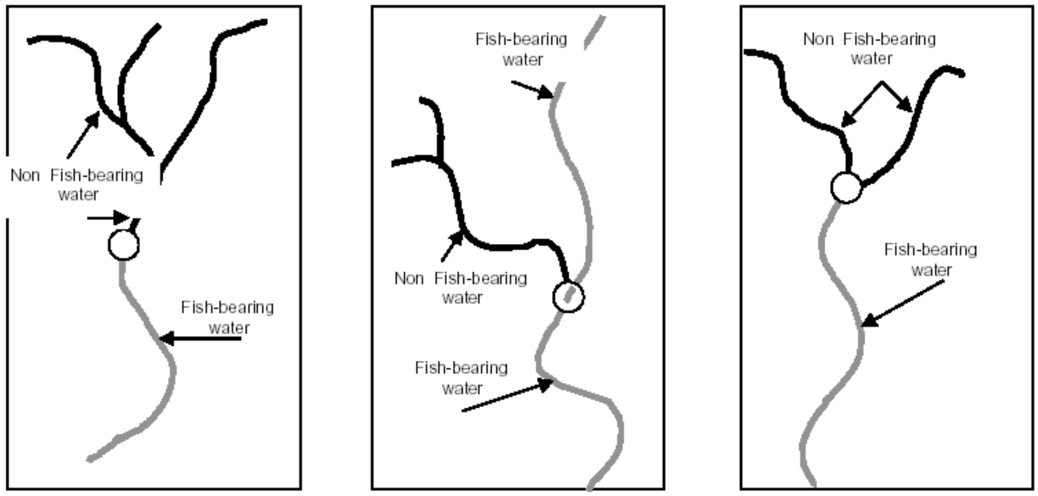

Figure 3. Schematic diagram illustrating the three boundary types between fish-bearing and non fish-bearing waters (from Conrad et al 2003). EOFPs are indicated by circle.

2.6 Cluster Sampling with Probabilities Proportional to Size

Up to this point, the sampling designs that have been discussed involve random samples of clusters of EOFPs. Because we want optimize crew efficiency to estimate the mean prediction error (ΔEOFP) by sampling clusters of EOFPs (all points within a sample basin) in a given geographic strata (ecoregion), the estimates can be improved by varying the probabilities with which the clusters are sampled from the population. Typically, many clusters are small and contain few EOFPs, whereas some basins will be larger, contain many EOFPs (Figures 1 and 2). Moreover, the larger clusters will contain more terminal points, which have been demonstrated to exhibit greater and more variable ΔEOFP then the lateral points (Conrad et al. 2003). In a simple random sample of clusters, cluster size is not taken into account, and a typical sample will consist of mostly small basins, which contain fewer terminal predicted EOFPs. The overall prediction error, especially of the more variable terminal predictions, is heavily influenced by the larger basins. Thus, we should be able to improve the estimate of prediction error by giving the large basins a greater chance to appear in the sample. A method for accomplishing this is called sampling with probabilities proportional to size (Cochran 1977; Scheaffer et al. 1996).

This approach gives larger basins (larger clusters) a higher probability of being selected because of their greater number of individual EOFPs contributed to the sampling frame. However, rather than randomly selecting sample basins weighted by size (number of EOFPs per basin), individual predicted EOFPs will be randomly selected. Once selected, the cluster (basin) to which the point belongs will be identified and all other EOFPs contained within the identified sample basin will be surveyed.

The number of clusters selected will be based on estimates of variance (from pilot studies conducted in 2003) and the maximum sampling error that can be tolerated. Sample-size equations for cluster sampling will estimate the number of clusters that need to be sampled within each of the six geographic strata. All predicted EOFPs would be surveyed within each randomly selected sample basin.

2.7 Synopsis

In summary, we propose to implement a stratified random cluster sampling with probability proportional to size design combined with proportional allocation among strata. The study area will first be stratified into homogeneous, non-overlapping geographic strata (ecoregions). Within each ecoregion, we will randomly select clusters of EOFPs (sample basins) in proportion to the size of the ecoregions in which they belong. That is, more clusters will be randomly selected within larger ecoregions than within smaller ecoregions. The clusters will be selected with a probability proportional to the number of predicted EOFPs contained within the basin. Then, within each randomly selected cluster, we will survey all predicted EOFPs and determine the upstream distribtution of fish within the entire stream network of the sample basin.

Because the maximum sampling error that we are willing to tolerate indirectly affects sample size and therefore cost, we will estimate sample size needed for a range of precisions. Sample size is also affected by the EOFP boundary type. For example, lateral confluence EOFPs have less variability (small variance) and therefore would require a much smaller sample size than mid channel and tributary junction EOFPs (collectively referred to as terminal EOFPs) to attain the same level of precision. Using information from pilot studies and the preliminary analysis conducted by Conrad et al. (2003), we will estimate the number of clusters needed to estimate ΔEOFP for all EOFP types combined and for each EOFP type separately. Procedures outlined by Scheaffer et al. (1996) will be used for determining appropriate sample size (number of clusters) needed to estimate the mean ΔEOFP with a desired level of precision. These procedures are especially useful for these data, as they do not rely on a sampling values being taken from a normal distribution.

3 Methods

3.1 Estimating the Sample Size

The major goal in conducting this study is to evaluate the reliability of the water type model for predicting fish presence, fish absence, and the upstream end of fish habitat. In Section 2 we presented a sampling method (stratified cluster sampling) for estimating the reliability of the water type model. We now address the important problem of determining how large a sample (how many clusters) is needed for estimating the "true" error of the model.

It is important to note that there are two different errors of concern here. The first is the error in the water type model prediction at each site. This error is simply the difference between the observed and predicted EOFP (measured as the lineal distance between the two points referred to as "ΔEOFP") and measures the accuracy of the model. It is this error that is of most interest. The second error deals with the degree that the sample estimate (e.g., average ΔEOFP of all sampled sites) differs from the "true" value (e.g., true average ΔEOFP of all predicted points). It is important to reduce this error in order to reliably estimate ΔEOFP. That is, we want to be certain that the ΔEOFP estimated from sampling a small number of the total predicted EOFPs within the population is an accurate representation of model performance.

When selecting an appropriate sample size it is important to avoid making the sample so small that the estimate of prediction error is too inaccurate (large variance) to be useful for generalization to the whole population. Equally, we want to avoid taking a sample that is too large, in that the added costs of each additional sample does little to improve the accuracy (decrease the variance) of the estimate. In general, the total sample size (i.e., number of clusters to sample) depends upon the number of clusters and relative cluster size. More specifically, sample size is directly related to the number of clusters in the population and the population variance, and indirectly to the average cluster size and the maximum error that we are willing to tolerate. Here, error refers to the difference between the "estimated" mean ΔEOFP as determined from samples and the "true" mean ΔEOFP value.

