Evaluation of Fall Chinook and Chum Salmon Spawning Habitat near Ives and Pierce Islands in the Columbia River

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Progress Report 1999-2001

EVALUATION OF FALL CHINOOK AND CHUM SALMON SPAWNING HABITAT NEAR IVES AND PIERCE ISLANDS IN THE COLUMBIA RIVER

September 2003

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BONNEVILLE POWER ADMINISTRATION

EVALUATION OF FALL CHINOOK AND CHUM SALMON SPAWNING HABITAT NEAR IVES AND PIERCE ISLANDS IN THE COLUMBIA RIVER

PROGRESS REPORT 1999-2001

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Acknowledgments

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Executive Summary

The area around Ives Island below Bonneville Dam on the Columbia River supports spawning populations of chum and fall chinook salmon. Because this area is sensitive to water level fluctuations caused by changes in discharge from Bonneville Dam and from tidal cycles, we initiated a study to quantify flow-dependent changes in available spawning habitat for chum and fall chinook salmon. We conducted surveys to characterize the substrates available in the Ives Island study area. Detailed bathymetry was also obtained to serve as a foundation for two-dimension hydrodynamic modeling, which was used to estimate water velocities, depths, and wetted area over a range of simulated flows. Habitat surveys were conducted and logistic regression was used to identify physical habitat variables that were important in determining the presence of chum and fall chinook salmon redds. The physical habitat data were analyzed using the logistic regression models to create probability coverages for the presence of redds in a Geographic Information System. There was generally good agreement between chum and fall chinook salmon redd locations and areas where we predicted suitable spawning habitat. We found that at Columbia River discharges less than 120 kcfs, an important chum salmon spawning area below the mouth of Hamilton Creek could only be supported by discharge from Hamilton Creek. Chum salmon did not appear to spawn in proportion to habitat availability, however our predictive model did not include all variables known to be important to chum salmon redd-site selection. Fall chinook salmon spawning habitat was less sensitive to flow and the main channel of the Columbia River along Pierce Island was predicted to contain sufficient habitat at all modeled flows.

Introduction

Chum salmon (*Oncorhynchus keta*) have the widest natural geographic distribution of all Pacific salmon species and historically may have made up to 50% of the annual biomass of all the Pacific salmon in the North Pacific Ocean (Salo 1991). Chum salmon once ranged as far south as the San Lorenzo River in Monterey, California (Scofield 1916), but they have been extirpated from most of their southern range, and only small numbers of fish spawn in northern California and southern Oregon (Salo 1991; Kostow 1995; Johnson et al. 1997). Prior to the 1940s, chum salmon were also abundant in the Columbia River (Salo 1991). However, dramatic declines of Pacific salmon in the northwestern United States has led to the listing of many populations, including Columbia River chum salmon as "threatened" in 1999 (NMFS 1999). Flood plain development, habitat degradation, water diversions, harvest, and artificial propagation are all major anthropogenic factors contributing to the decline of chum salmon (NMFS 1998).

Chum salmon spawning in the Columbia River is primarily limited to tributaries below Bonneville Dam (Johnson et al. 1997), but a spawning population has been documented in the main stem of the Columbia River around Pierce and Ives islands below Bonneville Dam (Hymer 1997; this study). Nearby Hamilton and Hardy creeks also support chum salmon spawning, however, access to these creeks is often dependent upon stream flow and the water elevation of the Columbia River. Although the Columbia River in this area is unimpounded, water levels are subject to water regulation from Bonneville Dam, as well as from fluctuations caused by tidal action and downstream tributary inflows, primarily the Willamette River. Also, the ocean itself acts as an impoundment preventing the river from freely flowing. These water level fluctuations likely influence the amount and quality of spawning habitat available to chum salmon.

In addition to chum salmon, fall chinook salmon (*Oncorhynchus tshawytscha*) also spawn in the main stem of the Columbia River around Pierce and Ives islands and were first observed in 1993, when the Washington Department of Fish and Wildlife (WDFW) found fresh, spawned-out carcasses downstream of the islands (Hymer 1997). Two stocks of fall chinook have been documented to spawn in the Ives Island area. One is the Lower Columbia River fall chinook stock, also referred to as Tule, and is currently listed as "threatened" (U.S. Fish and Wildlife Service 1999). The other stock is the upriver bright stock, which is healthy by comparison (Huntington et al. 1996) and primarily spawns 325 km upstream in the Hanford Reach.

Both chum and fall chinook salmon spawn in the fall at a time when Columbia River and tributary flows are at a seasonal low. Fish that spawn in the shallow water at the mouth of Hamilton Creek and in the channel between Ives and Pierce islands are particularly influenced by water level fluctuations at this time. Changes in water elevations in these areas caused by hydroelectric power generation at Bonneville Dam and tidal variations have disrupted spawning behavior, dewatered redds, and entrapped adults in pools during the spawning season. Consequently, fishery and hydroelectric managers are interested in determining the effects of Bonneville Dam operations and tributary and river discharge on the amount of available chum and fall chinook salmon spawning habitat in the Ives Island area in order to protect and enhance the fish populations. The purpose of this study was to describe the abiotic characteristics of chum and fall chinook salmon spawning habitats, and to predict the amount of potential spawning area at different stages and discharges below Bonneville Dam.

Study Area

The Columbia River has an average discharge of 258 kcfs, the largest on the Pacific Coast, and drains a basin of 660,500 km^2. The Cascade Mountain range of Oregon and Washington divides the Columbia Basin in an east-west direction. The western sub-basin contains about 8% of the total surface area, but contributes almost 25% of the total river discharge (Orem 1968). Our study site lies at the junction of these two basins and is subject to effects from both. Hydroelectric development has reduced peak annual discharges by an average of >40% and peak river stages by 0.5-2.0 m during the spring and summer migration of juvenile salmonids (Bottom et al. 2001).

Tidal fluctuations also influence the hydrology of our study area. Tidal variation at the mouth of the Columbia River ranges between approximately 1.7 to 3.6 vertical meters, and increases to a maximum of between 2.0 and 4.0 m at Astoria (river kilometer (Rkm) 29) (Oregon Graduate Institute, unpublished data). Tidal stage decreases in an inland direction toward Bonneville Dam. Little information or analysis of tidal influences to Bonneville Dam is available, however, both cyclical tidal action and discharge from the Willamette River

(Rkm 162) can create a backwater effect in the Columbia River to Bonneville Dam. As an example, we have documented instances when discharges into the Columbia River from the Willamette River at Rkm 162 exceeded the total discharge of the Columbia River and created a substantial backwater 71 kilometers upstream to Bonneville Dam.

Our study area was located 3.5 km below Bonneville Dam between Rkm 226.9 and 231.5, as measured from the mouth of the Columbia River (Figure 1). Within the study site are two islands (Ives and Pierce), and three tributaries (Woodward, Hardy, and Hamilton creeks; Figure 1). Discharge from these tributaries is typically low but can vary dramatically in both volume and time with rain events. The study area is generally characterized by a low gradient bed comprised of gravels and cobbles and low to moderate velocities. For analytical purposes, we divided the study area into six sections based on hydraulic and substrate characteristics (Figure 1). Study section one, located between Ives Island and the Washington shoreline, starts at the upstream end of Ives Island and extends almost to Hamilton Creek. Study section two starts just above Hamilton Creek and extends along the Washington shoreline to the bottom of Ives Island. This section receives all of the river flow at discharges <140 kcfs. Study section three is isolated from study section two on its northern side by a small island at higher flows. Chum salmon spawning has been documented in this section at flows >140 kcfs. Study section four includes the main channel of the Columbia River. Study section five includes the channel between Pierce and Ives Islands. This section contains complex bathymetry that chinook salmon use for spawning, and its downstream boundary is characterized by a significant drop in water velocities. The final study section (six) starts at the downstream end of study section five and includes a large, low velocity area between Pierce Island and the Washington shoreline. It ends at the bottom of Pierce Island at its intersection with the main channel of the Columbia River. Splitting our study area into sections allowed us to examine these areas in detail with respect to spawning characteristics and changes in total predicted spawning habitat area.

Methods

Riverbed bathymetry

We required a digital elevation model (DEM) of the study area for two-dimensional hydrodynamic modeling and a Geographic

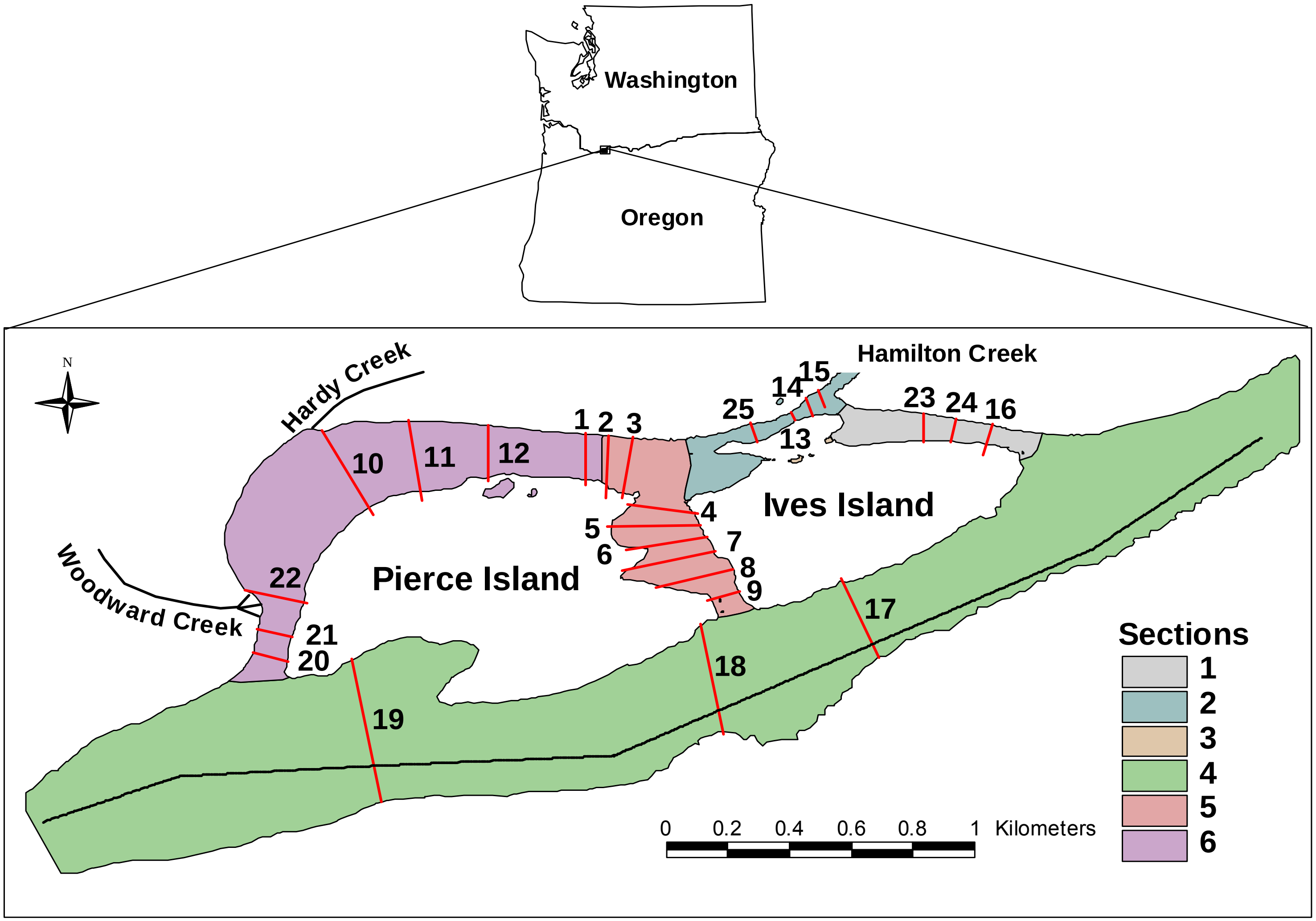

Figure 1.- The Ives Island study area of the Columbia River showing the locations of study sections and velocity verification transects.

Information System (GIS)-based analysis of chum and fall chinook salmon spawning habitats. We produced the DEM using three existing sources. First, elevation data for Pierce and Ives islands, as well as the Washington shoreline north of these islands, originated from 1-ft contour topographic data created in 1999 using photogrammetry (John Moore, Bonneville Power Administration, unpublished data). Aerial adjustments and data collection used a Zeiss P1 analytical stereo plotter. Photogrammetry resolution was 0.06 m (horizontal) and 0.15 m (vertical). Second, the U.S. Army Corps of Engineers (COE) provided data from a bathymetric survey for the main Columbia River channel of our study area. Data collection used hydrographic soundings and a differential correcting geographic positioning system (DGPS) to collect horizontal positions at approximately 26-m intervals along cross sections spaced approximately 152 m apart (Ken Kleczynski, COE, unpublished data). Finally, to define the upper shorelines of the Oregon shore of our study area, we used U.S. Geological Survey (USGS) 7.5 minute (10x10 m) DEM data (USGS 1992).

For areas with missing elevation data or areas that required higher resolution, we used a boat-mounted sonar system coupled with a DGPS, and an electronic total station (ETS). The boat-mounted sonar system collected depth data in areas too deep to wade. We surveyed transects in the side-channel between the Washington shoreline and the two islands and in the channel between the two islands. Sonar data provided us with depth information, which we later converted to elevations. We did this by determining the water surface elevations for each individual transect using an ETS and then subtracting the water depth from the water surface elevation. We conducted ETS surveys in areas where wading was possible and in areas of complex topography. We created a complete DEM of our study area by combining all data sets (Figure 2).

Substrate

We mapped the spatial extent of textural patches (i.e. grain-size facies) of dominant and subdominant substrates (Table 1; Buffington and Montgomery 1999), as well as the percentage of substrate material <4 mm within our study area (hereafter referred to as percent fines; Table 2). Visual classification of bed-surface substrate groups used a method modified from Bovee (1982). Percent fines classification also used visual assessments to create sufficiently large categories (Table 2). We surveyed 1x1-m areas of dry land and water <0.5 m deep to assign the dominant substrate, subdominant substrate, and

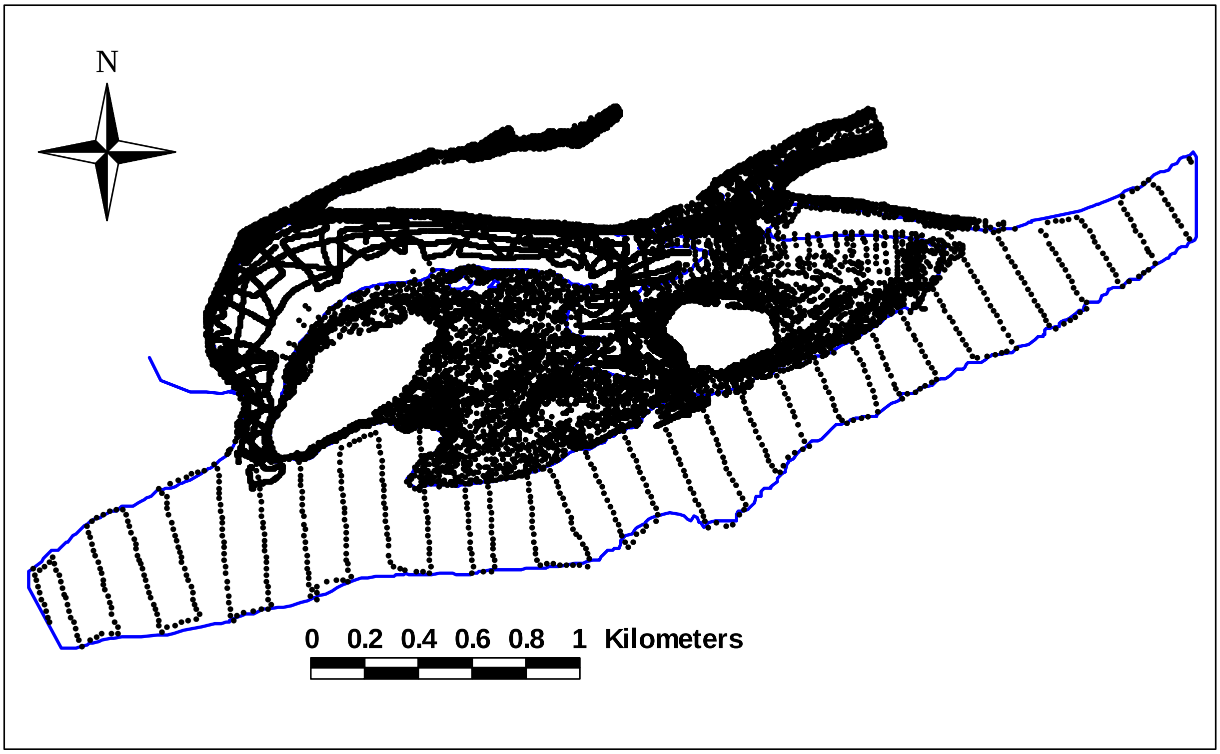

Figure 2. - Distribution of elevation points in each of the study sections of the Ives Island study area on the Columbia River.

Table 1. - Substrate codes, particle sizes, and descriptions used to classify dominant and subdominant substrates.

Code	Particle Size (mm)	Particle Size (inch)	Description
3	≤4	≤0.2	Sand/Silt
4	>4-75	>0.2-3.0	Gravel
5	>75-150	>3.0-6.0	Small Cobble
6	>150-300	>6.0-12.0	Large Cobble
7	>300	>12.0	Boulder
8	NA	NA	Bedrock

Table 2. - Percent fines codes and descriptions used to classify percent fine substrate.

Code	Description
1	≥0–25 percent of substrate ≤4 mm.
2	≥25-50 percent of substrate ≤4 mm.
3	≥50-75 percent of substrate ≤4 mm.
4	≥75-100 percent of substrate ≤4 mm.

percent fines. Geographic positions were collected with a DGPS at each location. We delineated textural patches using an approach similar to the facies-stratified random approach described in Buffington and Montgomery (1999), which resulted in the collection of 4,512 substrate data points in our study area.

For in-water areas deeper than 0.5 m, we collected substrate and percent fines information using a boat-mounted video camera. The sampling used a 24-V hoist/winch system, underwater video sled (Figure 3) equipped with lasers for scale referencing, and onboard video monitors and mapping equipment. Sampling occurred in cross sections parallel to the stream flow following bathymetric contour lines, and substrates were mapped every 30 to 75 m. Due to gear restrictions, boat draft, and water current, sampling was limited to depths between 0.5 and 18 m. Sample spacing varied with channel morphology, channel width, and substrate heterogeneity. The winch operator maintained the camera sled 0.5–1.0 m above the riverbed and classified the substrates with the data collector. The data collector classified the substrates in real-time on a video monitor and recorded the substrate codes as attributes within a DGPS unit. The lasers were mounted in parallel and at a width matching the transition size between small and large cobble substrates (codes 5 and 6). We completed additional transects at increasingly greater distances from shore in deeper water, collecting 206 samples.

Production of the final textural patch maps of dominant, subdominant, and percent fines employed a Thiessen interpolation (ESRI 1998) within a GIS to guide creation of the maps. We compared the generated Thiessen polygons to field notes, collected data points, and aerial photographs. Adjustments to the Thiessen polygons of textural patches resulted in the final map, which represented the best possible interpretation of surface textural patches.

We then determined bed-surface grain-size distributions for randomly selected locations within the textural patches. We used a pebble count method to determine grain-size (Wolman 1954; Kondolf and Li 1992; Kondolf 1997). Sampling occurred at random locations within textural patches, which we determined using a random locator in the Animal Movement program within a GIS (Hooge et al. 1999). We navigated to locations using a DGPS, and collected samples along a 30.5-m transect, following a compass direction determined by a random number generator. We measured exactly 100 grains (in mm) along the intermediate axis of each grain at 0.3-m intervals for each transect. Substrates

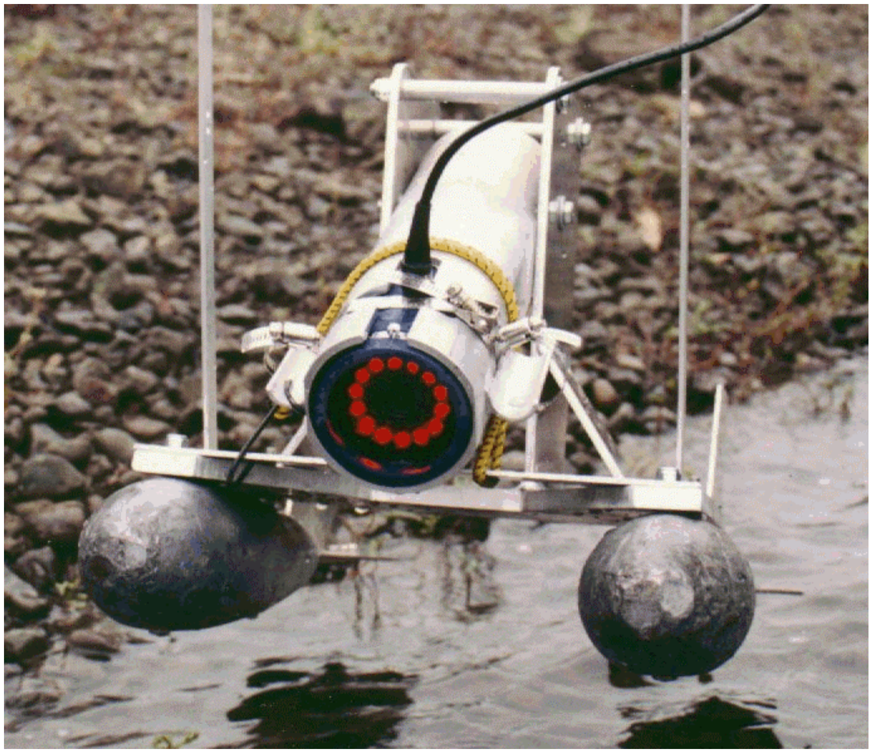

Figure 3. - Configuration of boat mounted sampling sled for underwater substrate sampling.

smaller than 4 mm were classified as "<4 mm" (Wolman 1954; Kondolf 1997). Grain size measurements provided the mean, D50 (median diameter), and D84 (the size below which 84% of the samples are finer) for each transect.

Hydrodynamic modeling

We estimated depth-averaged water velocities for the Ives Island study area under a range of Columbia River discharges likely to be encountered by spawning chum and fall chinook salmon. We modeled water velocities at ten steady-state Columbia River discharges ranging from 115 kcfs to 160 kcfs in 5-kcfs increments using a two-dimensional hydrodynamic model (RIVER_2D; Ghanem et al. 1996). This model applies a two-dimensional finite-element method to solve the shallow-water flow equations. Model inputs included riverbed topography with geographic position, elevation, and substrate roughness (height) information, as well as inflow discharges and the water surface elevation at the downstream end of the modeled area. We used substrate roughness values determined from the D84 information collected as part of the textural patch study. D84's were applied to each textural patch, converted to meters, and doubled to estimate the substrate roughness (Peter Steffler, University of Alberta, personal communication).

Position, elevation, and riverbed substrate roughness data were used to create a triangulated mesh of points, or nodes, for use in the hydrodynamic model. Nodes were uniformly spaced in a 25-m^2 grid for the main channel and areas with little bathymetric complexity. In areas with greater bathymetric complexity, and areas of interest for salmon spawning, we increased the number of nodes, with some areas having approximately 1-m^2 spacing. The final non-uniform meshes contained 10,062 nodes for discharges <120 kcfs, and 18,351 nodes for discharges >120 kcfs. We generated and smoothed the computational mesh and assigned inflow discharges to the upper end of the modeled area in the Columbia River and to Hamilton Creek 250 m upstream of its mouth, and we assigned a water surface elevation to the downstream end of the study area. We estimated discharges from Hamilton creek using the method described by Linsley et al. (1982), where a cross-channel transect was divided into 20 (5% of cross-channel width) sections, and velocity and depth measures were made at the midpoint of each section. Discharge for each section was calculated by the estimated area (width X depth) multiplied by the velocity, and all sections were summed. We obtained discharge data for the Columbia River at Bonneville

Dam from the COE. We did not include discharge inputs from either Hardy or Woodward creeks since little water flows from these creeks and it would have unnecessarily increased modeling complexity. Combined flows from both tributaries are typically less than 1% of Columbia River discharges.

Numerous water surface elevations were possible for any given discharge within our study area because of tidal and backwater effects. We determined minimum and average water surface elevations for each discharge increment from hourly stage data collected from October 1980 to January 1988 at the USGS Warrendale gage station (14128910), which represents the most recent period of record. The Warrendale gage also marked the downstream boundary of our study area. To collect more recent data, we established a new gage at the location of the original Warrendale gage in December, 2000. We matched the stage data by date and time with discharge data from the COE for the Columbia River (COE, unpublished data) to determine the minimum and average water surface elevation for every 1-cfs increment of discharge. Using the constraints of inflow discharge and downstream water surface elevation, the hydrodynamic model produced a simulated water depth, water surface elevation, velocity, and flow direction for each node. The final matrix of modeled outputs included simulated Columbia River discharges from 115 kcfs to 160 kcfs, in 5-kcfs increments, at two (minimum and mean) ending water surface elevations. We also varied Hamilton Creek discharges from 0 to 388 cfs for each 35-cfs increment (12 increments) for Columbia River discharges <125 kcfs. This resulted in a total of 52 modeled flows with different combinations of Columbia River discharges, Hamilton Creek discharges, and water surface elevations. Water surface elevations are presented in meters above mean sea level (National Vertical Geodetic Datum 29).

Because Columbia River fishery and hydroelectric system managers use water surface elevation data from the USGS gage station below Bonneville Dam (Bonneville gage; USGS gage station 14128870) to maintain appropriate water levels for chum salmon spawning, we established a relationship between the Bonneville and Warrendale gages. This was done by matching, by date and time, the Bonneville and Warrendale gage data where both overlapped in the historical record and preforming a simple linear regression using the Bonneville gage data as the predictor variable. We then predicted Warrendale water surface elevations from recent history (January 1, 2001 to December 31, 2001) and compared them with measured values.

We validated velocity outputs from the hydrodynamic model using empirical data collected with an acoustic Doppler current profiler (ADCP) and a DGPS. For depths greater than 1 m, we measured water velocities along cross sections, which were oriented perpendicular to the current at randomly designated locations. A GIS was used to establish transects at 20-m intervals in each study section, and a subset of at least three transects were randomly selected for each study section. Additional transects were randomly selected in areas with greater topographical complexity. Main-channel cross sections in the Columbia River were divided into a grid of rectangular bins that measured 2 m long, which we refer to as segments, and 0.25 m deep, whereas all transects in the shallower side channels were divided into bins that measured 1 m long and 0.1 m deep. The midpoint of each segment was georeferenced using a DGPS. The ADCP calculated the water velocity for each bin, which we averaged to determine the total water column velocity at each segment location. For areas along cross sections <1 m deep, we used a wading rod, current meter, and DGPS. Water velocity measurements were collected at 60% of the depth if water was <0.76 m deep, or averaged at 20% and 80% of the depth for water >=0.76 m deep (Orth 1983).

We measured velocities at 25 cross sections (Figure 1) and collected 3-10 replicates at each site to capture the variation caused by water turbulence and natural pulsing of flows. Polynomial regression was used to determine the line that best fit the average water column velocities measured by the ADCP (SAS 1998). Measured water velocities were graphically compared to those predicted by the model at each site and discharge (Ghanem et al. 1996).

In addition to velocity data, water surface elevations were collected for comparison to modeled water surface elevations. We concentrated our collection of this information in the side channel located in study section 2, below Hamilton creek. Water surface elevations were collected using an ETS, in conjunction with collecting the discharge from Hamilton Creek. Predicted water surface elevations were compared to observed values.

GIS

Water velocities, depths, and water surface elevations derived from the RIVER_2D hydrodynamic model for each modeled flow were input into a raster format in a GIS. We interpolated both of these habitat metrics into 1-m^2 grid cells using an inverse distance weighted (IDW) interpolator (Watson 1994; ESRI

1998). Use of a 1-m^2 cell allowed us to roughly match the resolution of modeled node resolutions in areas of highest interest for chum salmon spawning, and is biologically realistic in terms of spatial scale.

Water surface elevation profiles were constructed for the mean discharges for the 1998 (November 17 through December 8) and 2000 (October 27 through November 29) fish spawning data collection period. For 1998, we created water surface elevation profiles using the average downstream elevation and the modeled flow of 140 kcfs. This modeled flow was close to the mean hourly discharge for the sampling period of 133 kcfs (SE = 13.3; COE, unpublished data). Line coverages were then created for the main channel of the Columbia River (Main Channel), the northern most channel downstream of Hamilton Creek (North Channel), the channel that flows around a small island located between the north channel and Ives Island (Ives Channel), and the channel between the two islands (Ives-Pierce Channel; Figure 4). Using these lines, we extracted profiles from the water surface elevation grids for the modeled flows that were constructed in the GIS (ESRI 1998). We repeated this process for 2000 using the average downstream elevation and the modeled flow of 130 kcfs. The mean hourly discharge for the 2000 sampling period was 130 kcfs (SE = 9.57; COE, unpublished data). At this flow, however, water does not flow through the Ives Channel, so we only extracted profiles for the remaining three areas.

Spawning habitat

Data collection.--We collected physical habitat data for chum and chinook salmon that spawned in the Ives Island area in 1998 and 2000. In 1998, only data related to actual redds were collected—primarily in known spawning areas that were shallow enough to wade. In 2000, we attempted to describe the characteristics of physical habitat that were used and not used by spawning fish. We also tried to sample a broad range of the variability present in the habitat variables of interest. To guide efforts, we constructed two substrate x velocity sampling matrices; one for depths <0.9 m and one for depths >0.9 m. Dominant substrates were grouped into four size categories: fines (<4 mm), gravel (4-75 mm), small cobble (75-150 mm), and large cobble (150-300 mm) (Table 1). Velocity categories were <0.15 m/s, 0.15-0.91 m/s, and >0.9 m/s. The resulting matrix for each depth category comprised twelve substrate x velocity combinations. We attempted to collect habitat use and nonuse data for both chum and fall chinook

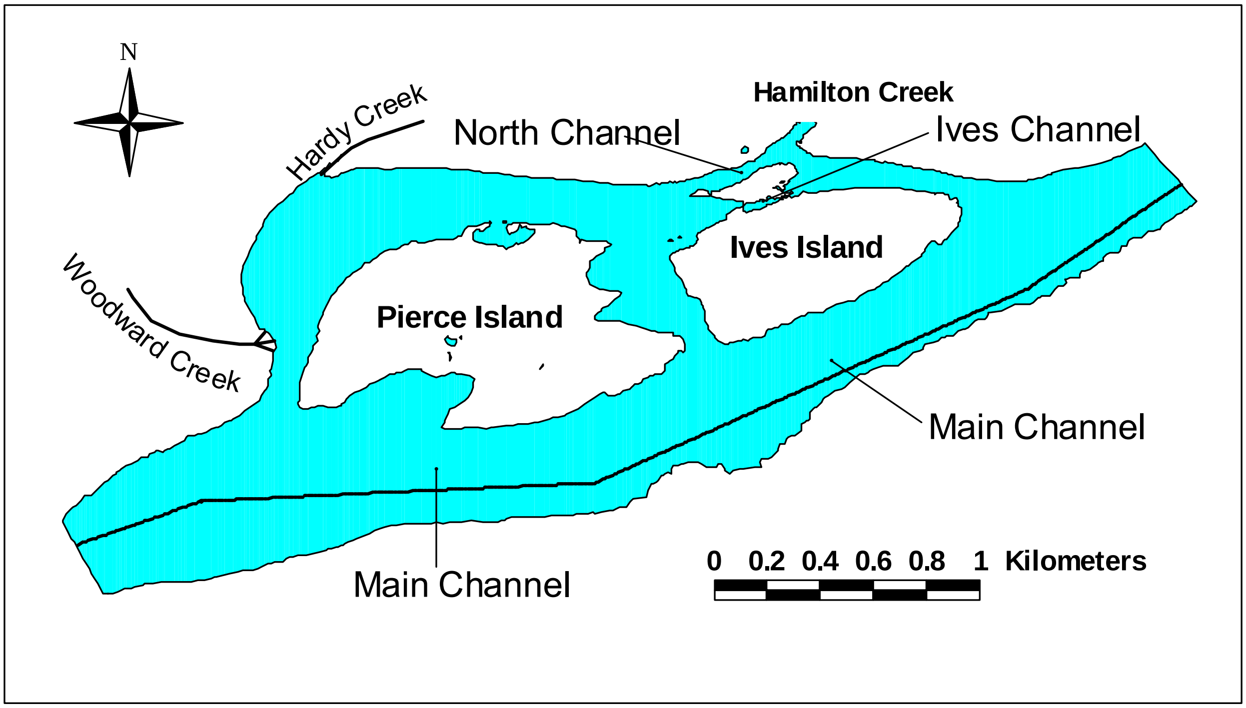

Figure 4. - Channel names for the Ives Island study area on the Columbia River.

salmon for each matrix cell, however, some habitat combinations did not exist in our study area (e.g., fast water over fine substrate).

Habitat use data were collected in areas where spawning occurred. Data were collected directly adjacent to redds so minimize disturbance. At each redd, we measured the water depth, dominant and subdominant substrate size, mean water column velocity, estimated nose velocity (15 cm above the bottom), percent fines (0-25%, 25-50%, 50-75%, and 75-100%) (Table 2), and recorded the location with a DGPS. These same data were also recorded at nonuse sites.

To collect nonuse habitat data, we first divided the study area into broad areas of dominant substrate type. In shallow areas, we then randomly established transects perpendicular to the river flow and then randomly sampled up to five points along each transect. In areas too deep to wade, we used divers or a boat-mounted video camera to search for redds along transects and collected habitat use data if redds were found or nonuse data if none were found. Substrate information was collected with an underwater video camera fitted with two lasers separated by 150 mm so that substrate size could be determined. Depth and water velocities were collected with a Marsh-McBirney current meter suspended by a weighted cable from the boat. Location information was collected with a DGPS.

Logistic regression.--We constructed two logistic regression models to predict the probability, P_i, of chum and fall chinook salmon redd presence in i habitat cells given habitat characteristics of each cell. P_i can be expressed as:

$$P_i = \frac{e^{g(x)}}{1 + e^{g(x)}}$$

where $g(x)$ is the linear combination of parameter estimates of the predictor variables. We only considered habitat variables compatible with a GIS, which included water velocity, depth, substrate, and percent fines in the chum and fall chinook salmon analyses. We converted substrate categories to design variables with fines serving as the reference category for chum salmon and with gravels serving as the reference category for the fall chinook salmon analysis. Redd presence was assigned a value of 0 if redds were observed and 1 if redds were absent from samples, which is the convention of the statistical software we used for analyses (SAS 1998).

Model development began by regressing redd presence against each habitat variable separately to determine if each one-variable model was significantly different from the constant-only model. This was done using the likelihood ratio test, whose statistic, G, is equal to minus twice the difference between the log likelihoods ($-2\log_e L$) of the two models. This statistic was then compared to the chi-square distribution with 1 df at α=0.05 (Hosmer and Lemeshow 1989). We also considered habitat variables with *P* values <0.25 as candidates for multivariate analyses.

One of the assumptions of logistic regression regarding continuous variables is that the relationship between a predictor and the logit will be linear. We examined this assumption following the methods of Demaris (1992) for velocity and depth, which were identified as significant continuous variables in univariate analyses for both chum and fall chinook salmon. Because this assumption did not hold for velocity in the chum salmon analysis, we modeled velocity as a design variable (Hosmer and Lemeshow 1989; Hardy 1993). The velocity design variables were V_1 (0.2 - 0.29 m/s), V_2 (0.3 - 0.39 m/s), V_3 (≥0.4 m/s), and the reference category was represented by velocities <0.2 m/s.

Multivariate logistic regression proceeded by estimating a model that included all variables that were significant in univariate analyses. Variables were then removed one at a time based on their Wald chi-square statistic. The importance of each variable was determined using the likelihood ratio test for the models with and without the variable. A nonsignificant result indicated that the variable did not contribute to the model. Significance was assumed at *P* <0.05.

The fit of our final models were evaluated using the Hosmer-Lemeshow statistic (Hosmer and Lemeshow 1989), for which a high *P* value, or nonsignificant result, indicates a good fit. We evaluated the performance of our logistic regression models using cross-validation. Cross-validation involves removing one observation from the data set and re-estimating the logistic model using the remaining observations. The probability of redd presence in the excluded observation is then estimated according to this model. This process is repeated for each observation in the data set, and classifications of redd presence and absence were then tabulated. Probabilities ≥0.6 were used to define redd presence. We chose a probability level of 0.6 because it matched well with observed chum and fall chinook salmon redd locations. Statistical analyses were performed using SAS software (SAS 1998).

Predicting the quantity of spawning habitat

We predicted the quantity of chum and fall chinook salmon spawning habitat at different Columbia River discharges, water surface elevations, and Hamilton Creek discharges by analyzing the physical habitat data in a GIS, in conjunction with the logistic regression models. GIS coverages were created for habitat variables that were included in our final logistic regression models. Habitat attributes of each GIS cell were used in the logistic regression models to determine the probability of redd presence for each cell. We created probability coverages in GIS and considered habitat cells with probabilities ≥ 0.6 as suitable spawning locations for chum and fall chinook salmon. We set probabilities to zero in areas where the depth was ≤ 0.21 m, because we observed no chum or fall chinook salmon redds in areas this shallow. Additionally, we observed no fall chinook salmon spawning in water deeper than 4.2 m, however, we also expended little effort in water deeper than this. Therefore, we set a maximum spawning depth limit of 6.5 m based upon work by Mueller and Dauble (2000) and Mueller (2001), and assumed no spawning occurred at depths greater than this. We then summed the areas of all cells with probabilities ≥ 0.6 to determine the total hectares of potential spawning area at each flow and in each study section. Finally, we calculated the percent potential spawning area for each study section by dividing the total hectares of potential spawning area by the total hectares of wetted surface area and then multiplied by 100. We graphed the percentage and total hectares of potential spawning area for different Columbia River discharges, Hamilton Creek discharges, and average and minimum water surface elevations. This was done for potential spawning areas for both chum and fall chinook salmon.

Results

Substrate

The dominant substrates available to spawning salmon in the Ives Island area are primarily gravel and small cobbles (Figure 5). Fine substrate is generally present on the tops of the islands and shorelines above high water, and in-water in low velocity areas. The percentage of fine material in the substrate is generally less than 25% in most areas available to

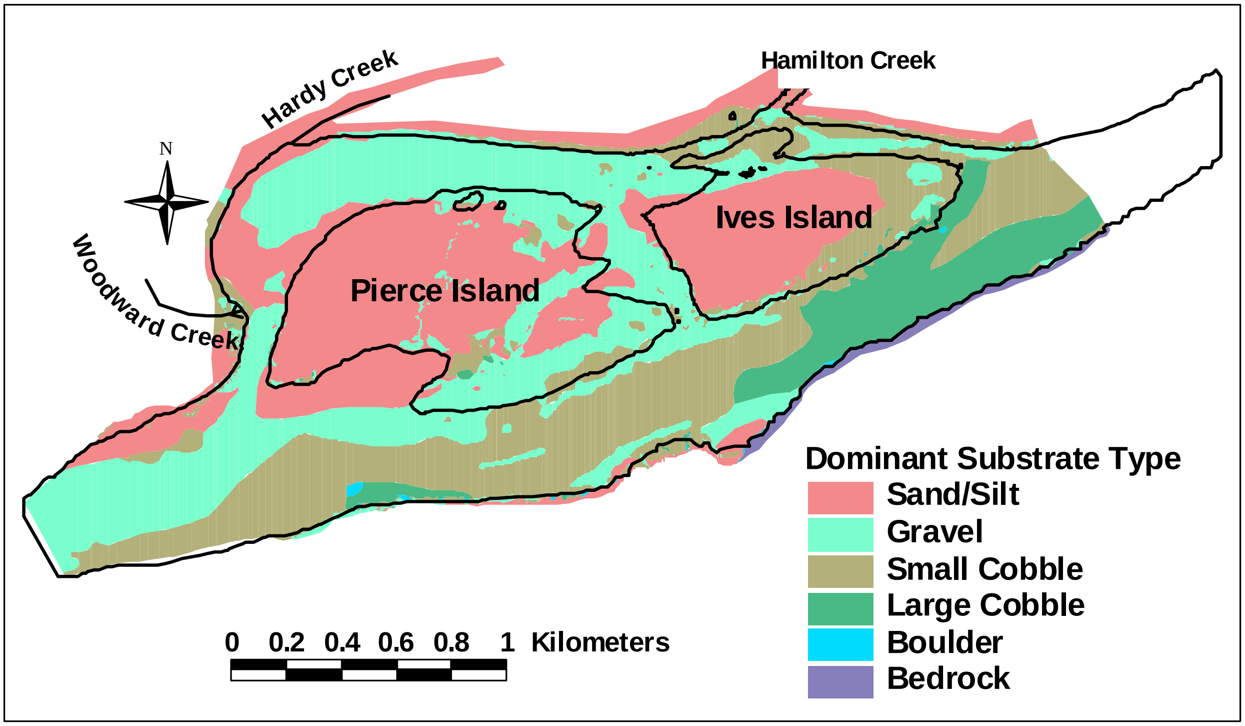

Figure 5. – Final dominant substrate map of textural patches in the Ives Island study area on the Columbia River.

spawning salmon (Figure 6). There were however, some areas with higher percent fines adjacent to where fish spawn. Subdominant substrates were typically similar in size or smaller than the dominant substrates, but there were some areas where subdominant substrate sizes were larger than 150 mm (Figure 7). Of the eighteen quantitative substrate transects that we surveyed, all but two matched the underlying textural patches determined from our visual-assessment surveys (Table 3).

Water surface elevations

We used historical stage data from the Warrendale and Bonneville gages to predict water surface elevations at Warrendale for use in hydrodynamic modeling because the USGS Warrendale gage is no longer maintained. Minimum, maximum, and average water surface elevations for the Warrendale gage between 1980 and 1988 for each 5-kcfs increment are shown in Table 4. The difference between minimum and maximum elevations was generally about 1 m except at higher flows. The simple linear regression equation between the Warrendale and Bonneville gages was:

$$Y = -0.4049 + 0.8421X$$

where Y is the predicted water surface elevation (m) for the Warrendale gage and X is the water surface elevation (m) of the Bonneville gage (r^2=0.92). Comparison of predicted and measured elevations for 2001 (Figure 8) showed a mean difference of only 0.045 m.

Hydrodynamic modeling and validation

The flows we modeled were generally representative of the flows available to spawning chum and fall chinook salmon from 1998 to 2001 (Figure 9). Flows were highest in 1999 and lowest in 2001. We successfully modeled most flows of interest with the RIVER_2D hydrodynamic model. Some flows, such as 115 kcfs with a Hamilton Creek discharge of 0 cfs and at minimum water surface elevation, did not achieve steady-state due to model run-time constraints. We felt the additional time necessary to model the few flows that were not completed was not warranted, as these flows would not affect the results of this study.