We propose to use the sample size equations presented in Scheaffer et al. (1996) to estimate the number of clusters that need to be sampled within each ecoregion stratum. We will use the information collected during the pilot study in 2003 to estimate population variance. We will have information on total number of clusters and average cluster size. Because the maximum sampling error that we are willing to tolerate indirectly affects sample size and therefore cost, we propose to estimate sample sizes with a number of different sampling errors. We will calculate sample sizes using errors of 10, 25, 50, 100, 150, 200, and 300 feet. That is, we will calculate the number of samples needed to estimate the average ΔEOFP with a bound of 10, 25, 50, 100, 150, 200, and 300 feet. Clearly, the larger the error, the smaller the sample size.

Sample size is also affected by the type of EOFP. For example, lateral confluence EOFPs have little variability (small variance) and therefore would result in a much smaller sample size estimate than mid channel and tributary junction EOFPs, which have larger variances. We propose to estimate sample sizes for EOFP types separately and combined. The use of different sample errors and types of EOFPs will allow us to choose a sample size based on reliability and cost. Once the number of samples is determined to achieve the desire level of statistical precision, samples will be allocated across the study area as follows.

3.2 Sample Selection Procedures

The ISAG water-type model will be applied to predict EOFPs throughout the entire stream network in western Washington under the jurisdiction of the Washington State Forest Practice Rules. This will constitute the entire population of predicted EOFPs. The population of predicted EOFPs will then be divided into cluster sample units, or sample basins, as described in section 2.3.

Each predicted EOFP will be grouped by ecoregion and the relative size of each region computed. Relative size will be determined by the region's contribution of predicted

EOFPs to the total number of predicted EOFPs in the entire study population. A cumulative unique identifying number will be assigned to each predicted EOFP. Using cluster sampling with probabilities proportional to size combined with proportional allocation among strata, the targeted number of cluster sample units will be randomly selected, where the samples are allocated among the regions proportional to the relative size of the geographic region.

For illustrative purposes, assume the number of sample clusters is 10. Further assume that the study population is divided into three ecoregions (A,B, and C), where region A contains 30% of the study populations EOFPs, region B contains 50%, and region C contains 20%. Under this example, the targeted 10 samples would be allocated as follows: (region A = 3, region B = 5, and region C = 2). Using the table provided below to represent region A clusters and attendant predicted EOFPs, we must select three random numbers between 001 and 241. For this example, lets assume the numbers selected are 17, 92, and 231. The first random number selected appears in the sub-basin cluster 2, the second appears in the range of cluster 5, and the third appears in the range of division 14. Thus clusters 2, 5, and 14 would constitute the sample for region A. In this fashion, all predicted EOFPs have an chance equal of being selected during the sampling process, regardless of the size of the basin in which they are situated. Because individual EOFPs will be randomly sampled, this sample selection process will result in an unbiased representation of cluster sizes known to occur throughout the study area.

Sub-basin cluster	Basin order	Number of Predicted EOFPs	Cumulative ID Number
1	2	5	1-5
2	4	22	6-27
3	4	27	28-54
4	4	32	55-86
5	3	17	87-103
6	4	32	104-135
7	1	1	136-136
8	3	22	137-158
9	2	7	159-165
10	2	5	166-170
11	3	14	171-184
12	4	22	185-206
13	4	24	207-230
14	2	11	231-241
		241	

3.3 Map and Database Preparation

Upon selection of sample basins, maps and databases will be produced for eventual use in the field in ArcGIS format that include:

- DEM generated stream network
- DNR Hydrolayer stream network lines
- Contour lines
- 8 ft. orthophoto coverage
- Predicted end of fish point and boundary type
- Individual cells representing the stream network

Geomorphic features and other information for each cell within the stream network will be estimated via digital elevation models, including:

- Information provided for each cell along the DEM generated stream network will included:
- Mapping coordinates of each predicted EOFP
- FAFP designation based on LRM of each cell in stream network
- Upstream 100 meters mean gradient
- Gradient to upstream cell
- Gradient to downstream cell

The viewing maps and databases will be used for locating predicted EOFPs in the field, mapping field observed EOFPs, comparing DEM generated stream locations and geomorphic features to field observed conditions, and comparison of the DEM and DNR Hydrolayer stream locations in the field. These map views can be produced in sufficient quality and detail to use as hardcopy field maps, or when available, be downloaded onto a Personal Digital Assistant (PDA) unit linked to GPS units for field use. Prior to field work, the most recent air photograph coverages will be assembled and predicted EOFPs will be identified for field use.

3.4 Field Surveys

Field surveys include eight basic steps: 1) locate predicted EOFPs on the ground; 2) assess the accuracy of the DEM portrayed channel network; 3) if available, locate previously observed EOFP in the field; 4) conduct new last fish surveys for all streams within the sample basins, regardless if they have been previously sampled; 5) measure the distances between the current observed EOFP, previously established EOFP if available, and predicted EOFP; 6) map current observed EOFP; 7) characterize stream geomorphic characteristics at, between, above and below the predicted and observed EOFP for comparison with DEM generated geomorphic parameters; and 8) identify habitat features associated with end of fish locations.

Field crews will determine the literal predicted EOFP locations along the channel network using GPS coordinates units or other established orienteering techniques when GPS units are not available. This point is referred to as the **mapped predicted EOFP**. In cases where inaccuracies in the DEM portrayed channel network area apparent, an **adjusted predicted EOFP** location will be identified on the ground. The upstream end of fish point will field verified through electrofishing surveys and its location monumented in the field. Both a **mapped** and **adjusted observed EOFP** location will be identified on the DEM stream map. Model prediction error distances (ΔEOFP) will be determined for both the mapped and adjusted locations in the field and in a GIS framework. The following section describes the procedures for locating model predicted EOFPs on the ground and placing field observed EOFPs on the DEM stream maps.

3.4.1 Locating Predicted and Mapping Observed EOFPs

A pilot study conducted in 2003 demonstrates that most of the EOFPs can be easily located or mapped by use of GPS locations or by readily apparent map and photo reference points. Given that we have digital air photos registered with the DEM-generated stream network, the location of the predicted EOFP can be accurately depicted on the digital orthophotographs, which in turn can be readily located on stereo pairs of the most recent air photographs.

However, it is recognized that in some cases inaccuracies and misrepresentations of stream locations derived through DEM analysis can increase the difficulty in locating mapped points on the ground or placing field observed points on a map. Because of this, field crews should have a variety of tools at their disposal to locate and map EOFPs. The tool(s) and technique used will vary depending upon the correspondence between map and field conditions, as well as the availability of features readily apparent on air photos. We believe that the DEM maps, DNR water type layers, USGS topographic maps, orthophotos, stereo pairs of aerial photographs and GPS units capable of portraying the stream network and other pertinent features should all be available during field surveys to enable survey crews to locate the predicted EOFP and accurately map the field surveyed EOFP.