The water velocities predicted by the hydrodynamic model were generally within the observed variability of the ADCP data for most transects (Appendix A; Figure 1). The best-fitting

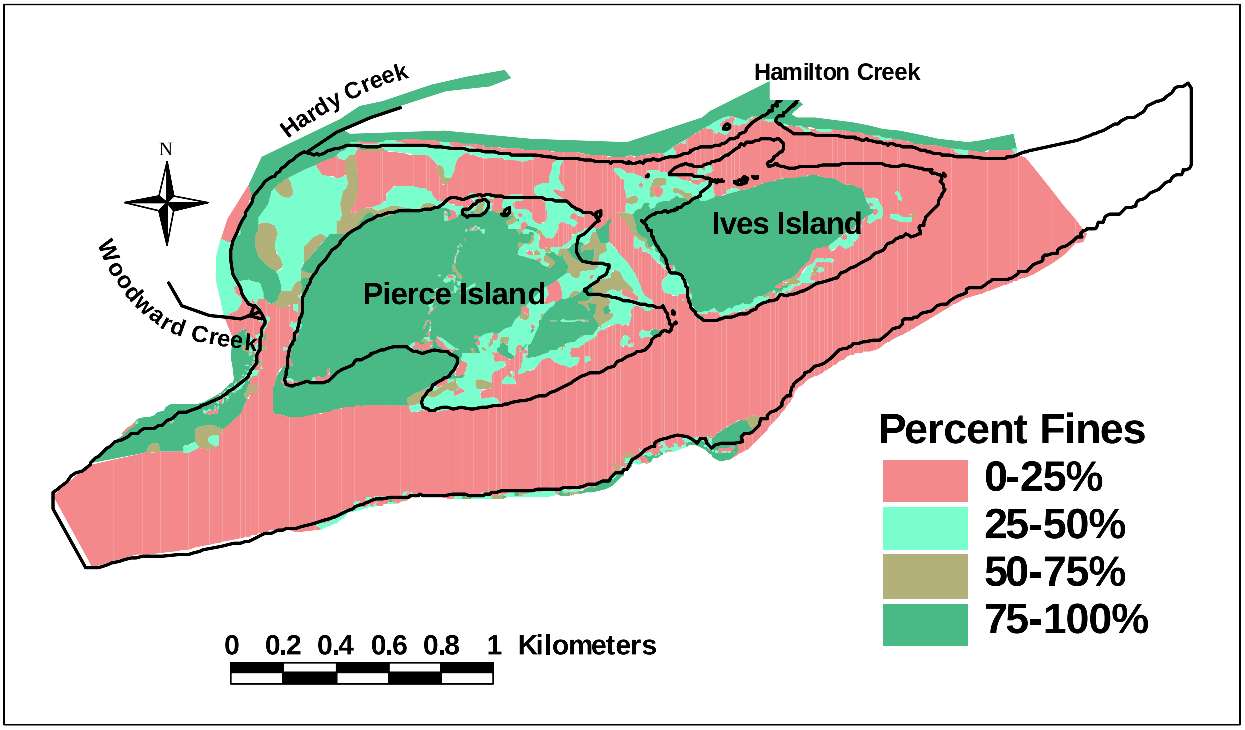

Figure 6. –Percent fines map of the Ives Island study area on the Columbia River.

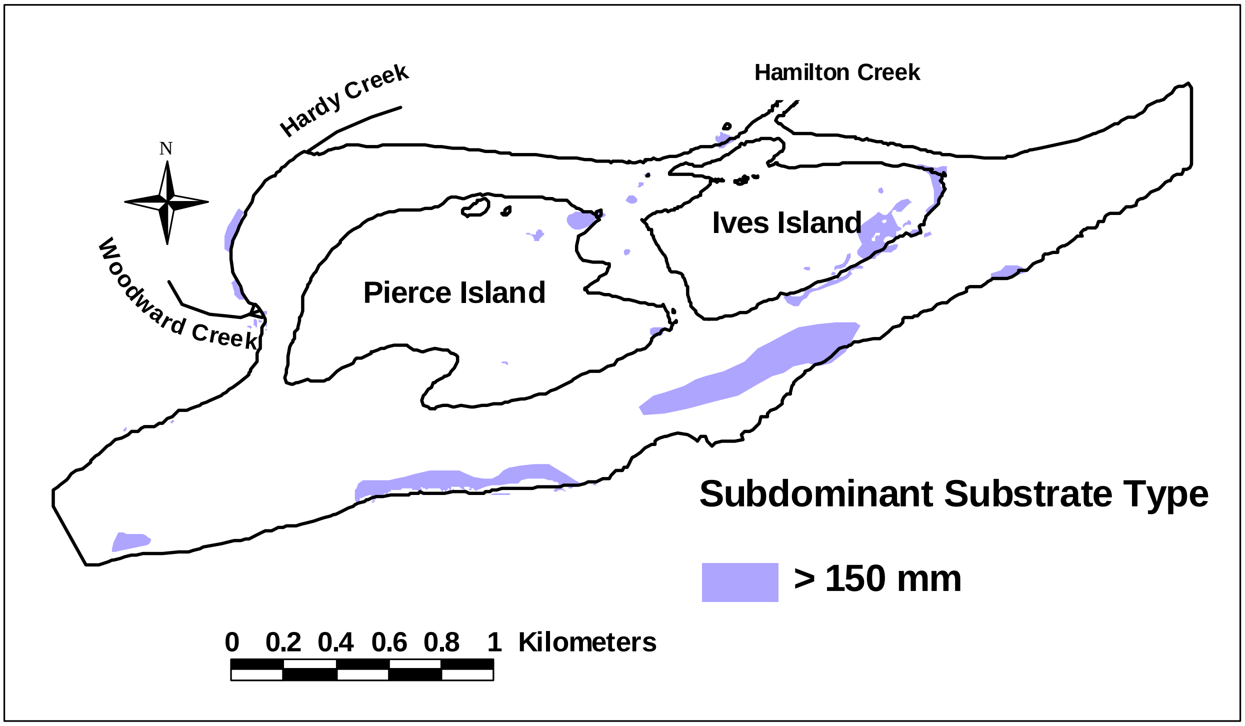

Figure 7. -Map of textural patches of subdominant substrates >150 mm in the Ives Island study area on the Columbia River.

Table 3. – Substrate validation transects, expected dominant substrate code, measured dominant substrate code, and calculated D84 values for the Ives Island study area on the Columbia River. See Table 1 for list of substrate codes.

Transect	Expected dominant substrate	Measured dominant substrate	D84 (mm)
1	5	5	140
2	4	4	70
3	3	3	< 4
4	4	4	65
5	3	3	< 4
6	6	6	220
7	4	4	130
8	5	4	80
9	4	4	55
10	3	3	< 4
11	5	4	95
12	4	4	40
13	4	4	50
14	5	5	105
15	4	4	60
16	4	4	60
17	5	5	160
18	4	4	75

Table 4. – Minimum, maximum, mean, and the standard deviation of water surface elevations of the USGS Warrendale gage station with Bonneville tailwater elevations in parentheses from October 1980 to January 1988 for Bonneville discharges used to conduct hydrodynamic modeling.

Flow (m^3/s)	Flow (kcfs)	Min (ft)	Max (ft)	Mean (ft)	Standard deviation
2548.5	90	5.9 (8.6)	8.2 (11.3)	6.9 (9.8)	0.18
2690.1	95	5.9 (8.6)	7.9 (10.9)	6.9 (9.8)	0.16
2831.7	100	5.9 (8.6)	9.2 (12.5)	7.2 (10.1)	0.21
2973.3	105	6.2 (9.0)	9.2 (12.5)	7.5 (10.5)	0.30
3114.9	110	6.9 (9.8)	9.5 (12.9)	8.5 (11.7)	0.16
3256.5	115	6.9 (9.8)	10.2 (13.7)	8.2 (11.3)	0.27
3398.0	120	7.2 (10.1)	12.2 (16.0)	8.5 (11.7)	0.23
3539.6	125	6.9 (9.8)	10.2 (13.7)	8.9 (12.1)	0.20
3681.2	130	7.9 (10.9)	10.8 (14.4)	8.9 (12.1)	0.19
3822.8	135	7.5 (10.5)	11.5 (15.2)	9.2 (12.5)	0.28
3964.4	140	7.9 (10.9)	14.1 (18.3)	9.8 (13.3)	0.37
4106.0	145	8.2 (11.3)	11.5 (15.2)	9.8 (13.3)	0.28
4247.6	150	8.5 (11.7)	14.8 (19.1)	9.8 (13.3)	0.42
4389.4	155	9.2 (12.5)	13.8 (17.9)	10.5 (14.0)	0.48
4530.7	160	9.2 (12.5)	13.1 (17.2)	10.8 (14.4)	0.29

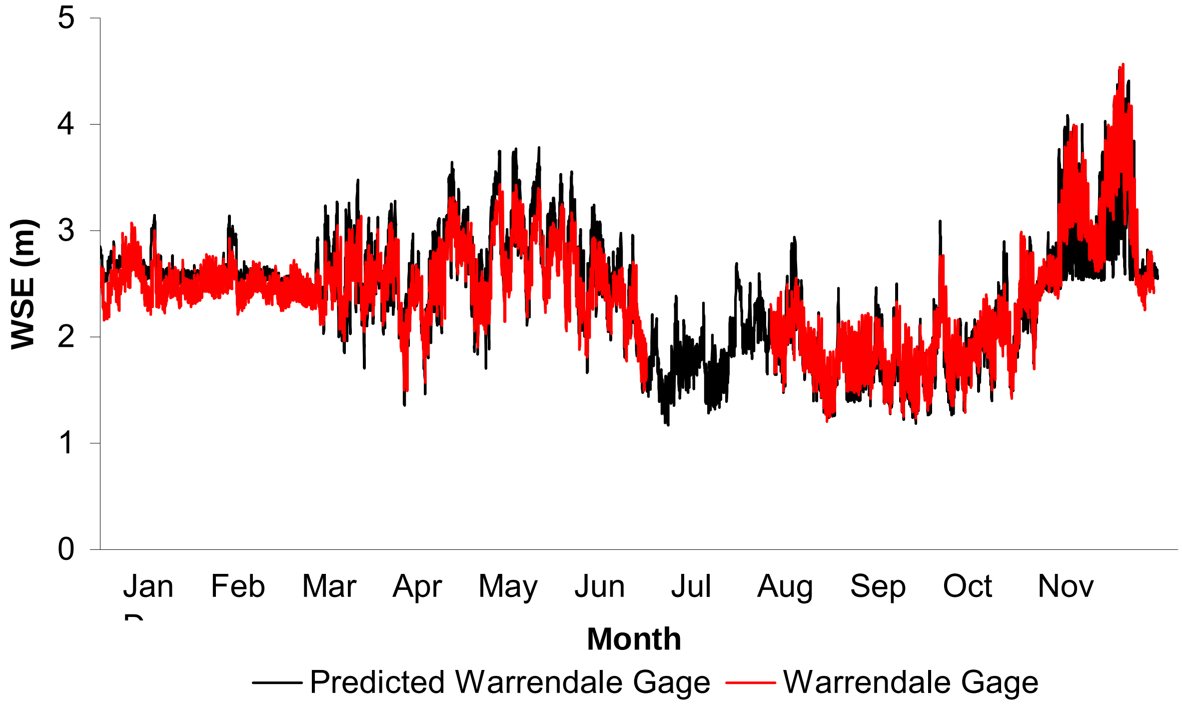

Figure 8. - Comparison of predicted and observed Warrendale gage water surface elevation for 2001.

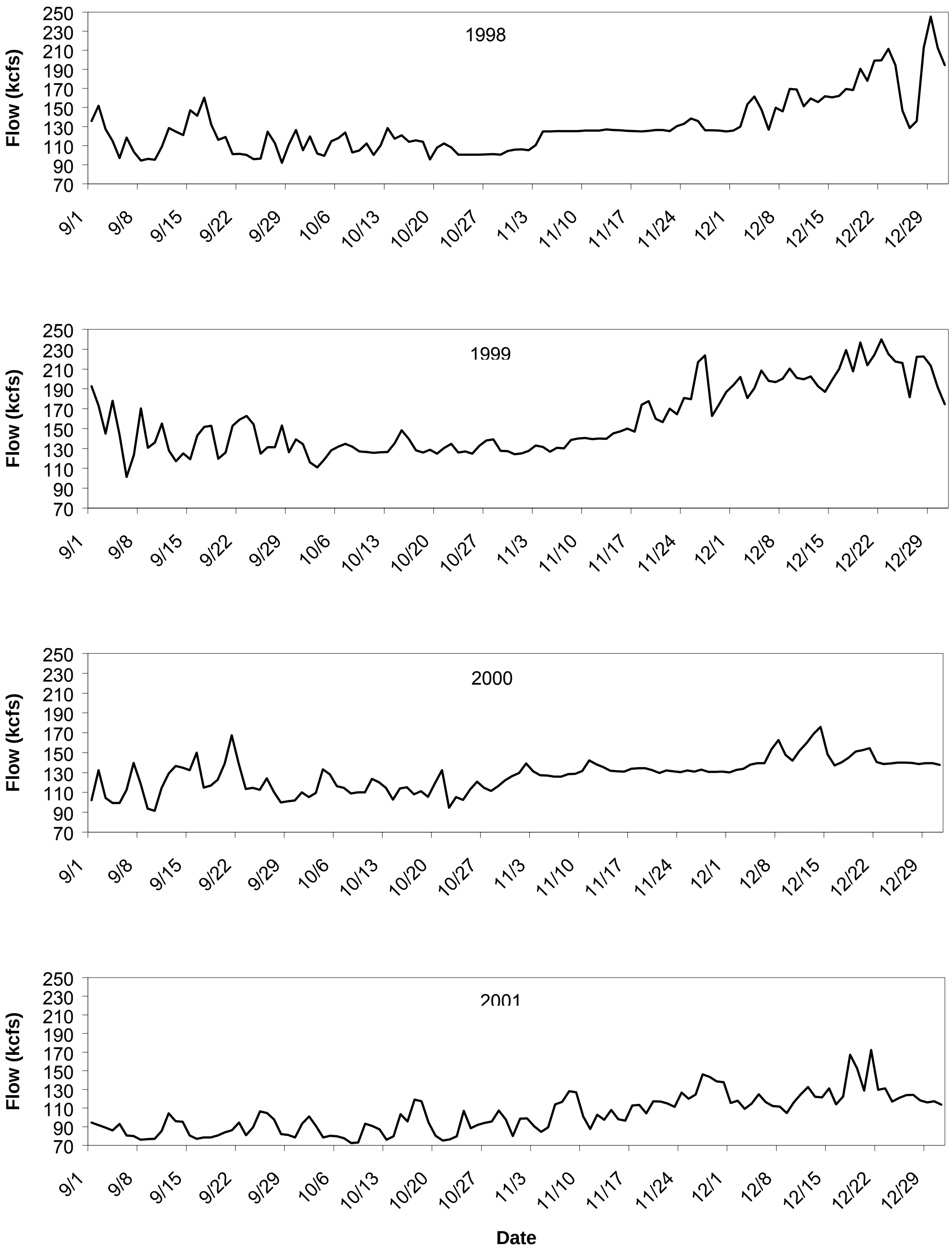

Figure 9. - Daily average flows at Bonneville Dam during the chum and fall chinook spawning period from 1998 to 2001.

polynomial regression lines fit to the empirical data showed similar patterns to modeled data with most transects having generally higher measured velocities than predicted by the model. Agreement between the empirical and modeled velocities was sensitive to how accurately the morphology of the riverbed was characterized. The density of elevation data was sparse for river study sections 4 and 6, moderate for sections 1 and 5, and highest for sections 2 and 3 (Figure 2). Empirical velocities collected at transects 23 and 24 showed poor agreement with modeled velocities, and these two sites were in a center-channel area with sparse bathymetry information. Transects 4-9 showed general agreement between the empirical data and the modeled data. This is an area of complex bathymetry, and we believe that the more complex empirical velocity profile reflects the complex bed topography, whereas the model output showed a more generalized velocity profile. Transects 20-22 were located near the mouth of Woodward Creek, whose inflow was not modeled, which likely contributed to the higher velocities observed there.

Water surface elevation profiles

Water surface elevation data collected below Hamilton creek showed good agreement between the modeled and empirical data. We found only a 0.033 m difference between modeled water surface elevations below Hamilton Creek and below a hydraulic control. Just upstream of this site, above the hydraulic control, we only found a difference of 0.027 m between empirical and modeled water surface elevations.

Water surface profiles showed that side-channels where salmon spawn have water surface elevations that are different from the main channel of the Columbia River (Figure 10-11). For the two flows examined, water surface elevations in the Ives and North channels were greater than those in the Main Channel upstream of Hamilton Creek (Figures 10-11). In both 1998 and 2000, water surface elevation rapidly declined starting just upstream of Hamilton Creek to the downstream end of Ives Island. After this point, elevations for the side channels were lower than those for the Main Channel until equilibrium was achieved upstream of the mouth of Hardy Creek. The water surface elevations in the Ives-Pierce Channel dropped rapidly at its divergence from the main channel of the Columbia River in both years (Figures 10-11).

Locations of chum salmon redds of showed a relationship to water surface elevations in 2000 (Figure 11). Almost all chum salmon redds were located in the North Channel where the water

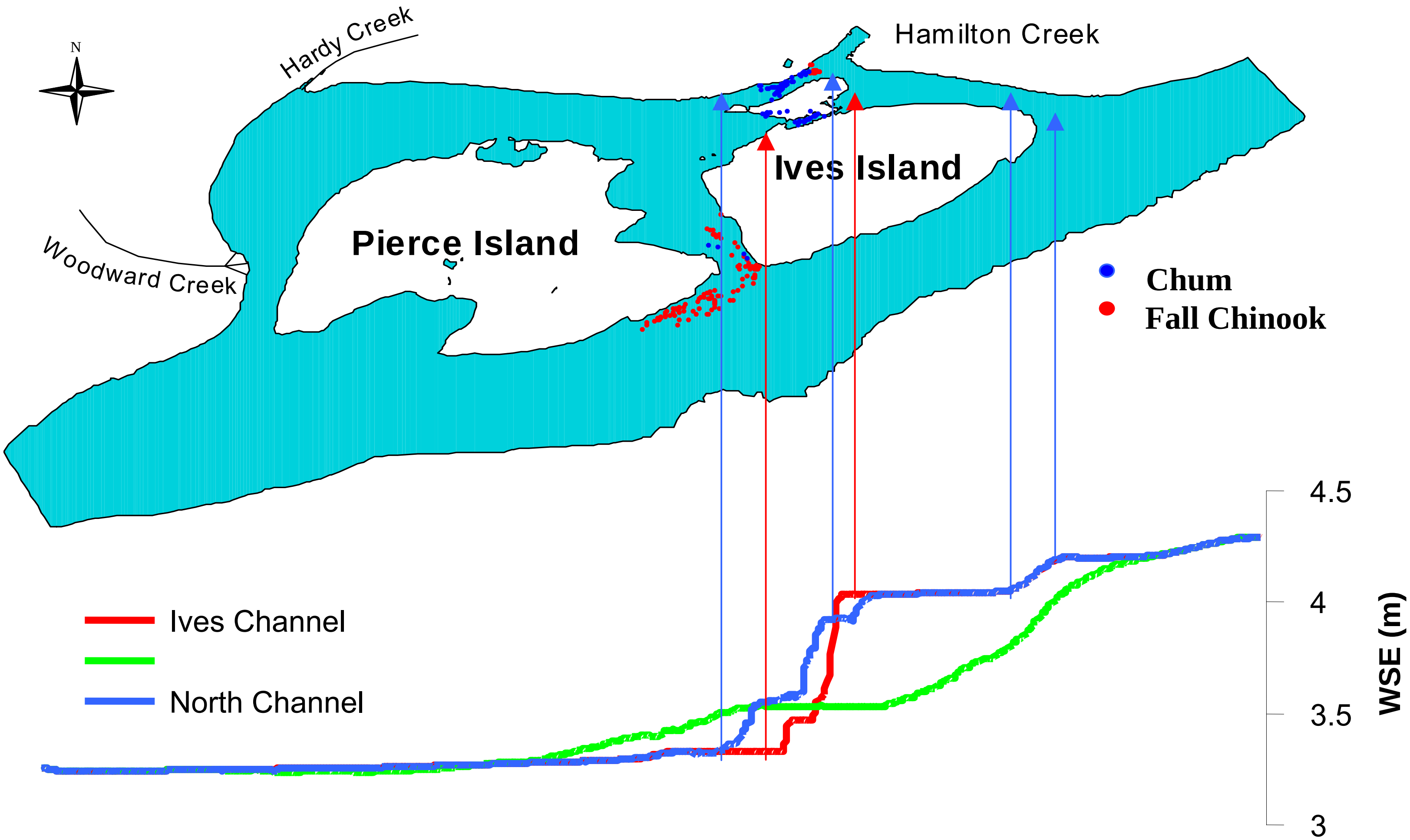

Figure 10. - Water surface elevations and chum (blue) and fall chinook (red) redd locations for the Main, North, and Ives-Pierce Channel of the Ives Island study area on the Columbia River for a flow of 140 kcfs, average downstream water surface elevation (WSE) above mean sea level, and Hamilton Creek discharge of 388 cfs.

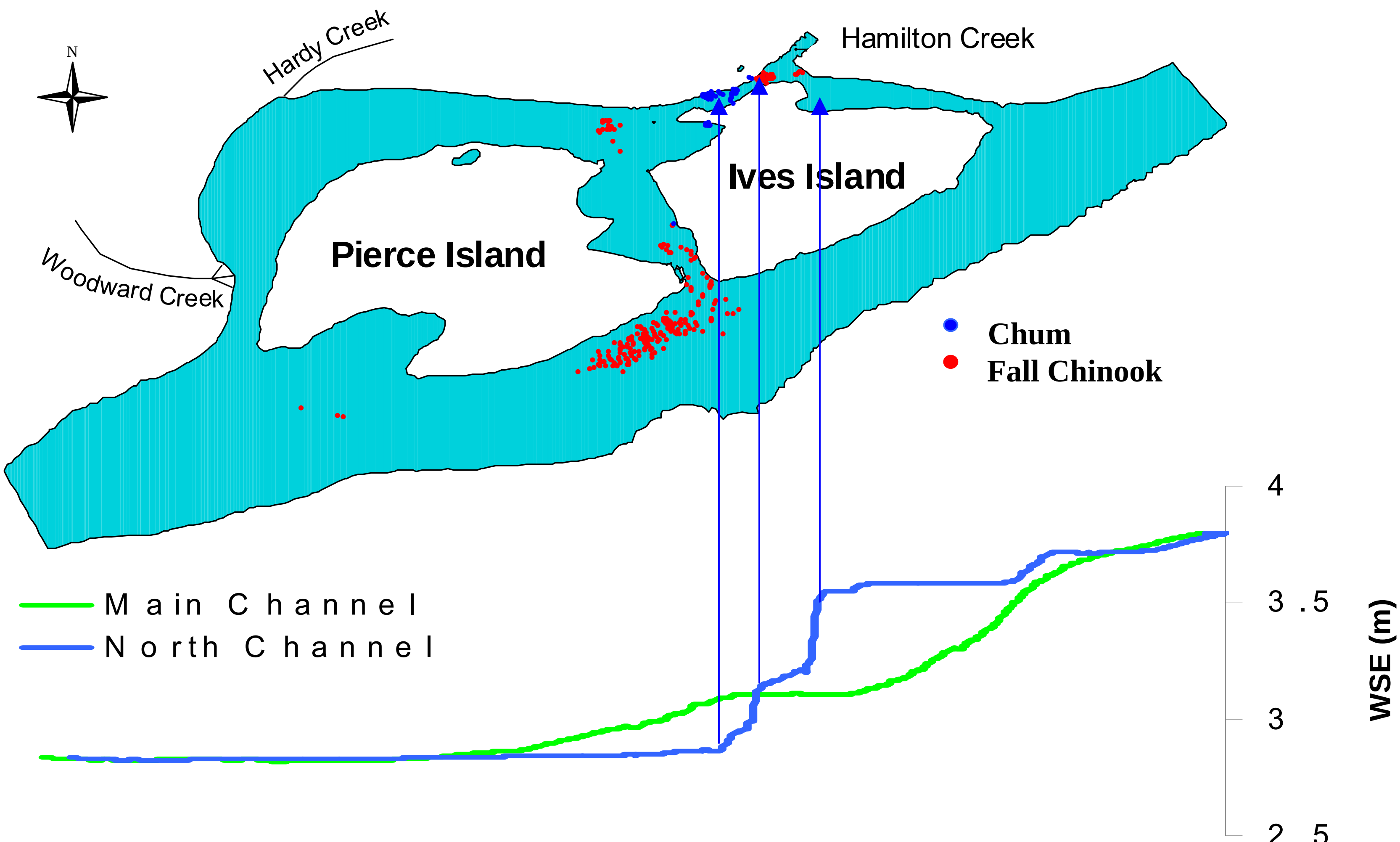

Figure 11.-Water surface elevations and chum (blue) and fall chinook (red) redd locations for the Main, North, and Ives-Pierce Channel of the Ives Island study area on the Columbia River for a flow of 120 kcfs, average downstream water surface elevation (WSE) above mean sea level, and Hamilton Creek discharge of 388 cfs.

surface elevation was lower than that of the main channel of the Columbia River. This relationship was less distinct for fall chinook salmon. In the side channels, fall chinook salmon tended to spawn on hydraulic controls, which represented points of change in water surface elevation (Figure 11). In the Main Channel of the Columbia River and the lower section of the Ives-Pierce Channel, fall chinook salmon redds were located in areas where Main Channel water surface elevations were greater than those in the side channels. We could not include redd locations from 1998 surveys because they were not georeferenced.

Logistic regression

Univariate analyses of chum and fall chinook salmon spawning habitat variables showed that each variable was significantly different from the constant-only model. Our final multivariate model for chum salmon included velocity and depth (Table 5), and is expressed as:

$$g(x) = 1.21 - 2.38D + 1.34V_1 + 1.42V_2 + 0.90V_3$$

where D represents depth and V_{1-3} represent different categories of water velocity (Table 5). Because we modeled velocity as a design variable, an individual variable will assume a value of 1 when its category contains a measure for a given habitat cell, otherwise its value will be 0. The 0.3-0.4-m/s velocity category had the highest associated probability of redd presence, and the odds of finding a redd within this velocity range was 4.14 times more likely than finding a redd where the velocity was <0.2 m/s (Table 5). The probability of chum salmon redd presence was highest for water velocities <0.4 m/s. Depth was more important than water velocity in determining presence of chum salmon redds. Figure 12 provides examples of velocity and depth coverages in GIS that were used to predict chum salmon spawning habitat with our logistic regression model.

Univariate analysis of fall chinook salmon spawning habitat variables revealed they did not use substrates dominated by sand/silt (code 3) and substrates greater than 300 mm (codes 7 and 8), as well as subdominant substrates of sand/silt and those greater than 300 m. There was also a complete lack of use of percent fines classifications 2 through 4 (>25%). One solution to this problem is to collapse variable categories (Hosmer and Lemeshow 1989), however, we felt this would be inappropriate since collapsed categories would contain too wide a range of substrate sizes to be meaningful. Therefore, we eliminated 63

Table 5. - Summary of the final logistic regression model used to predict the probability of chum salmon spawning in the Ives Island study area on the Columbia River. The category of each design variable is shown with respective water velocities less than 0.2 m/s serving as the reference category. The −2LogL of the model was 48.1 (P<0.0001; df=4).

Variable	Variable category	Regression coefficient (95% Wald CI)	Standard error	Odds ratio
Intercept		1.21 (0.45 to 1.98)	0.390	
Depth		-2.38 (-3.50 to −1.25)	0.574	0.09
Velocity (V_1)	0.2-0.3 m/s	1.34 (0.51 to 2.18)	0.426	3.82
Velocity (V_2)	0.3-0.4 m/s	1.42 (0.59 to 2.25)	0.422	4.14
Velocity (V_3)	≥ 0.4 m/s	0.90 (0.08 to 1.72)	0.417	2.46

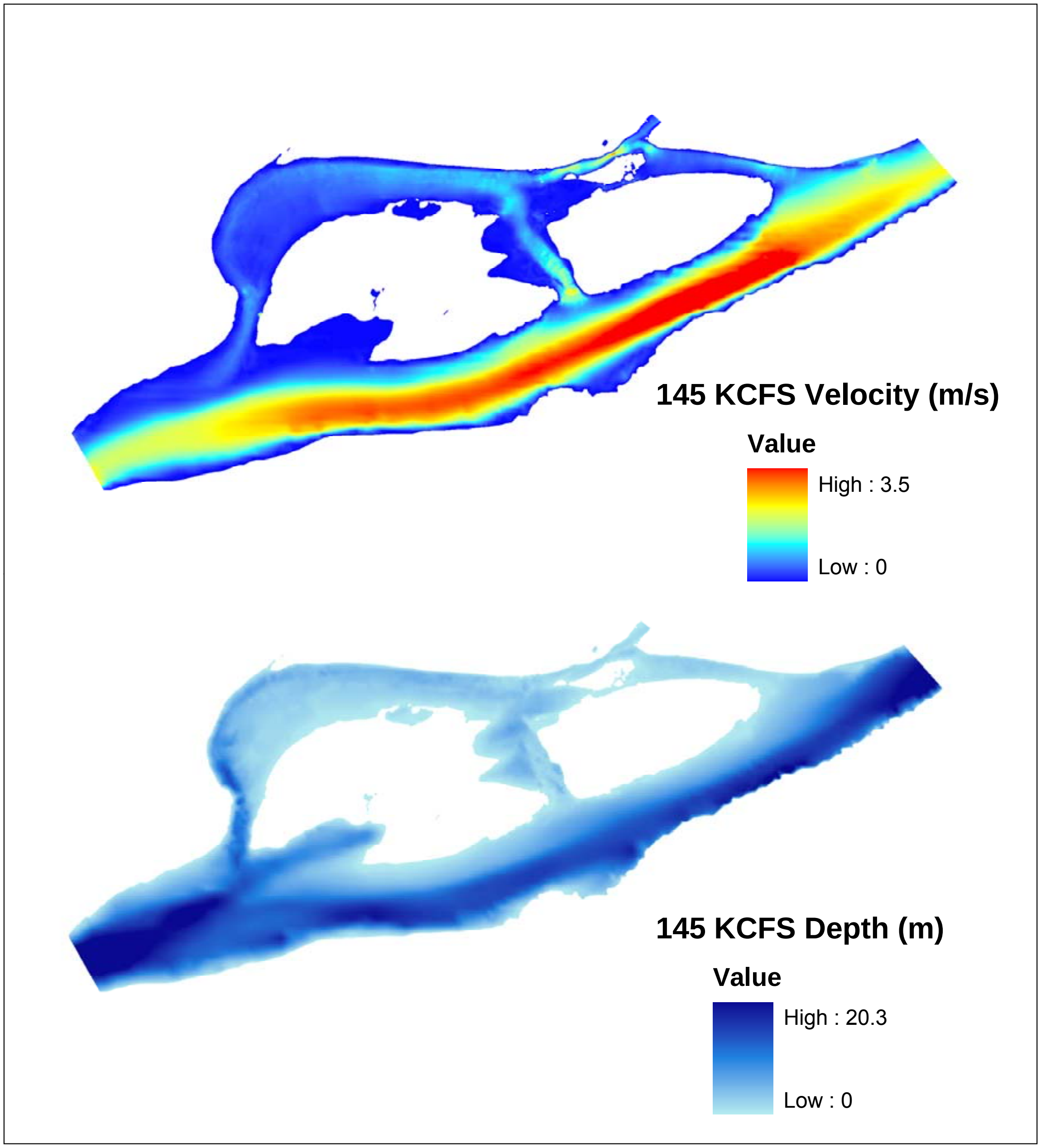

Figure 12. - GIS coverages of predicted velocity (top panel) and depth (bottom panel) at 145 kcfs in the Ives Island study area. This type of information was used in logistic regression models to predict the amount of available chum and fall chinook salmon spawning habitats at different flows.

nonuse observations with these substrate and percent fines characteristics from our final analysis (Hosmer and Lemeshow 1989). However, we incorporated the importance of nonuse of these substrates in our GIS analysis. Our final multivariate model for fall chinook salmon included velocity, depth, and two substrate classifications (Table 6), and is expressed as:

$$g(x) = -1.41 + 2.44V + 2.59S - 1.04D$$

where *V* represents velocity, *S* represents substrate , and *D* represents depth. Substrate was the most important variable determining the probability of fall chinook salmon redd presence (Table 6). Fish were 13 times more likely to construct a redd in small cobbles than in gravel substrate. Velocity was more important than depth in determining the presence of fall chinook salmon redds. As both velocity and depth increases, so did the probability of redd presence.

The Hosmer-Lemeshow statistic for our final chum salmon model, 3.66 (P=0.8864, 8 df), indicates a good fit to the data. The correct cross-validation classification of redd presence and absence in spawning habitats was 66%. The correct prediction rate of redd presence was 72%, whereas redds were absent in the remaining 28% of the habitats predicted to contain redds (error of commission). Conversely, redds were present in 44% of the habitats where our model predicted them to be absent (error of omission). The Hosmer-Lemeshow statistic of our final model for fall chinook salmon, 8.34 (P=0.4013, 8 df), indicates an adequate fit to the data. The correct cross-validation classification of redd presence and absence in spawning habitats was 79%. The correct prediction rate of redd presence was 81%, whereas redds were absent in the remaining 19% of the habitats predicted to contain redds (error of commission). Conversely, redds were present in 23% of the habitats where our model predicted them to be absent (error of omission).

Predicted Amount of Habitat

Chum salmon.—The amount of suitable chum salmon spawning habitat varied with flow in individual study sections, but the amount of habitat for the entire study area did not increase with flow (Figures 13-14). Increases in Columbia River flows changed the spatial distribution of available spawning habitat in the study area. Appendices B.1-B.27 provide graphical representations of the amount of suitable habitat at flows ranging from 115 to 160 kcfs. Chum salmon spawning habitat was primarily located in the channel between Ives Island and the Washington shore,

Table 6. - Summary of the final logistic regression model used to predict the probability of chinook salmon spawning in the Ives Island study area on the Columbia River. The category of the design variable is shown with respective dominant substrate of gravel (4-75 mm) serving as the reference category. The −2LogL of the model was 97.6 (P<0.0001; df=3).

Variable	Variable category	Regression coefficient (95% Wald CI)	Standard error	Odds ratio
Intercept		-1.41 (-2.10 to −0.72)	0.390	
Velocity		2.44 (1.14 to 3.73)	0.662	11.42
Dominant substrate	75-150 mm	2.59 (1.85 to 3.34)	0.380	13.37
Depth		-1.04 (-1.68 to −0.40)	0.328	0.35

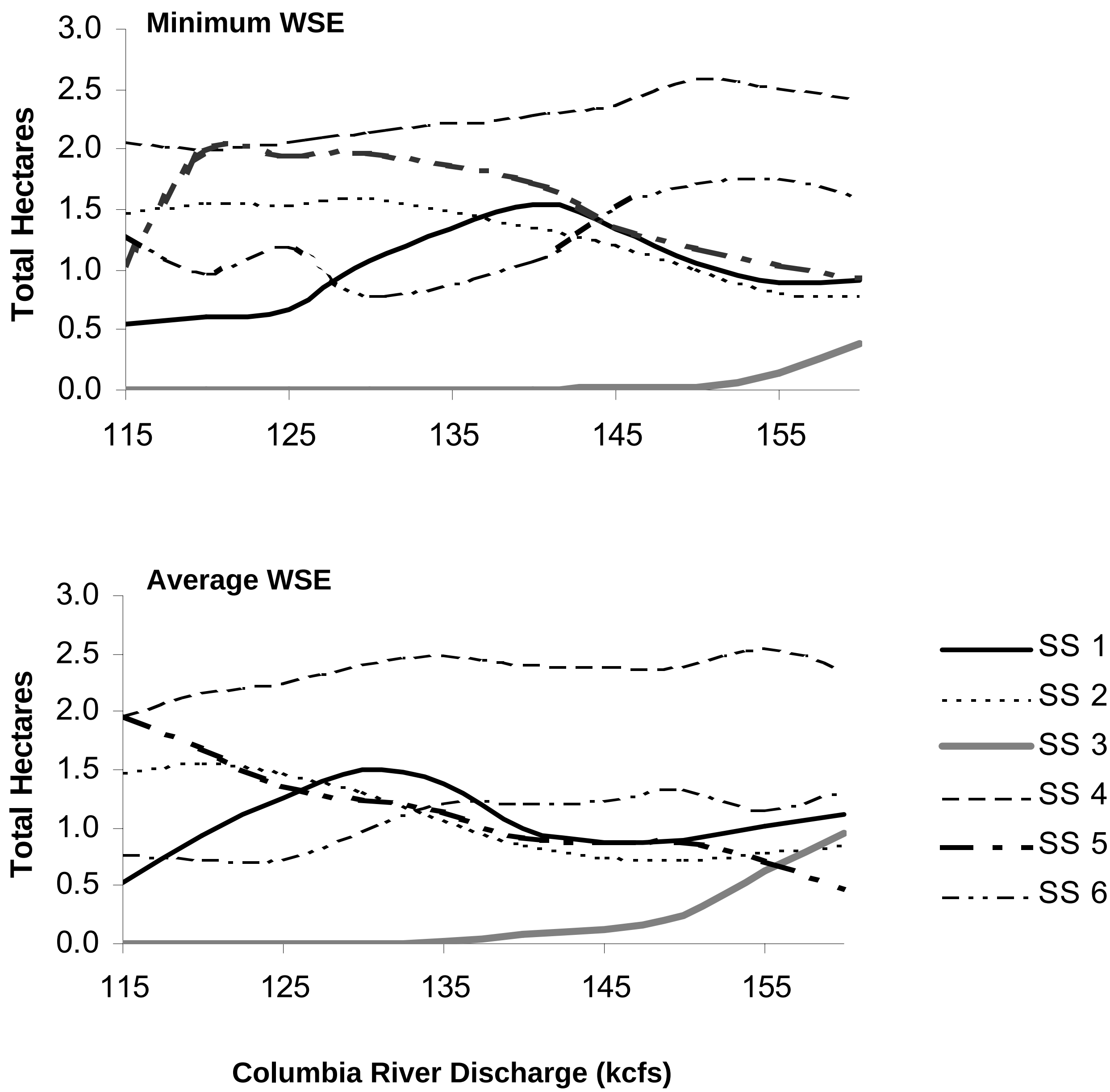

Figure 13. –Total area (ha) predicted to be chum salmon spawning habitat for Columbia River discharges from 115 kcfs to 160 kcfs by study section (SS) at minimum (top panel) and average (bottom panel) water surface elevations (WSE) above mean sea level.

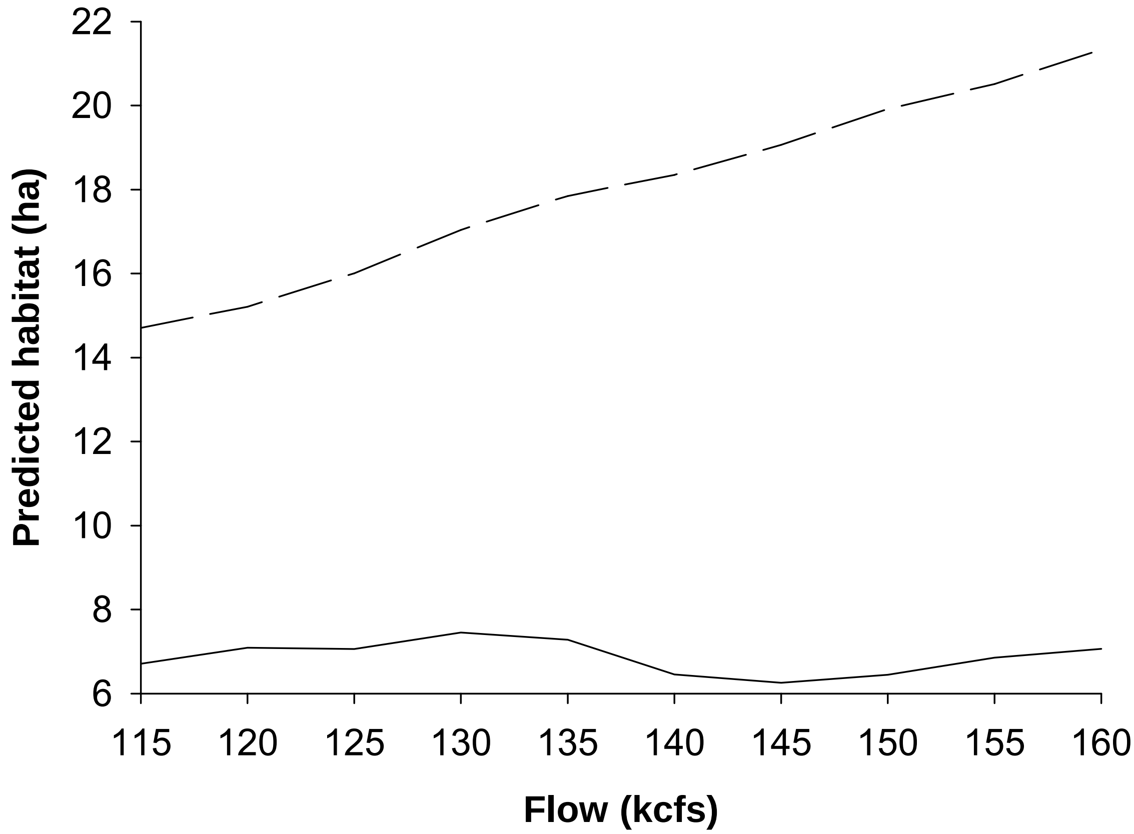

Figure 14.—The relationship between Columbia River flow and total predicted chum salmon (solid line) and fall chinook salmon (broken line) spawning habitat in the Ives Island area.

particularly below the mouth of Hamilton Creek, on the north and south sides of Pierce Island, and in the channel between Ives and Pierce islands. The amount of available habitat was greatly reduced below the mouth of Hamilton Creek when its discharge was 0 cfs (Appendices B.4, B.7, and B.11) at Columbia River flows of 115 to 125 kcfs. When flows increased above 140 kcfs, the amount of spawning habitat decreased in the area below the mouth of Hamilton Creek and increased in the channel immediately to the south of it (Appendices B.19, B.21, B.23, B.25, and B.27). There was also more habitat in this area when flows were modeled at the average Warrendale water surface elevation rather than the minimum.

The total hectares of spawning area available to chum salmon for each study section showed that study section four had the most habitat and study section three had the least (Figure 13, Appendix C.1), however, many chum salmon spawned in study section three in 1998 and 1999 when flows exceeded 140 kcfs. Study section three contained no flowing water until Columbia River discharge was ≥140 kcfs for the average water surface elevation modeled (Figure 15). Study sections one, two, and three generally had the greatest percentage (25-65%) of their area available for chum salmon spawning (Appendix C.1).

Hamilton Creek discharge had the greatest influence on the percentage of potential chum salmon spawning habitat in study section two. This section was located at the mouth of Hamilton Creek and generally contained less spawning habitat at lower Hamilton Creek discharges than at higher discharges (Figure 16; Appendix C.1). The Columbia River did not supply water to this area via the channel between Ives Island and the Washington shore until discharges reached 120 kcfs at the minimum water surface elevation (Figure 17). At flows less than this, discharge from Hamilton Creek supplies the only water to the channel downstream of its mouth where many chum salmon spawn (Figure 18). Fish are excluded from this area when Hamilton Creek is dry. The percentage of available area for chum salmon spawning more than doubled in this section when discharge from Hamilton Creek increased from 35 to 212 cfs at a Columbia River flow of 125 kcfs and minimum water surface elevation (Figure 16). When the flow in the Columbia River was 120 kcfs, the amount of available habitat almost tripled at the aforementioned Hamilton Creek discharges. Study section 1, which was located just upstream of the mouth of Hamilton Creek, was minimally affected by Hamilton Creek flow, as was section 5 located just downstream of section 2 (Figure 16). All other study sections

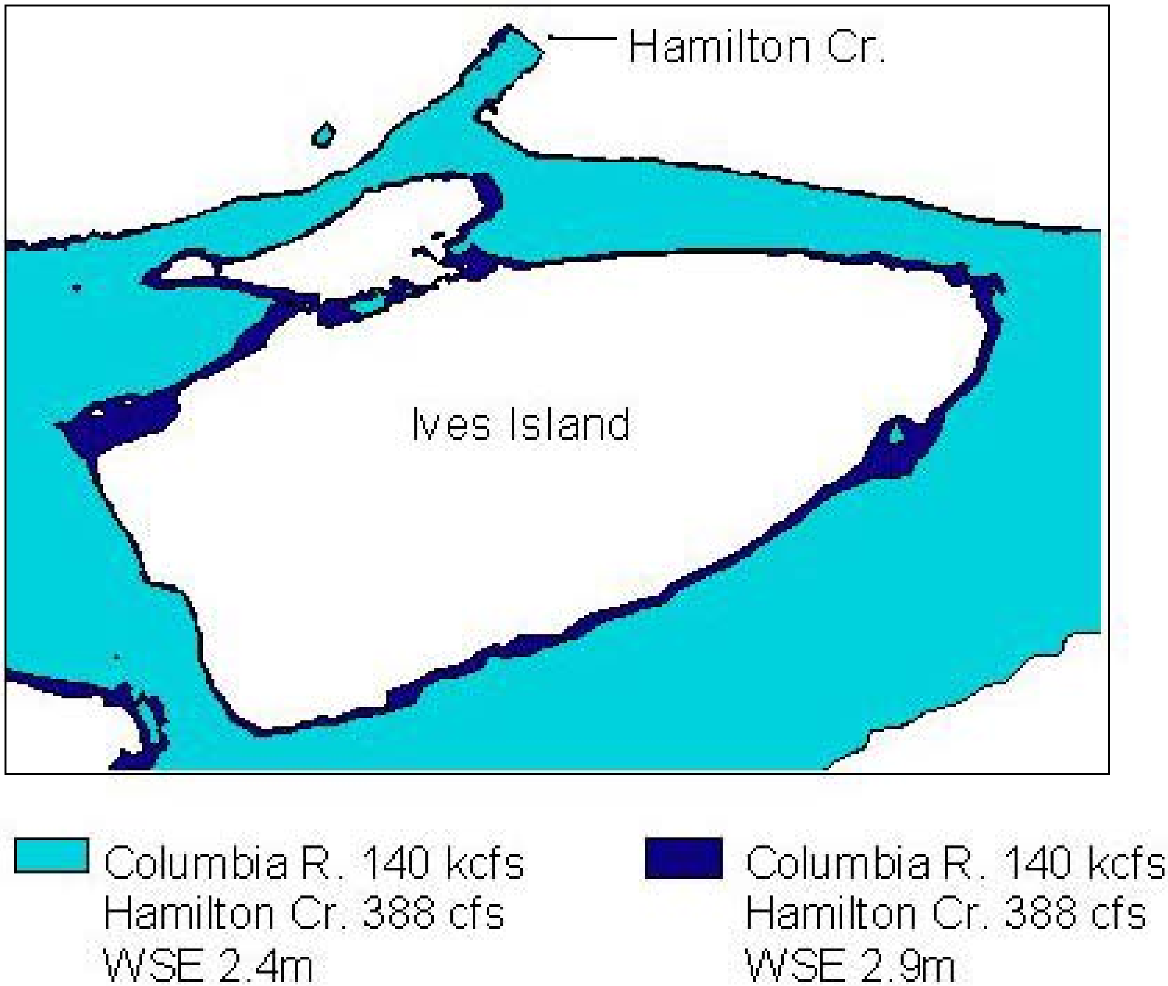

Figure 15. - The difference between the extent of shorelines at Ives Island when a flow of 140 kcfs was modeled using the minimum (2.4 m) and average water (2.9 m) surface elevations (WSE) above mean sea level measured at Warrendale, OR.

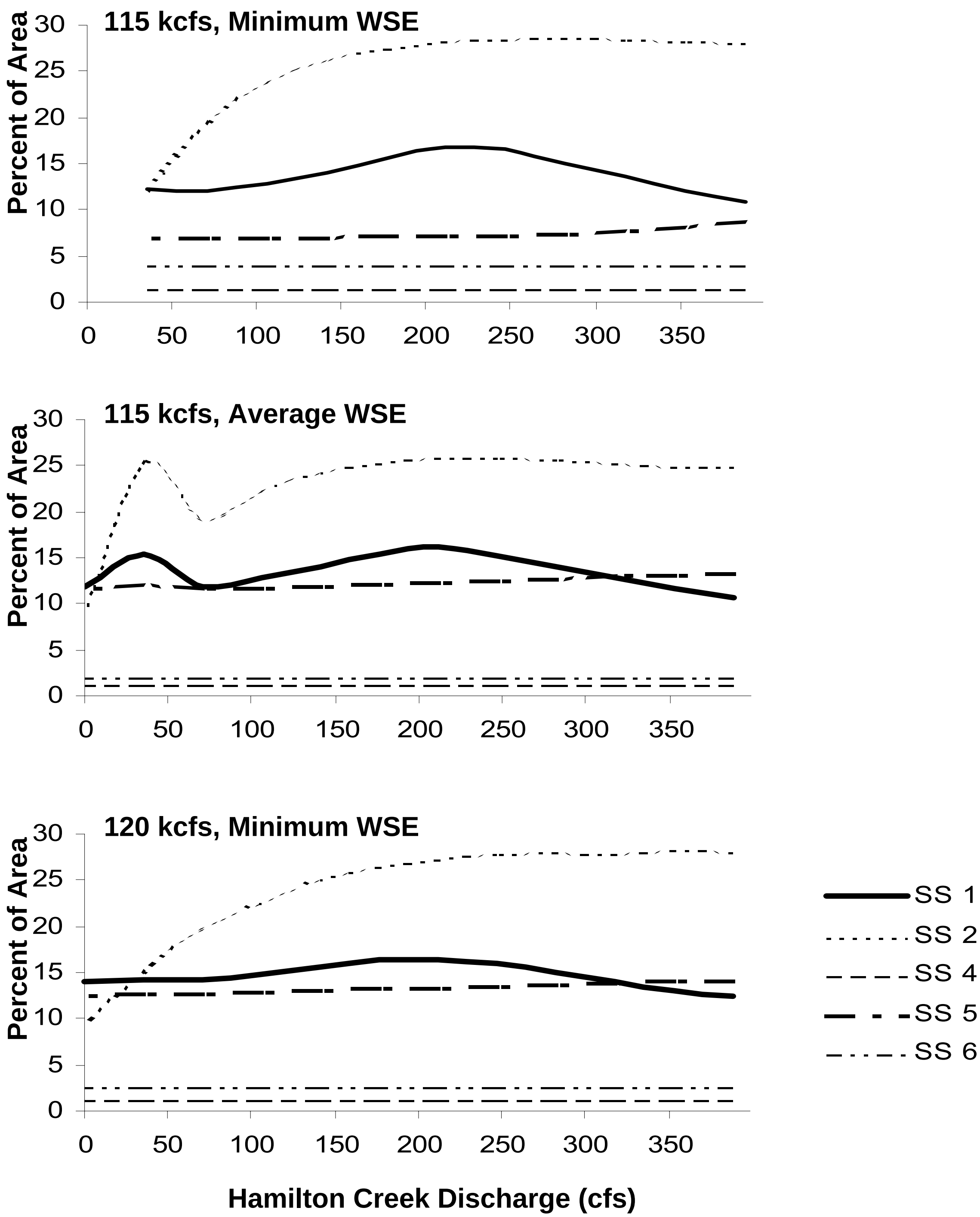

Figure 16. - Percent of total area predicted to be chum salmon spawning habitat for Hamilton Creek discharges from 0 to 388 cfs by study section (SS) for the Columbia River discharge of 115 kcfs and minimum water surface elevation, Columbia River discharge of 115 kcfs and average water surface elevation (WSE) above mean sea level, and Columbia River discharge of 120 kcfs and minimum water surface elevation.

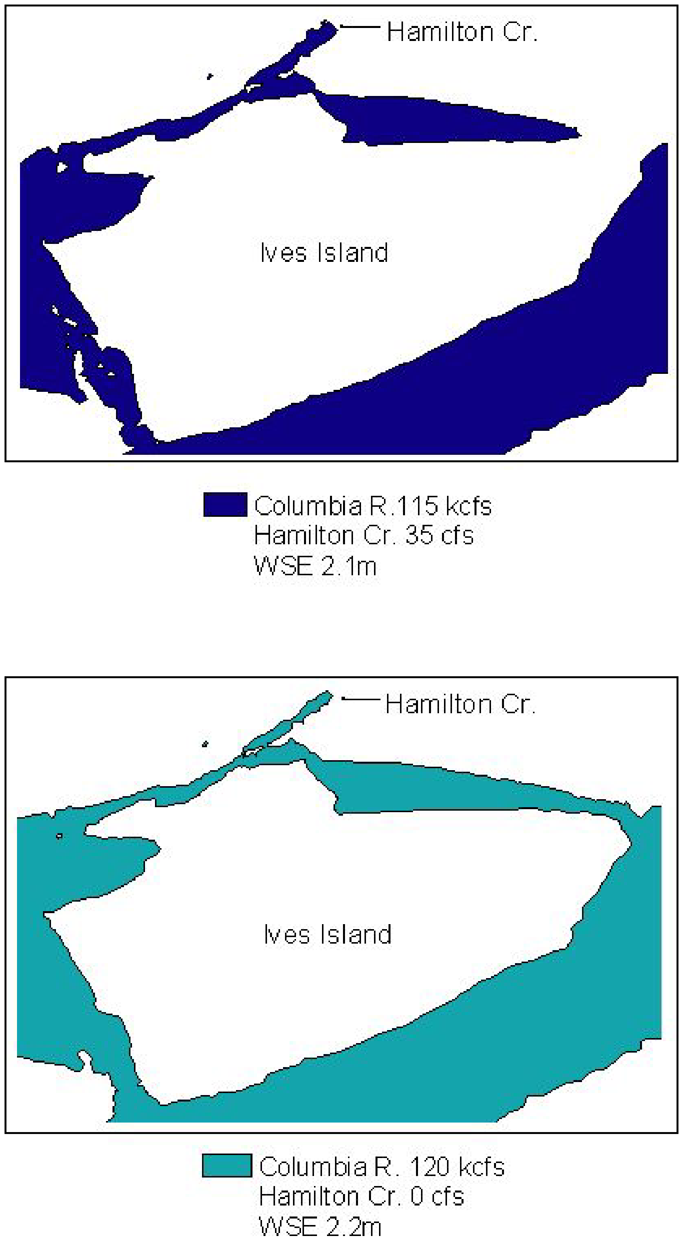

Figure 17. - A comparison of the extent of shorelines in the Ives Island area showing the connection of the channel between Ives Island and the Washington shore to the Columbia River as flows increase from 115 to 120 kcfs.

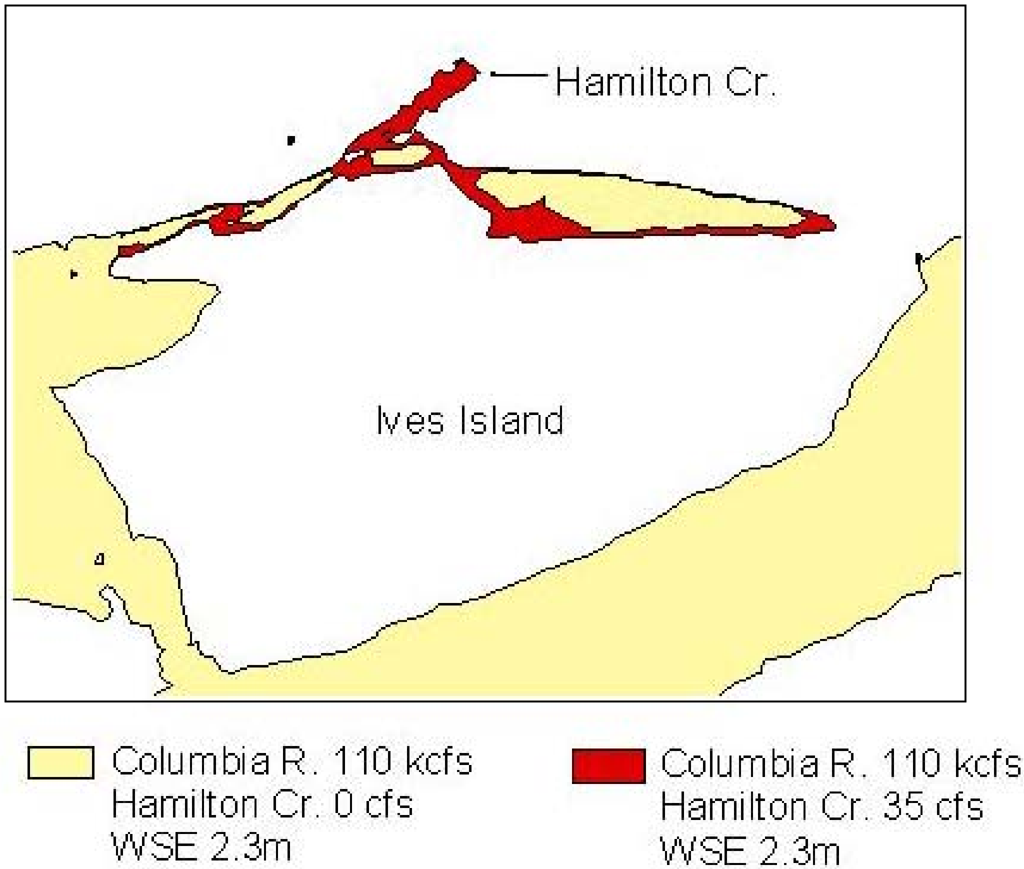

Figure 18. - A comparison of the extent of shorelines in the Ives Island area with and without discharge from Hamilton Creek when the Columbia River flow is 110 kcfs.

were only slightly affected by fluctuations in Hamilton Creek discharge.

Changes in Columbia River flow also changed the amount of available chum salmon spawning habitat. Figure 19 provides an example of the daily changes in predicted habitat from 1998 through 2001 in study section 2 below the mouth of Hamilton Creek. Figure 9 shows the average daily flows from Bonneville Dam for these same time periods. The availability of chum salmon spawning habitat was most stable during the November spawning period in 1998 and 2001, and most variable in 1999 and 2000. The effect of Hamilton Creek discharges on estimates of available habitat in this section is unknown because no flow records exist.

Our chum salmon habitat model performed reasonably well at predicting chum salmon spawning habitat in our study area. Figures 20-23 provide examples of the general agreement between predicted habitat and observed chum salmon redd locations at one flow from 1998-2001. From 1998-2000, most chum salmon spawning occurred in the area below the mouth of Hamilton Creek where our model predicted suitable habitat. In 2001, chum salmon spawning occurred in this area as well as in new areas where fish had not spawned previously, such as below the mouths of Woodward Creek on the Washington shore and McCord Creek on the Oregon shore (Figure 23). Our model also predicted suitable habitat where fish did not spawn. Fish also spawned in areas that we did not predict to be suitable, Figures 20-23 show the habitat available at one flow. Chum salmon spawned over a range of flows in all years and the amount and location of spawning habitat varied with flow.

Fall chinook salmon.—Fall chinook salmon spawning habitat was primarily located in the channel between Ives Island and the Washington shore, on the south side of Pierce Island, and on the upstream end of Ives Island (Appendix D.1). The total amount of predicted spawning habitat increased with Columbia River flows (Figure 14). Spawning habitat located adjacent to Ives and Pierce islands in the main channel of the Columbia River was not particularly sensitive to changes in flows as depths were greater in these areas. Minimal changes in the amount of available spawning habitat were evident elsewhere in the study area at the different flows and water surface elevations modeled.

The main channel of the Columbia River (study section four) contained the most spawning habitat for fall chinook salmon, but

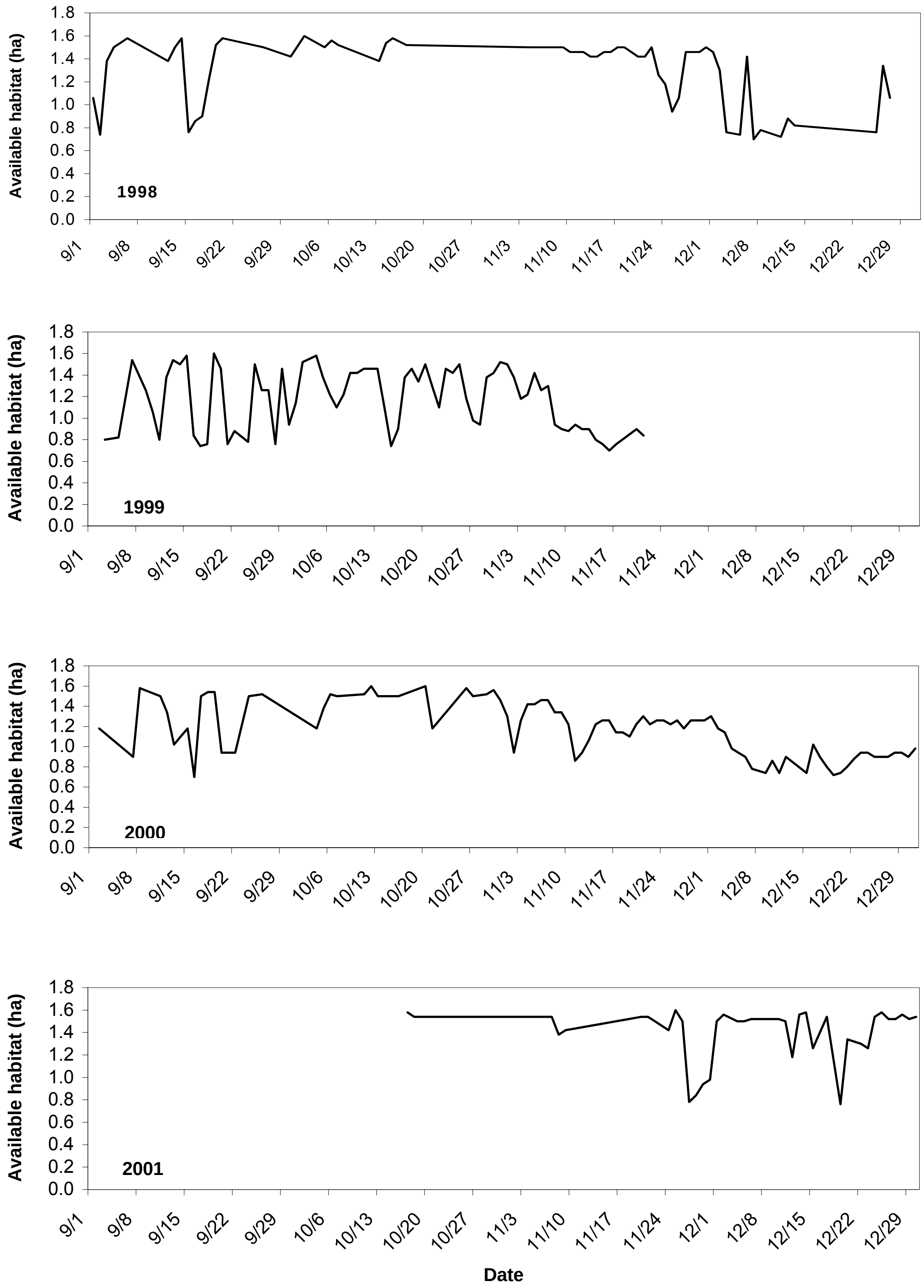

Figure 19. – Predicted daily changes in chum salmon spawning habitat in study section 2 below the mouth of Hamilton Creek based on changes in the observed average daily flows from Bonneville Dam from 1998 to 2001. Gaps indicate that flows were outside the range of those we modeled.

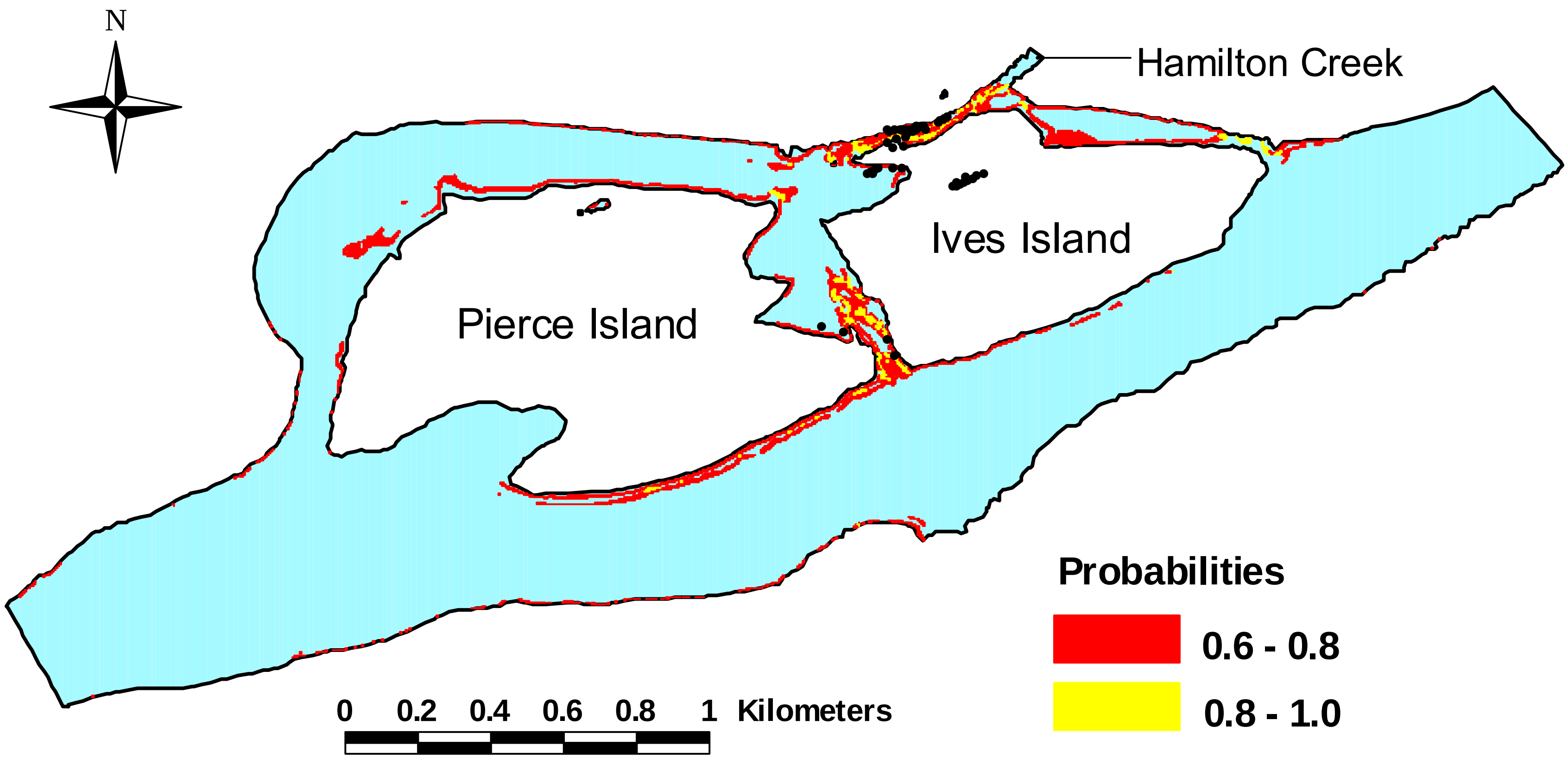

Figure 20. - Chum salmon redd locations (gray) in 1998 and areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs (average flow from October 1 to December 15). Areas in yellow have the highest probability of use. Redds above the shoreline were constructed at higher flows.

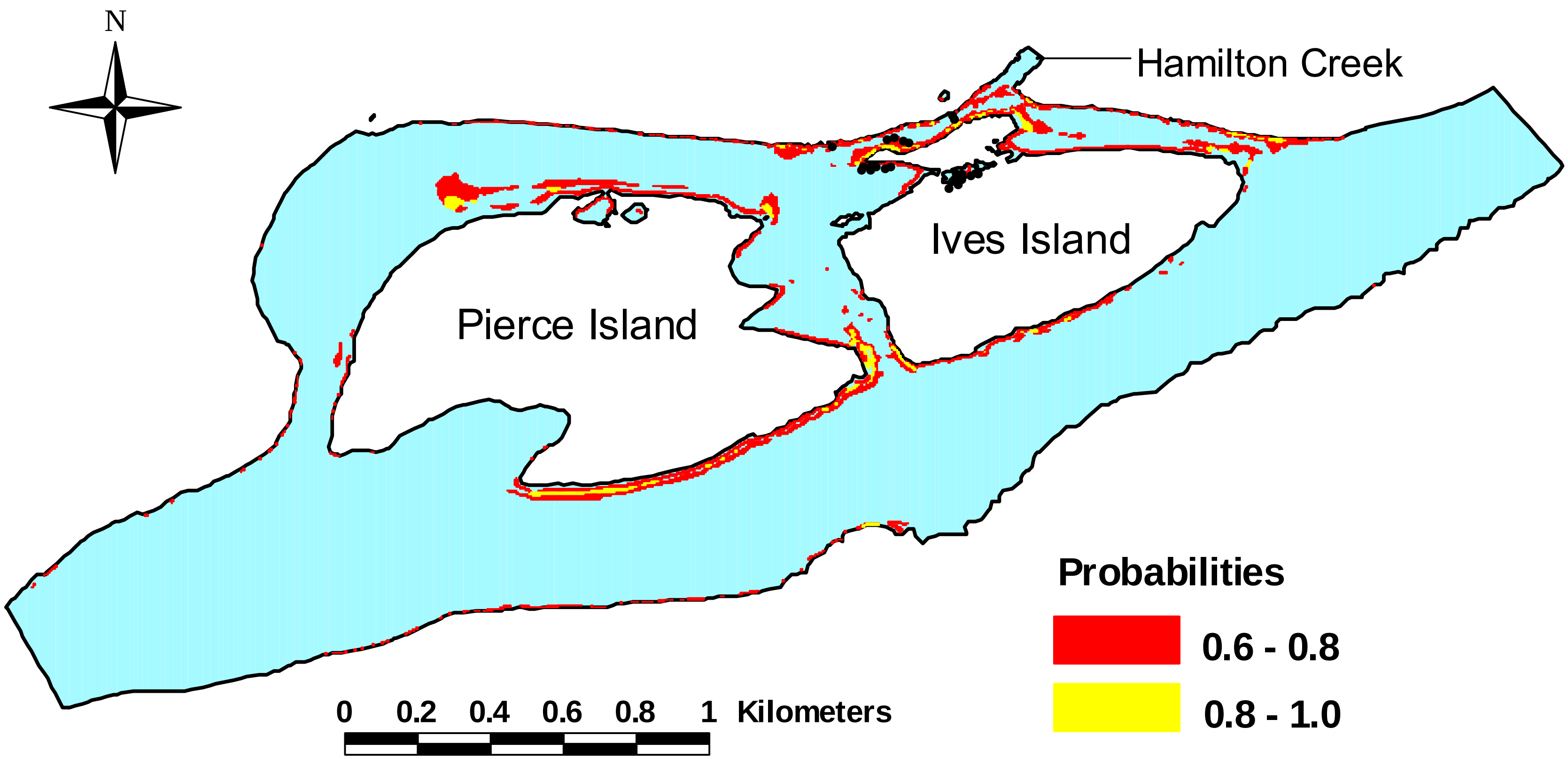

Figure 21. - Chum salmon redd locations (gray) in 1999 and areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 150 kcfs (average flow from October 1 to December 15). Areas in yellow have the highest probability of use. Redds above the shoreline were constructed at higher flows.

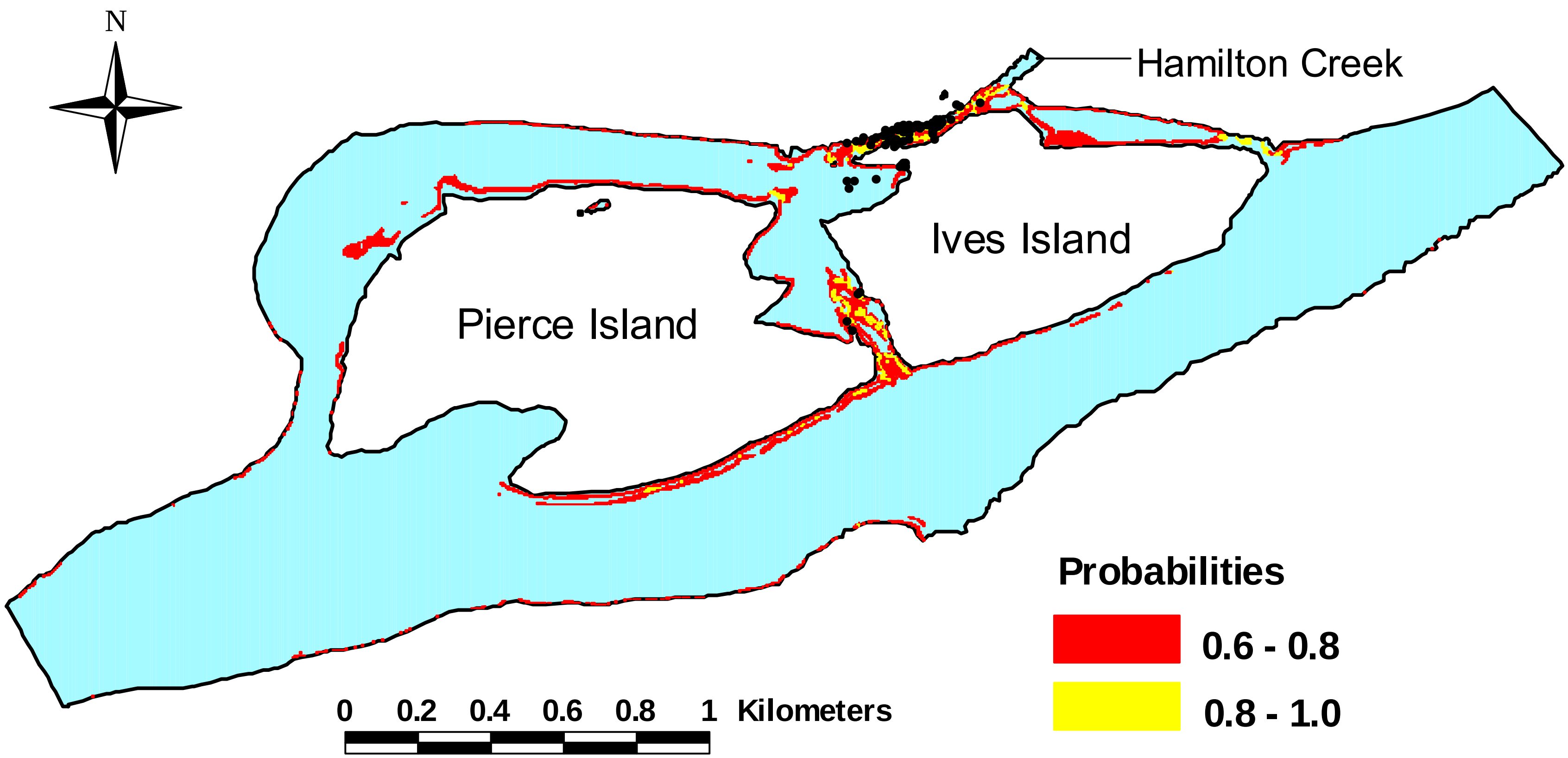

Figure 22. - Chum salmon redd locations (gray) in 2000 and areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs (average flow from October 1 to December 15). Areas in yellow have the highest probability of use.

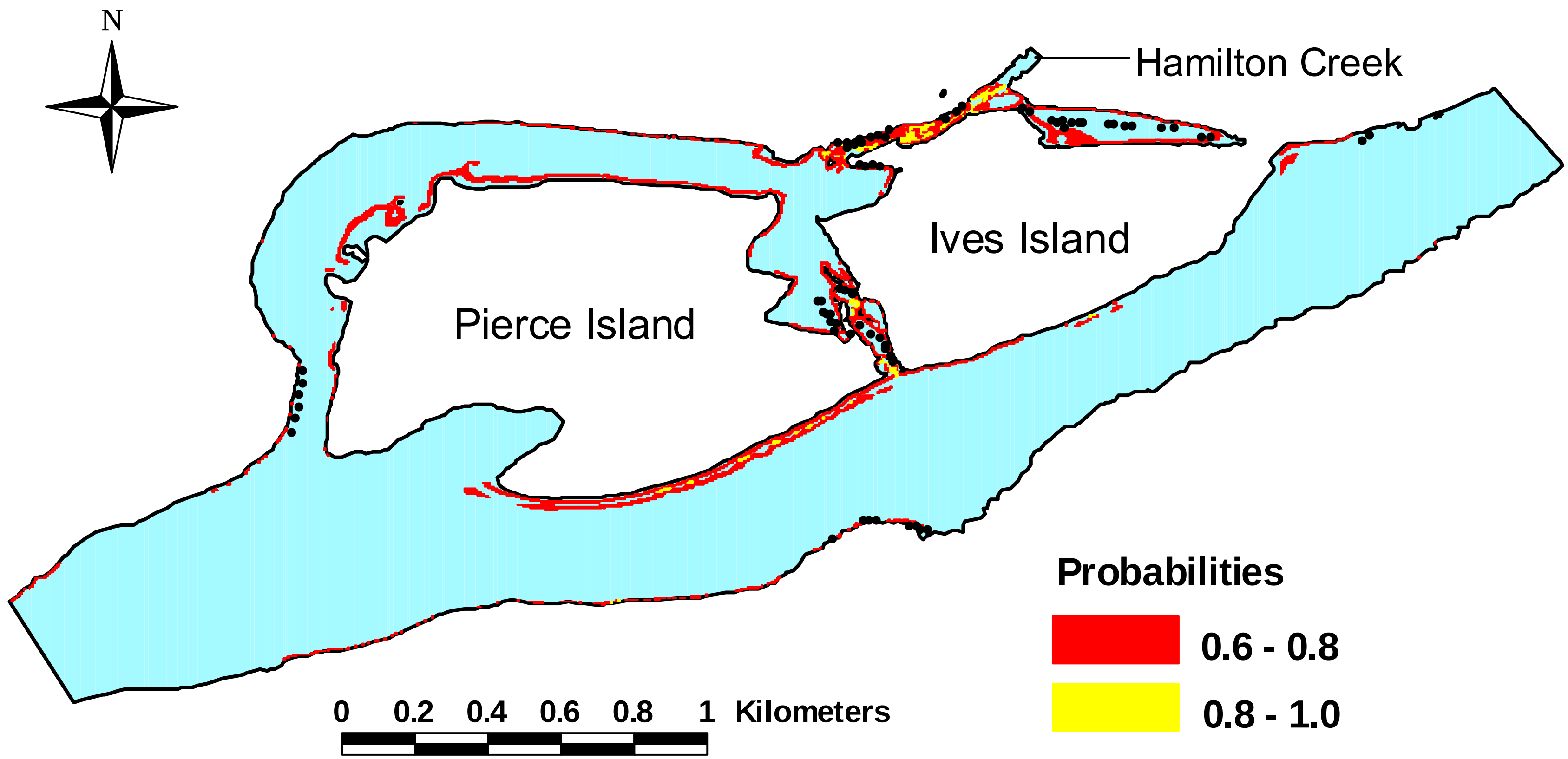

Figure 23. - Chum salmon redd locations (gray) in 2001 and areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, our lowest flow modeled (average flow from October 1 to December 15 was 104 kcfs). Areas in yellow have the highest probability of use.

it also contained the most area (Figure 24). However, study sections one and two contained the greatest percentages of available spawning habitat (Figures 25; Appendix E.1). In general, as Columbia River discharge increased, the percentage of spawning habitat increased in sections one and two, but remained constant in sections four through six.

Fall chinook salmon spawning areas were also affected by discharges from Hamilton Creek, similar to chum salmon areas, but to a lesser degree (Figure 26). Spawning area in study section two was influenced most by Hamilton Creek at all flows and elevations modeled, while other study sections were largely unaffected (Appendix D.1). As with chum salmon, Hamilton Creek discharge was an important determinant of chinook salmon spawning habitat in study section two when Columbia River flows were low. Daily fluctuations in Bonneville Dam discharges affected the amount of available spawning habitat similar to that of chum salmon below the mouth of Hamilton Creek (Figure 27).

Our fall chinook salmon habitat model performed reasonably well at predicting spawning habitat in our study area. Figures 28-31 provide examples of areas predicted to contain suitable spawning habitat and observed fall chinook salmon redd locations at one flow from 1998-2001. The area on the south side of Pierce Island was a primary spawning location in all years, although there was not complete overlap between redd locations and habitat. The channel between Ives and Pierce islands was heavily used from 1998-2000, but our model failed to predict much habitat there. Fall chinook salmon also spawned on the hydraulic controls in the channel between Ives Island and the Washington shore where our model predicted high quality habitat.

Discussion

The River_2D two-dimensional hydrodynamic model was a useful tool for estimating water velocities, depths, and shorelines under different scenarios likely to be present during the fall spawning season. This model performed well and provided estimates of water velocities that compared favorably with field observations (e.g., higher water velocities over hydraulic controls than in pools). Predicted water velocities were generally within the range of variability observed with the ADCP. Where differences between observed and predicted water velocities existed, predicted water velocities were slightly

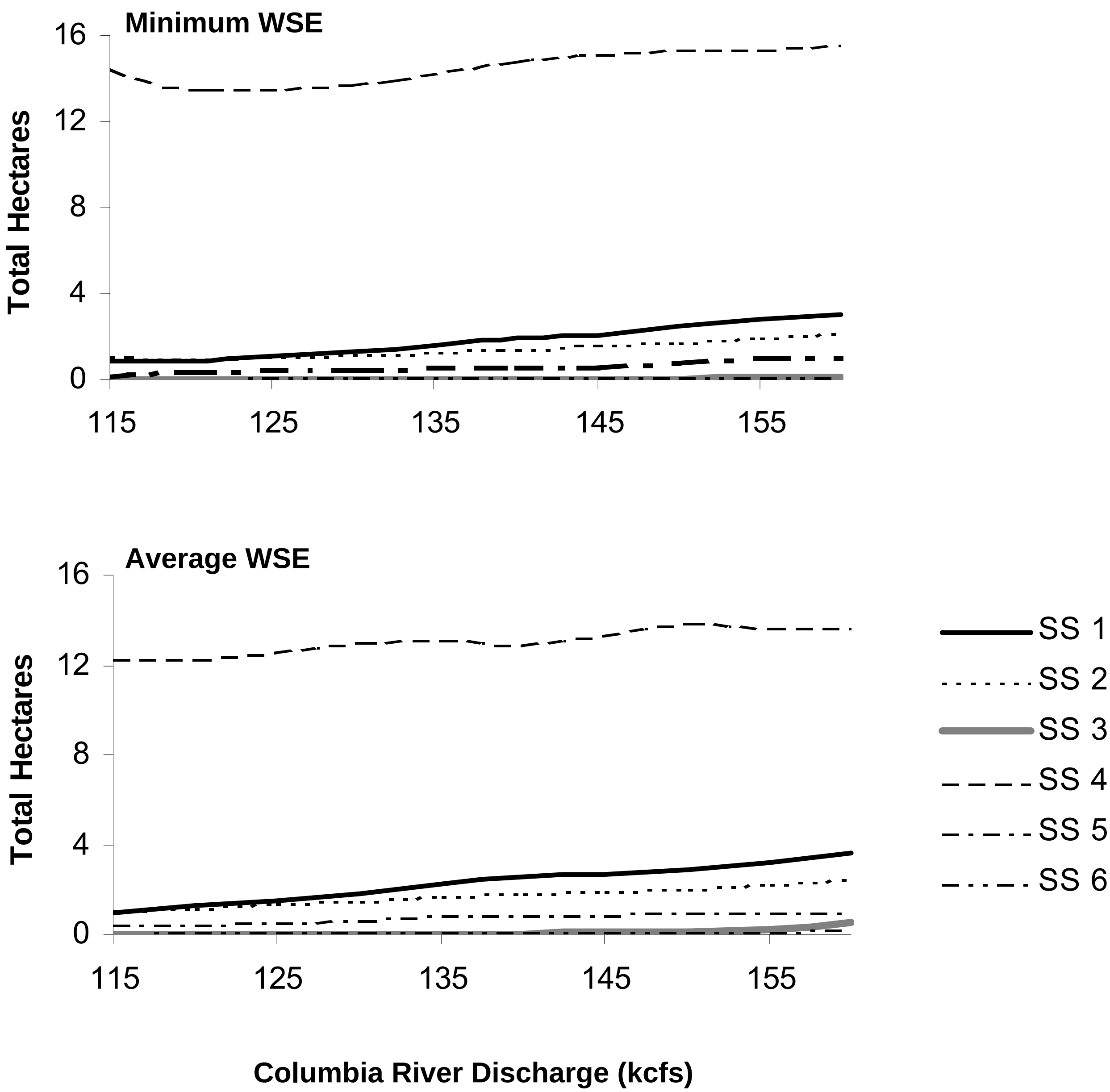

Figure 24. –Total hectares predicted to be fall chinook salmon spawning habitat for Columbia River discharges from 115 to 160 kcfs by study section (SS) at minimum and average water surface elevations above mean sea level.