3.4.1.1 Field Procedures

All field activities will begin by assessment of the maps described under section 3.3. Predicted EOFPs should be transferred to the most recent air photo coverage. In addition, all predicted points, DEM stream network layer, topographic contours, and other pertinent GIS layers, will be uploaded on PDA units linked to GPS receivers for use by field crews.

In ideal situations, the DEM generated streams and their estimated geomorphic characteristics accurately portray field conditions, with close correspondence between map coverages and stream features readily apparent on air photos and digital orthophotographs. In these cases, accurately placing mapped points on the ground can be done by the use of GPS locations, measuring from reference points readily apparent on air photos or maps, and/or by location of abrupt shifts in channel gradient as depicted by the DEM. GPS location will be the primary means to locate the predicted point on the ground or to map a field observed point where available. However, GPS units may be unreliable at fixing coordinates in dense forests or in some mountainous terrain. Thus, it is critical that field crews continually orient themselves using maps and photos, even when GPS locations are available during portions of the survey.

Most predicted EOFPs will be relatively easy to place on the ground, as the majority are identified as lateral confluence or tributary junction boundary types. These points are generally simple to identify on maps, locate on aerial photographs, and subsequently transfer to the ground. The location of mid-channel predictions situated near these junctions often can often be accurately located by referencing back to these readily identifiable tributary junctions. Due to the nature of the DEMs used to model fish habitat, however, there may occasionally be inaccurately mapped predicted EOFPs.

For instance, the DEM may not accurately represent the abundance and distribution of channels observed in the field. In some situations, the DEM generated stream networks portray stream channels where none actually exist in the field. Such problems are most pronounced in landscapes with subdued topography, especially in association with forested wetlands. Other, but less common, problem situations occur where stream channels observed in the field are not included in the DEM derived stream network. In other cases, the location of stream junctions as portrayed by the DEM network may not correspond to actual field locations, and field staff need to decide which mapped stream corresponds to the field located stream. And even where the number and distribution of streams generally correspond to field conditions, DEM estimates of the stream network may not accurately portray abrupt shifts in channel slope or their exact location in the field. In each of these cases, field crews need to locate the point on the ground that best represents the mapped predicted EOFP location as follows. This process is facilitated by beginning survey efforts from a readily apparent photo reference point (preferably one located along the stream network).

Prior to entering the field, the mapped stream distance between a readily identifiable valley bottom photo reference point and EOFPs, as well as the distance between individual tributary confluences will be determined. The distance from the reference point to individual EOFPs and between the lateral confluences will be measured along the axis of the valley bottom. This measuring will be done in the GIS framework and recorded on the field maps. The field crew then measures the distance from the reference point to the EOFP predictions and between the lateral confluences along the valley bottom in the field using a hip chain or measuring tape. As tributary streams are encountered, the distance of each stream from the photo reference point is recorded. By this method, the distribution and abundance of lateral confluences can be determined and crew positions can be continually referenced. In addition, field located tributary junctions not represented by the DEM (or the DNR Hydrolayer) can be systematically identified. Moreover, DEM portrayed channels and attendant lateral EOFPs where no defined stream channel exist in the field can also be identified.

If no tributary junctions, road crossings, or other photo reference point are situated along the stream network within a reasonable distance, crews will determine the azimuth and horizontal distance between the EOFP and a nearby identifiable upland photo reference point (e.g., road junction, landing, harvest boundary corners, individual trees, etc). Working with a handheld compass and hip chain, the compass bearing and distance will be used to locate the predicted point in the field. Continually shooting fore- and back-azimuths between crew members and adjusting for horizontal distance is crucial to accurately locating points using this technique.

An alternative to using a photo reference point is to "grab" a GPS location reference point anywhere possible along the valley bottom or nearby uplands and determine the distance between that location and the EOFP point. The field distance between the nearest available GPS location and the EOFP would be measured in the same way as an identifiable photo reference point.

3.4.1.2 Adjustments for Mapping Discrepancies

There is a wide range of how well the DEMs represent the landscape, but in general mapping inaccuracies of stream locations rarely exceed 200 feet, and are most commonly within 100 feet of field locations. However, these mapping discrepancies can be effectively accounted for by the use of a variety of orienteering techniques previously described.

Both a mapped and adjusted predicted EOFP location will be identified on the ground. Likewise, both a mapped and adjusted observed EOFP location will be identified on the DEM maps. The distance between the mapped and the adjusted locations will be measured for all EOFPs. Where there is close correspondence between map and field conditions, the mapped and adjusted locations will be identical. The following rules will be applied to consistently account for mapping inaccuracies where they occur.

<u>Lateral confluence and tributary junction EOFP boundary types</u>

Inaccuracies in locating and mapping EOFPs are most commonly associated with mismapped stream confluences. There may be situations where a tributary junction EOFP is portrayed by the DEM to occur at a certain location in the field, but map location is clearly in error in either an upstream or downstream direction along the primary stream as determined by methods described in Section 3.4.1.1. In these situations, two points will be identified in the field (for placing predicted points on the ground) and on the map (for mapping observed EOFPs). The location of the mapped point will first be identified on the ground, regardless of whether the tributary junction is accurately mapped. This will be considered the mapped EOFP location. Secondly, the location of the tributary junction in the field will be identified and mapped, and this point will be considered the adjusted EOFP location. The mapping error of the tributary confluence will measured in the field (distance between adjusted and mapped EOFP) and the actual location of the confluence will be identified on DEM map.

<u>Mid-channel EOFP boundary types</u>

Accounting for mapping discrepancies of mid-channel boundary EOFP types has it own set of circumstances requiring attention. When GPS readings are unavailable at the point, mid-channel predictions may sometimes be field located by determining the distance the EOFP is situated from a road, other readily identified reference, offsite GPS grab point reference, or tributary confluence. If the references are apparent on the viewing maps, the points are placed in field or on the DEM map by simply measuring the distance from the reference location to the EOFP. This would be considered a mapped EOFP location.

However, stream confluences are sometimes inaccurately located on the DEM depicted channel network, which in turn may result in incorrect field placement or mapping if the surveyor is relying on the junctions to place mid-channel EOFPs. Whenever possible, the accuracy of stream confluence location should be determined if used to locate mid-channel EOFPs. If the accuracy of the DEM portrayed confluence location can be determined, then distance between the field located confluence and the mid channel prediction point can be corrected accordingly. As an example, envision a mid-channel

EOFP prediction portrayed by the DEM as being situated 350 feet upstream of a tributary confluence. One means to field locate the point would be to measure that distance in the field from the confluence. However, because the actual field location of the tributary confluence in this example is readily apparent on the view map, it is known to be situated 200 feet upstream from the location depicted by the DEM. In this case, the distance between the confluence and the predicted EOFP would be corrected accordingly and the predicted EOFP would established at 150 feet upstream of the actual confluence location instead of 350 feet. Despite the correction in measurement, this point is still considered the mapped location, as it is considered to be "accurately" placed in accordance to its literal mapped location. In this case, the actual field location of the tributary junction would be used as a readily identifiable reference point.