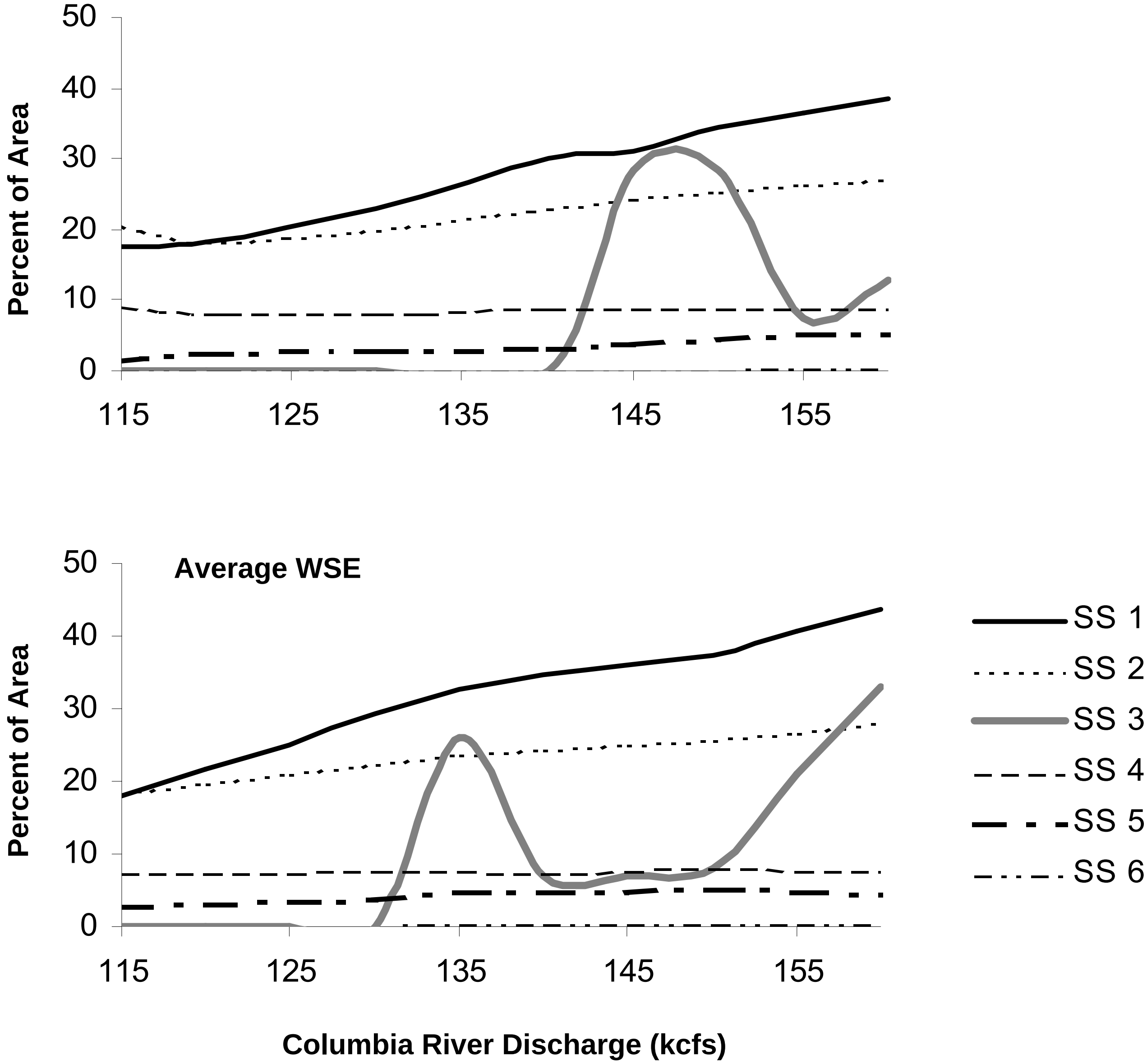

Figure 25. - Percent of total area predicted to be fall chinook salmon spawning habitat for Columbia River discharges from 115 to 160 kcfs by study section (SS) at minimum and average water surface elevations (WSE) above mean sea level.

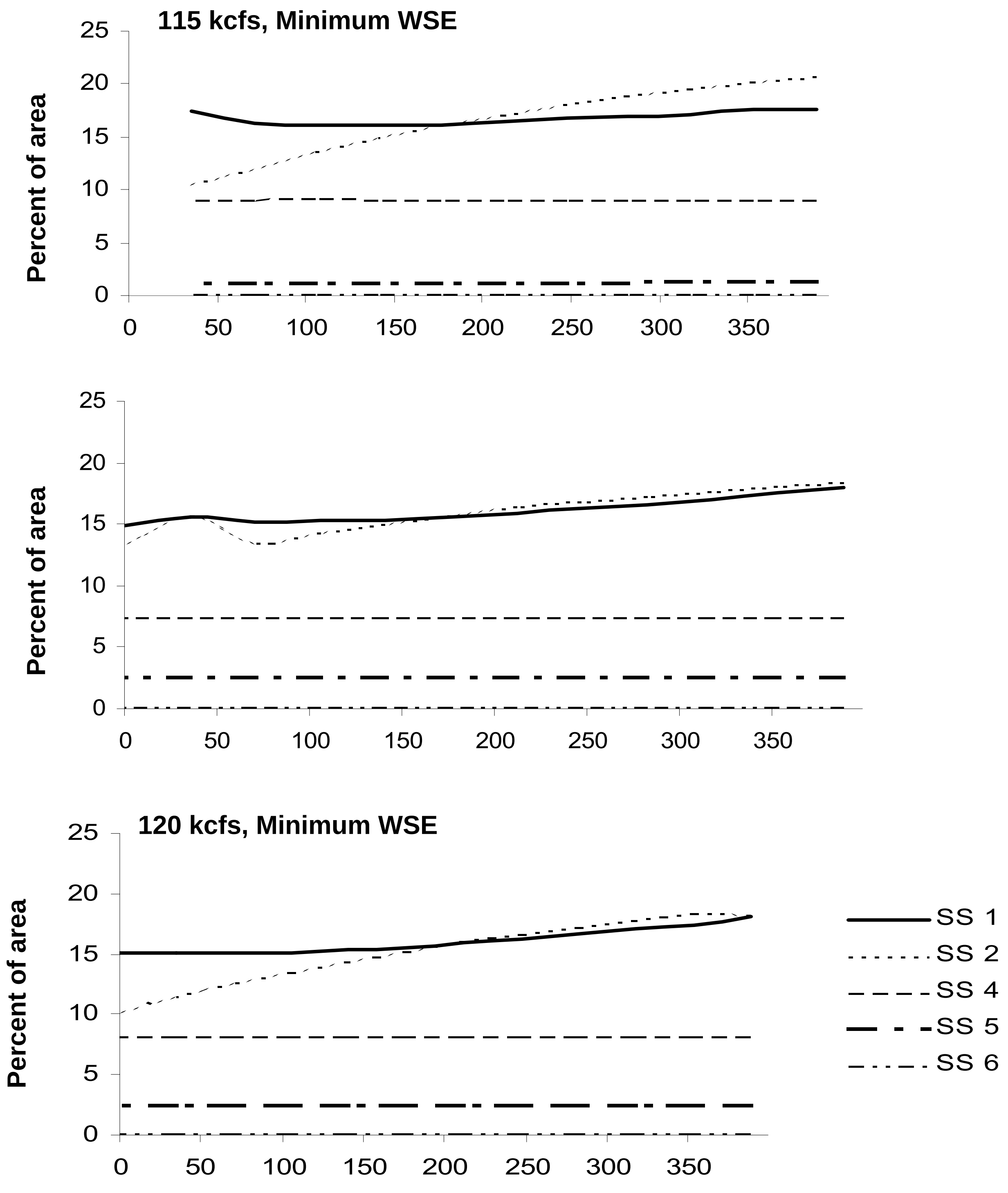

Figure 26. - Percent of total area predicted to be fall chinook salmon spawning habitat for Hamilton Creek discharges from 0 to 388 cfs by study section (SS) for the Columbia River discharge of 115 kcfs and minimum water surface elevation (WSE), and Columbia River discharge of 115 kcfs and average WSE, and Columbia River discharge of 120 kcfs and minimum WSE above mean sea level.

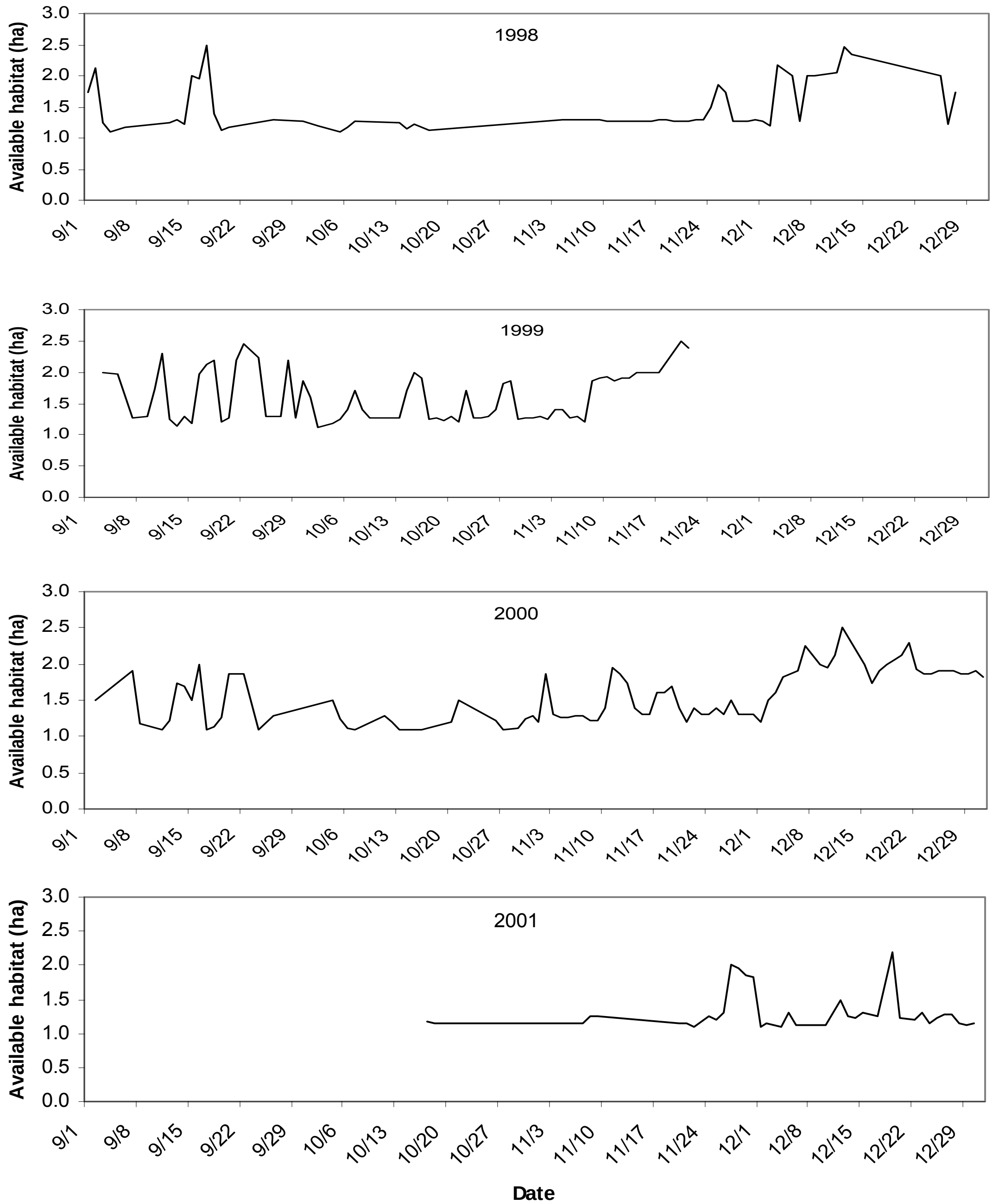

Figure 27. - Predicted daily changes in chinook salmon spawning habitat in study section 2 below the mouth of Hamilton Creek based on changes in the observed average daily flows from Bonneville Dam from 1998 to 2001. Gaps indicate that flows were outside the range of those we modeled.

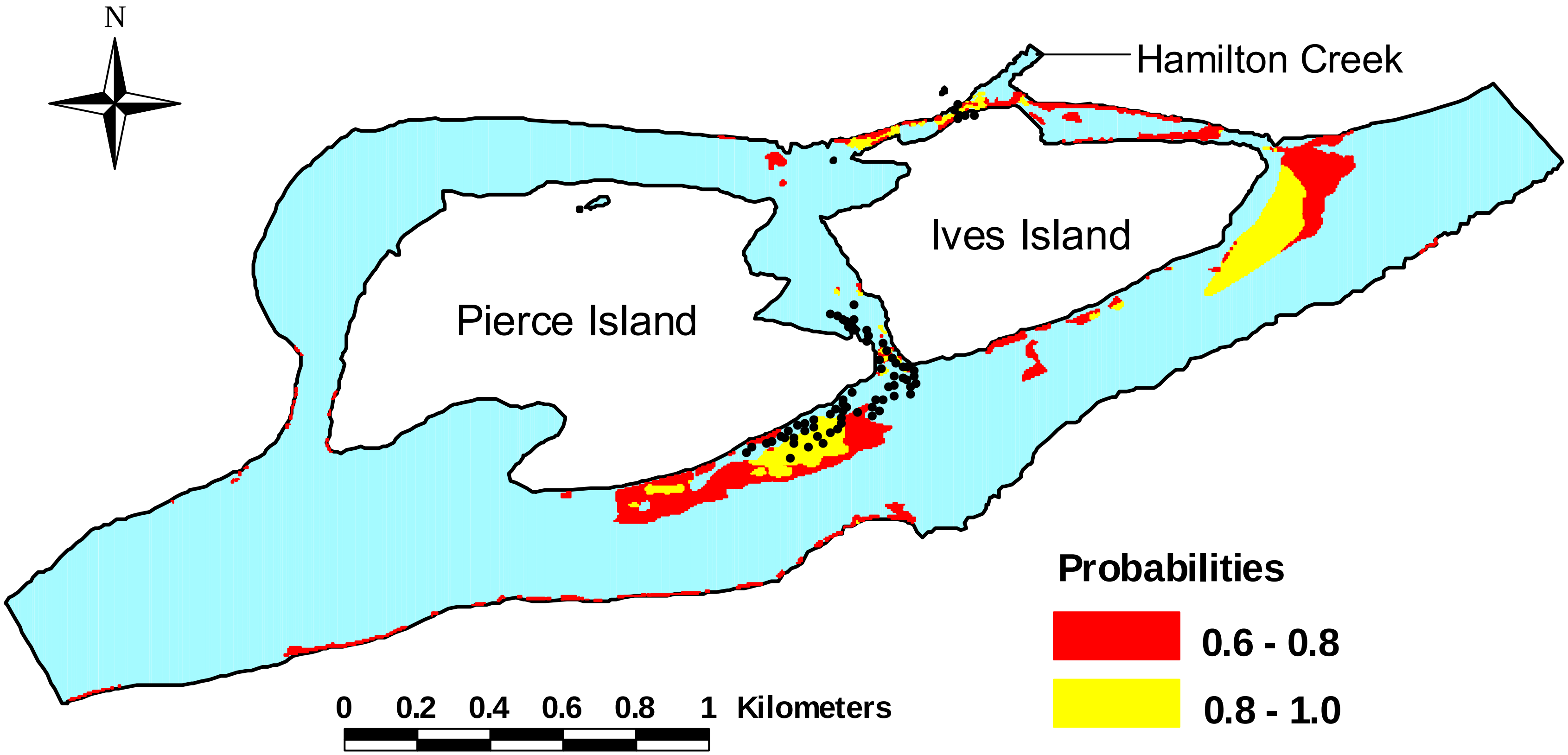

Figure 28. - Fall chinook salmon redd locations (gray) in 1998 and areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs (average flow from October 1 to December 15). Areas in yellow have the highest probability of use.

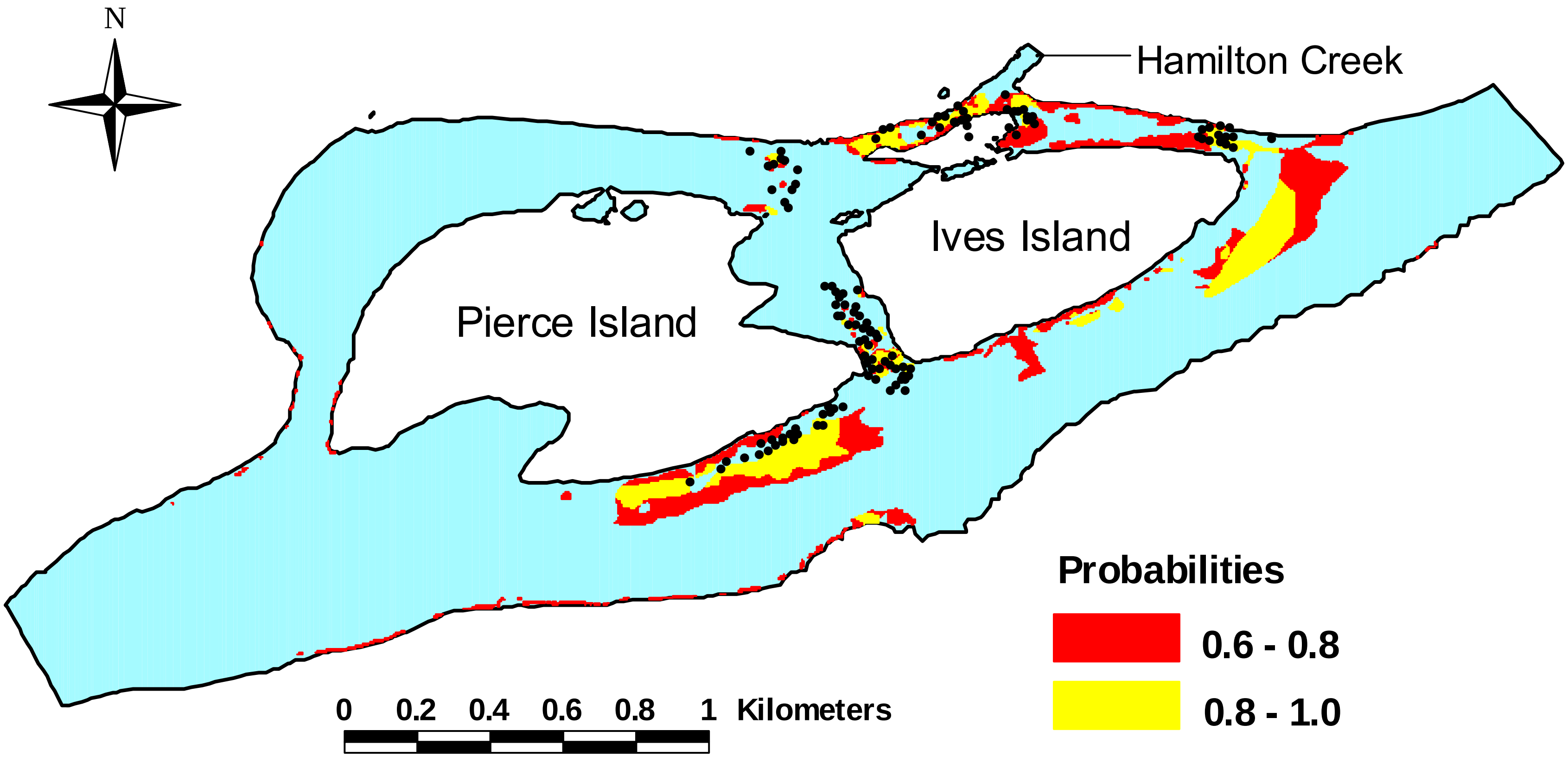

Figure 29. - Fall chinook salmon redd locations (gray) in 1999 and areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 150 kcfs (average flow from October 1 to December 15). Areas in yellow have the highest probability of use.

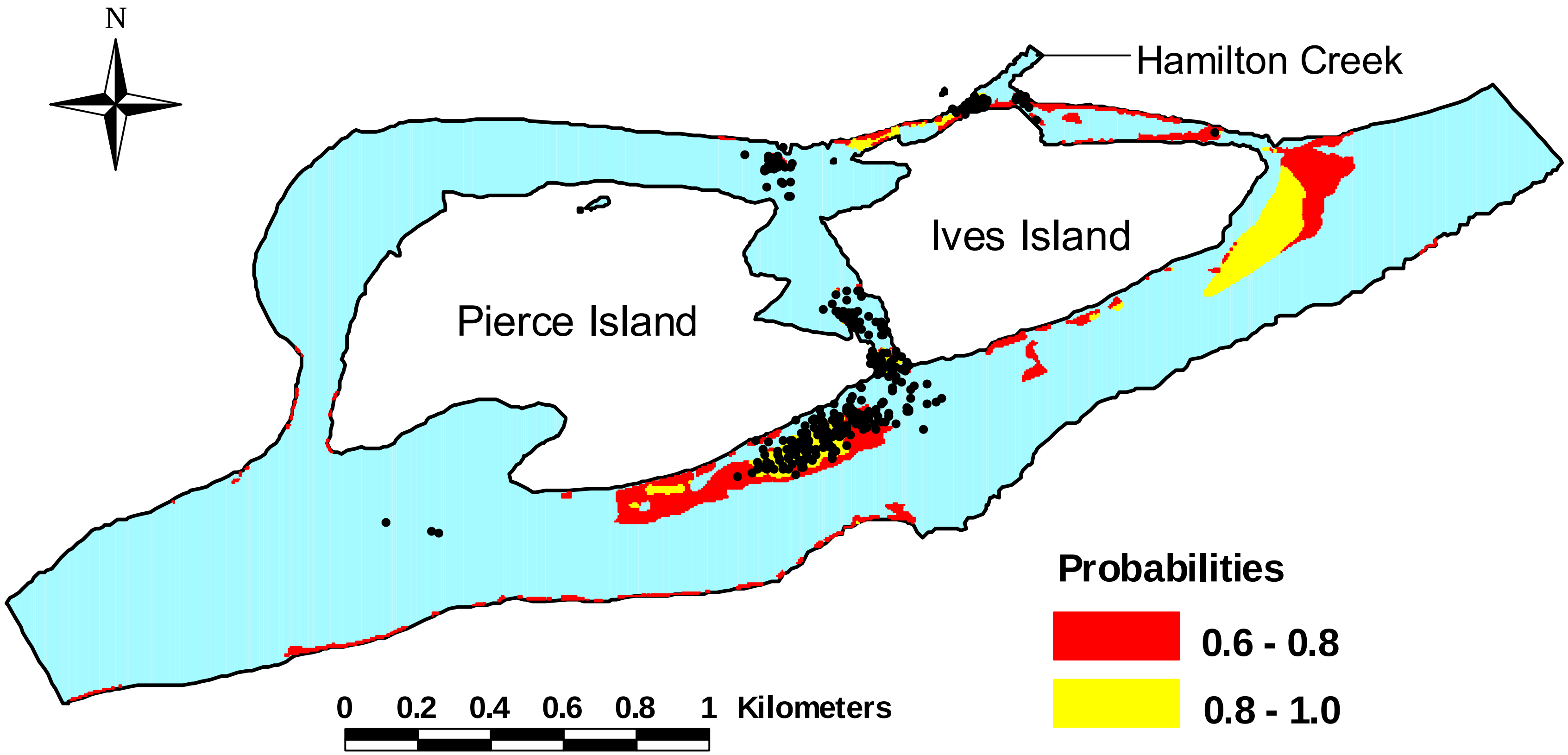

Figure 30. - Fall chinook salmon redd locations (gray) in 2000 and areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs (average flow from October 1 to December 15). Areas in yellow have the highest probability of use.

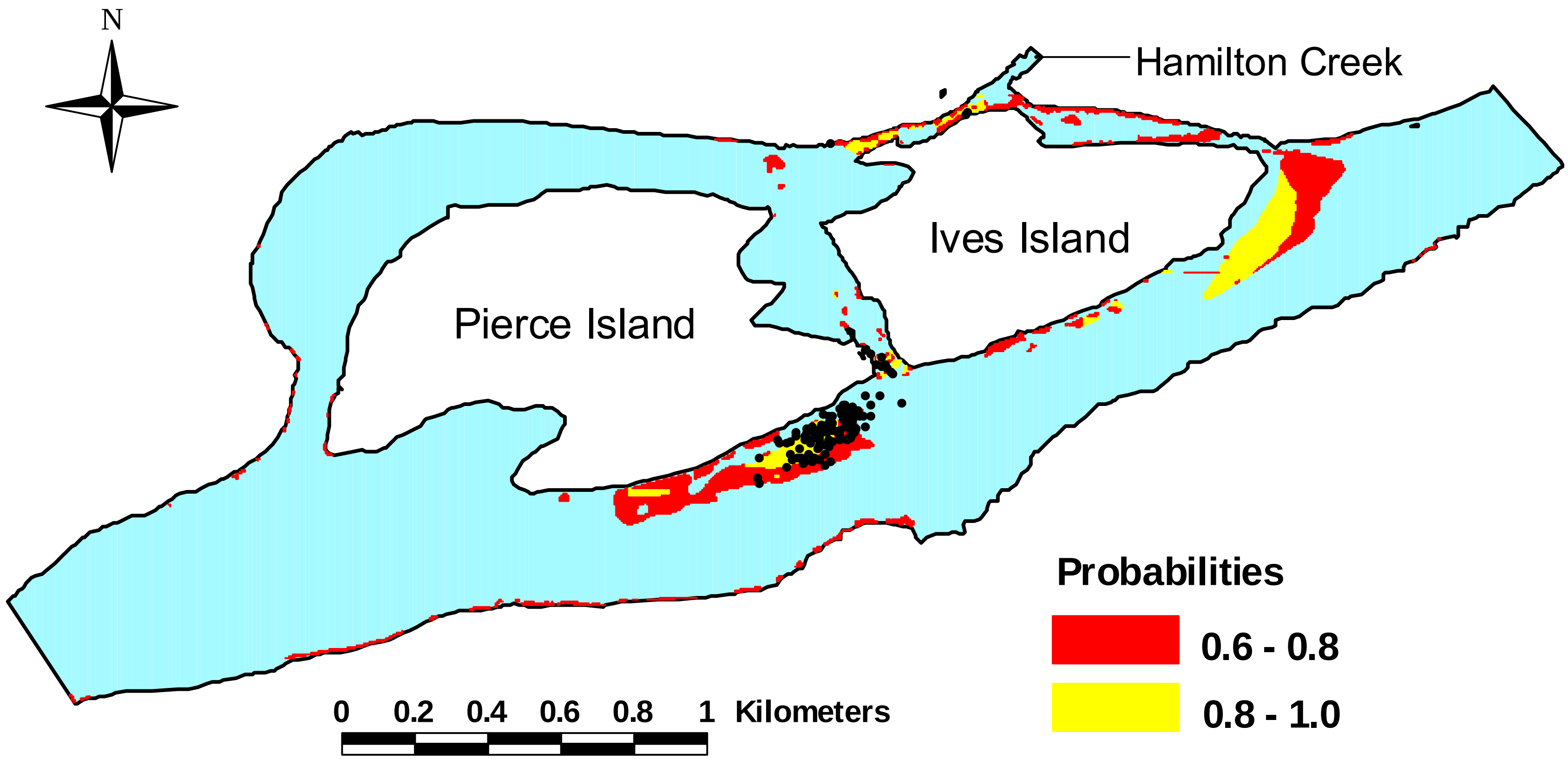

Figure 31. - Fall chinook salmon redd locations (gray) in 2001 and areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, our lowest flow modeled (average flow from October 1 to December 15 was 104 kcfs). Areas in yellow have the highest probability of use.

underestimated. These differences were likely due to the accuracy of describing the riverbed bathymetry, variations between the model and ADCP spatial scales of measurement, and comparing steady-state modeled flows to dynamic, empirical flow data.

Substrate is an important determinant of salmon redd-site selection. Because of the large size of our study area, our substrate surveys in the Ives Island area relied primarily on visual surface assessments, which were most efficient given our available resources. However, our methods did not allow us to make inferences about subsurface sediment composition, which may influence redd-site selection and subsequent fry survival. High amounts of fine sediments at 10-30 cm depth in the substrate, where salmonids typically deposit their eggs (Everest et al. 1982), can decrease subsurface water flow, oxygen availability, and reduce fry emergence (Phillips 1975; Iwamoto et al. 1978; Lotspeich and Everest 1981). This may explain why fish were observed spawning in distinct areas within our study area despite the availability of apparently similar habitats that were not used. In addition, although substrate composition may be relatively stable over time, the amount of fine sediments may be more transient. In 2001, Hamilton Creek discharged a large amount of fine sediment below its mouth, where chum salmon typically spawn, following a rain event. However, it is likely that much of this sediment was flushed from that area during the following spring runoff.

Our analysis of chum and fall chinook salmon habitat was limited to variables that were compatible with a GIS. Our final logistic regression model for chum salmon included both depth and velocity. We generally found chum salmon spawning in water less than 1 m deep and in moderately slow velocities. This agrees with the findings of Bazarkin (1990) who determined the mean depth and velocity of chum salmon spawning in the Kamchatka River to be 0.3 m and 0.36 m/s, respectively. Our model predicted that water velocities between 0.3 to 0.4 m/s would have the highest associated probability of chum redd presence. Although substrate was not included in our final chum salmon model, it is an important determinant of where they spawn. We found that chum salmon spawned over gravel and small cobble substrate exclusively, and no spawning occurred over large cobble, boulder, or fine substrates. Rukhlov (1969) found that autumn-spawning chum salmon spawned over gravel-shingle (4-16 mm) substrate with sand composing 14% of the substrate. In the Kamchatka River, summer chum salmon spawning grounds were described as 60% gravels with diameters >20 mm, 25% 10-15-mm diameter particles, a trace of 5-7-mm diameter particles, and the remaining being sand (Bazarkin 1990). Chum salmon can generally spawn in areas with higher percentage of fine material than other salmon.

One of the most important spawning habitat variables for chum salmon may be hyporheic water temperature. Sites with upwelling flows of hyporheic water and groundwater are typically selected by chum salmon of both the summer and autumn races (Leman 1988; Putivkin 1989; Leman 1993). In this study, Geist (2001) found that most chum salmon redds were located in areas of hyporheic upwelling where the bed temperatures were 7 to 11°C warmer than the ambient river temperature. The importance of this temperature differential was increased at sites where there was no measurable water velocity. Given the difficulty of measuring thermal characteristics in our large study area, we could not incorporate this variable in our analysis. Consequently, our chum salmon spawning model is liberal in its estimation of available spawning habitat.

Our analysis of fall chinook salmon spawning habitat variables found depth, velocity, and substrate to be important predictors of redd presence, and supports the results from other studies in the Snake and Columbia rivers (Swan 1989; Groves and Chandler 1999; Dauble and Geist 2000). Fall chinook salmon spawning in the Hanford Reach of the Columbia River used depths ranging from 0.3 to 9.0 m, near-bed water velocities ranging from 0.4 to 2 m/s, and substrates ranging from 2.5 to 15 cm in diameter (Chapman et al. 1986; Swan 1989; Geist 1997). Similarly, in the Hells Canyon Reach of the Snake River, Groves and Chandler (1999) described fall chinook salmon spawning in water 0.2 to 6.5 m deep, in near-bed velocities ranging from 0.1 and 2.0 m/s, over medium to large gravels (2.6–7.5 cm), and to a lesser degree over small cobbles (7.6–15 cm). Fall chinook salmon spawning near Ives Island displayed similar spawning habitat preferences, which likely contributed to our final logistic regression model predicting redd presence with 81% accuracy.

As with chum salmon, our final fall chinook salmon model did not include variables known to be important to spawning fish. Geist et al. (2000), studying fall chinook salmon spawning in the Hanford Reach of the Columbia River, found that upwelling waters originating from hyporheic discharge was an important criteria for spawning site selection. He found that the up-welled water was composed mostly of river water with no evidence of a temperature gradient between the hyporheic and surface waters. In contrast, Leman (1988) found fall chinook salmon in the Kamchatka River Basin to be salmonid that spawned where water infiltrated downward into the riverbed. Fall chinook salmon may use up and downwelling cues to select sites for redds in the Ives Island area since many redds were observed in the immediate vicinity of hydraulic controls, although fish spawned in other locations as well.

Our predictions of chum and fall chinook salmon spawning habitat were consistent with areas where spawning actually occurred. However, we generally predicted more available habitat than was actually used, and some fish also spawned in habitats with low predicted probabilities of redd presence. One explanation is that our models were not adequately parameterized to include variables of known importance, such as water temperature differentials. Our estimates of physical habitat conditions also may not have represented true conditions at the time redds were constructed. Finally, the lack of agreement between redd locations and predicted habitat may be an artifact of representing redd locations at a single flow while fish actually spawned over a range of flows each year.

The lack of use of habitats that were predicted to be suitable may be the result of the area not being fully seeded with spawners. Evidence for this was observed in the location of chum salmon redds in 2001. Prior to 2001, chum salmon spawned consistently in the same locations year after year. In 2001, chum salmon were observed spawning in these same areas but also in the channel between Ives and Pierce islands (study section 5), at the mouth of Woodward Creek, and at the mouth of McCord Creek on the Oregon shore. The greater number of chum salmon in 2001 may have contributed to their expanded use of available habitats.

Spatial overlap of chum and fall chinook salmon redd locations was minimal during our study. Chum salmon primarily spawned in the pools below the mouth of Hamilton Creek while chinook salmon used the hydraulic controls in this area for spawning. In 2001, a number of chum salmon redds were located in the channel between Ives and Pierce islands (Figure 22), which was also used by chinook salmon in all years (Figures 27-30). The use of this area by chum salmon may have resulted from velocities being lower in this area because 2001 was a low flow year. Differences in depth, velocity, and substrate preferences of each species contributed to the spatial segregation of spawning locations.

Fall chinook and chum salmon spawning habitats responded differently to increases in Columbia River discharge. Fall chinook spawning habitat increased slightly as flows increased (Figure 23). This was the result of suitable habitat being created as shallow areas became inundated at higher flows. However, most fall chinook salmon spawning habitat was located in the main channel where the habitat is less sensitive to flow changes except in shallow areas near the shore. Chum salmon spawning habitat, in contrast, shifted location as flows increased, while the total amount of habitat remained unchanged For example, at flows of 120 kcfs chum salmon spawning habitat was present in the channel below the mouth of Hamilton Creek (Appendix B.10). As flows increased to 155 kcfs, this area was predicted to be unsuitable due to high velocities, but the previously dry channel immediately to the south (study section three) was predicted to contain suitable habitat (Appendix B.25). These changes in habitat locations are the result of chum salmon being more sensitive to changes in water velocities as flows increase. Consequently, the fish will move to new areas of preferred velocities and depths as long as other conditions, such as temperature and substrate, are suitable.

Our study showed that the Ives Island area contained suitable spawning habitat for chum and fall chinook salmon at all flows modeled. Sustaining fall chinook salmon spawning in this area is less dependent on flows because these fish can use deeper, main channel habitats. In contrast, chum salmon spawned primarily in shallow-water habitats that were sensitive to Columbia River and Hamilton Creek flows. In the absence of discharge from Hamilton Creek, providing a flow of 120 kcfs from Bonneville Dam (mean tailwater elevation of 11.7 ft) would support chum salmon spawning in the channel between Ives Island and the Washington shore where these fish have repeatedly spawned for the past four years. Our study did not address the amount and relative importance of available spawning habitat for chum salmon in Hamilton and Hardy creeks, but we know that main-stem habitats are certainly important when Hamilton and Hardy creeks are dry or contain little water.

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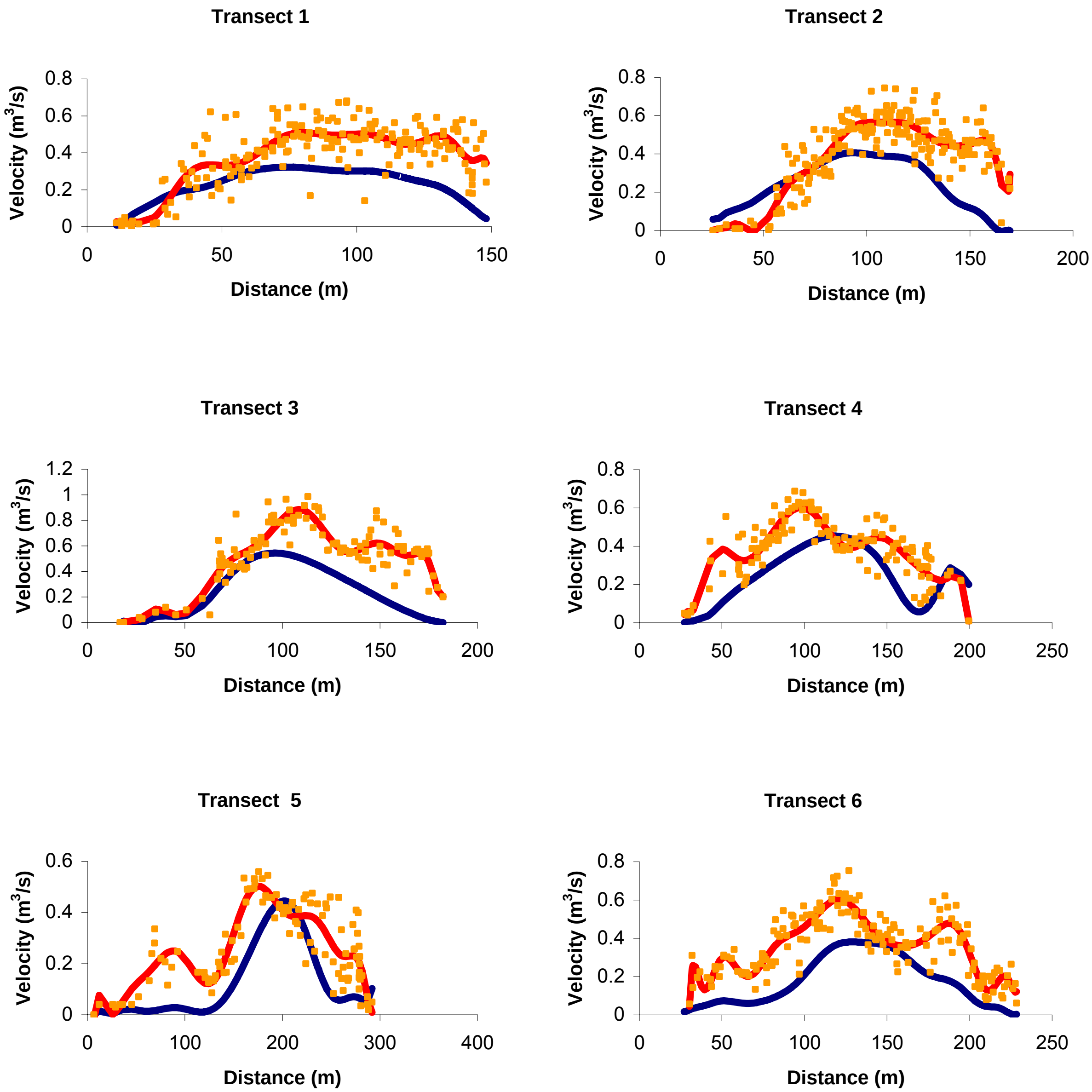
APPENDIX A

Appendix A.1 - Velocity verification transect data for the Ives Island study area, where points indicate individual water velocity measures, the red line indicates the polynomial regression best-fit line of these points, and the blue line indicates the modeled water velocities. Distances are measured starting from the southern shoreline.



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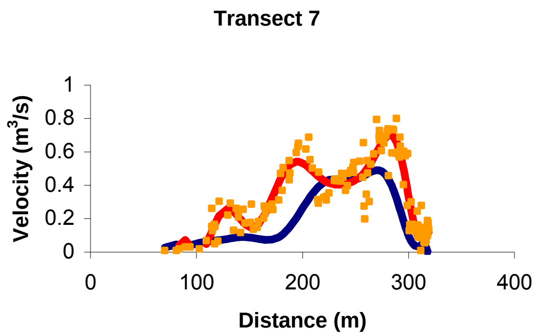

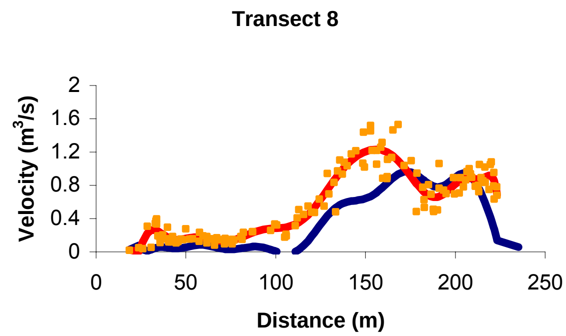

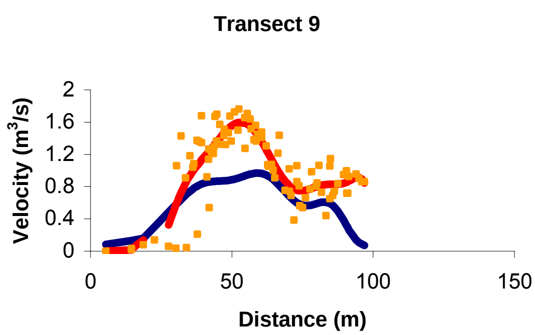

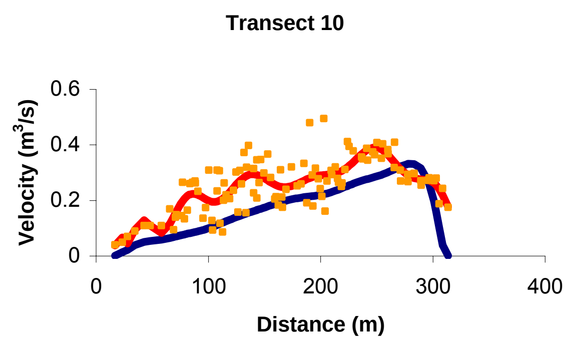

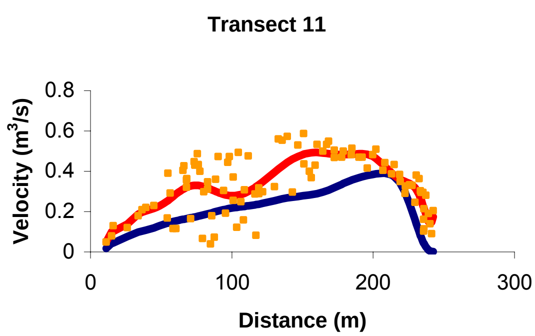

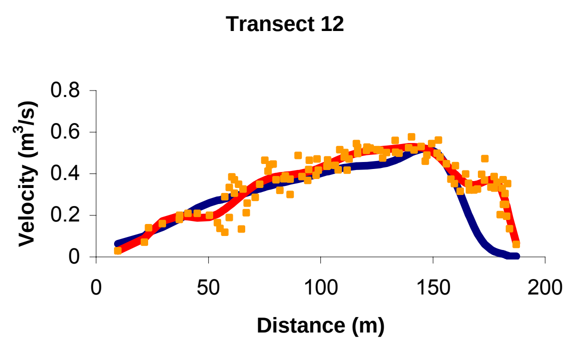

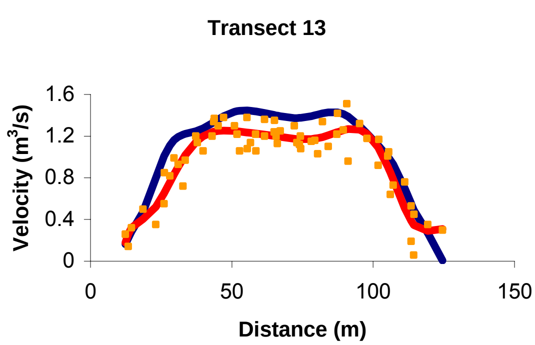

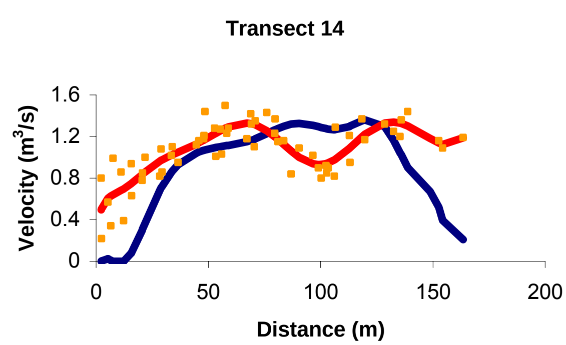

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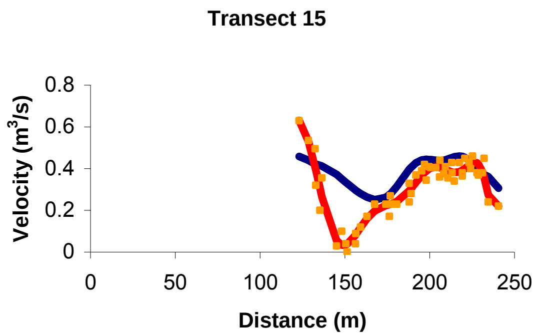

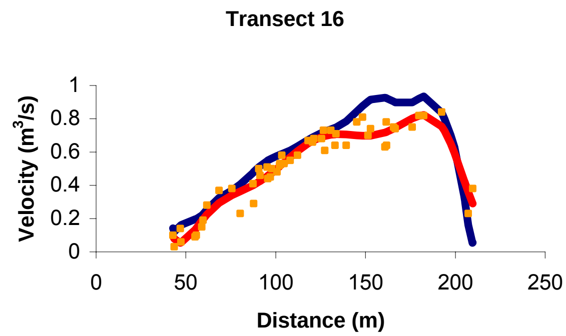

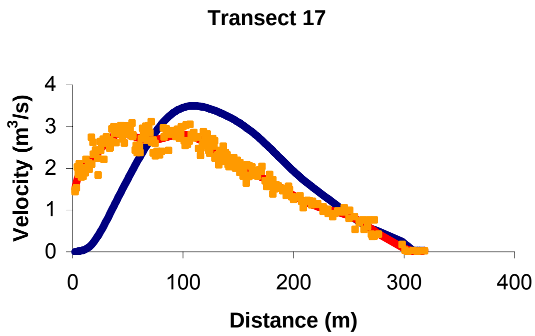

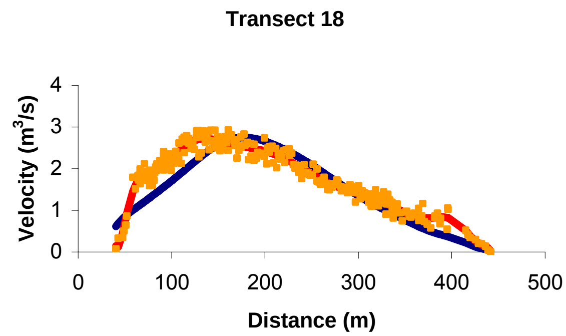

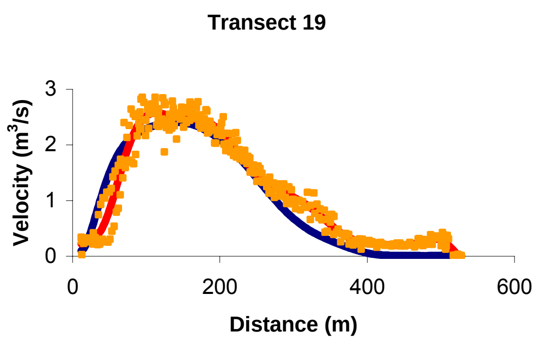

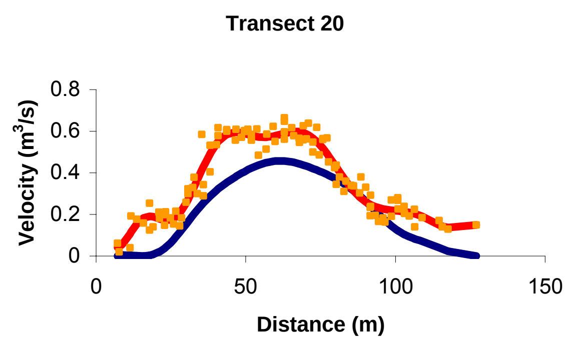

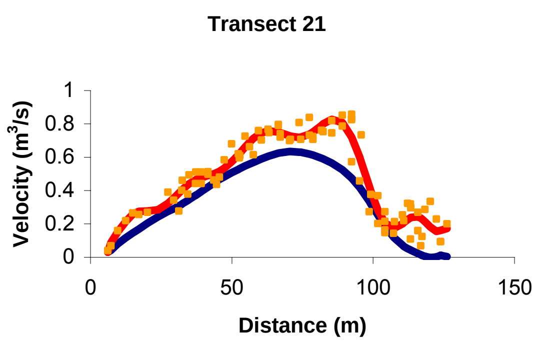

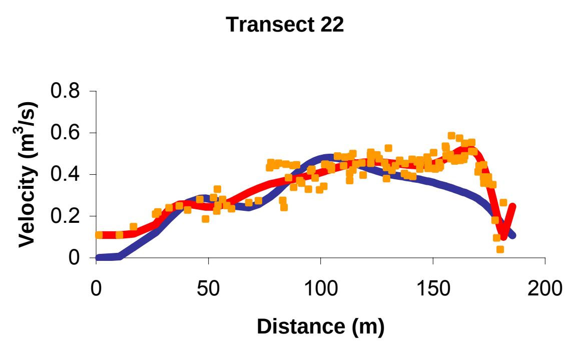

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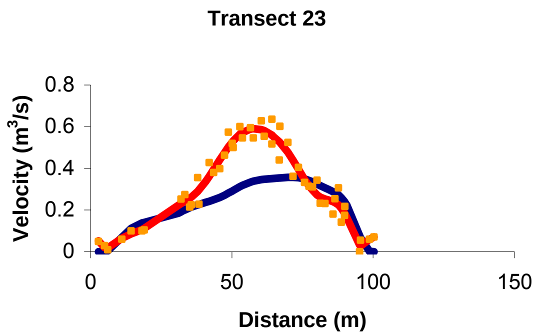
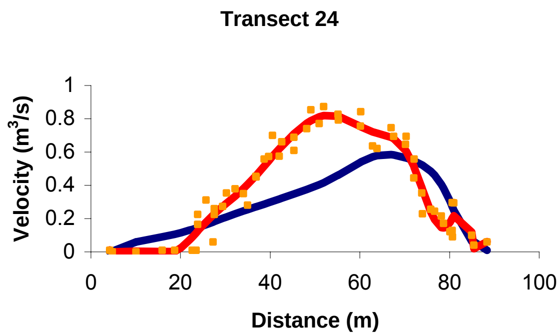
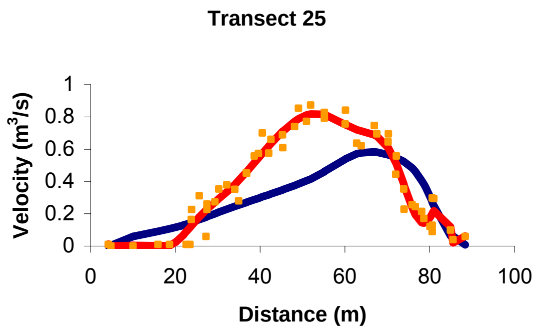
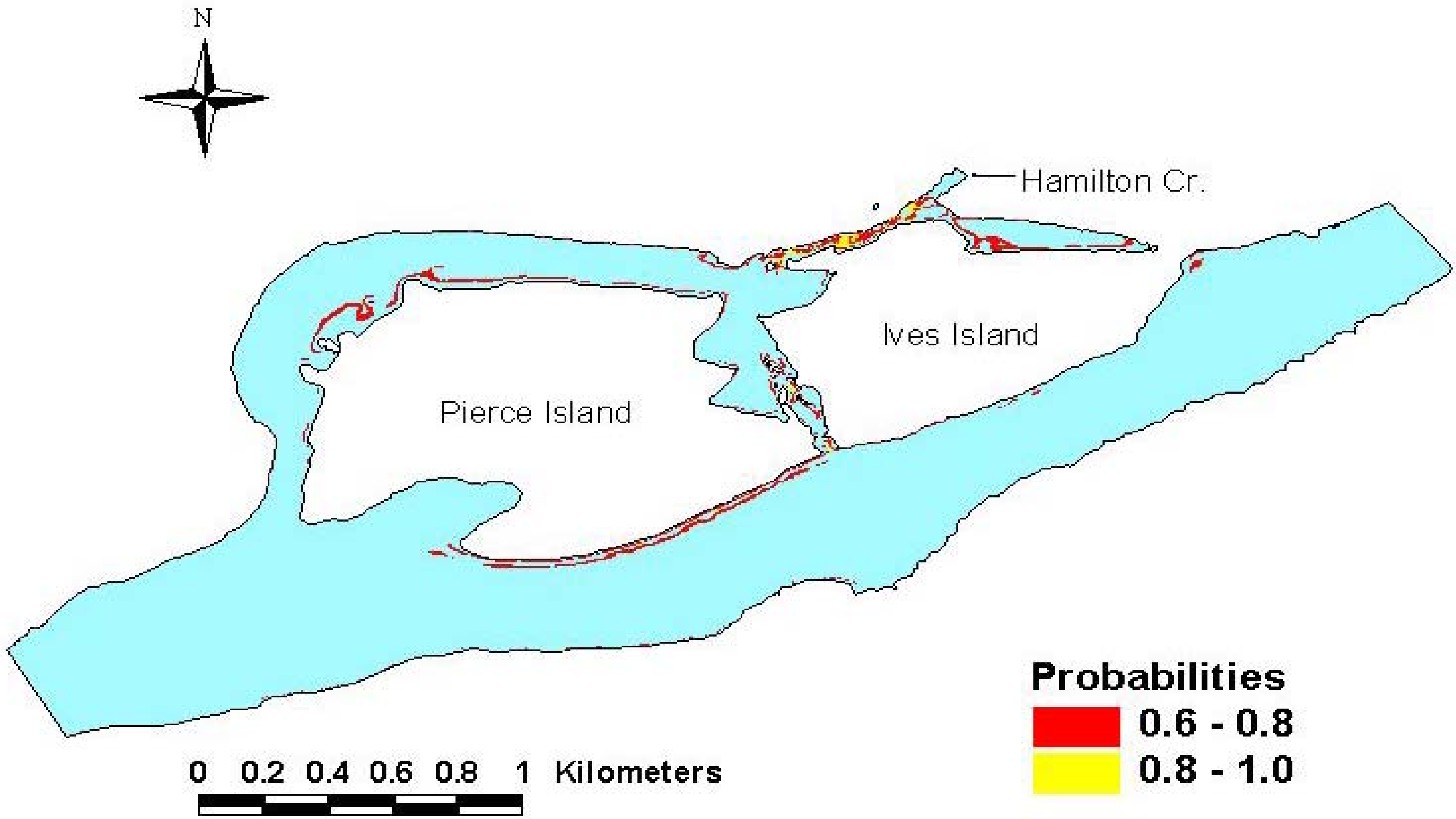




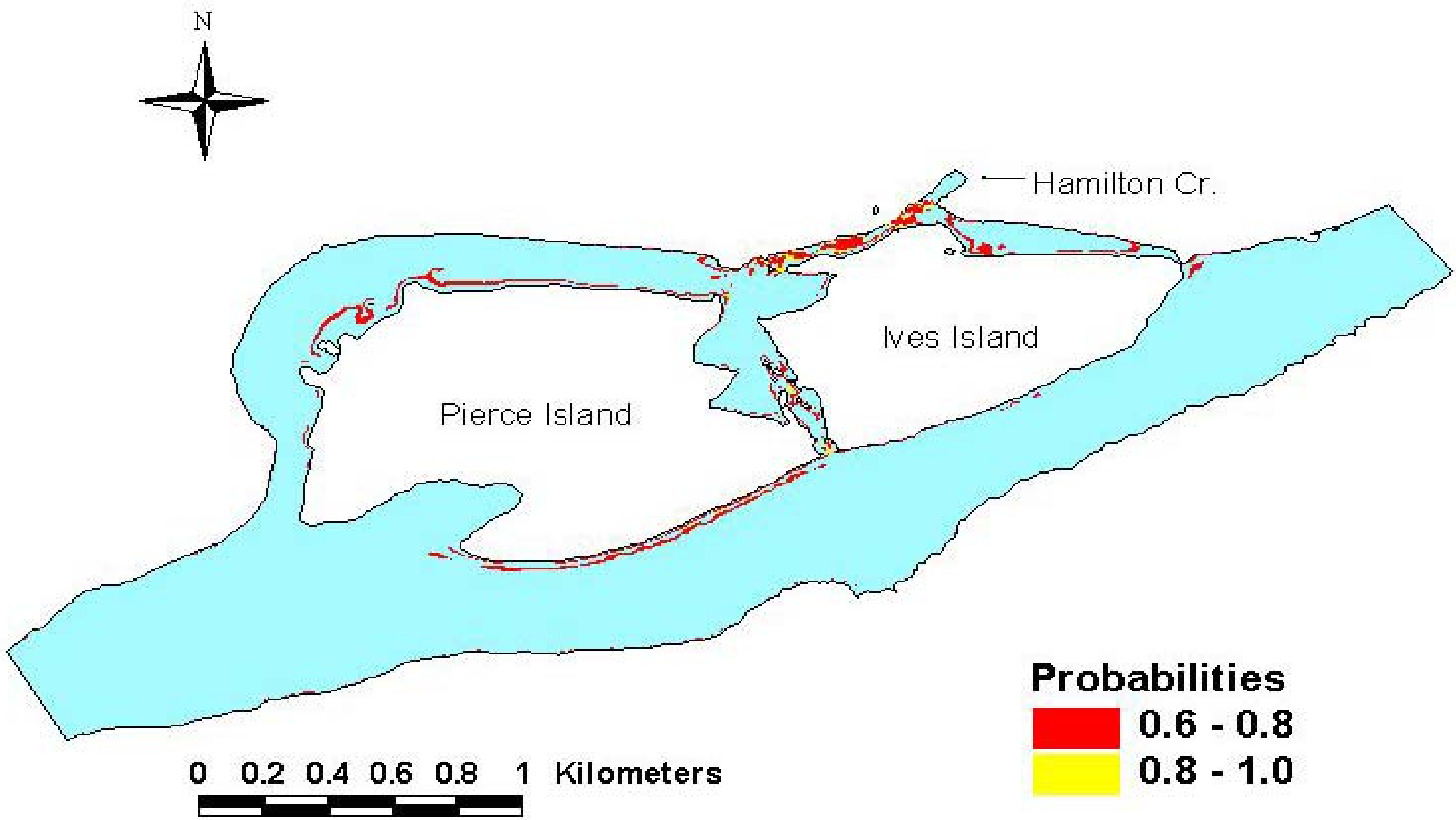


APPENDIX B

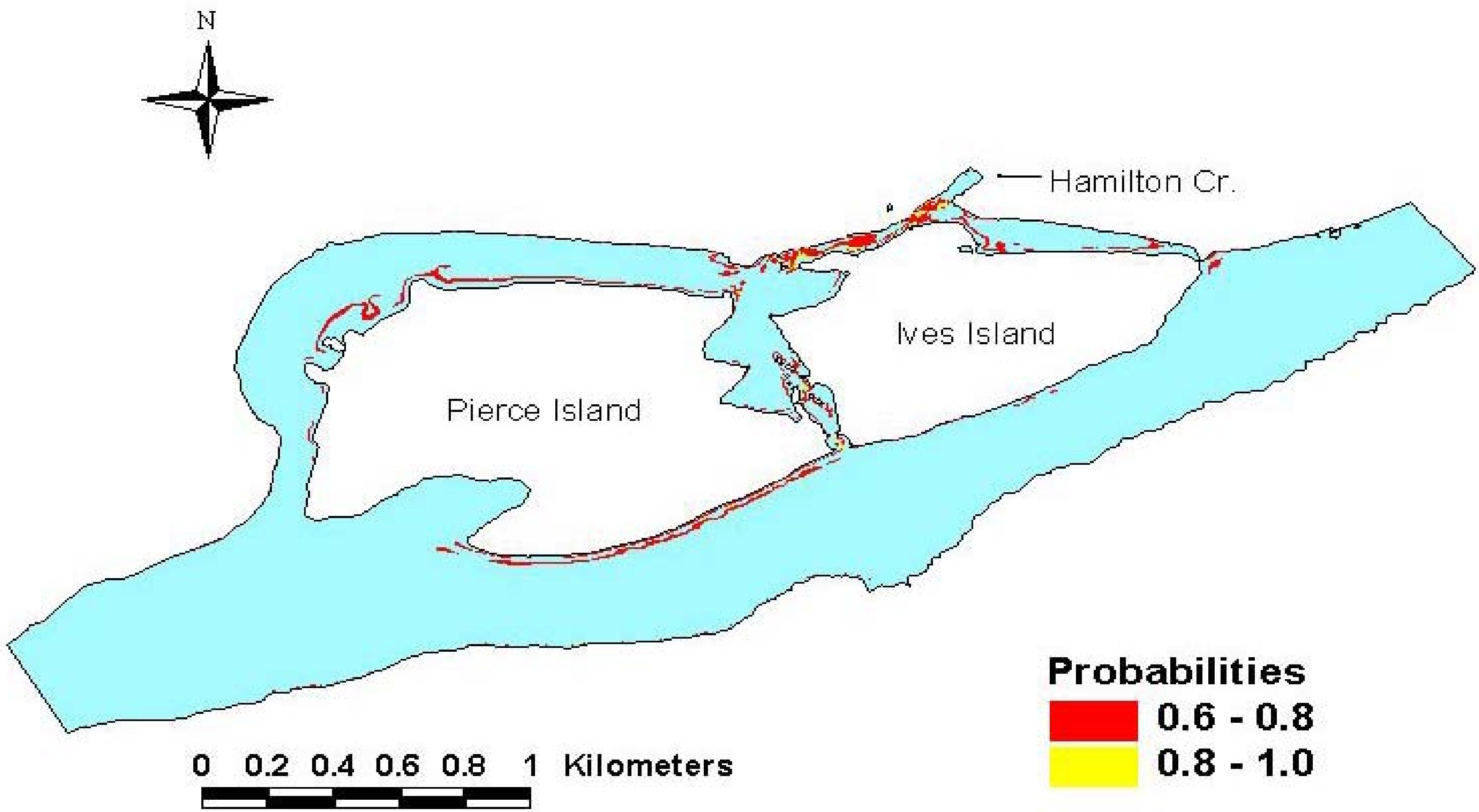
Appendix B.1 – Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 177 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



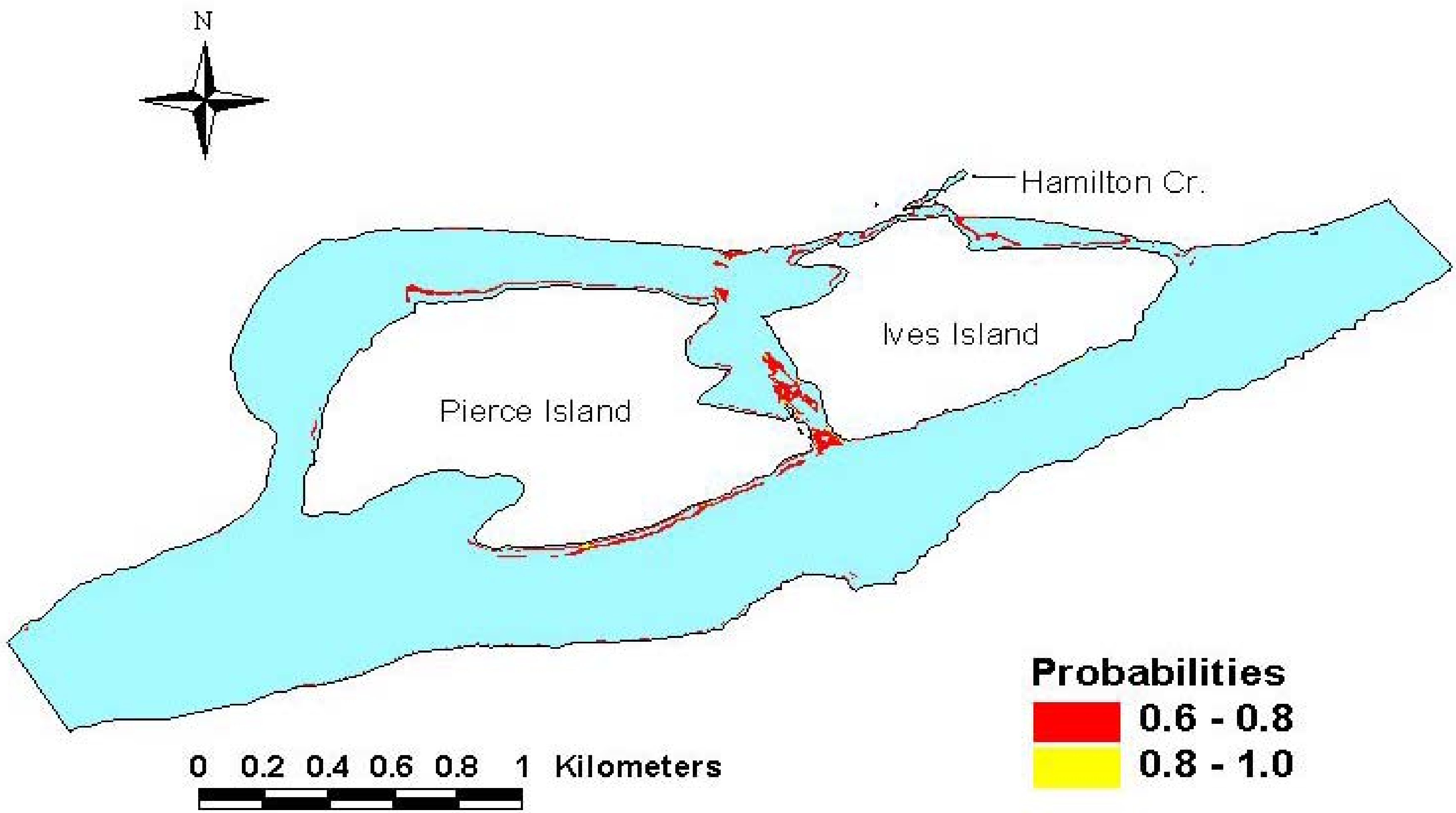
Appendix B.2 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 353 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



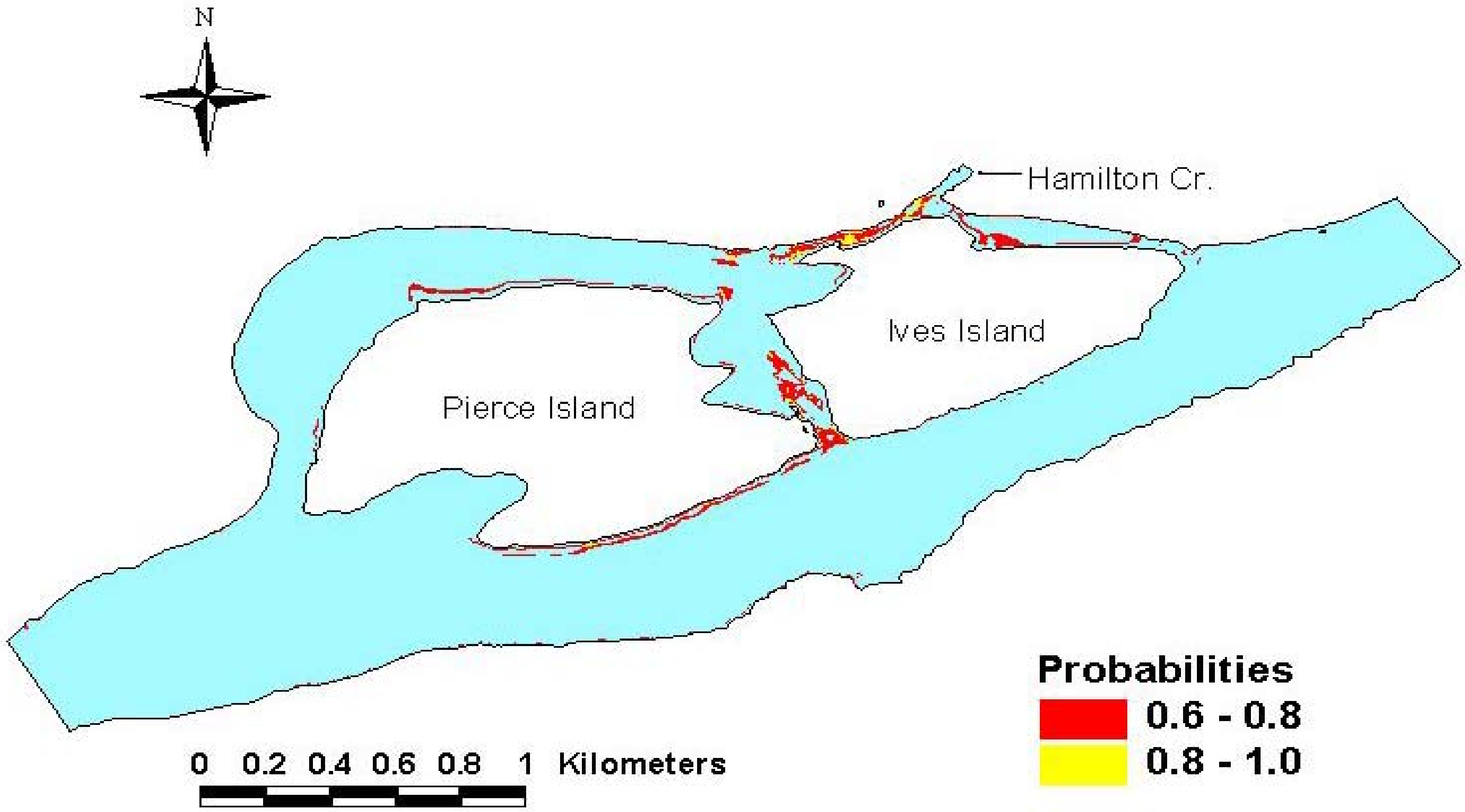
Appendix B.3 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



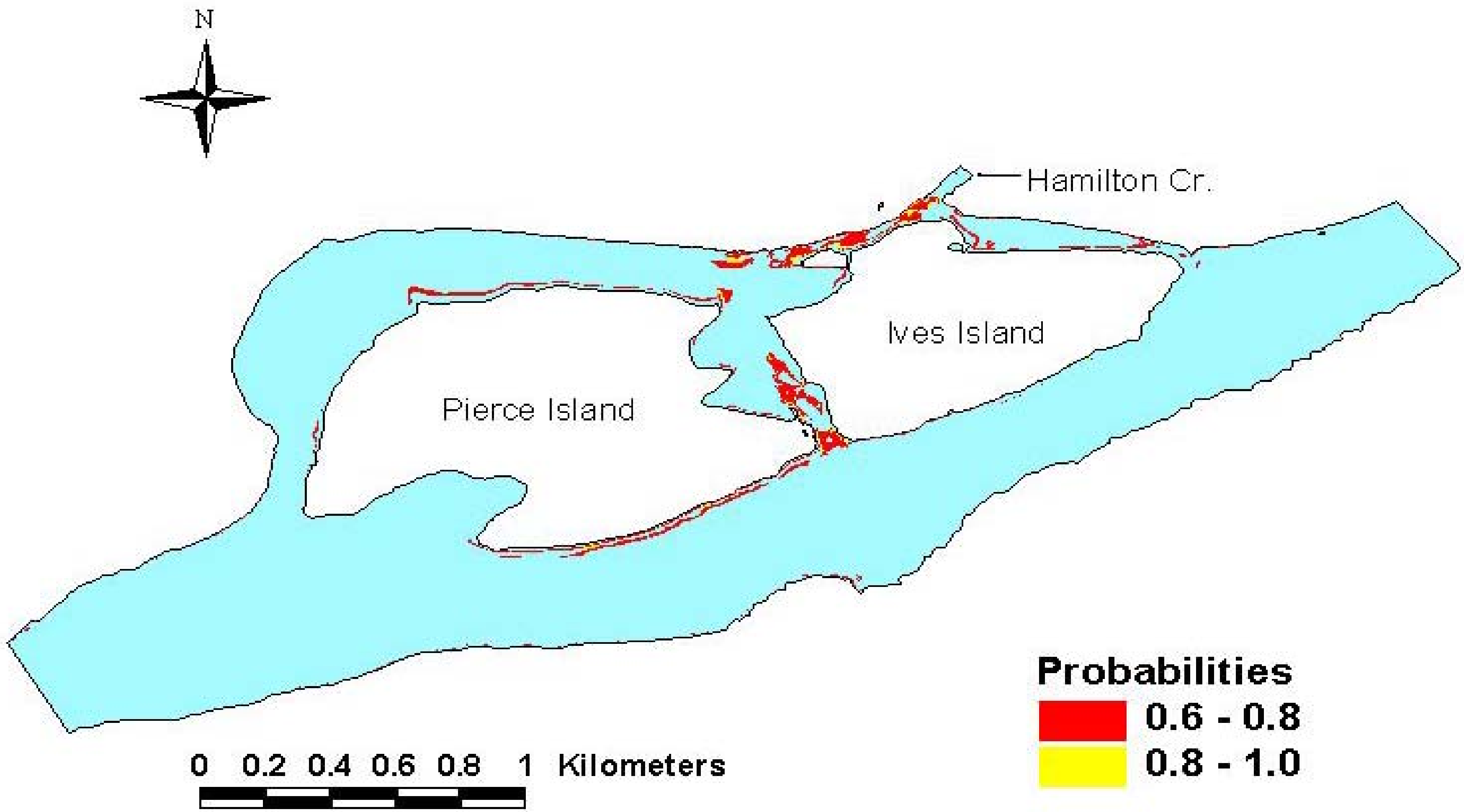
Appendix B.4 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 0 cfs, and an average Warrendale water surface elevation of 2.5 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



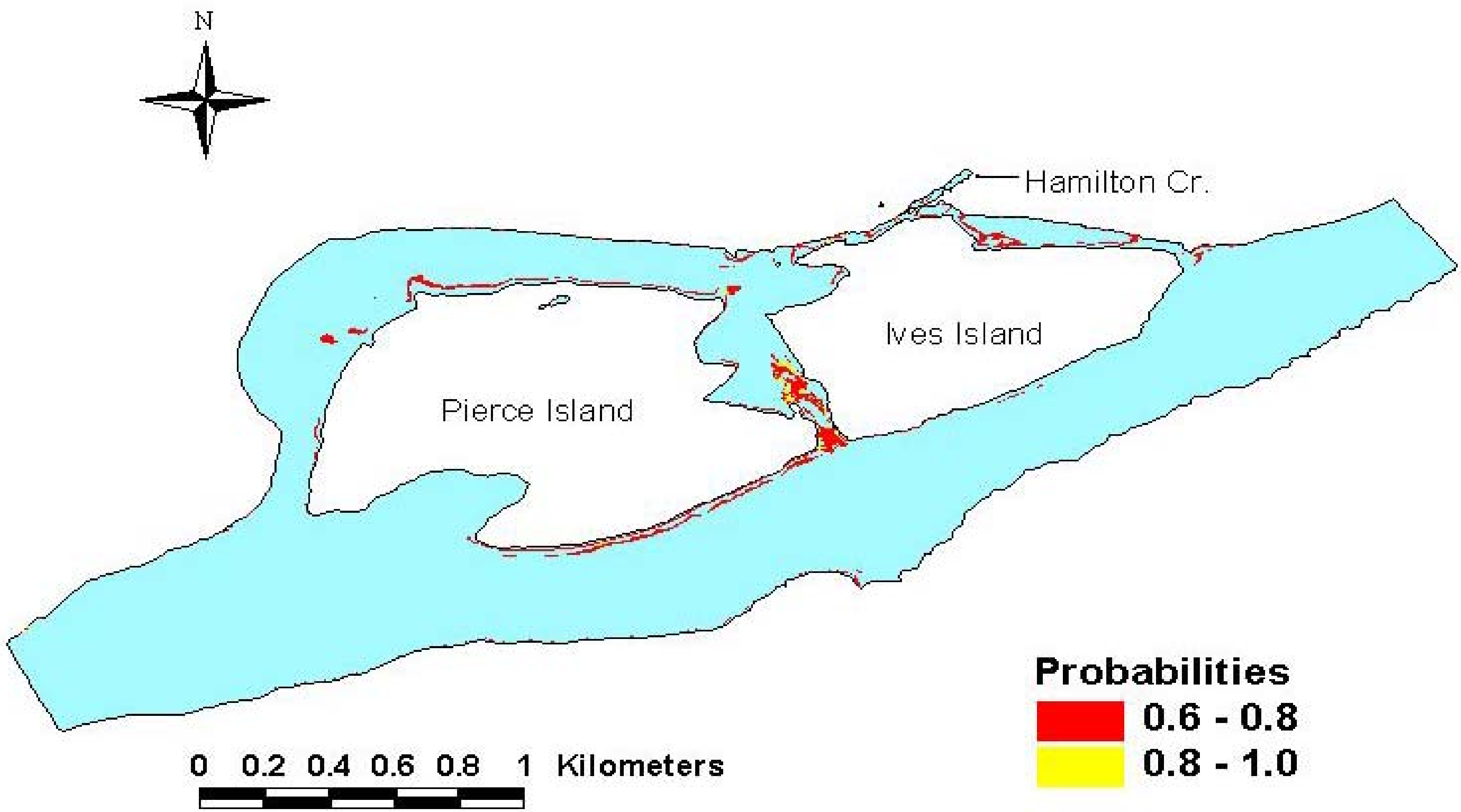
Appendix B.5 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 177 cfs, and an average Warrendale water surface elevation of 2.5 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



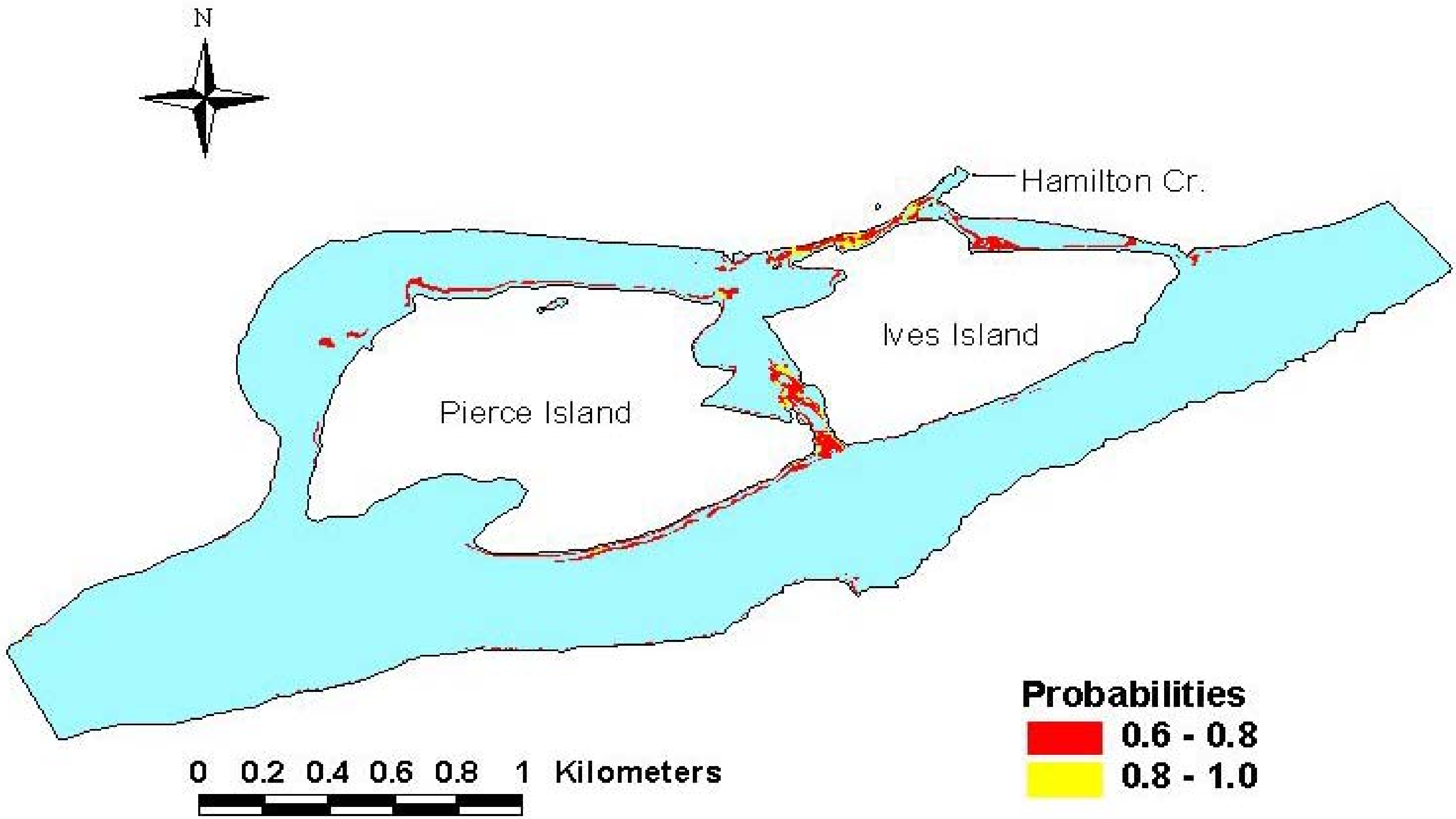
Appendix B.6 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.5 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



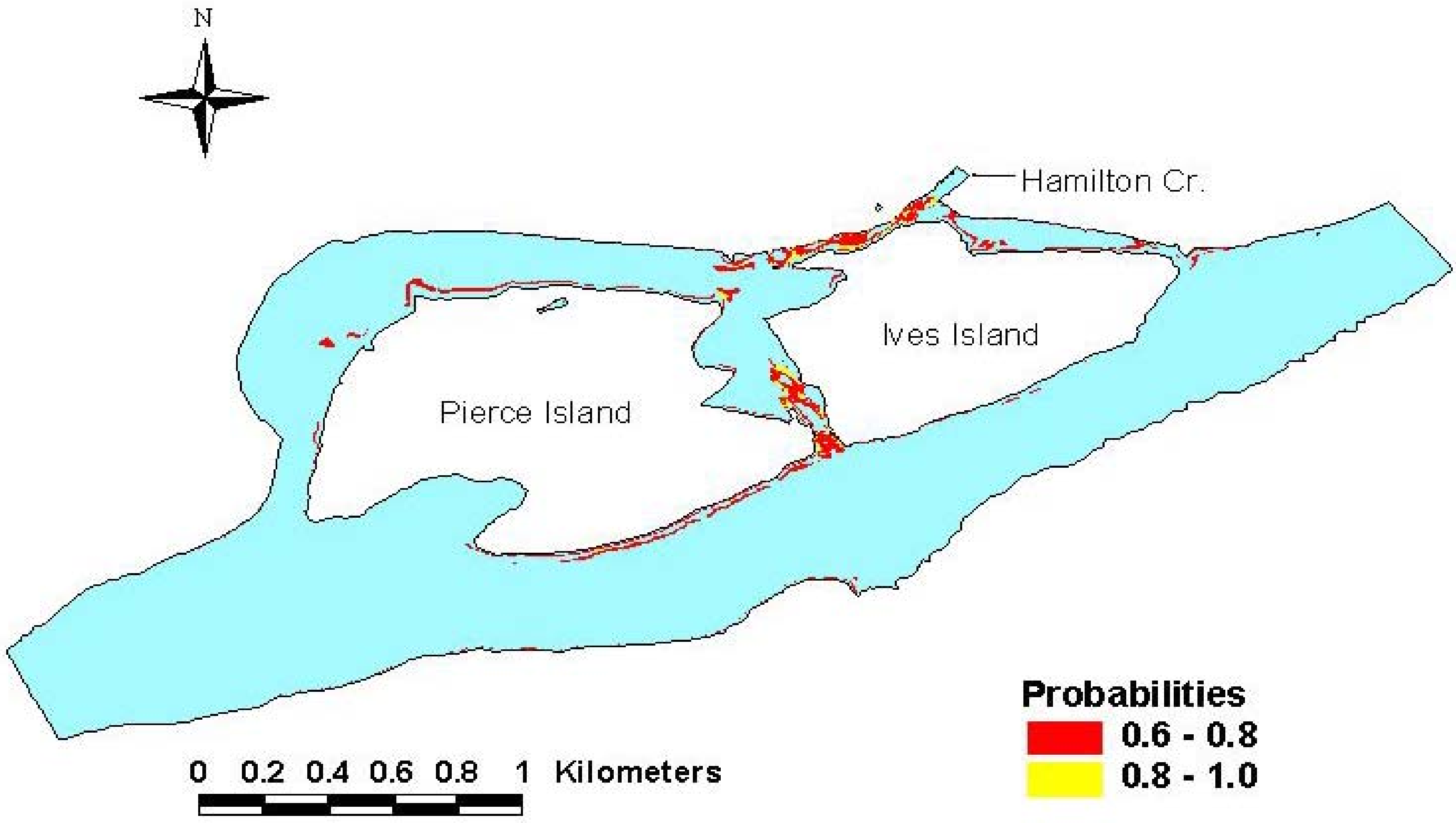
Appendix B.7 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 120 kcfs, Hamilton Creek discharge of 0 cfs, and a minimum Warrendale water surface elevation of 2.2 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