The need to locate both mapped and adjusted EOFP occur most commonly where mid-channel EOFP predictions correspond to abrupt changes in channel gradient portrayed on the DEM channel network. Likewise, observed EOFPs may (and often do) occur at abrupt changes. If a predicted mid-channel EOFP is associated with a *gradient break* feature and there is close agreement between map and field conditions, the gradient break will be located on the ground and the predicted EOFP placed at that point. In this situation, there would be no need to identify an adjusted EOFP location. However, if the location of the abrupt change in gradient as portrayed by the DEM is not within 30 feet of the field location (30 feet is the approximate distance between DEM points), the EOFP will be placed at the location depicted on the map irregardless of channel conditions and denoted as a mapped EOFP location. An adjusted EOFP location would be identified at the gradient break feature that corresponds to the DEM portray channel profile.

Adjusted EOFP locations will be installed only if the channel profile depicted by the DEM reasonably portrays the gradient profile near the observed or predicted EOFP in the field, but the mapping discrepancy appears to be a matter of spatial inaccuracy (much like the discrepancies associated with confluence locations). Adjustments should not be made to field locations of predicted EOFP simply because a point on the stream appears to be a reasonable location for upstream fish use. Likewise, adjustments should not be made to mapped locations of observed EOFPs simply because the feature found in the field resembles the gradient profile at one individual point. To reiterate, adjustments should be made to field located predictions and mapped located observations only when there is close correspondence between the DEM portrayed and field observed channel profiles. In addition, these adjustments should be made only when there are definitive changes in channel profile depicted on the DEM network, and not because the gradient of one individual DEM cell matches the field gradient at the point of interest.

For <u>all EOFP types</u>, DEM estimates of the stream network may not accurately portray the exact location in the field. For instance, DEM estimates occasionally depict streams on adjacent hillslopes or terraces. These problems are easily rectified by moving perpendicular from the mapped location to the field located channel to place the point. In these situations, both the mapped EOFP location and adjusted EOFP location are identical. Map and adjusted locations differ only when points are moved upstream or downstream along the channel network.

3.4.1.3 Unresolved Predicted EOFPs and Unmapped Observed EOFPs

There may be some situations where predicted EOFPs (especially lateral confluence types) cannot be associated with any stream in the field. Each of these points will be appropriately noted as associated with a non defined channel and not included in the final assessment of model performance. Other situations infrequently occur where a small, defined channel joins a larger channel in the field but there is no associated DEM channel or predicted EOFP. On these channels, a "field predicted EOFP" will be installed at the confluence and field surveys conducted. "Field predicted EOFP" will be appropriately noted in the database and the frequency of fish use in streams otherwise "missed" by the water type model determined.

3.4.2 Determine End of Fish Points in the Field

Standardized field protocols will be used to determine end of fish point locations. All last fish surveys will be conducted using backpack electrofishing, or by combination of diver counts and electrofishing. Last fish locations will be determined following guidelines provided by (WAC 222-16-030) - Guidelines for Determining Fish Use for the Purposes of Typing Waters. These guidelines call for identifying the upstream extent of fish by electrofishing a minimum of 1/4 mile upstream beyond the last fish detected

Electrofishing begins at or below the field located predicted end of fish point as depicted on maps produced with procedures described in Section 3.3. If fish are encountered at the starting point, sampling continues in an upstream direction, electrofishing throughout the entire wetted channel area where practicable, including extended stretches of shallow riffles and intermittent pools. Efforts are particularly concentrated in pools or other backwater areas that afford sufficient water depth and concealment. All tributary channels encountered during survey efforts will be electrofished for a minimum of 1/4 mile upstream beyond the last fish detected and for a minimum of 500 feet upstream of the tributary confluence. If fish are present in the mainstem but are determined absence in the tributary, a lateral observed EOFP is established at the mouth of the tributary.

Once fish are no longer encountered, the point of the last fish observed is temporarily marked in the field as a possible last fish point. Sampling then continues upstream. If no fish are encountered at the starting point, the stream is surveyed in a downstream direction until a fish is encountered. While sampling in a downstream direction, electrofishing efforts are focused only on "quality" pool habitat where fish are generally easily captured and conducted in a rapid fashion so to avoid pushing fish downstream. Once fish are encountered, the point is temporarily marked in the field as a possible last fish point. Intensive sampling then resumes in an upstream direction as described in the previous paragraph.

While electrofishing upstream of temporary last fish points, stream conditions are examined for recognizable barriers to upstream migration. Any feature that presents a potential barrier, transitory or permanent, will be mapped, measured, and described. Human-made blockages will also be identified.

If fish are encountered above a temporary last fish point, a new temporary last fish point is established and electrofishing and barrier evaluation efforts described above are continued from that point on. If a barrier to upstream migration is encountered less than

0.25 mile above the last fish observed, electrofishing continues until a full 0.25 mile is covered upstream of the last fish point. In addition, low gradient stream reaches (< 8% for a minimum length of 1000 feet or more as identified by topographic maps) located more than 0.25 mile upstream of last fish points are electrofished for at least 0.25 mile to confirm the absence of isolated fish populations situated above apparent downstream migration barriers or dewatered reaches. When dry stretches are first encountered above the last fish point, the channel is investigated to ensure that the stream indeed has no water for a distance of at least 500 feet. The distance of stream electrofished upstream of the last fish encountered will be mapped and measured in the field.

After confirming the absence of fish past the temporary last fish point, the surveyor returns to the last fish point, ensures all required data are collected and locates the point on the map using the protocol described in the following section. After all information on the last fish point is collected and marked, the surveyors clearly and permanently mark the last fish point in the field for future reference using a combination of orange flasher tags, numbered aluminum tags, and flagging. GPS coordinates will be recorded where possible.

Survey crews will work their way up the stream network basin, visiting each mapped stream course, until the last fish point is located on each stream of the sample basin. Streams that were falsely depicted on water type maps (i.e., no defined channel in the field despite map depiction) will be appropriately noted on field maps. Prior to computation of prediction errors, the string of cells representing these inaccurate stream depictions will be identified as “no defined channel” and will not be considered in the assessment of model error. Likewise, the location of streams encountered in the field that were not depicted on DEM generated stream network will be mapped and noted accordingly in the database. .