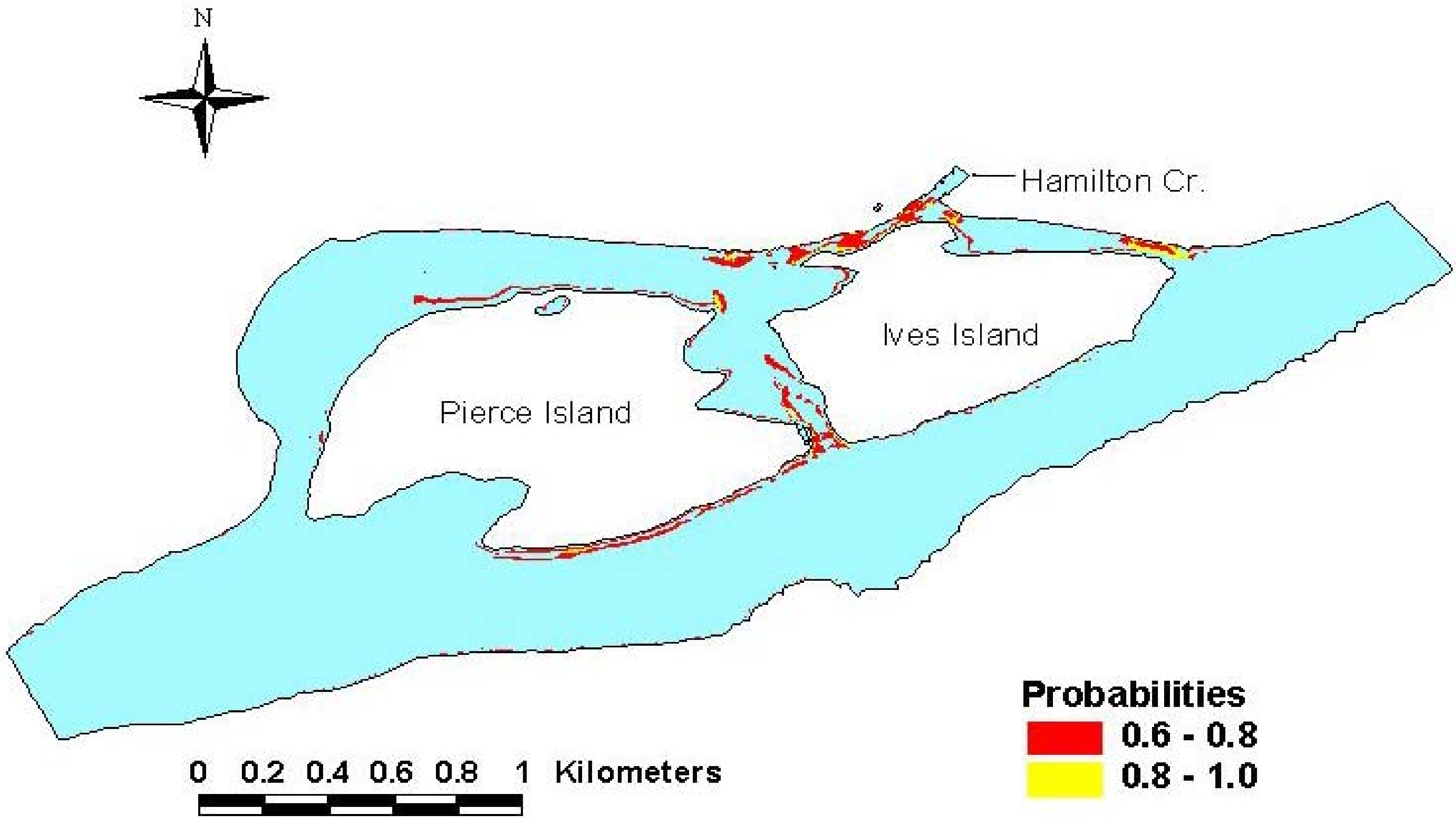
Appendix B.8 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 120 kcfs, Hamilton Creek discharge of 177 cfs, and a minimum Warrendale water surface elevation of 2.2 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



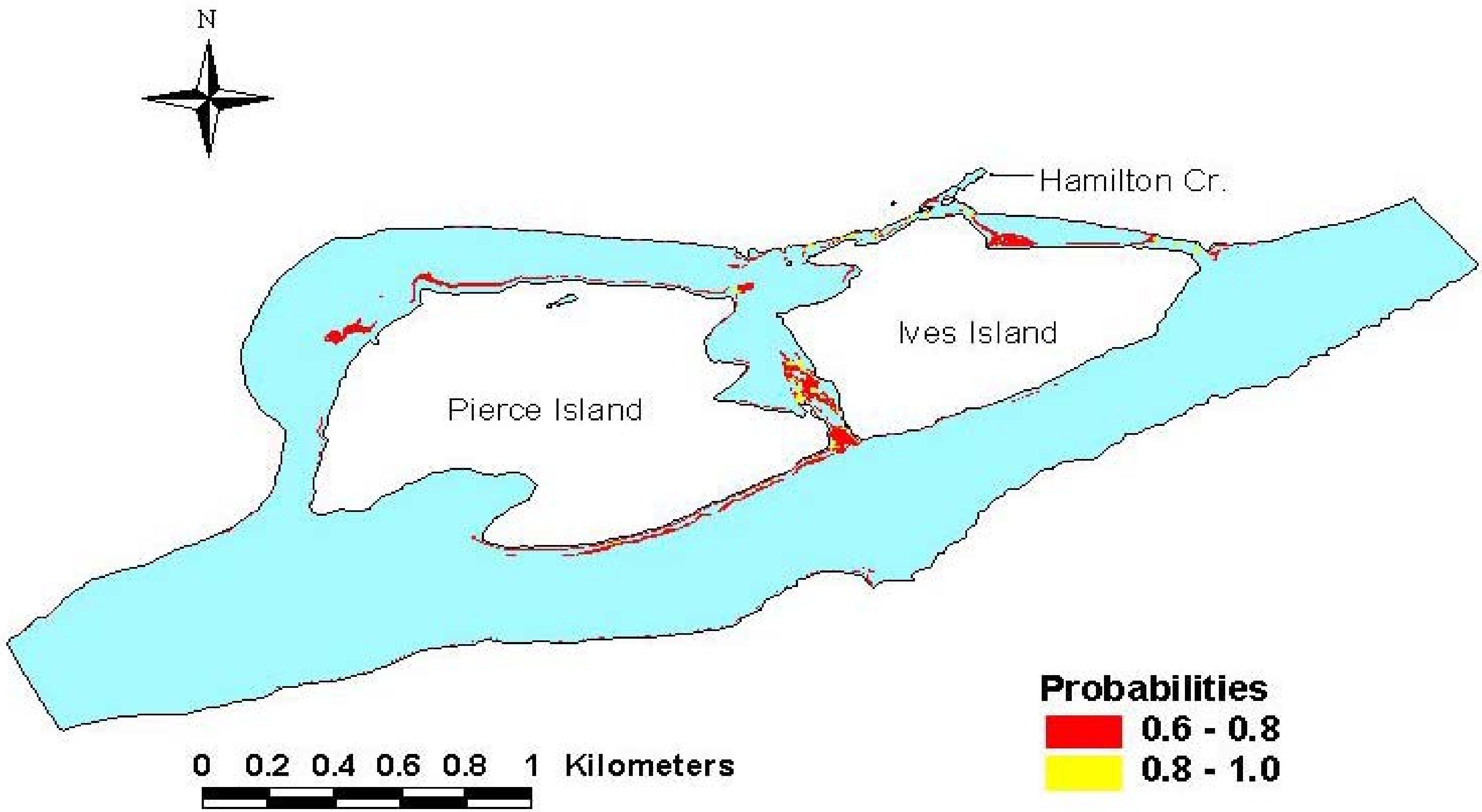
Appendix B.9 – Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 120 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.2 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



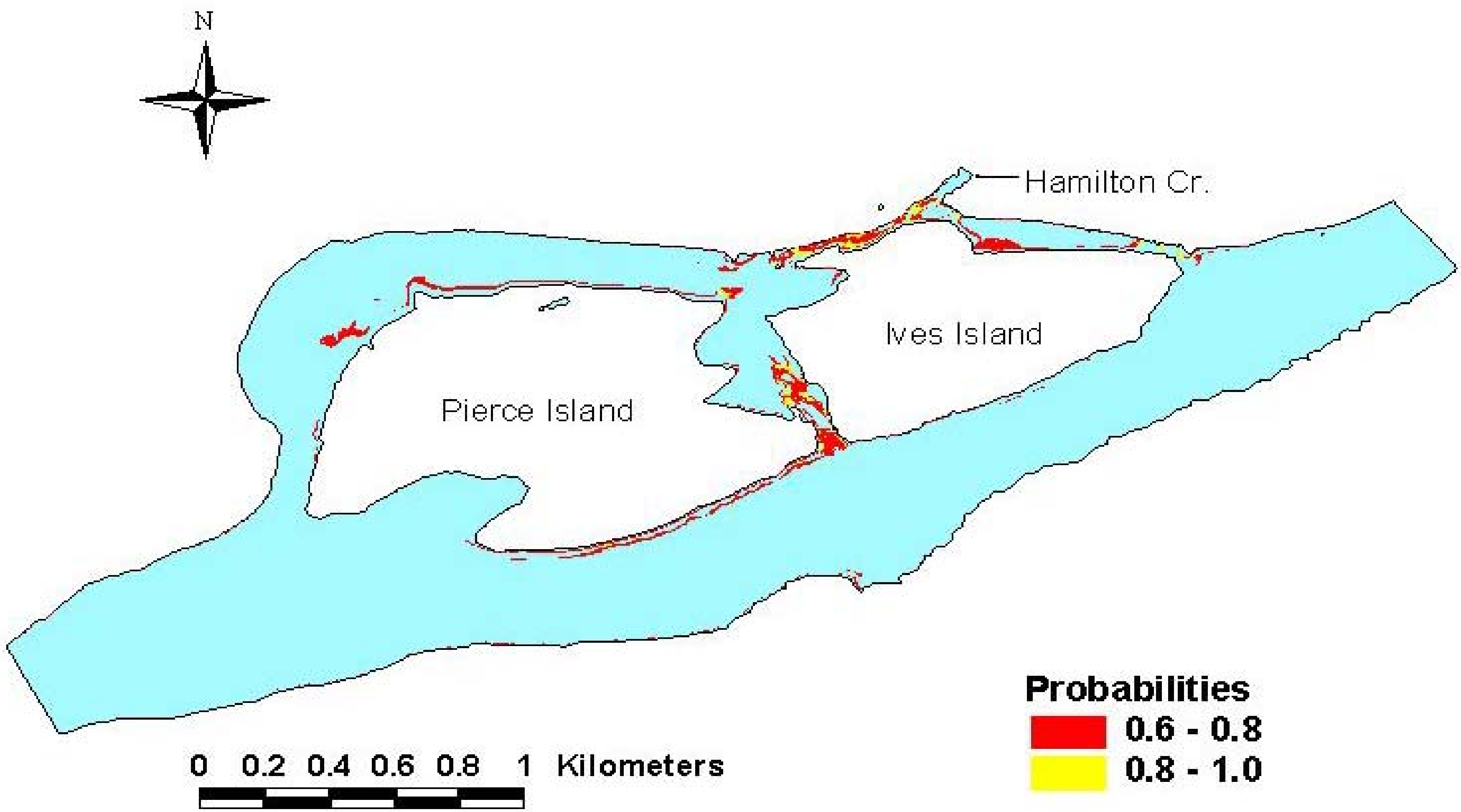
Appendix B.10 – Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 120 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.5 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



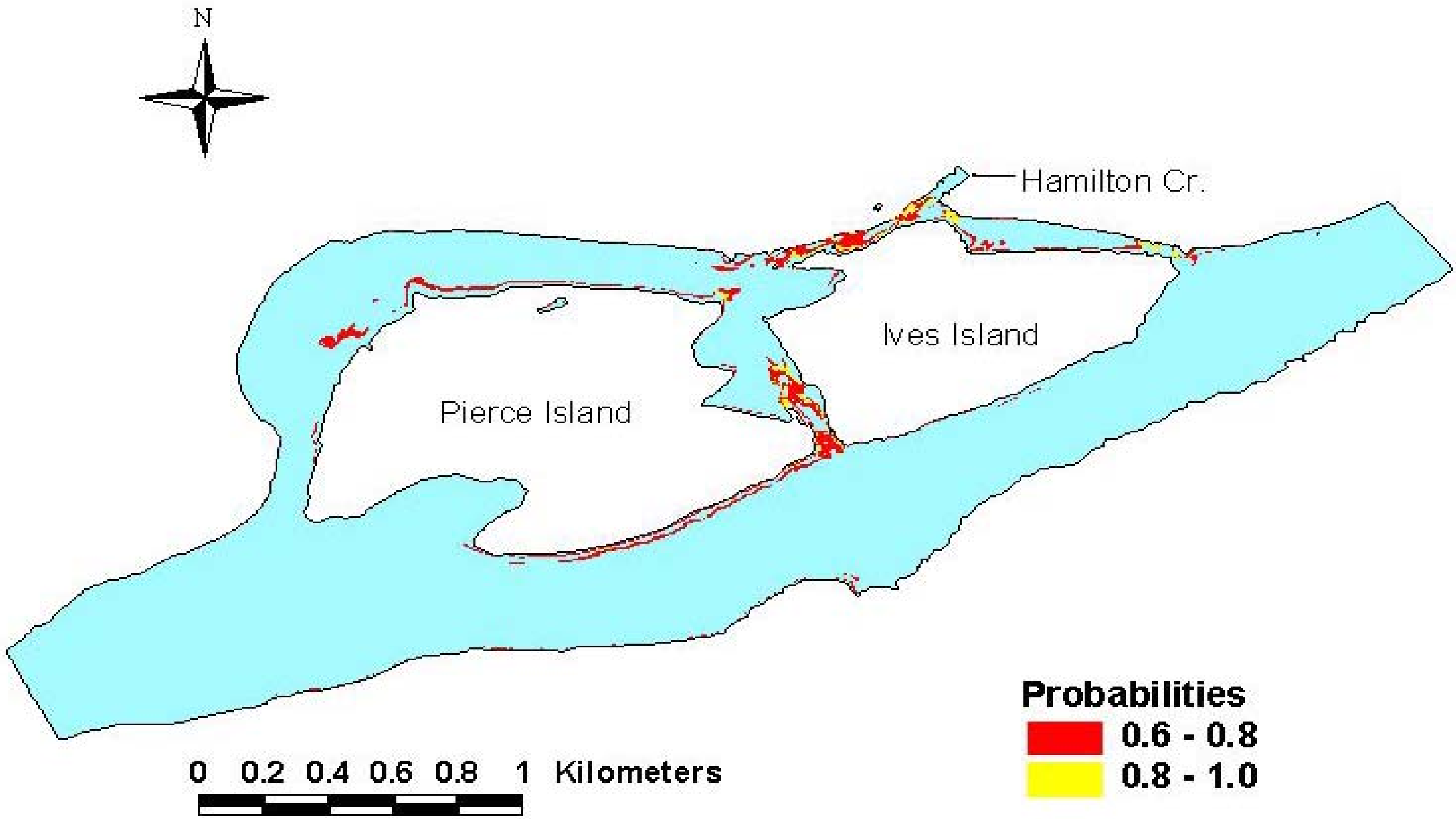
Appendix B.11 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs, Hamilton Creek discharge of 0 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



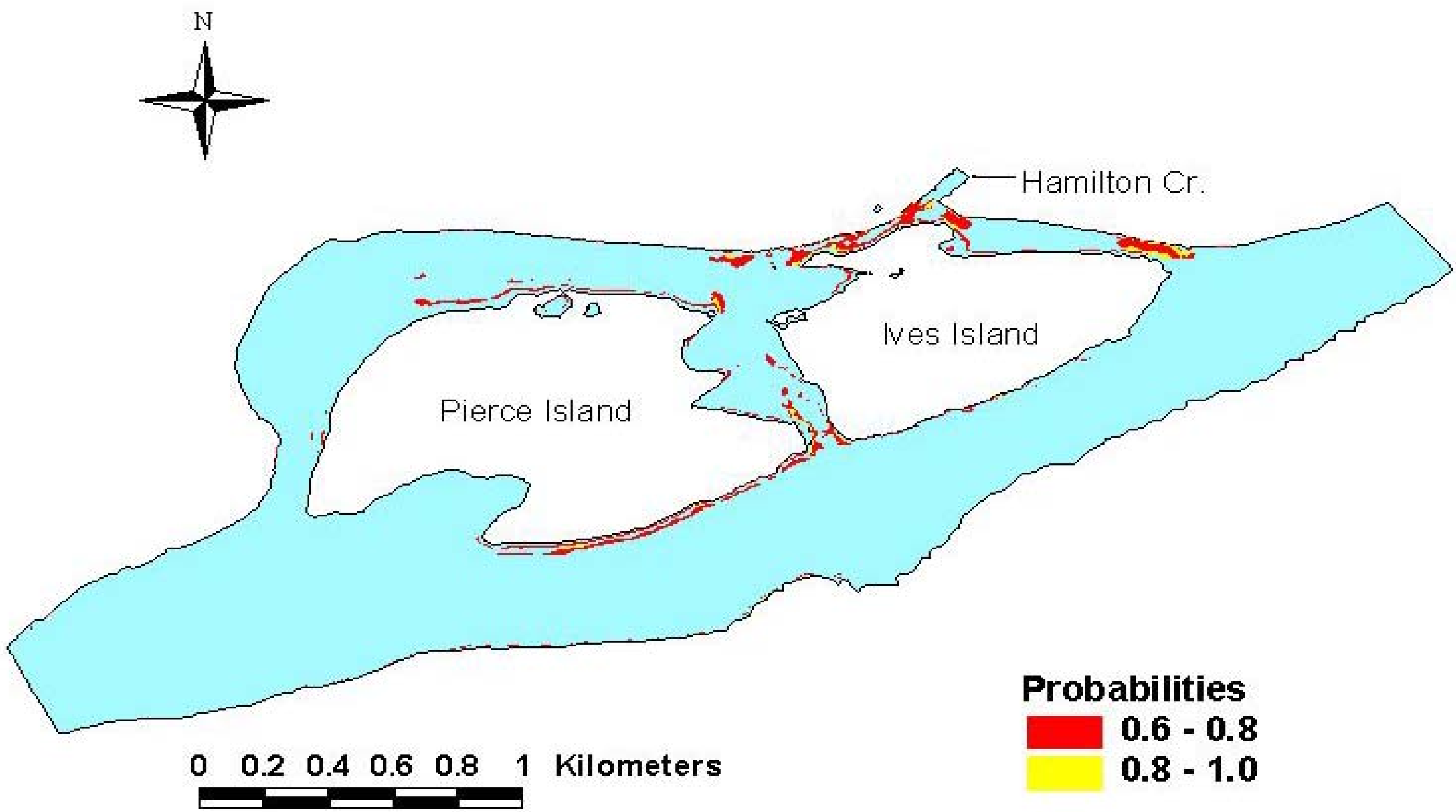
Appendix B.12 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs, Hamilton Creek discharge of 177 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



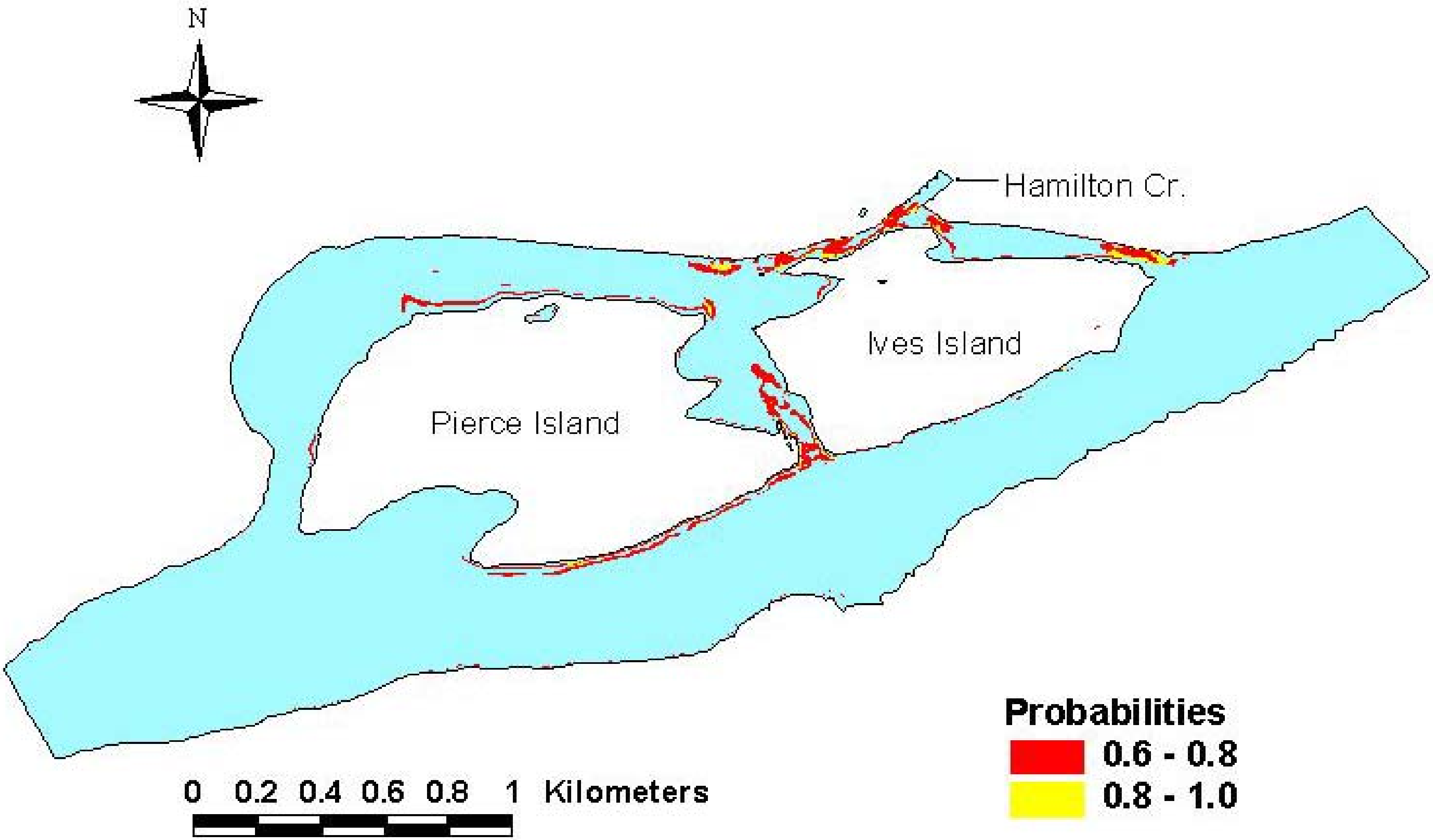
Appendix B.13 – Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



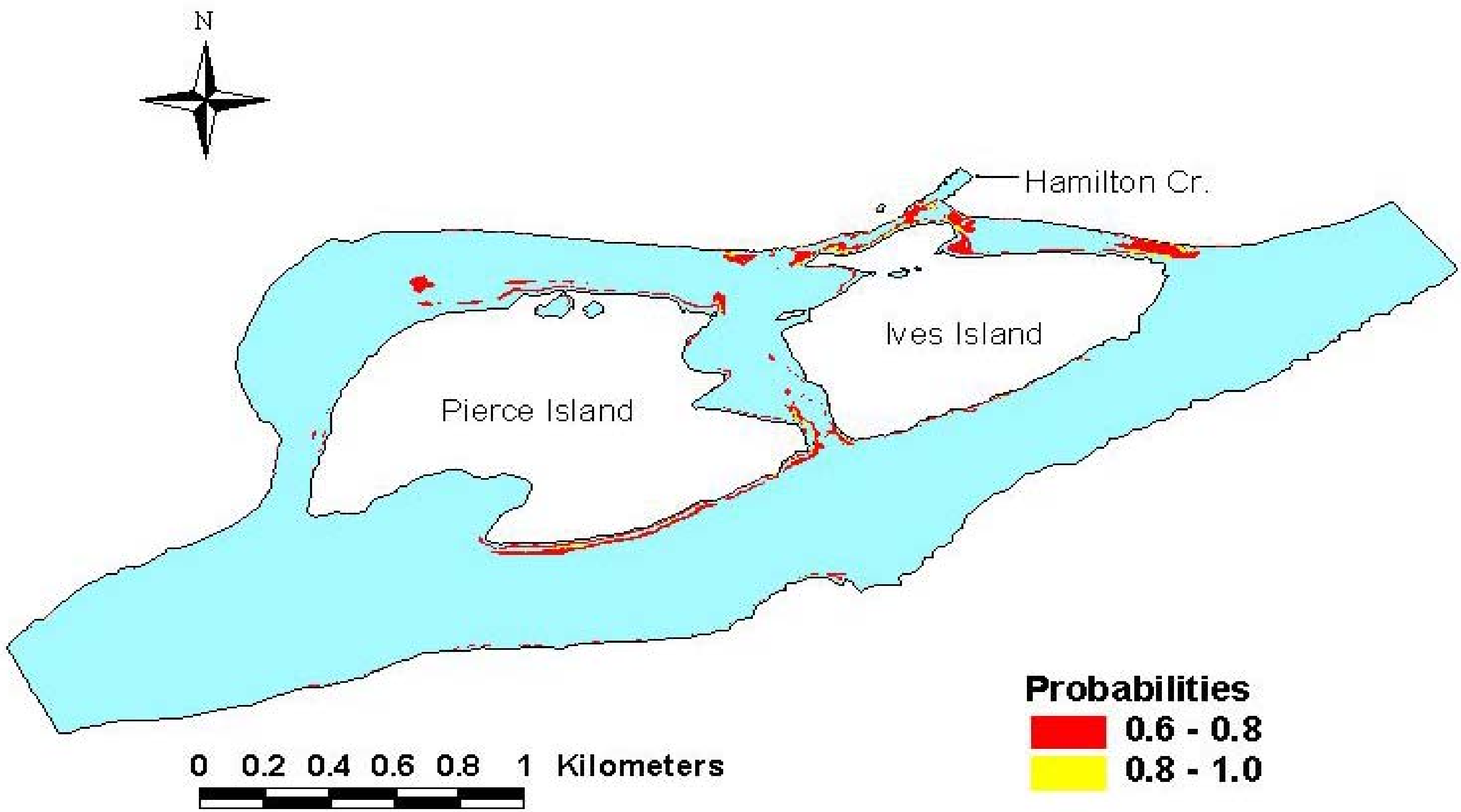
Appendix B.14 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.6 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



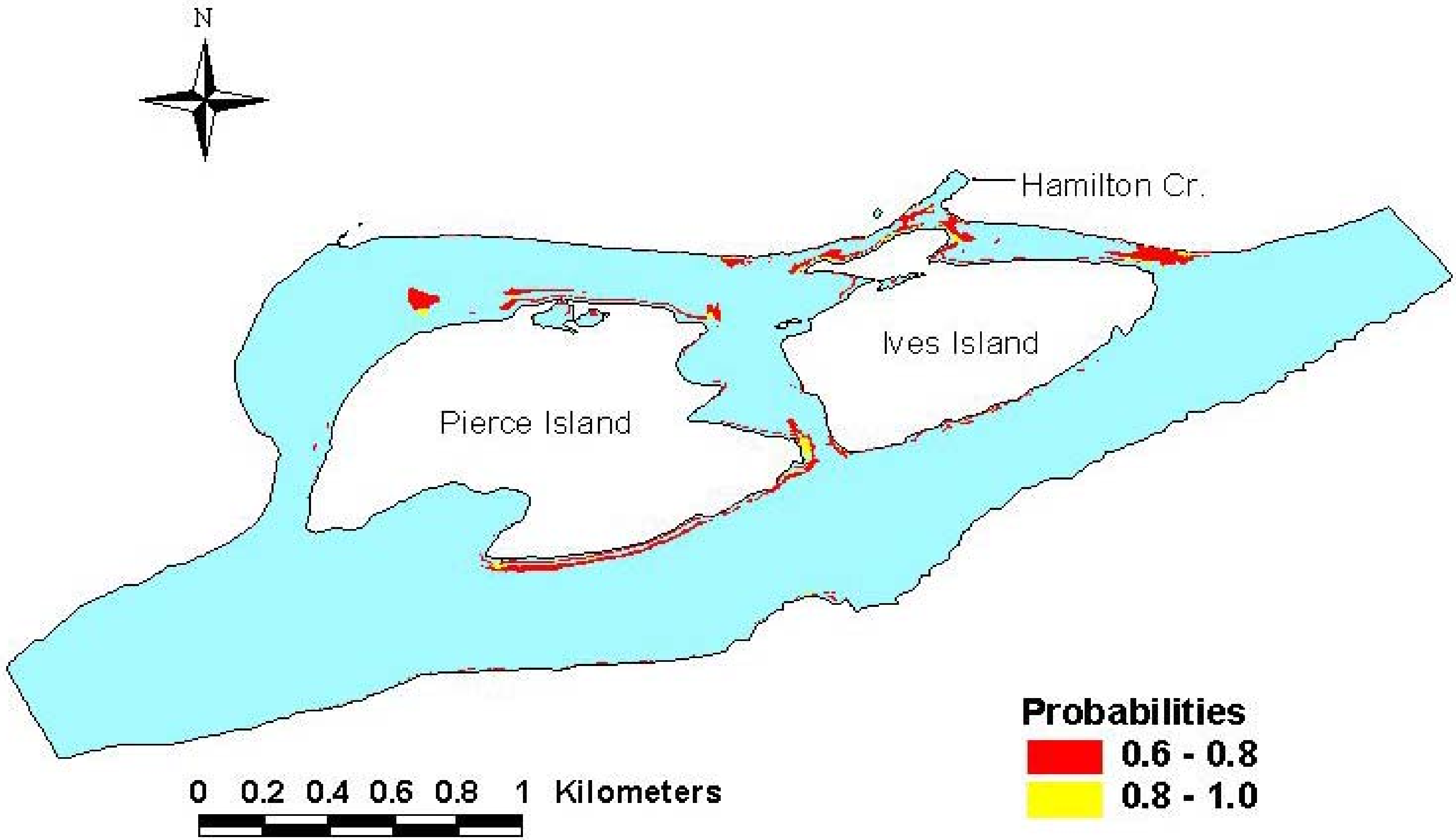
Appendix B.15 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 130 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.3 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



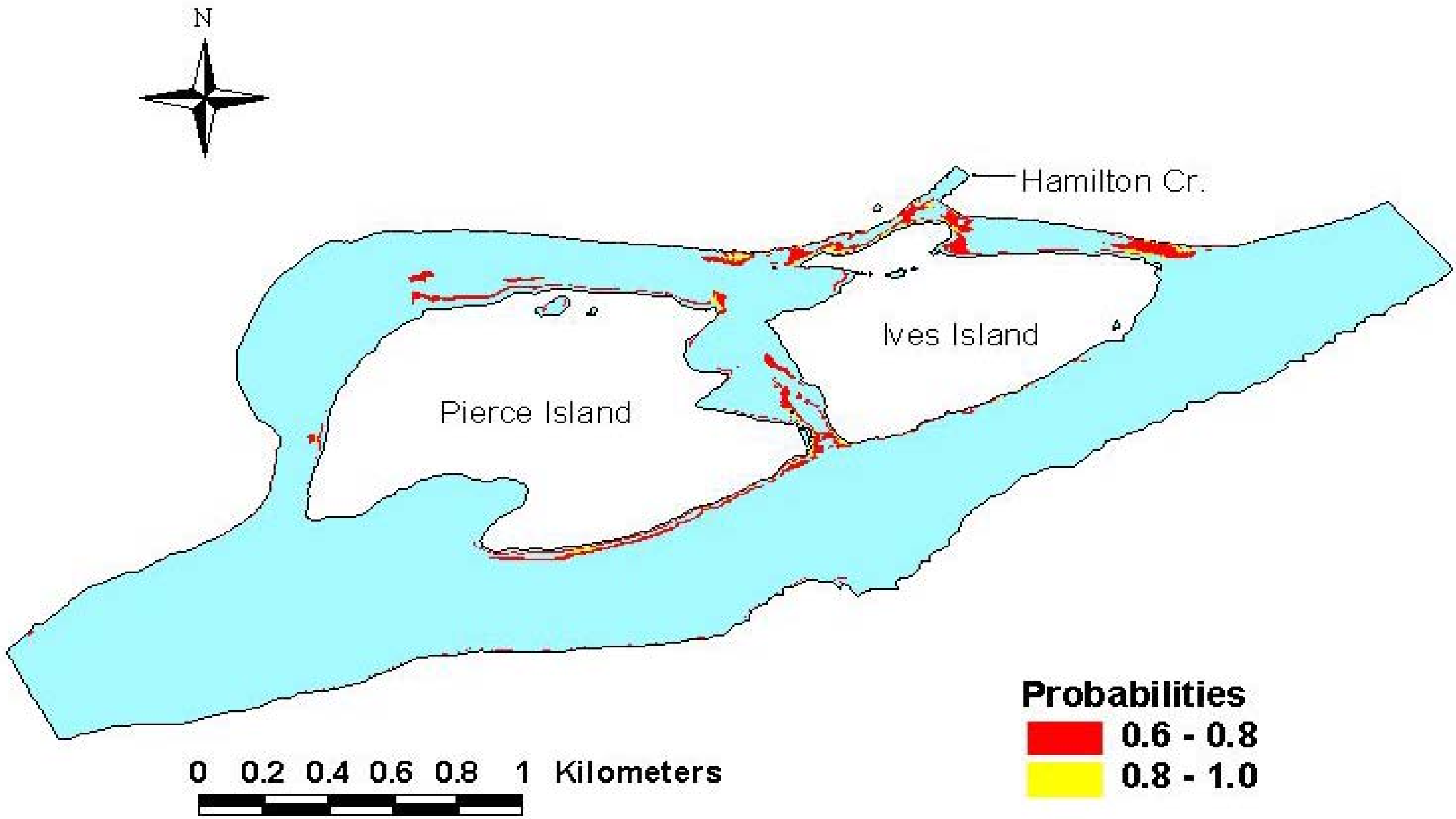
Appendix B.16 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 130 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.6 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



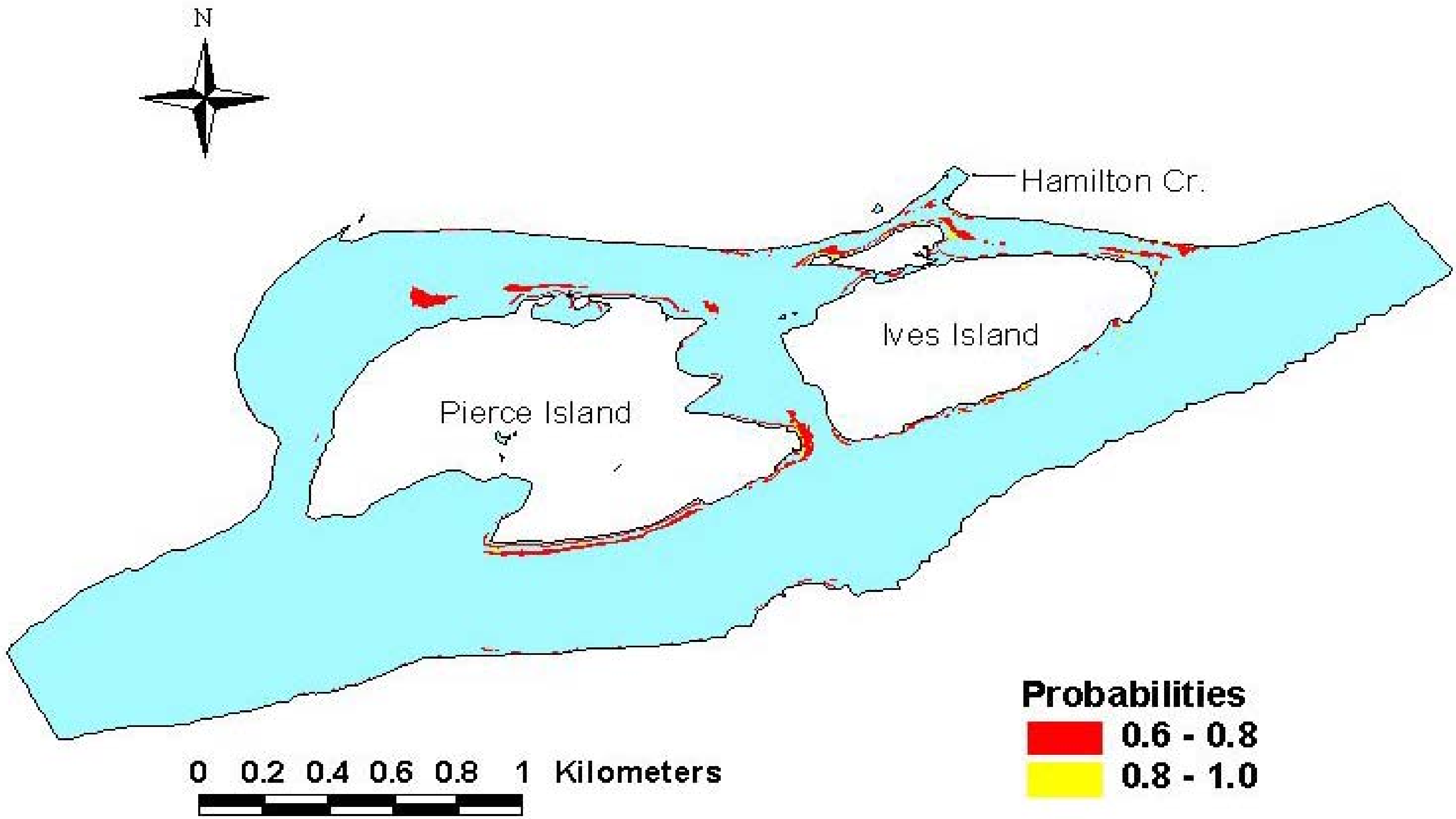
Appendix B.17 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 135 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.8 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



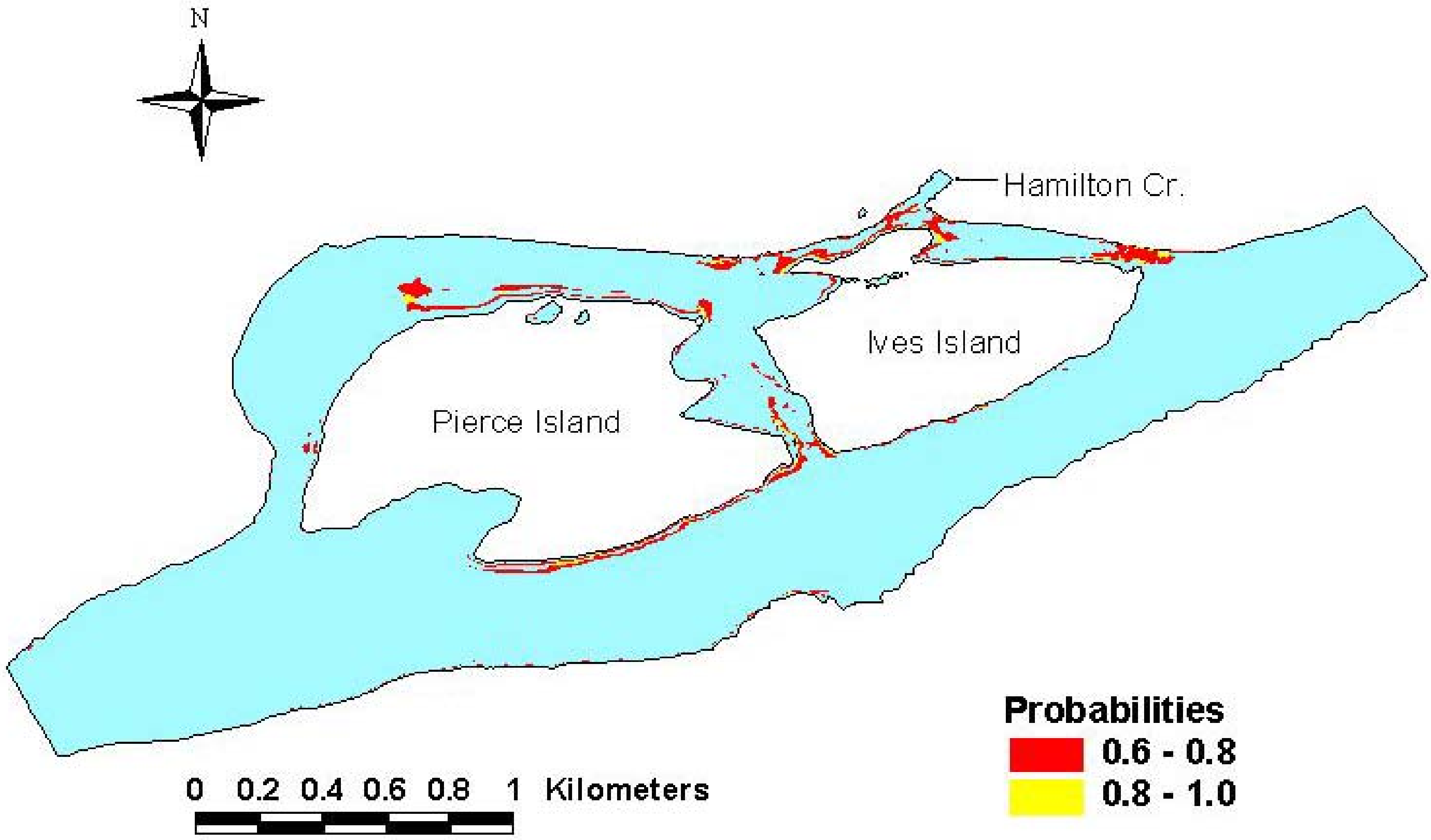
Appendix B.18 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 140 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.4 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



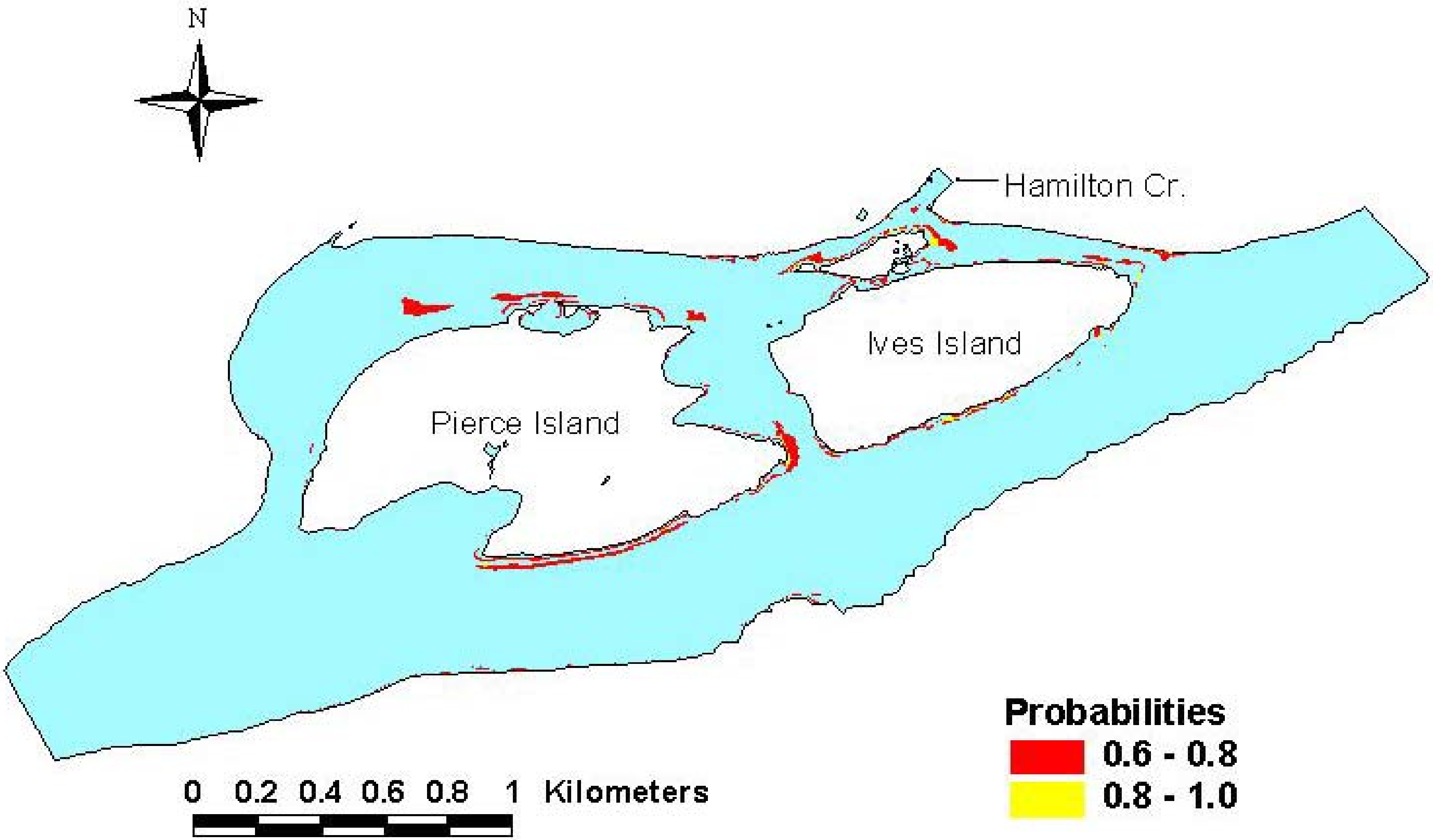
Appendix B.19 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 140 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.9 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



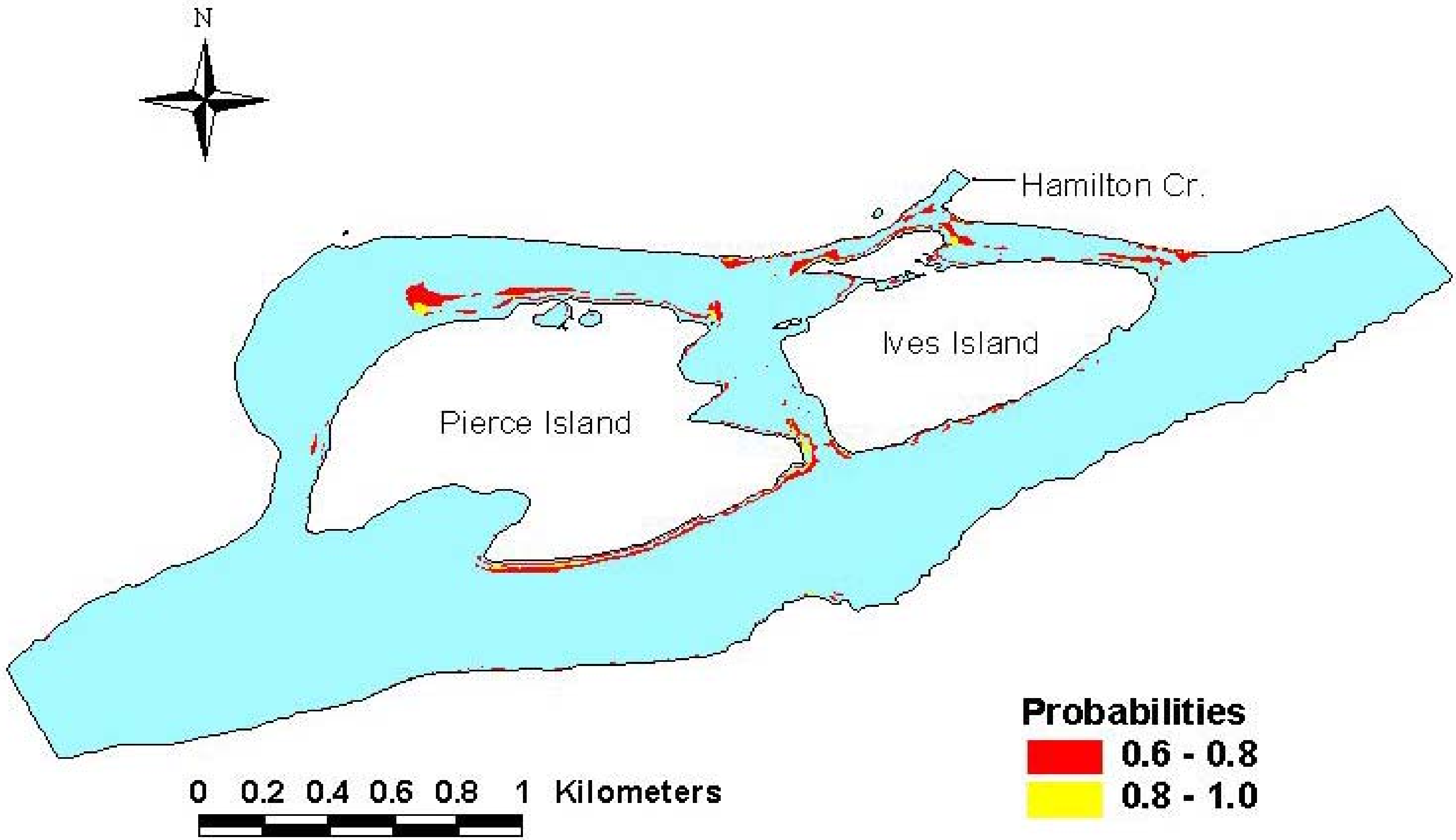
Appendix B.20 – Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 145 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.4 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



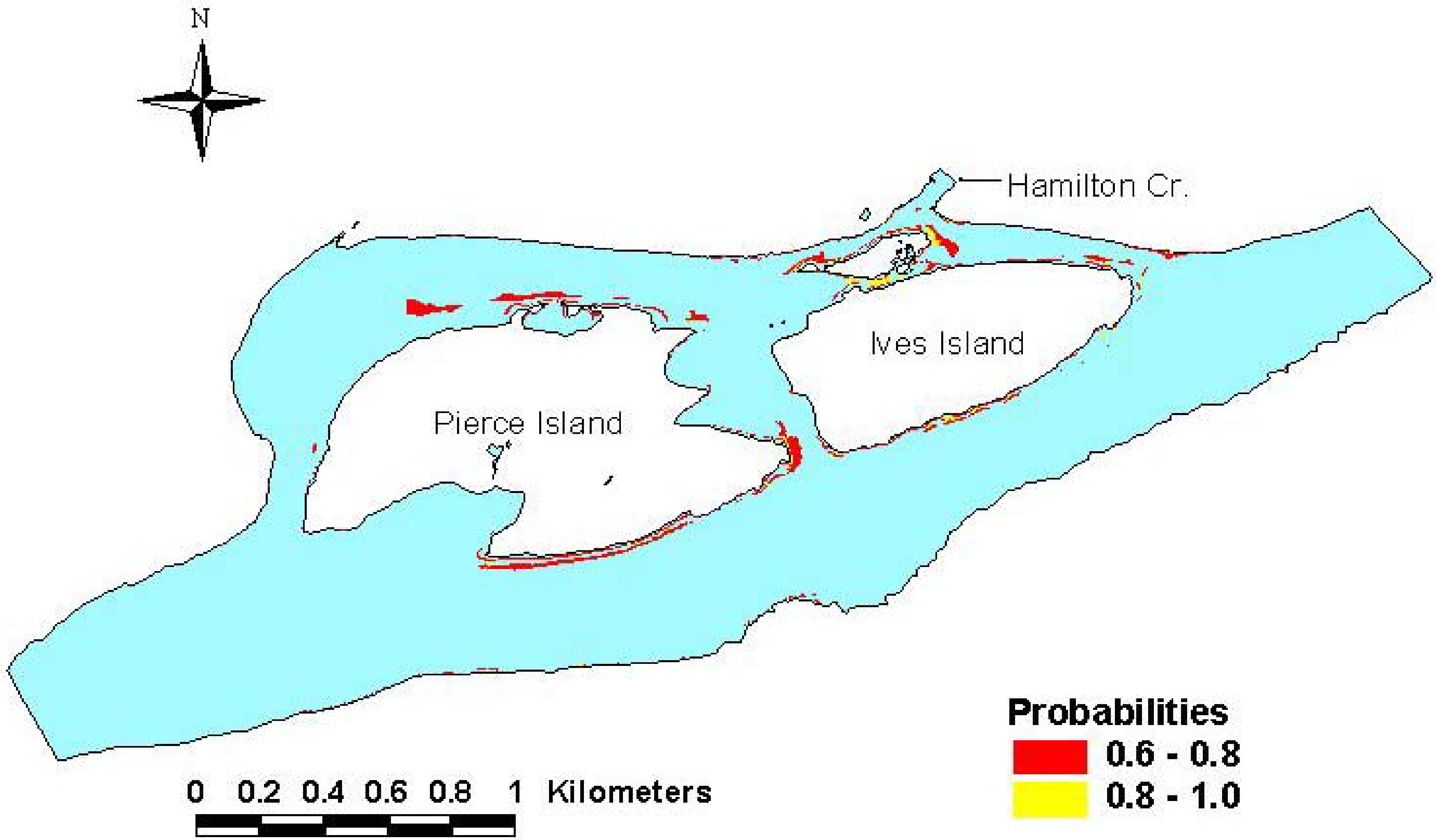
Appendix B.21 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 145 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 3.0 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



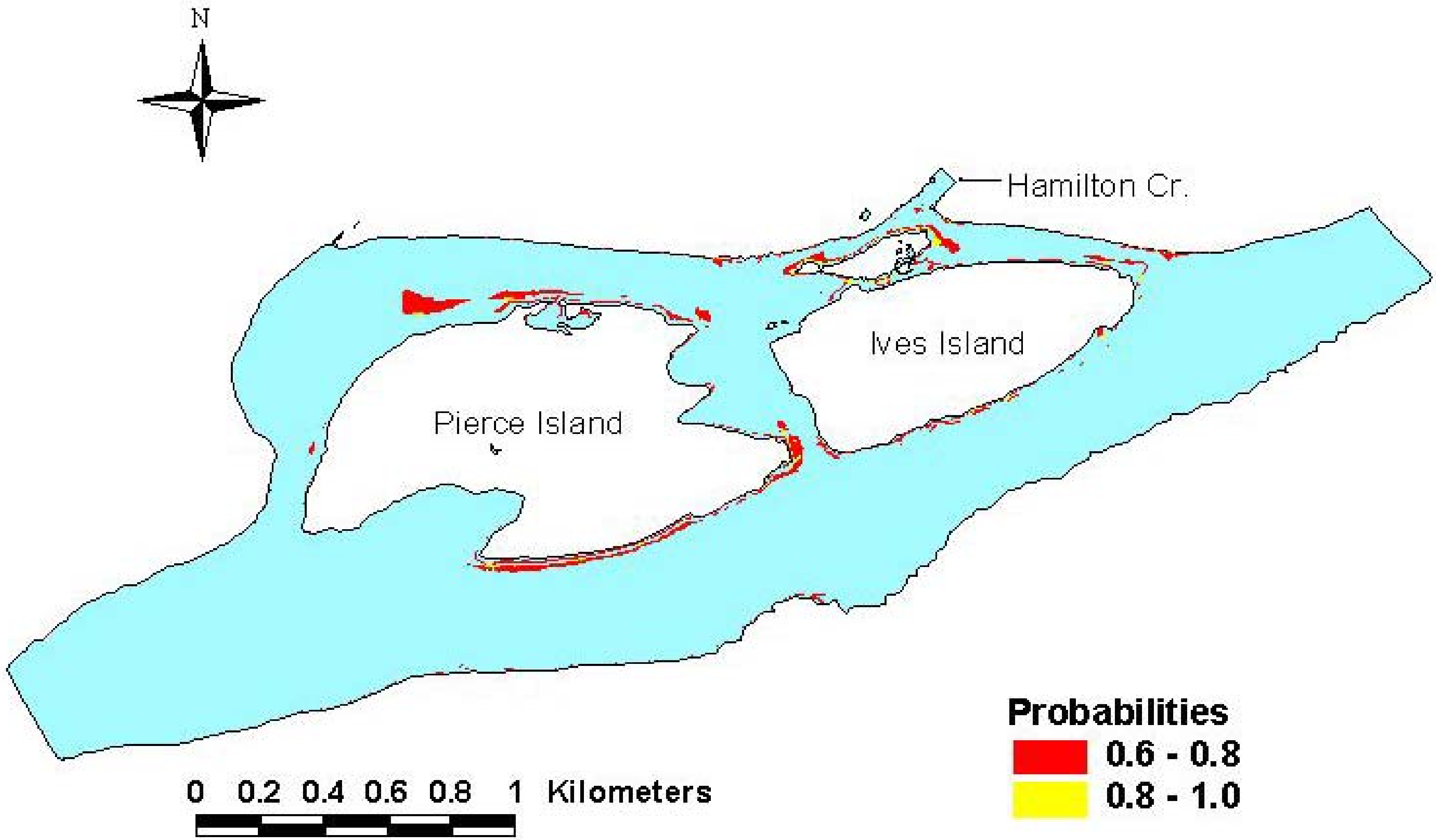
Appendix B.22 – Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 150 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.6 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



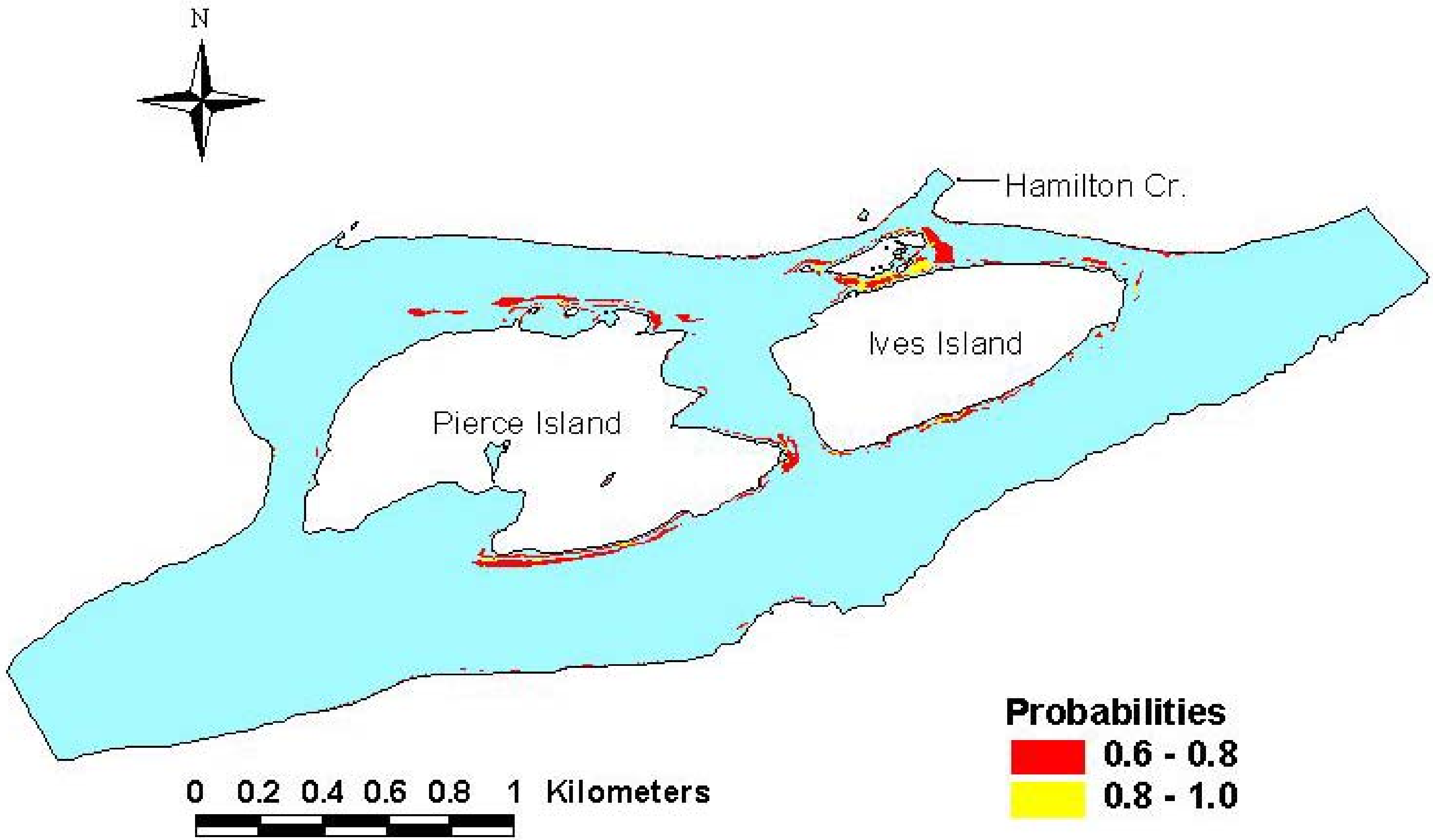
Appendix B.23 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 150 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 3.0 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



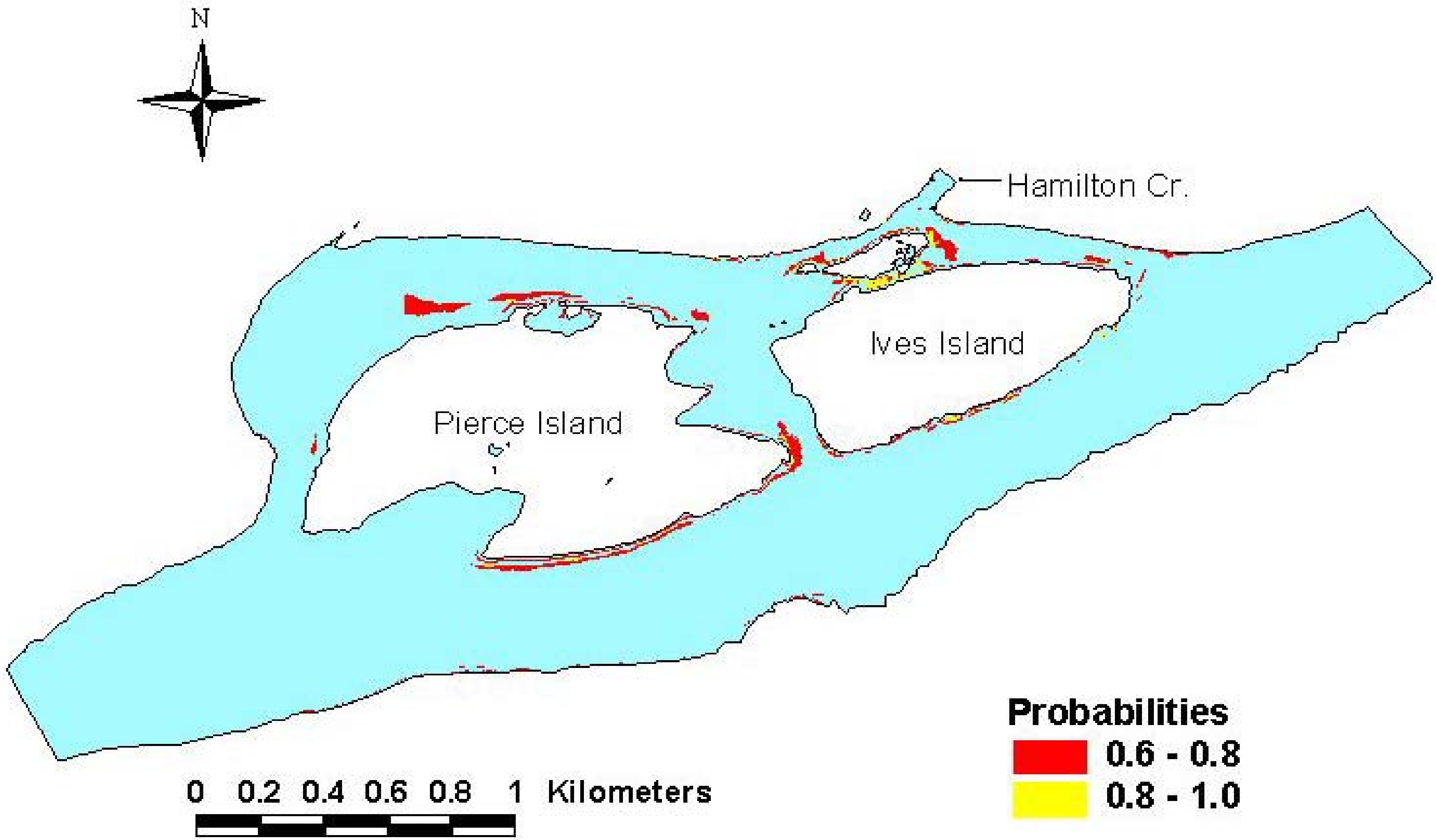
Appendix B.24 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 155 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.7 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



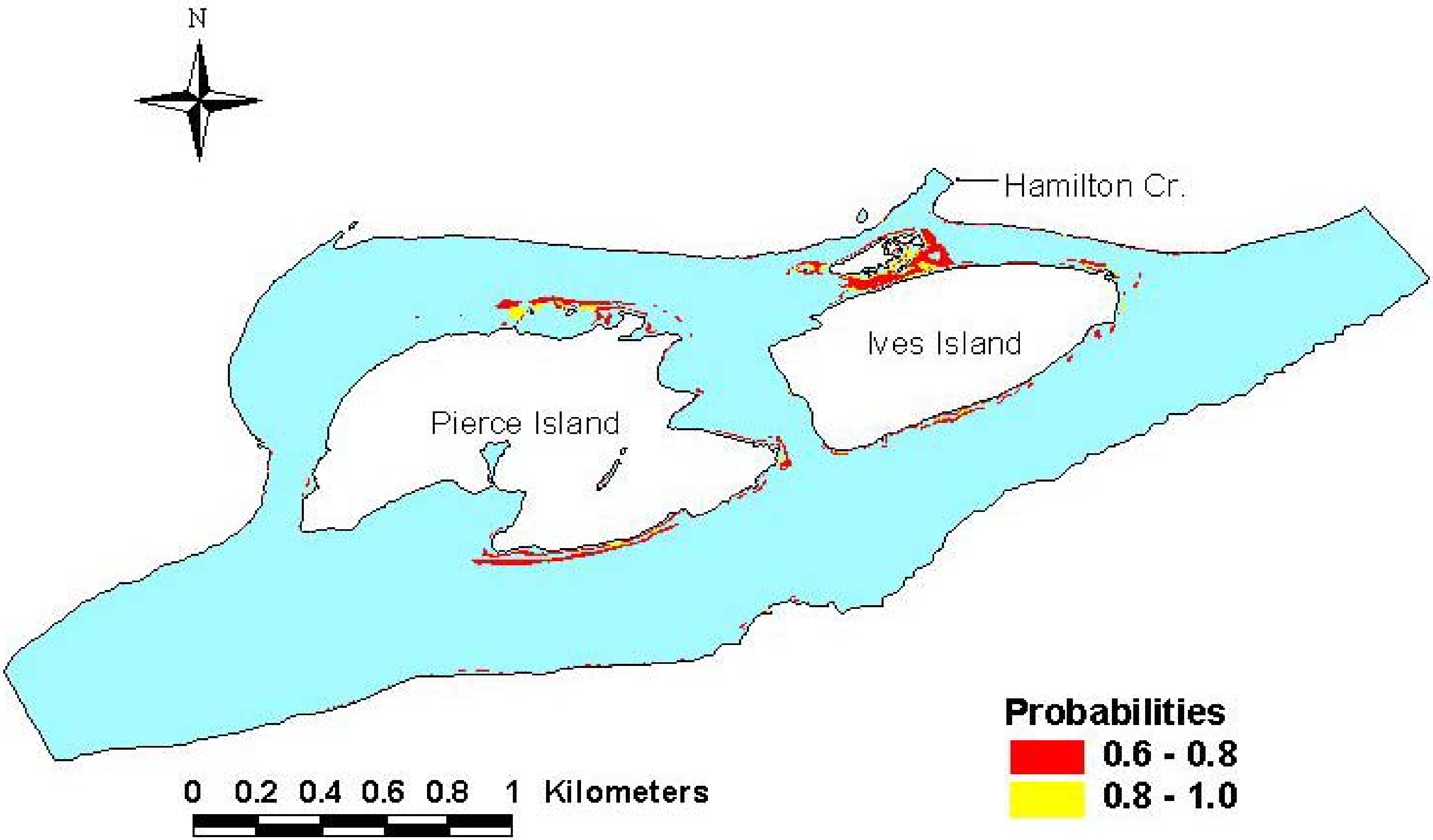
Appendix B.25 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 155 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 3.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



Appendix B.26 – Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 160 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.8 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



Appendix B.27 - Areas predicted to be suitable spawning habitat for chum salmon at Ives Island at a Bonneville Dam discharge of 160 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 3.3 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



APPENDIX C

Appendix C.1 - Chum salmon spawning total wetted area, total area of predicted chum salmon spawning area with a probability ≥0.6, and percentage of area suitable (probability ≥0.6) for spawning for each study section (SS) for different combinations of Columbia River discharges, Hamilton Creek discharges, and water surface elevations (WSE).

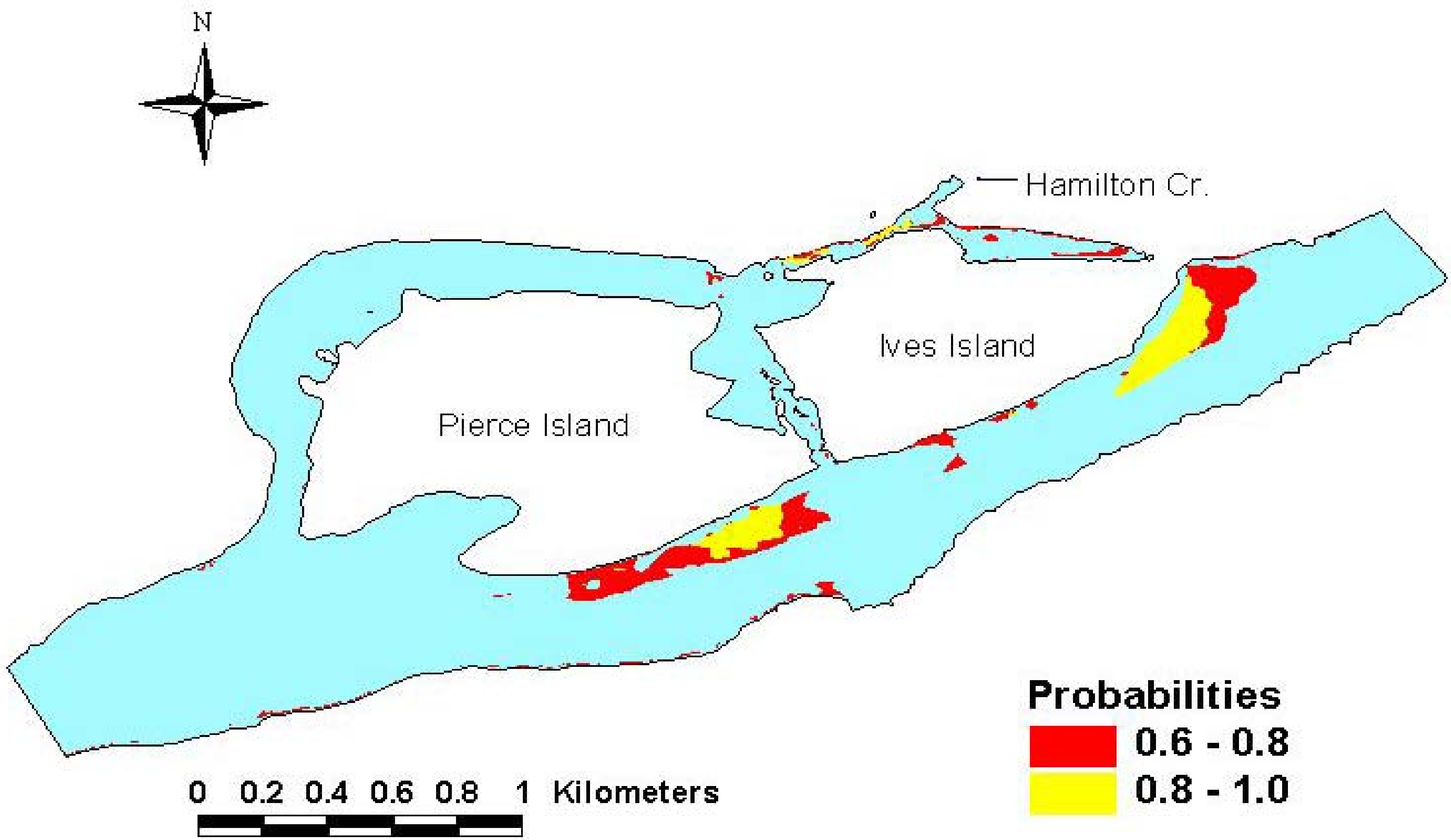
Columbia River Dis-Charge (kcfs)	Hamilton Creek Dis-charge (cfs)	Down-Stream WSE (m)	SS 1 Total Area (ha)	SS 1 Total Area ≥0.6 (ha)	SS 1 Percent ≥0.6	SS 2 Total Area (ha)	SS 2 Total Area ≥0.6 (ha)	SS 2 Percent ≥0.6	SS 3 Total Area (ha)	SS 3 Total Area ≥0.6 (ha)	SS 3 Percent ≥0.6	SS 4 Total Area (ha)	SS 4 Total Area ≥0.6 (ha)	SS 4 Percent ≥0.6	SS 5 Total Area (ha)	SS 5 Total Area ≥0.6 (ha)	SS 5 Percent ≥0.6	SS 6 Total Area (ha)	SS 6 Total Area ≥0.6 (ha)	SS 6 Percent ≥0.6
115	388	2.5	5.1	0.5	10.6	6.0	1.5	24.8	0.0	0.0	0.0	165.5	2.0	1.2	14.9	2.0	13.2	38.9	0.8	2.0
115	353	2.5	5.0	0.6	11.6	5.9	1.5	25.0	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.9	13.1	38.9	0.8	2.0
115	318	2.5	4.9	0.6	12.8	5.9	1.5	25.3	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.9	12.9	38.9	0.8	2.0
115	282	2.5	4.9	0.7	14.1	5.8	1.5	25.7	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.9	12.7	38.9	0.8	2.0
115	247	2.5	4.8	0.7	15.3	5.7	1.5	25.9	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.9	12.4	38.9	0.8	2.0
115	212	2.5	4.7	0.8	16.1	5.7	1.5	25.9	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.8	12.3	38.9	0.8	2.0
115	177	2.5	4.6	0.7	15.3	5.6	1.4	25.3	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.8	12.1	38.9	0.8	2.0
115	141	2.5	4.6	0.6	14.0	5.5	1.3	24.3	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.8	11.9	38.9	0.8	2.0
115	106	2.5	4.5	0.6	12.7	5.4	1.2	22.3	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.7	11.7	38.9	0.8	2.0
115	71	2.5	4.4	0.5	11.9	5.3	1.0	19.2	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.7	11.5	38.9	0.8	2.0
115	35	2.5	4.6	0.7	15.3	5.6	1.4	25.3	0.0	0.0	0.0	165.5	2.0	1.2	14.9	1.8	12.1	38.9	0.8	2.0
115	0	2.5	4.4	0.5	11.8	4.4	0.4	9.0	0.0	0.0	0.0	165.5	1.9	1.2	14.9	1.7	11.5	38.9	0.8	2.0
115	388	2.1	5.0	0.5	10.9	5.3	1.5	28.1	0.0	0.0	0.0	159.1	2.1	1.3	12.1	1.0	8.6	32.9	1.3	3.9
115	353	2.1	4.9	0.6	12.1	5.3	1.5	28.2	0.0	0.0	0.0	159.1	2.1	1.3	12.1	1.0	8.1	32.8	1.3	3.9
115	318	2.1	4.8	0.6	13.5	5.2	1.5	28.5	0.0	0.0	0.0	159.1	2.1	1.3	12.1	0.9	7.6	32.8	1.3	3.9
115	282	2.1	4.7	0.7	15.0	5.1	1.5	28.5	0.0	0.0	0.0	159.1	2.1	1.3	12.1	0.9	7.3	32.8	1.3	3.9
115	247	2.1	4.5	0.7	16.6	5.1	1.4	28.4	0.0	0.0	0.0	159.1	2.1	1.3	12.1	0.9	7.2	32.8	1.3	3.9
115	212	2.1	4.4	0.7	16.9	5.0	1.4	28.1	0.0	0.0	0.0	159.1	2.1	1.3	12.1	0.9	7.1	32.8	1.3	3.9
115	177	2.1	4.3	0.7	15.6	4.9	1.3	27.5	0.0	0.0	0.0	159.1	2.1	1.3	12.1	0.9	7.1	32.8	1.3	3.9
115	141	2.1	4.2	0.6	14.0	4.8	1.3	26.3	0.0	0.0	0.0	159.0	2.1	1.3	12.1	0.8	7.0	32.8	1.3	3.9
115	106	2.1	4.1	0.5	12.8	4.7	1.1	23.9	0.0	0.0	0.0	159.2	2.1	1.3	12.1	0.8	7.0	32.8	1.3	3.9
115	71	2.1	3.9	0.5	12.0	4.6	0.9	19.4	0.0	0.0	0.0	159.1	2.1	1.3	12.0	0.8	6.9	32.8	1.3	3.9
115	35	2.1	3.7	0.5	12.2	4.3	0.5	12.0	0.0	0.0	0.0	159.1	2.1	1.3	12.0	0.8	6.9	32.8	1.3	3.9
120	388	2.6	5.7	0.9	16.5	6.2	1.6	25.1	0.0	0.0	0.0	169.0	2.2	1.3	15.9	1.7	10.6	40.5	0.7	1.8
120	388	2.2	5.0	0.6	12.4	5.6	1.6	28.0	0.0	0.0	0.0	164.8	2.0	1.2	14.1	2.0	14.1	37.1	1.0	2.6
120	353	2.2	4.9	0.6	13.1	5.5	1.6	28.2	0.0	0.0	0.0	164.7	2.0	1.2	14.1	2.0	14.0	37.2	1.0	2.6
120	318	2.2	4.9	0.7	13.9	5.6	1.5	27.8	0.0	0.0	0.0	164.7	2.0	1.2	14.1	2.0	13.9	37.2	1.0	2.6

Appendix C.1 – Continued.

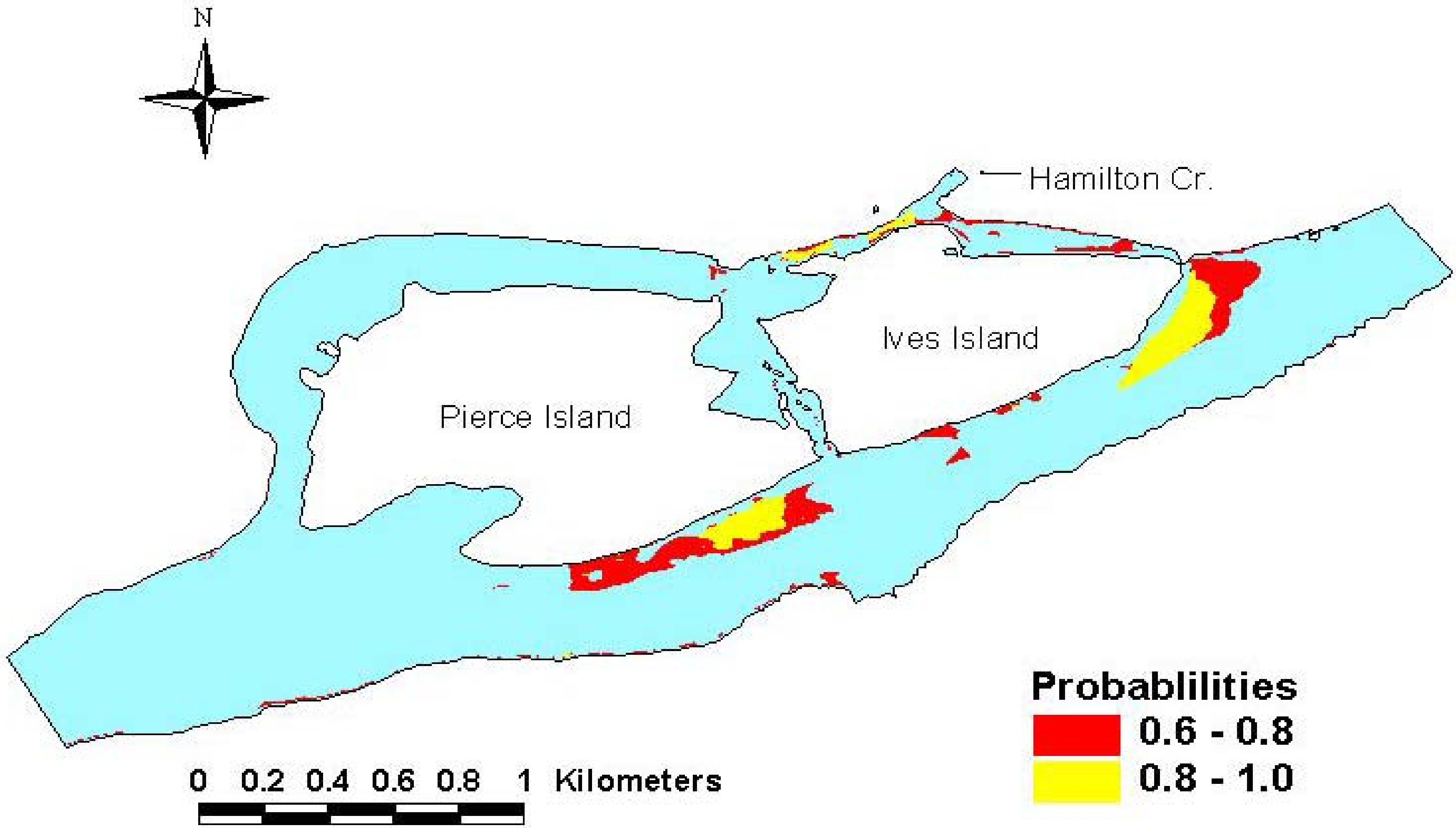
Columbia River Discharge (m^3/s)	Hamilton Creek Discharge (m^3/s)	Down-Stream WSE (m)	**SS 1** Total Area (ha)	**SS 1** Total Area ≥0.6 (ha)	**SS 1** Percent ≥0.6	**SS 2** Total Area (ha)	**SS 2** Total Area ≥0.6 (ha)	**SS 2** Percent ≥0.6	**SS 3** Total Area (ha)	**SS 3** Total Area ≥0.6 (ha)	**SS 3** Percent ≥0.6	**SS 4** Total Area (ha)	**SS 4** Total Area ≥0.6 (ha)	**SS 4** Percent ≥0.6	**SS 5** Total Area (ha)	**SS 5** Total Area ≥0.6 (ha)	**SS 5** Percent ≥0.6	**SS 6** Total Area (ha)	**SS 6** Total Area ≥0.6 (ha)	**SS 6** Percent ≥0.6
120	282	2.2	4.8	0.7	15.1	5.5	1.5	28.1	0.0	0.0	0.0	164.7	2.0	1.2	14.1	1.9	13.6	37.2	1.0	2.6
120	247	2.2	4.8	0.8	15.9	5.4	1.5	27.8	0.0	0.0	0.0	164.7	2.0	1.2	14.1	1.9	13.4	37.2	1.0	2.6
120	212	2.2	4.7	0.8	16.4	5.4	1.5	27.3	0.0	0.0	0.0	164.7	2.0	1.2	14.1	1.9	13.2	37.2	1.0	2.6
120	177	2.2	4.7	0.8	16.3	5.3	1.4	26.5	0.0	0.0	0.0	164.7	2.0	1.2	14.1	1.8	13.1	37.2	1.0	2.6
120	141	2.2	4.6	0.7	15.6	5.2	1.3	25.0	0.0	0.0	0.0	164.7	2.0	1.2	14.1	1.8	13.0	37.2	1.0	2.6
120	106	2.2	4.6	0.7	14.7	5.1	1.2	22.6	0.0	0.0	0.0	164.7	2.0	1.2	14.1	1.8	12.8	37.1	1.0	2.6
120	71	2.2	4.6	0.6	14.2	5.0	1.0	19.8	0.0	0.0	0.0	164.7	2.0	1.2	14.1	1.8	12.7	37.1	1.0	2.6
120	35	2.2	4.6	0.7	14.2	4.9	0.7	15.0	0.0	0.0	0.0	164.7	2.0	1.2	14.0	1.8	12.5	37.1	1.0	2.6
120	0	2.2	4.6	0.6	14.0	4.5	0.4	9.2	0.0	0.0	0.0	164.7	2.0	1.2	14.0	1.7	12.4	37.1	1.0	2.6
125	388	2.7	6.0	1.3	20.8	6.4	1.5	23.0	0.0	0.0	0.0	170.2	2.3	1.3	16.6	1.4	8.1	41.2	0.7	1.8
125	388	2.1	5.0	0.7	13.2	5.6	1.5	27.5	0.0	0.0	0.0	164.6	2.1	1.3	13.9	1.9	13.9	36.8	1.2	3.3
125	177	2.1	4.8	0.8	16.7	5.3	1.4	27.2	0.0	0.0	0.0	164.6	2.1	1.3	13.9	1.9	13.7	36.8	1.2	3.3
125	0	2.1	4.7	0.8	16.9	4.6	0.6	11.9	0.0	0.0	0.0	164.6	2.1	1.3	13.9	1.8	12.9	36.8	1.2	3.3
130	388	2.7	6.3	1.5	24.0	6.6	1.3	20.0	0.0	0.0	0.0	171.1	2.4	1.4	17.0	1.2	7.2	42.1	1.0	2.3
130	388	2.4	5.8	1.1	18.4	6.1	1.6	26.5	0.0	0.0	0.0	168.2	2.1	1.3	15.2	2.0	12.9	39.1	0.8	2.0
135	388	2.8	6.8	1.4	20.2	7.0	1.1	15.2	0.0	0.0	26.1	173.1	2.5	1.4	17.7	1.1	6.4	43.6	1.2	2.8
140	388	3.0	7.3	1.0	13.5	7.6	0.9	11.2	0.5	0.1	13.3	175.3	2.4	1.4	18.6	0.9	4.9	45.2	1.2	2.7
140	388	2.4	6.4	1.5	24.0	6.3	1.4	21.3	0.0	0.0	0.0	169.3	2.3	1.4	15.7	1.7	10.9	39.8	1.1	2.7
145	388	3.0	7.5	0.9	11.8	7.8	0.8	9.7	0.8	0.1	14.8	176.0	2.4	1.4	18.9	0.9	4.6	45.7	1.2	2.7
145	388	2.5	6.7	1.3	20.1	6.6	1.2	18.2	0.0	0.0	28.3	170.2	2.4	1.4	16.2	1.4	8.4	40.6	1.5	3.8
150	388	3.0	7.6	0.9	11.7	7.9	0.7	9.3	1.0	0.2	24.4	176.3	2.4	1.4	19.0	0.9	4.5	45.8	1.3	2.9
150	388	2.6	7.2	1.0	14.6	7.0	1.0	14.4	0.1	0.0	18.1	172.5	2.6	1.5	17.3	1.2	6.8	42.3	1.7	4.1
155	388	3.2	7.9	1.0	12.8	8.4	0.8	9.4	1.2	0.6	51.3	178.3	2.6	1.4	19.9	0.7	3.6	47.4	1.2	2.4
155	388	2.8	7.5	0.9	11.7	7.6	0.8	10.8	0.8	0.1	17.4	174.4	2.5	1.4	18.1	1.0	5.7	44.2	1.8	4.0
160	388	3.3	8.2	1.1	13.6	8.9	0.9	9.7	1.6	0.9	60.1	180.1	2.4	1.3	20.6	0.5	2.2	48.7	1.3	2.7
160	388	2.8	7.7	0.9	11.8	7.9	0.8	10.0	1.1	0.4	37.0	175.7	2.4	1.4	18.7	0.9	5.0	45.1	1.6	3.6