3.4.3 Measure Error Distance in the Field

Once last fish points have been located, the slope distance from the field located predicted EOFP and the field verified, or observed, EOFP will be measured in the field to the nearest foot. Measurements will be made along the central axis of the valley bottom. Distance upstream from the predicted EOFP will be recorded as a positive number, distance downstream will be recorded as a negative number. If field verified EOFPs have been previously identified on surveyed channels, field crews will attempt to locate previously monumented last fish points and measure the distance between them, the newly established field verified EOFP, and the predicted EOFP. The field error distances (field measured ΔEOFP) between observed and predicted EOFPs will be measured by determining the distance from the field located, observed EOFP to both the mapped and adjusted predicted EOFP locations (see section 3.4.1.2) and identified as either field measured, mapped ΔEOFP and field measured, adjusted ΔEOFP, respectively.

3.4.4 Field Verify Stream and Basin Geomorphic Characteristics

Channel characteristics will be assessed over a minimum distance of 300 feet above and below the predicted and field-observed last fish points. Data collected at each predicted and observed EOFP will include:

- Stream gradient measured with a handheld clinometer within 300 ft above and below each point taken at 30 ft increments if abrupt changes occur
- Stream bankfull and wetted width
- Changes in habitat features upstream of point (pre-defined categories described in field form data code book)
- Information on apparent impassable barriers (characteristics and distance from observed and predicted EOFP) when encountered during the course of the survey
- Fish species encountered during the course of the surveys, and specie(s) that defined the upstream limit of fish distribution.
- Each predicted and observed EOFP will be assigned to a landform class based on stream position in a drainage network and surrounding topography point (pre-defined categories described in field form data code book).

3.4.5 Processing and Mapping Field Verified EOFP Features

For model assessment purposes, we ultimately need to associate field locations of observed EOFPs with individual cells along the DEM generated stream network. To do this, we first mark the location of the observed EOFP or other feature (i.e. migration barrier or tributary junction) directly onto the viewing maps in the field. Points should be placed where DEM gradient and stream network cues closely match the conditions observed in the field following the general methods described in Section 3.4.1. Ultimately, if field observed channel gradient portrayed by the DEM generated stream network data poorly correspond to the stream features within the general EOFP location, the surveyor will identify the appropriate DEM cell by GPS coordinates, air photo referencing, or distance measurements to the nearest road crossing or other readily identifiable feature along the stream network.

However, we recognize that there will be some discrepancies among the DEM generated stream network, DNR hydrolayer, orthophotographs, and GPS locations. For instance there are situations when the DEM strings are inaccurately mapped and it is readily apparent both on air photos and in the field. In other situations, the field location of GIS derived coordinates of DEM generated streams and predicted EOFPs as determined with GPS positions may fall on adjacent uplands. In these situations, if a DEM string is reasonably close to portraying the stream location, the surveyor will simply assign the end of fish point to the "best fit" DEM stream network cell by air photo referencing or other methods described in Section 3.4.1. All field surveyed EOFPs that cannot be placed on the DEM network will be identified as "unresolved".

In addition to mapping the observed EOFP, the data describing geomorphic features associated with predicted and observed EOFPs outlined above will be compiled. Ultimately the field verified features database would be linked to the DEM generated stream network datum for analytical purposes. For instance, the field verified gradients above and below EOFPs would be assigned to the corresponding “cells” of the DEM stream network. This will provide a direct comparison of map and field gradients, and help in identifying factors that contribute to prediction error. Table 1contains the information that will be contained in the final database that will be used to for analytical procedures described in Section 4.

4 Data Analysis and Interpretation

Methods to address each of the objectives listed under the Study Purpose Section are outlined in this section. Both descriptive statistics and statistical models to describe model performance are proposed. Other exploratory analyses are proposed to evaluate the relations between geographic regions, landform classes, geomorphic features and model performance. It should be noted that all measures of model performance relying on ground measures of error will be calculated using both the mapped EOFP locations and the field adjusted EOFP locations. These two separate metrics will provide information with regard to error associated with mapping discrepancies as compared to error associated with model predictions (described further in section 4.4.2)

4.1 Model Performance Measures

Model performance ultimately depends on of the accuracy of the model to demarcate the line between fish habitat and non-fish habitat. The distance between model-predicted end of fish point and the mapped observed end of fish point (ΔEOFP) on each stream is the primary measure of model performance. Smaller values of ΔEOFP indicate better performance. Error distances will be measured relative to the model predictions. That is, measurements will be computed from the predicted point to the observed point. For instance, an observed EOFP located 200 feet downstream of a predicted EOFP results in ΔEOFP of -200 feet. Negative values of ΔEOFP indicate predicted EOFPs are upstream of the observed EOFP (overestimation of fish use), whereas positive values indicate that predicted EOFPs are downstream of the observed EOFP (underestimation of fish use). The error distance (ΔEOFP) between the observed and predicted EOFPs will be measured directly in the field and also computed from maps in a GIS framework. However, there are a number of subtle difficulties when defining and computing ΔEOFP.

In some situations, measuring ΔEOFP for individual predictions results in repeatedly counting the same error distance on one particular stream reach. As an example, consider a situation where the predicted mid-channel EOFP is situated well upstream (i.e. 1000 feet) of the observed EOFP on a third order channel. Clearly, the distance between the predicted EOFP and the observed EOFP on the third order channel represents model error (in this case, overestimation represented by an error of -1000 feet), as 1000 feet of non-fish habitat was incorrectly classified as fish habitat. There may be several low order, non fish-bearing stream channels that join the third order channel, and each of these low order channels are correctly classified as non-fish habitat in their entirety. However, the model incorrectly establishes predicted lateral confluence EOFPs at the mouths of each of the low order tributary channels entering the primary trunk. Each of these predicted lateral confluence EOFPs would conceivably have an associated over-prediction error (i.e. the distance between the tributary confluence, or lateral confluence point, and observed mid-channel EOFP situated downstream on the primary trunk). Such an accounting system would result in duplicate counts of model error where predicted lateral confluence EOFPs are situated upstream of terminal observed EOFPs. Conversely, in some situations the predicted EOFP may be situated downstream of the observed EOFP on a primary trunk, and observed lateral confluence EOFPs are identified on one or more tributary channels joining the primary channel upstream of the predicted EOFP. Once again, there would be double counting of error (in this case under-prediction).

Table 1. Information associated with cells of the DEM generated stream network

Data Field	Data description
Unique ID	a unique identifying number
X coordinate	the X coordinate of the WA South, State plane
Y coordinate	the Y coordinate of the WA South, State plane
Stream Order	Stream order calculated from 10m DEM elevation information
Survey date	The date the field survey was conducted
Predicted Absence|Presence indicator	"Y" for a Fish Present point or "N" for a Fish Absent point based on logistic regression model
Observed Absence|Presence indicator	"Y" for a Fish Present point or "N" for a Fish Absent point based on field survey results
Modeled upstream channel gradient	Gradient to next upstream cell as generated by DEM model
Modeled average upstream channel gradient	Average of 330 ft reach gradient upstream of cell
Observed upstream channel gradient	Field verified gradient to next cell as measured in field; only determined for cells within 330 ft of Observed and Predicted EOFPs
Observed average channel gradient	Field verified average of 100 m reach upstream EOFP; only determined for cells within 330 ft of Observed and Predicted EOFPs
Boundary Type	Only attributed to the location of the Predicted EOFP on the stream: A = Mid-channel, B = Confluence point (non-fish bearing stream laterally intersecting a fish-bearing stream), or C = Tributary junction (two or more non-fish bearing streams join to form a fish-bearing stream)
Observed EOFP Feature	Habitat feature associated with end of fish point: 1 = None, 2 = Gradient increase of greater than 7%, 3 = Impassable Waterfall 4 = Impassable cascade 5 = Large woody debris jam, 4 = Road culvert, 5 = Mass-wasting event, 6 = Beaver dam or other non-permanent dam, 7 = Permanent dam, 8 = Water quality limiter, 9 = Diffuse and intermittent flow with no pools 10 = Loss of surface flow for at least 100 m 11 = Poorly defined channel 12 = No defined channel
Landform class	Geomorphic and topographic features of stream and adjacent uplands: 1 = Flat terraces associated with mainstem rivers 2 = Low relief basin 3 = Narrow inner gorge like topography 4 = Other landforms
Geographic region	From WDFW GAP Analysis 1 = Coastal 2 = East Olympics 3 = Puget Sound 4 = Southwest Cascades 5 = Northwest Cascades
Geologic unit	From DNR base maps
Soil type	From DNR base maps
Vegetation zone	From WDFW GAP analysis
Field measured error distance of mapped location EOFP	Distance between mapped location of predicted EOFP placed in field and observed EOFPs measured in field (see section 3.4.1.2)
Field measured error distance of adjusted location EOFP	Distance between adjusted location of predicted EOFP placed in field and observed EOFPs measured in field (see section 3.4.1.2)
GIS measured error distance of mapped location EOFP	Distance between mapped location of predicted EOFP placed in field and observed EOFPs measured in GIS framework
GIS measured error distance of adjusted location EOFP	Distance between adjusted location of predicted EOFP placed in field and observed EOFPs measured in GIS framework

4.1.1 Rules for Measuring Prediction Error

Rules for measuring and processing error distances associated with each prediction point to ensure that no length of stream counted more than once are as follows. Begin by matching up the predictions with the field observed points and measure error distances associated with each by the following rules.

- For each predicted mid-channel EOFP
  - If the observed EOFP is situated downstream, measure the error distance along the mainstem channel (i.e. branch with the largest basin area), ignoring all small tributaries channels and attendant predicted lateral confluence EOFPs.
  - If the observed EOFP is situated upstream, measure the error distance along the mainstem channel, and
    - If a tributary enters the mainstem between the observed and the downstream predicted point and there is no fish use in the tributary (e.g., observed lateral EOFP upstream of a predicted mid-channel EOFP) then there is the no error distance associated with the observed lateral EOFP.
    - If a tributary enters the mainstem between the observed and the downstream predicted point and fish are observed in the tributary (e.g. observed mid-channel EOFP within a tributary that enters a mainstem upstream of a predicted mid channel EOFP) compute the error as the distance between the observed EOFP and the mainstem tributary junction. This distance is then added to the error distance measured along the mainstem trunk.
- For each predicted lateral EOFP
  - If there are no fish observed in the lateral tributary upstream of the predicted point, then the error distance is 0 regardless of whether the observed EOFP on the mainstem is situated upstream or downstream of the lateral tributary confluence.
  - If fish are observed in the lateral tributary upstream of the predicted point, determine the error distance between the predicted lateral confluence point and the observed point.
- For each predicted tributary junction EOFP
  - If the observed EOFP is situated downstream, measure the distance between the predicted points along the mainstem.
  - If an observed EOFP is situated upstream of the junction in only one tributary fork, measure the error as the distance between the predicted point and observed point on that fork only. There would be no error associated with the other fork.
  - If an observed EOFP is situated upstream of the junction in both tributary forks, the error distance associated with both forks would be added to compute the prediction error for the tributary junction EOFP.

The ΔEOFP will be measured for both the ground-placed mapped EOFPs (referred to as mapped ΔEOFP location) and the ground-placed adjusted EOFPs (referred to as adjusted ΔEOFP location). Section 3.4 describes the distinction between the mapped and adjusted EOFP locations.

4.1.2 Prediction Error Metrics for Model Performance Analysis

The error distances computed in the preceding steps can be summed to provide a total error that does not include any overlap. The prediction errors will be used to derive the following metrics for model assessment:

- absolute prediction error (absolute value of error distance / predicted point)
- net prediction error (error distance / predicted point)
- mean absolute basin error (sum absolute value of error distance / miles of stream)
- mean net basin error (sum of error distances / miles of stream)

By calculating the mean or median of these values we can compare the lengths of stream that were misclassified in the two possible ways. Because the error distance is measured at the EOFP scale instead of the DEM network scale (like the metrics described in section 4.3), it is more appropriate for discussing error as it relates to an individual stream.

While measures of prediction error are easy to measure and summarize, pilot studies suggest that rules for inclusion of specific data into the analysis of model performance may be warranted. As described in section 3.4.1.3, the DEM may not accurately represent the abundance and distribution of channels observed in the field. Occasionally the DEM-generated stream network portrays stream channels where none actually exist in the field, and subsequently predicts EOFPs on non-channelized swales or uplands. Any predicted EOFP selected for sample that is found to have no defined stream channel in the field will be tallied as such and will excluded from analysis of model performance. This means that predicted EOFPs associated with non-defined channels and their attendant ΔEOFP (which would equal 0) will be excluded from the estimation of precision and balance at the EOFP scale described in section 4.2. Similarly, the length of stream portrayed upstream of these points and classified as "fish absent" will be excluded from the assessment at the stream network scale described in section 4.3.

On other occasions, defined channels may be located in the field, yet are unmapped by the DEM stream network and contain no predicted EOFP. In these situations, a "field predicted EOFP" will be established on the non-mapped stream at its confluence with a fish-bearing water and included in the model assessment The stream will be surveyed for the observed EOFP; error distance will be determined as for other predicted EOFPs portrayed on the map, and the results included in the error measurement at the EOFP scale. Similarly, unmapped streams will be included in the stream network scale assessment by estimating their total length based on air photo assessments and include the entire length as "predicted fish absence". If no fish are found in the unmapped stream, then its entire length would be considered correctly classified. The length of incorrect classification would be computed if an EOFP is verified upstream of its confluence by simply measuring the distance between the "field predicted EOFP" and the observed EOFP.

4.2 Precision and Balance of Prediction at the EOFP Scale

Purpose of Analysis: Examine the performance of the model to predict the upstream extent of fish habitat throughout forested lands in western Washington managed under the Forests and Fish Rules. Determine the magnitude, range, and balance of errors in model predictions at the EOFP scale.

4.2.1 Distribution of Errors

Model performance as defined by the magnitude of ΔEOFP will be presented as a cumulative frequency polygon, where the ΔEOFP data will be represented on the horizontal axis and both the cumulative and relative cumulative frequency will be on the vertical axis. Three distribution lines will be displayed on the plot. First the absolute magnitude of ΔEOFP will be plotted for all sample points. A second line will represent the absolute magnitude of the predicted EOFPs that were an underestimation of observed fish use (ΔEOFP with positive values), whereas a third line will represent the absolute values of the predicted EOFPs that were an overestimation of observed fish use (ΔEOFP with negative values). Addition of the latter two lines will sum to the line representing all of the ΔEOFP points. The line will provide a readily understandable display of the magnitude of error in model predictions that encompasses any given percentile predictions. If the model performance were perfectly balanced, the two lines representing overestimates and underestimates would be identical on the relative cumulative frequency plot.

A separate cumulative frequency polygon as described above will be constructed for each geographic region investigated (i.e. combination of geographic region and EOFP boundary type). Each will be reported separately in order to illustrate variability of model performance (if it exists) across the study area. We will also graphically display overall model performance for all EOFP boundary types and geographic regions combined.

4.2.2 Magnitude and Balance of Errors

The mean and median of ΔEOFP will be computed for each combination of EOFP boundary type and geographic region, as well as for all types and regions combined. Mean values of estimated net prediction error and estimated absolute prediction error and the variance associated with these estimates will be computed following methods for cluster sampling described by Scheaffer et al. (1990). Computing confidence bounds on these estimates takes into account variability in prediction error both within and among clusters. Combining performance measures taken from different geographic regions will be straight forward, as samples will be proportionally allocated among regions, therefore the sample will be self-weighted.

In addition, we avoid the one important problem encountered in the preliminary assessment conducted using the withheld data set. Conrad et al. (2003) reported that the total number of field observed EOFPs were not proportionally allocated among the three recognized EOFP boundary types. Prediction error is smaller and much less variable for the lateral confluence types, yet the are greatly under-represented in the existing dataset. Using the stratified cluster sample design with probability proportional to size approach, all basins and attendant predicted EOFPs will have a chance of being selected during the sampling process, regardless of basin size. In addition, any higher order stream channel situated between two identified sample basins will be included as part of the potential sample basin situated upstream. Therefore, the sampled population will represent the distribution of EOFP boundary types as they occur on the landscape. Using this approach, we can easily compute an overall estimated mean, median, and bounds on the prediction error estimates. Balanced performance would result in a mean net error estimate approximating zero.

4.3 Precision and Balance of Prediction at the Stream Network Scale

Purpose of Analysis: Examine the performance of the model to correctly classify fish presence / absence throughout basins in western Washington managed under the Forests and Fish Rules. Determine the magnitude, range, and balance of errors of model prediction at various basin scales as defined by the DEM network.

One means to assess model performance is to evaluate the success of the model to accurately predict the presence of fish habitat along the entire stream. Accuracy will first be measured by calculating the feet of absolute error per mile of stream, which relates directly to the classification accuracy. For instance, an error of 53 feet per mile (5280 feet) of stream corresponds to 1% error on the stream network.

Both feet/mile and % correct require conventions on the upper and lower limits of streams in a basin in order to get the total stream length. The ISAG Statistical Group convention for the upper limit is a GIS-based measure that amounts to 3.7 acres of basin area. The lower limit is the lower boundary of the sample basin.

The success of the combined logistic regression model and stopping rules to accurately predict the presence of fish habitat will be examined. We intend to begin by partitioning the overall classification success of the model by deriving confusion matrices (Fielding and Bell 1997). A confusion matrix tabulates the observed and predicted presence/absence patterns and thus provides a summary of the number and direction of correct and incorrect classifications produced by the model. First, the overall classification performance of the model will be quantified as the percentage of cells where the model correctly predicts the presence/absence of fish (overall correct classification). Second, the ability of the model to accurately predict species presence will be examined (model sensitivity). Third, the ability of the model to accurately predict species absence (model specificity) will be determined. This simple table provides an assessment of the balance of errors (i.e. model sensitivity and specificity rates equal) and whether overall correct classification, sensitivity, and specificity achieve a specified rate.

4.4 Identify Sources of Error in Model Performance

Purpose of Analysis: Identify factors that may contribute to errors in model prediction.

Regardless of the simplicity or complexity of any model, there are situations in which certain regions of the "curve" are "noisier" than others. The purpose of this analysis is to identify factors that are important in discriminating among model performance across the variety of conditions in western Washington. If differential model performances do occur, managers need to understand these differences so they can evaluate the cost/benefit of additional fine-tuning of the model for application purposes.

We recognize that this study is designed primarily to answer questions concerning the current status of the model performance (e.g., central tendencies of prediction error at the EOFP and basin-wide scale) with a certain precision and accuracy in summary statistics.

Data will be collected to observe trends in model performance that may not be well understood. The sample design focuses on examining the error associated with each predicted EOFP and describes the current condition and trend of model performance across the study population, but it has not been designed to specifically identify factors that affect model performance. That is, the study cannot tell us with a high degree of certainty why prediction error at a point increases or decreases. Put another way, conclusions about causation made from this study are not necessarily wrong. The problem is that there is little assurance that they are right.

Analysis described in this section will attempt to assess where a relationship exists between the response variable (ΔEOFP) and other predictive variables (e.g., elevation, landforms, geographic region, geology). This assessment is considered descriptive in that we cannot conclude that one variable is the cause of another; there may be a third factor that "causes" the response in model performance. This analysis does not establish cause-effect relationships, although it may indicate fruitful avenues of inquiry for further testing of cause-and-effect.

Three general groups of factors potentially related to variation in model performance include: differences in inherent watershed settings not accounted for in the model; inaccuracies in geomorphic parameters derived through DEM analysis that are used to run the model; and seasonal and annual variability in end of fish points. We will attempt to identify those factors that are important in discriminating among model performance across the variety of conditions in western Washington. Each of these three general sources of error will be investigated as follows.

4.4.1 Ecoregions, Landform Classes, EOFP Types, and other Covariates

The following procedure describes a general approach that investigates the relationship of ecoregion, landform class, and EOFP type to model performance. The basic premise of the approach is that model performance reflects landform settings (i.e. fish presence and end of fish points are easier to predict in some settings as compared to others) and that detectable spatial patterns that define landform settings exist. We believe there is value in having separate estimates of model performance for the different strata. Model performance could be accurate and unbiased in some strata, while other strata exhibit greater mean ΔEOFP and/or directional bias.

A variety of graphical and tabular data summaries will be examined for apparent trends in prediction error. Before testing associations between model performance and attributes used to define landform settings, model performance (ΔEOFP) will be screened for normality assumptions, variance patterns, and linearity. Appropriate data transformations will be conducted if necessary. Non-parametric tests will be conducted if data transformations are unsuccessful at normalizing data.

We intend to conduct a three-factor analysis of covariance (ANCOVA) to test for differences in model performance among geographic region, EOFP type, and position relative to migration barriers (barrier group). Each predicted EOFP will be grouped into geographic region, landform classes, and EOFP type as previously described. In addition, each predicted point will be grouped into one of two barrier groups as identified from field surveys by the presence of a prominent barrier to upstream migration between the predicted and observed EOFPs. A general linear model will be used to perform the

ANCOVA, in which the dependent variable (model performance) is modeled as a function of each of the factors and their interactions. We will use channel gradient, elevation, and upstream basin size computed from digital elevation models as covariates.

Pairwise comparisons of means, which are traditionally used to examine differences between groups following an ANCOVA, provide little information about the magnitude of the differences among groups. As an alternative, we will present geographic region, landform classes, and EOFP type specific means and 90% confidence intervals (or alternative non-parametric graphical displays) for examining the magnitude of differences in model performance among the factors and the precision of the estimates.

Other data sources will also be explored in an effort to improve and streamline future modeling efforts. For example, we will conduct a post-hoc analysis to examine the influence of lithology, geology, and vegetation zones on model performance. Each of these classifications are currently available in GIS coverages, which provides opportunity for identifying trends among map derived variables describing the basins and prediction error.

4.4.2 Digital Elevation Models

Inaccuracies or insufficient resolution in geomorphic variables derived through DEM analysis may be a contributing factor to poor model performance in some situations. Clearly, error in the model will also be a function of how well the DEMs represent the landscape. Because of this, it will be important in the model assessment process to identify and distinguish errors associated with the DEM resolutions from those due to other factors. Errors in model performance associated with DEM inaccuracies can be grouped into two general categories.

4.4.2.1 Reliability of DEM data to accurately locate streams

Inaccuracies and misrepresentations of stream locations derived through DEM analysis can be a confounding factor in assessing model performance. One source of error in model performance may be related to the mapping accuracy of the DEM-generated stream network, especially the accuracy in locating stream confluences. The distances between mapped and adjusted EOFP locations of stream confluences will provide one index of DEM stream network accuracy. A tally of map depicted streams with no defined channel in the field as well as unmapped streams encountered in the field will provide information about the frequency that DEM-derived streams are in error. Additionally, the analysis conducted at the EOFP scale (section 4.2) and the stream network scale (section 4.3) will be conducted using prediction errors computed from the mapped EOFP locations and the adjusted EOFP locations separately. Comparative analysis of these two prediction error measures will be used to evaluate mapping accuracy and its effects on model performance. Simple comparisons between the two error distances on a point by point basis will characterize the frequency of misrepresentation of field conditions. Another method of assessing the reliability of the DEM to depict the stream network is a direct comparison between the field measured and the GIS measured ΔEOFP.

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4.4.2.2 Accuracy of the Digital Elevation Models in identifying geomorphic features responsible for upstream extent of fish use

In some situations, digital elevation models alone may be insufficient to identify specific geomorphic features responsible for the upstream limits of fish distribution. It will be important for the error analysis to identify and distinguish this type of error associated with the DEM as compared to error associated with other factors. For instance, the current water type model runs rely on stream gradients as portrayed by DEM averaged over a 100 m reach. This reach averaging was established by an arbitrary decision that assumed that DEM were insufficient to capture smaller inflections in stream gradient that may be responsible for the upstream distribution of fish. However, field sampling commonly reveals that fish presence may end in areas with abrupt changes in gradient that may or may not be sustained for 100 m. This study proposes to investigate the correspondence among predicted and field observed gradient features in order to evaluate the reach averaging approach used in the model. Specifically, we will investigate if abrupt changes in channel gradient associated with observed EOFPs are effectively masked by the 100 m reach averaging rule used in the model development.

Field verified channel gradients upstream and downstream of both the observed EOFP and the predicted EOFP will be compared to the DEM estimated gradients. This assessment will provide information on the ability of the DEM to identify specific features (steep channel inflections or waterfalls) that limit the upstream distribution. We will determine if channel gradient estimated between individual DEM points (approximately 10 in length) or groups of points can account for field observed channel inflections associated with observed EOFPs.

4.4.3 Seasonal and Annual Variability

A basic premise of the modeling efforts collected to date assume that observed EOFP located using the "last fish" protocol represent an accurate assessment of the upstream distribution of fish. However, last fish points are not necessarily associated with barriers to upstream fish movement, and sometimes what appears to be suitable habitat situated upstream is clearly accessible. In fact, this is one of the issues that encouraged the use of the "last habitat" protocols in water typing efforts over the past several years. Changes in seasonal and annual upstream fish use could have ramification for model performance and eventual water typing calls for regulatory purposes, but the significance of these changes is has not been systematically addressed in western Washington.

In order to characterize seasonally variability in observed EOFPs in western Washington, a network of monumented survey locations will be established to allow for characterization of seasonal and annual variability, sampling efficiency, and other research requiring a repeated or representative sampling of upper distribution limits. Repeated visits to observed EOFPs will identify the magnitude and direction of temporal change in the upstream distribution of fish across different seasons and years. Repeated visits will determine how the changes effect ΔEOFP and if the most upstream extent of fish use over the seasons and years sampled extend beyond predicted EOFP locations. A plan describing the number of sites to be revisited and the frequency and timing of revisits is currently being prepared separately for CMER review.

5 Application of Study Results

The current model provided by Conrad et al (2003) and resulting assessments suggest that the fish habitat can be reasonably predicted given the limitations of the data set. However, caution is recommended when interpreting model results due largely to the fact that the existing dataset was not specifically intended for model development and assessment purposes. There was no deliberate sampling design and very few complete basins examined in the field. Nor was there one standard protocol used for establishing the observed EOFP in the field.

The ISAG Statistical Team recommended more field surveys be conducted to provide a more reliable assessment of model performance. This study design combines an examination of overall model performance with supporting components aimed at identifying potential sources of error in model predictions. Under this study, data will be collected following a statistically based sampling design that includes a consistent and easily reproducible field protocol. We have suggested a few analysis that will provide an unbiased and more accurate assessment of model performance, which will aid in identifying situations in which the model predictions are less reliable. There is a variety of approaches to evaluating the data collected, and early efforts will focus on identifying trends among map derived and field variables describing the stream network and prediction accuracy. Because of a consistent data collection and processing protocol, the dataset produced by this study plan will provide the ISAG an opportunity to re-evaluate the logistic regression model and stopping rules.

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