APPENDIX D

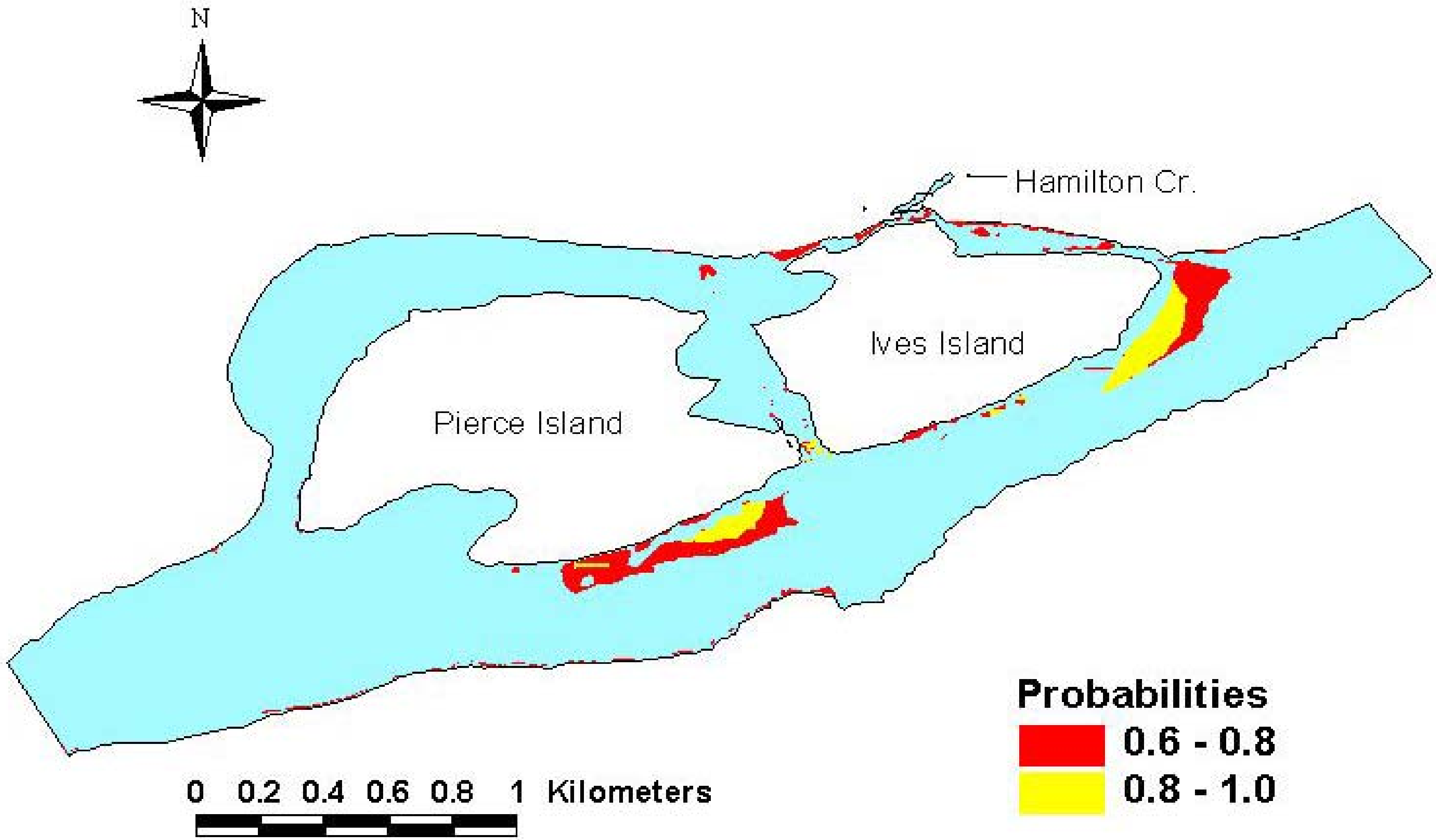
Appendix D.1 – Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 177 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



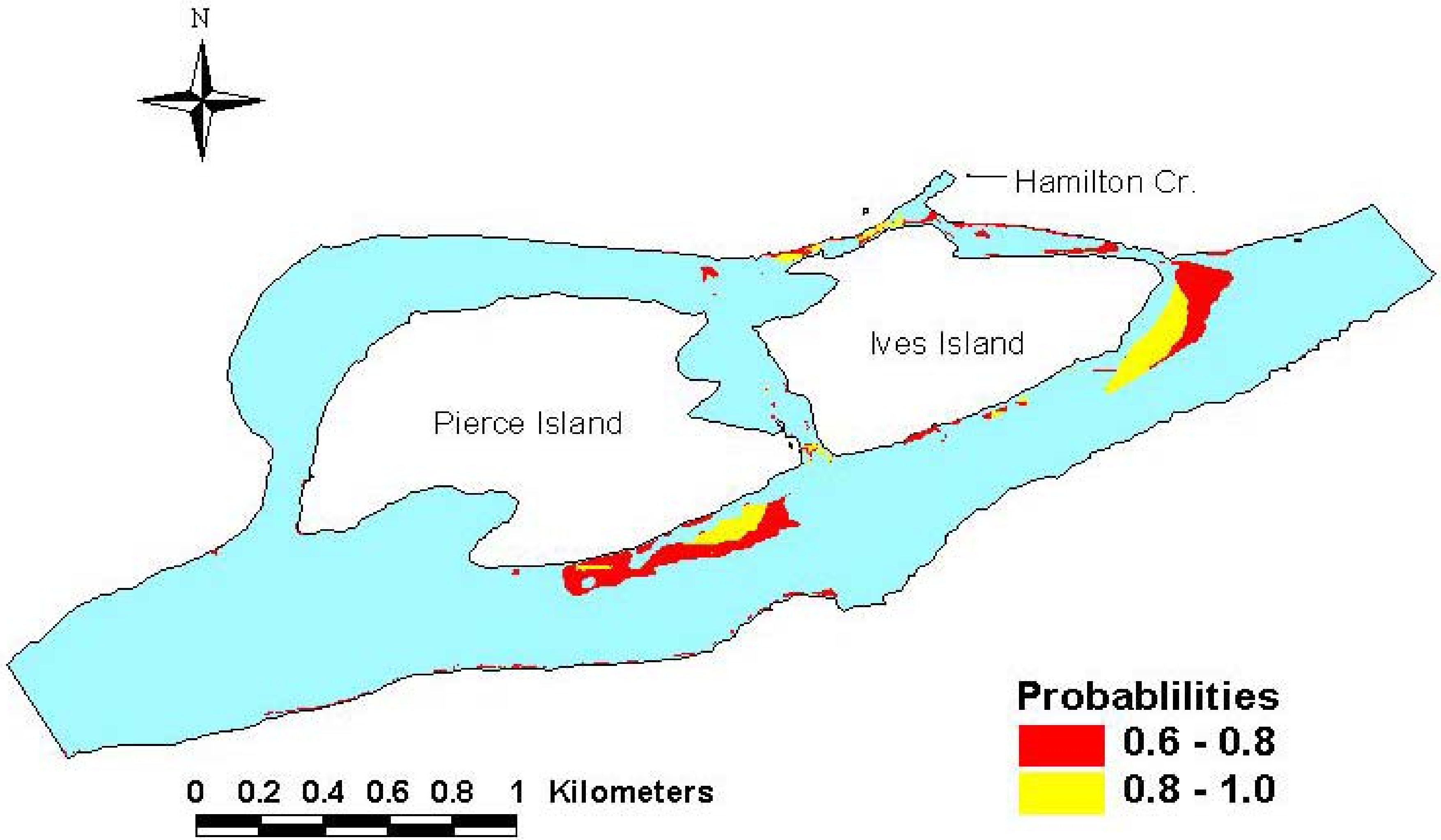
Appendix D.2 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



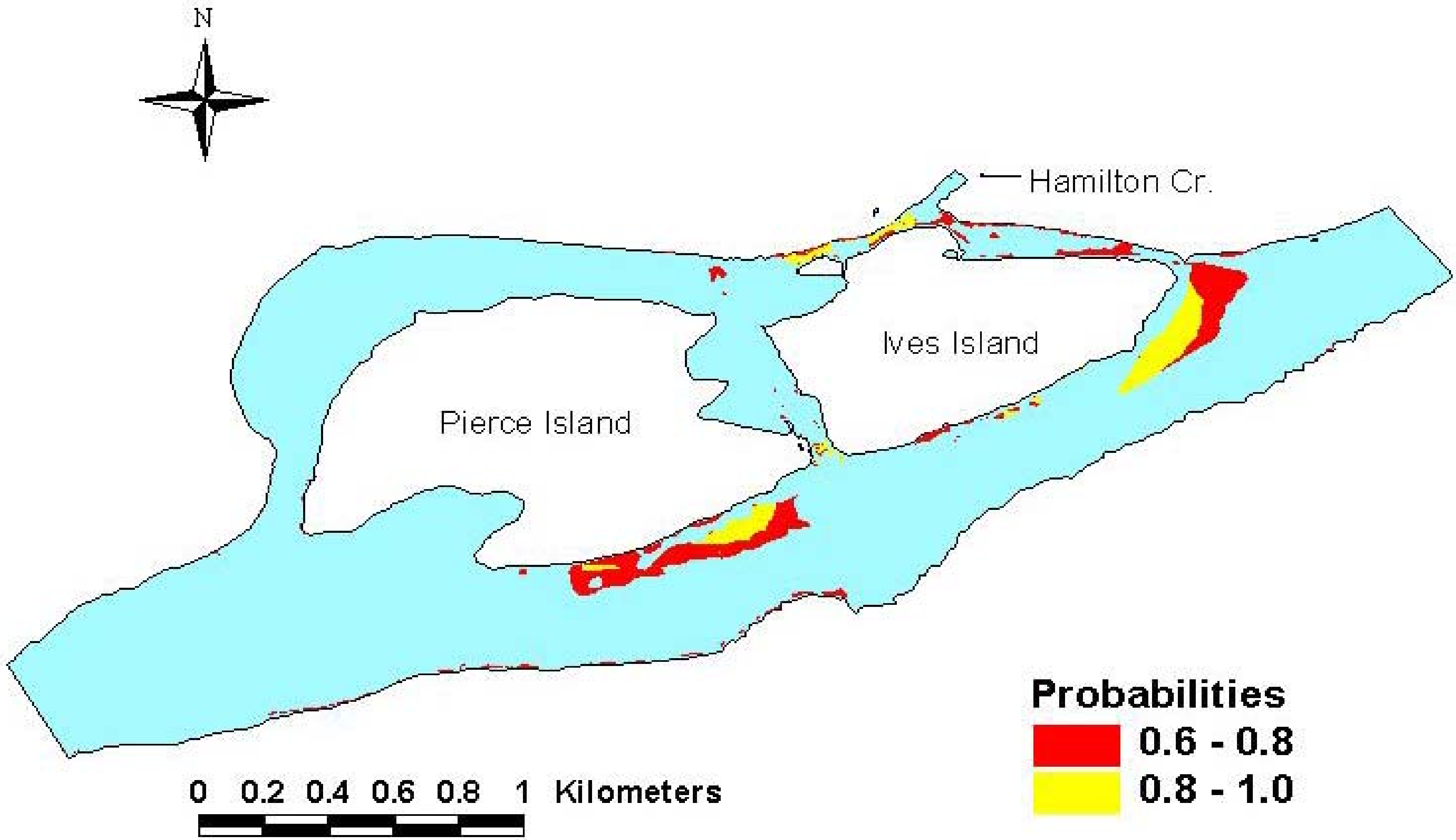
Appendix D.3 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 0 cfs, and an average Warrendale water surface elevation of 2.5 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



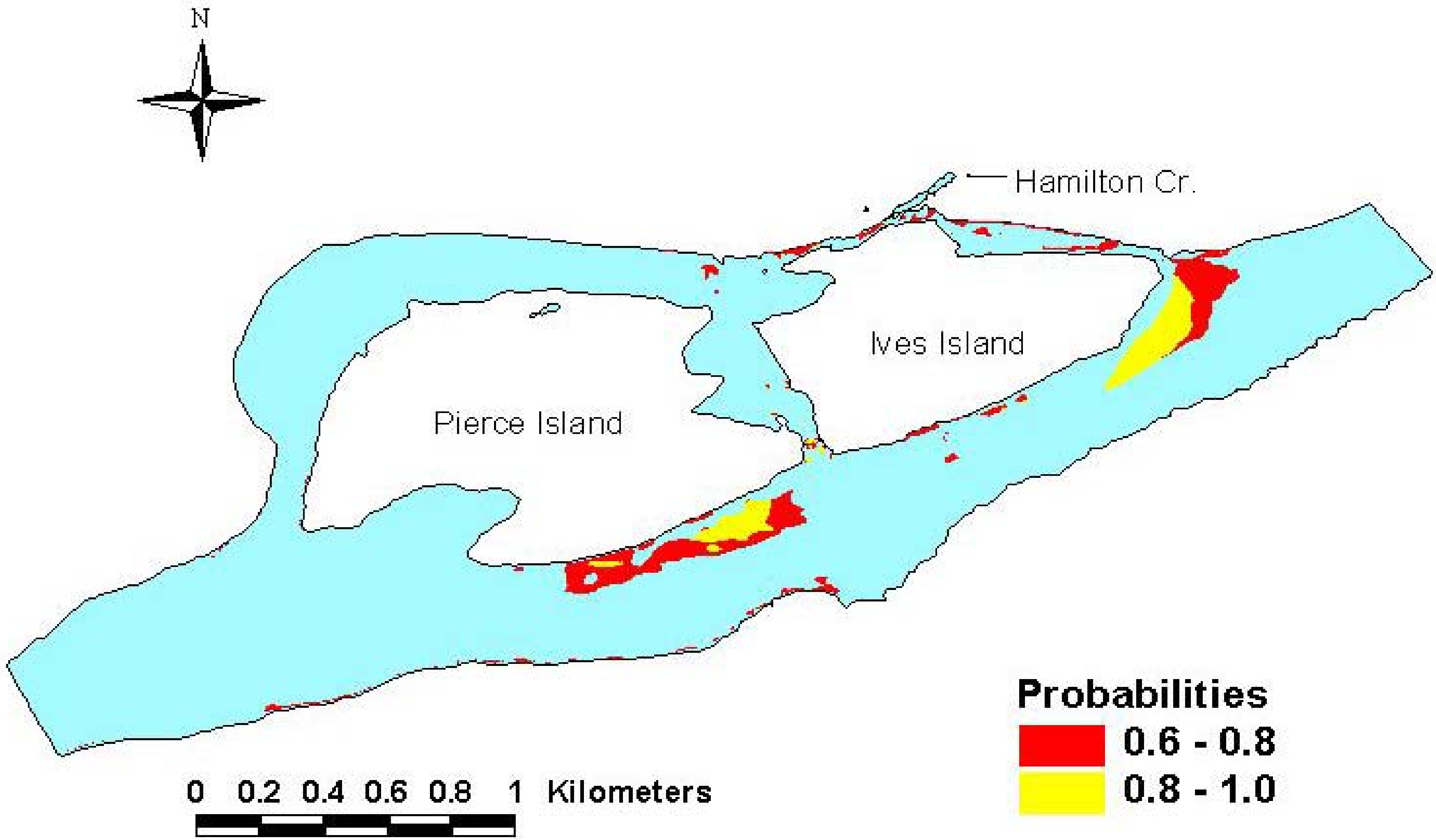
Appendix D.4 – Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 177 cfs, and an average Warrendale water surface elevation of 2.5 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



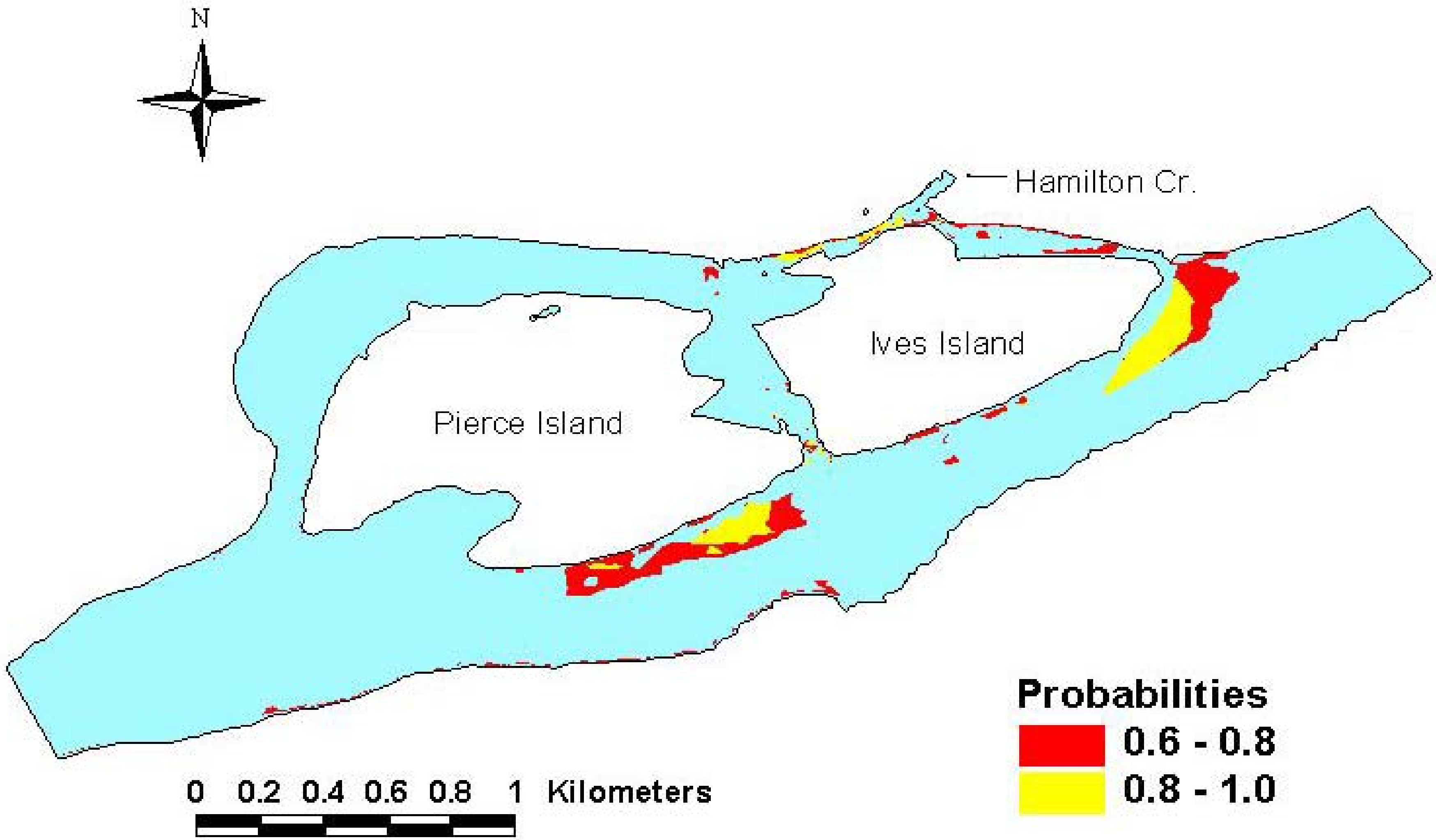
Appendix D.5 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 115 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.5 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



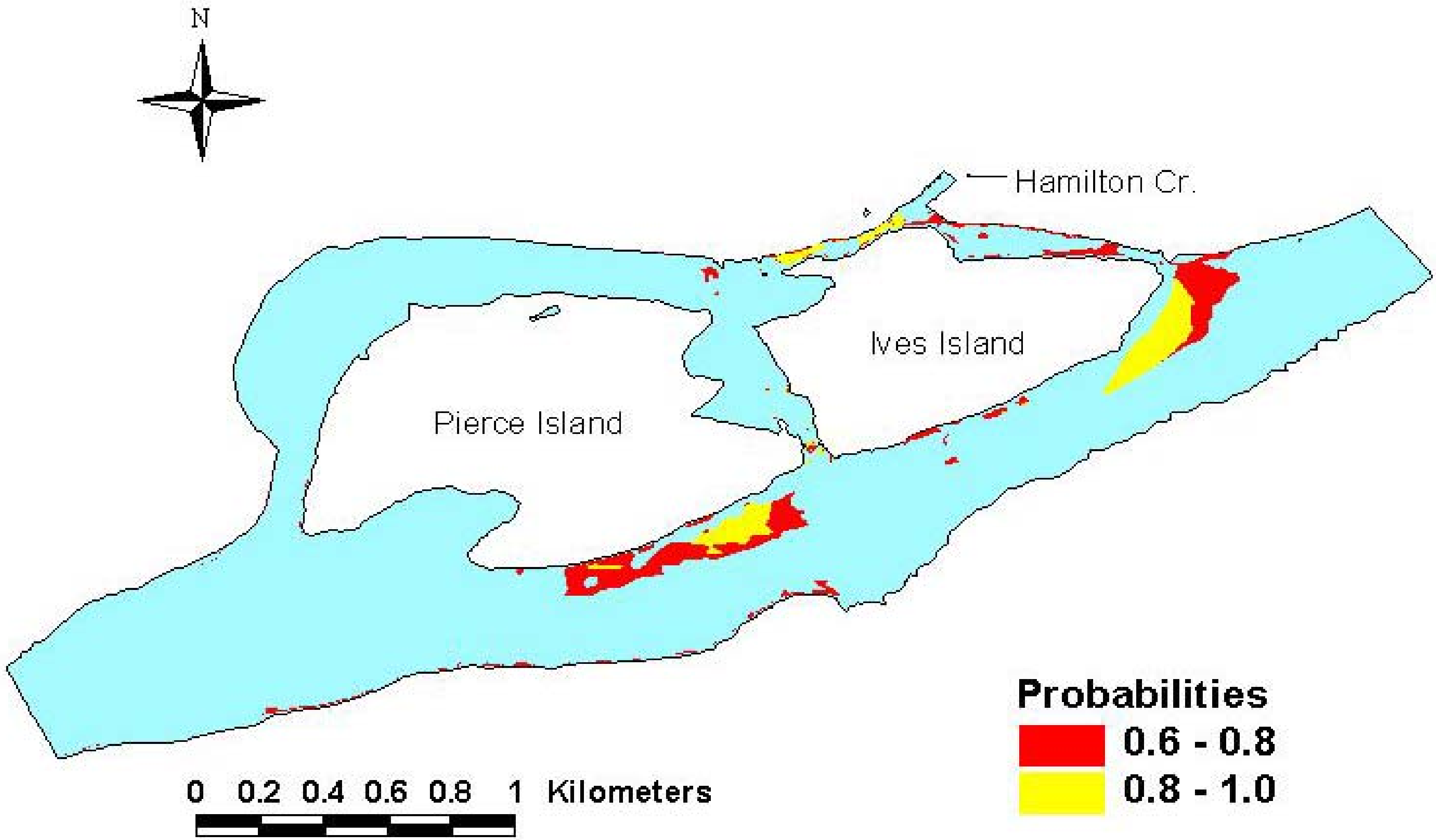
Appendix D.6 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 120 kcfs, Hamilton Creek discharge of 0 cfs, and a minimum Warrendale water surface elevation of 2.2 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



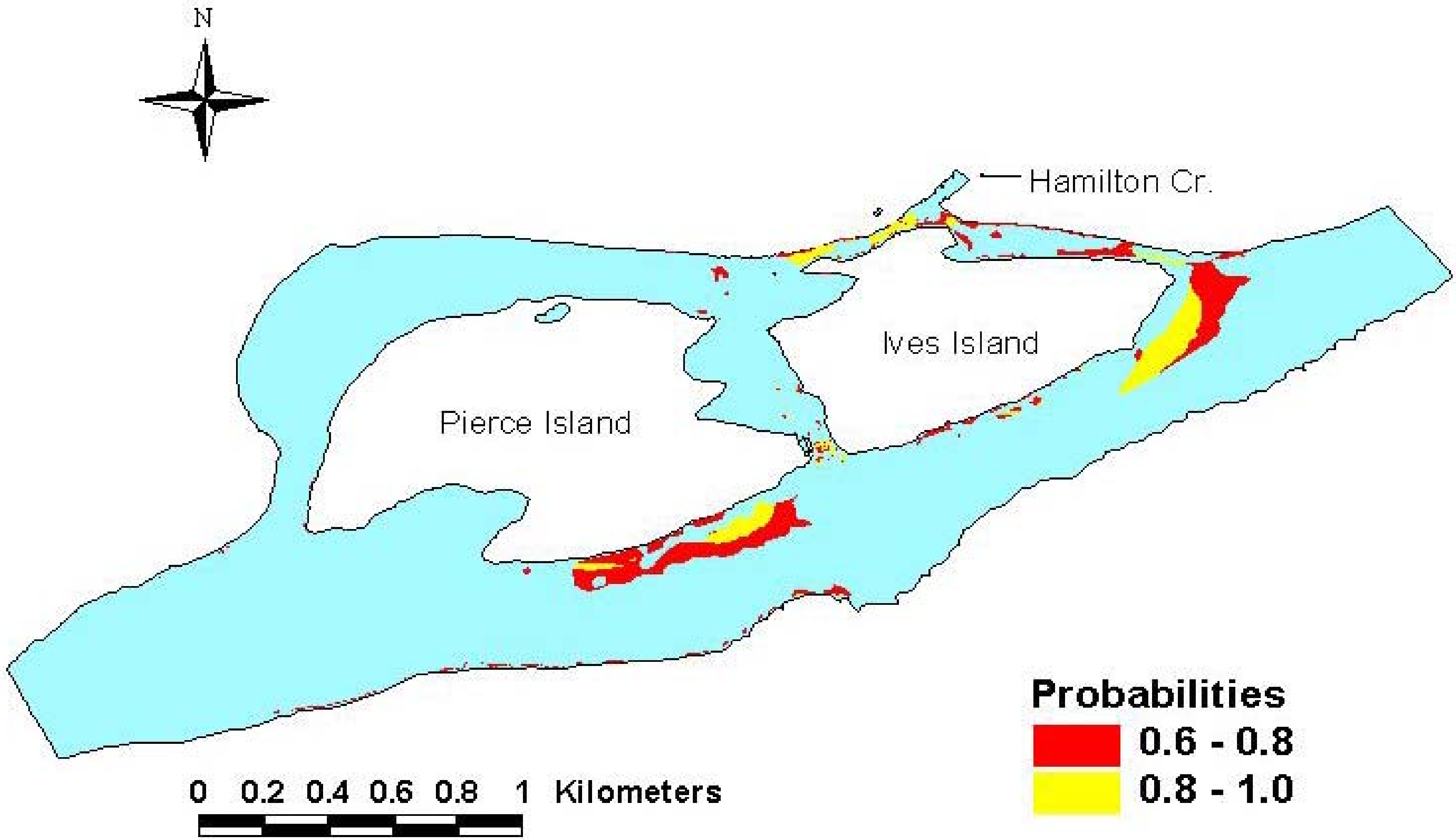
Appendix D.7 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 120 kcfs, Hamilton Creek discharge of 177 cfs, and a minimum Warrendale water surface elevation of 2.2 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



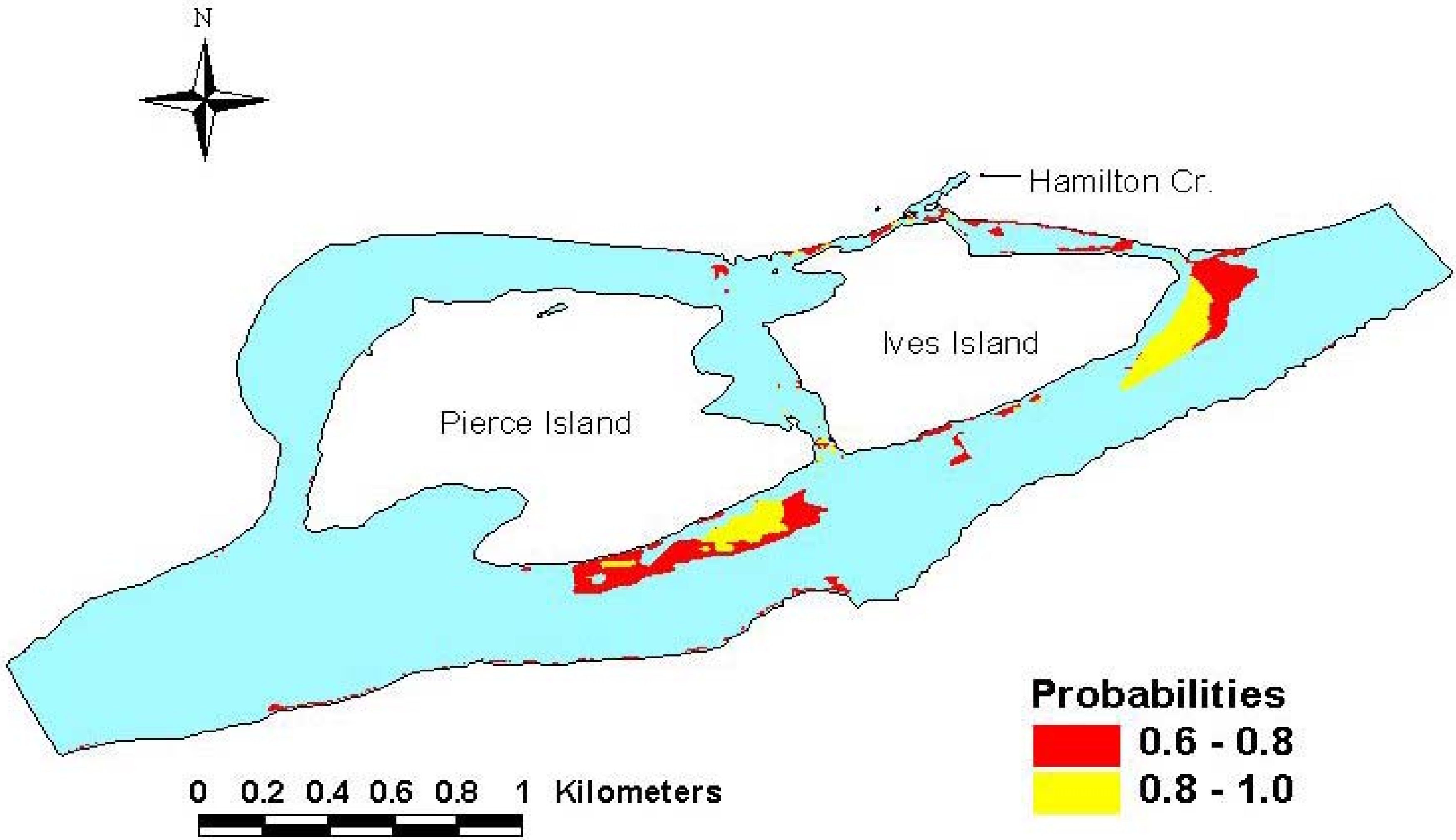
Appendix D.8 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 120 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.2 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



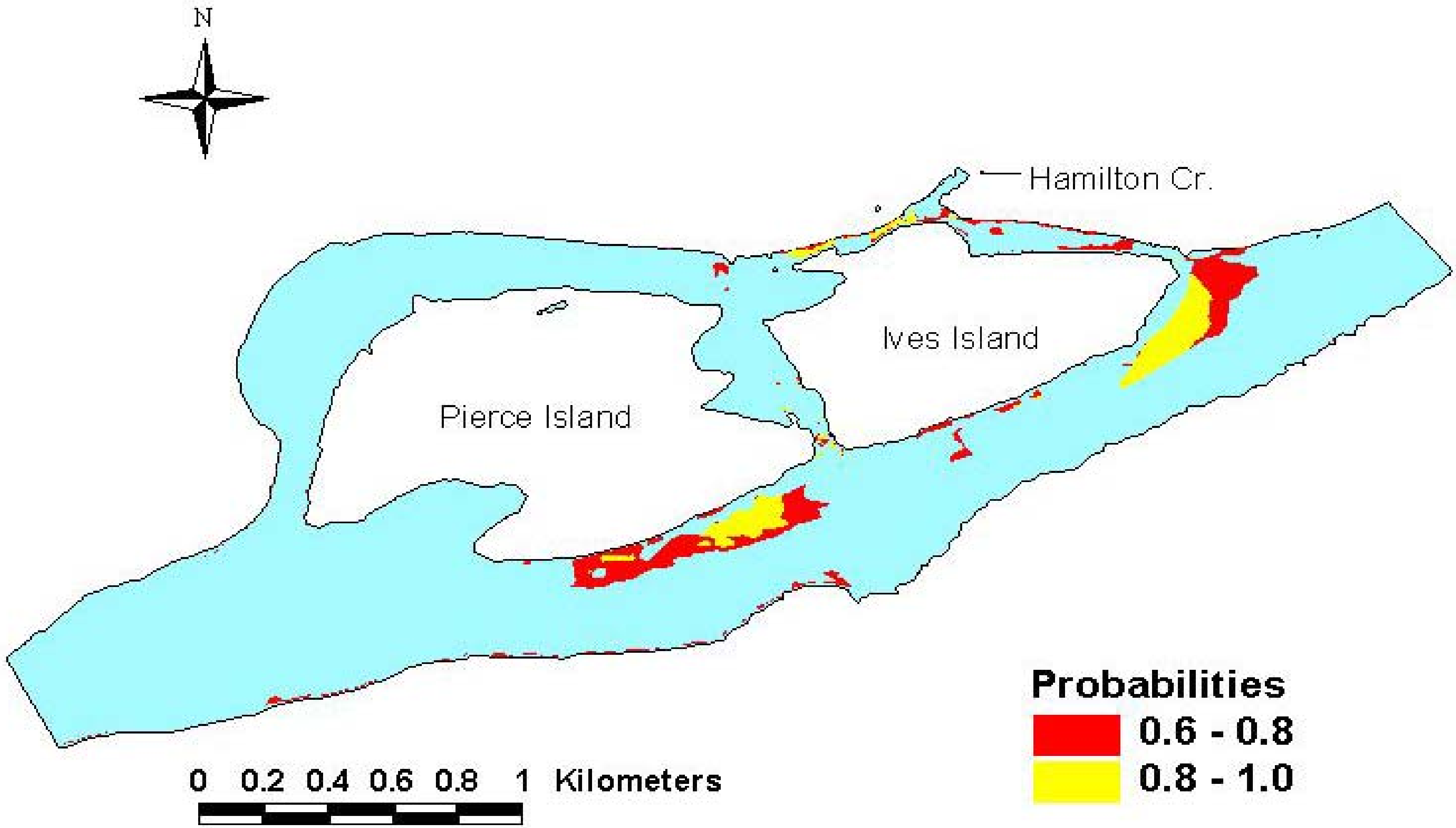
Appendix D.9 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 120 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.5 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



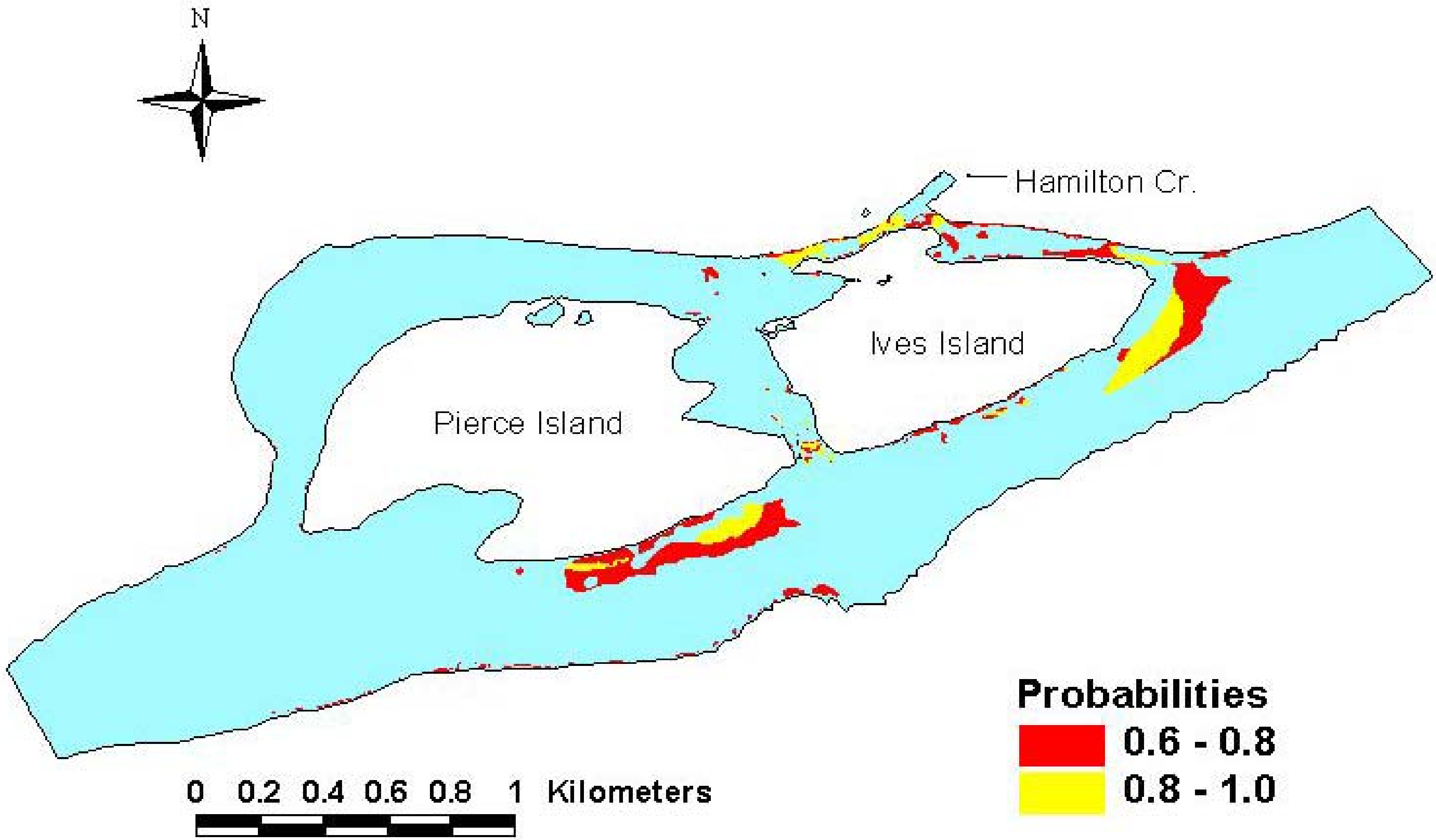
Appendix D.10 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs, Hamilton Creek discharge of 0 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



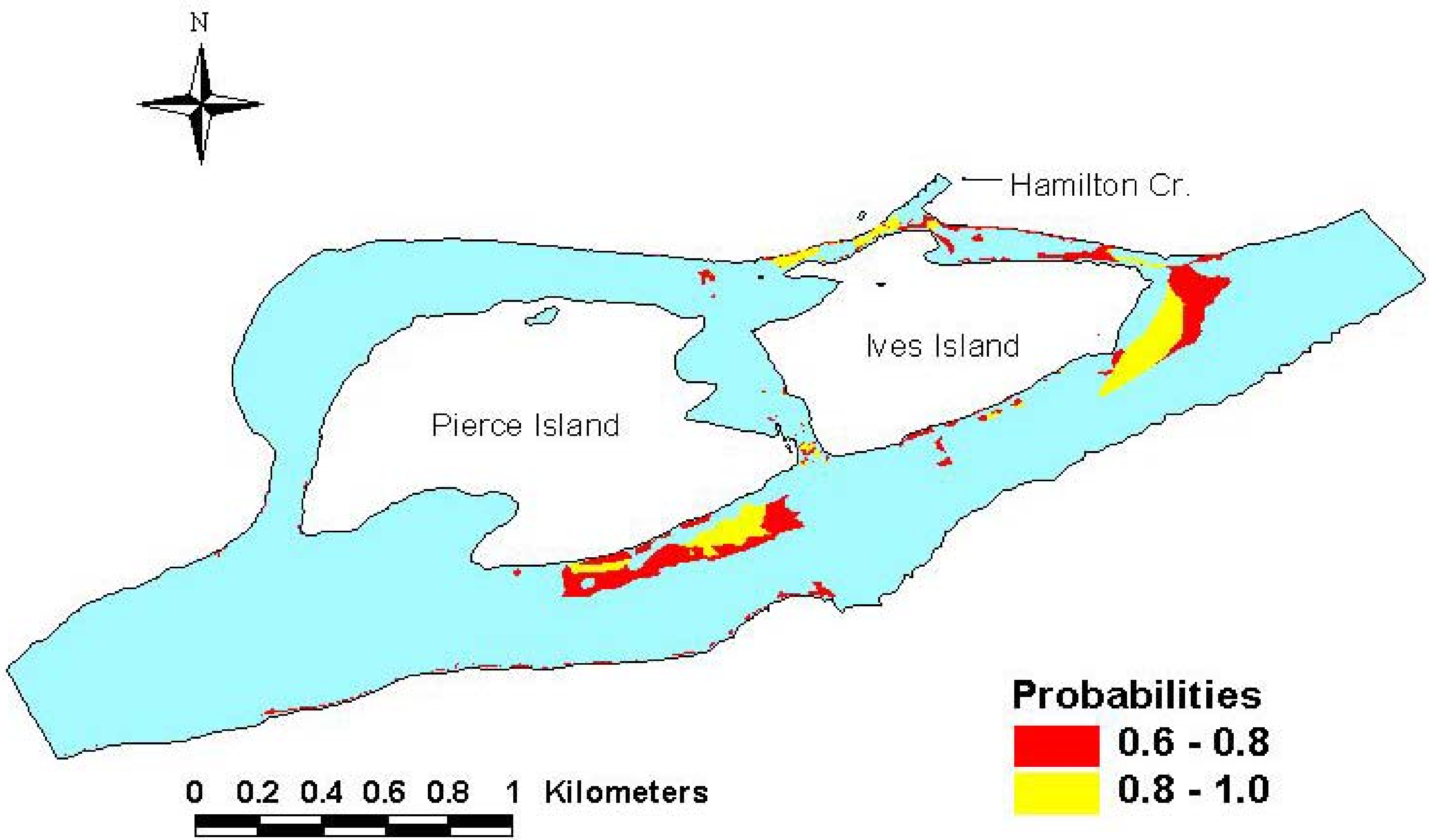
Appendix D.11 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs, Hamilton Creek discharge of 177 cfs, and a minimum Warrendale water surface elevation of 2.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



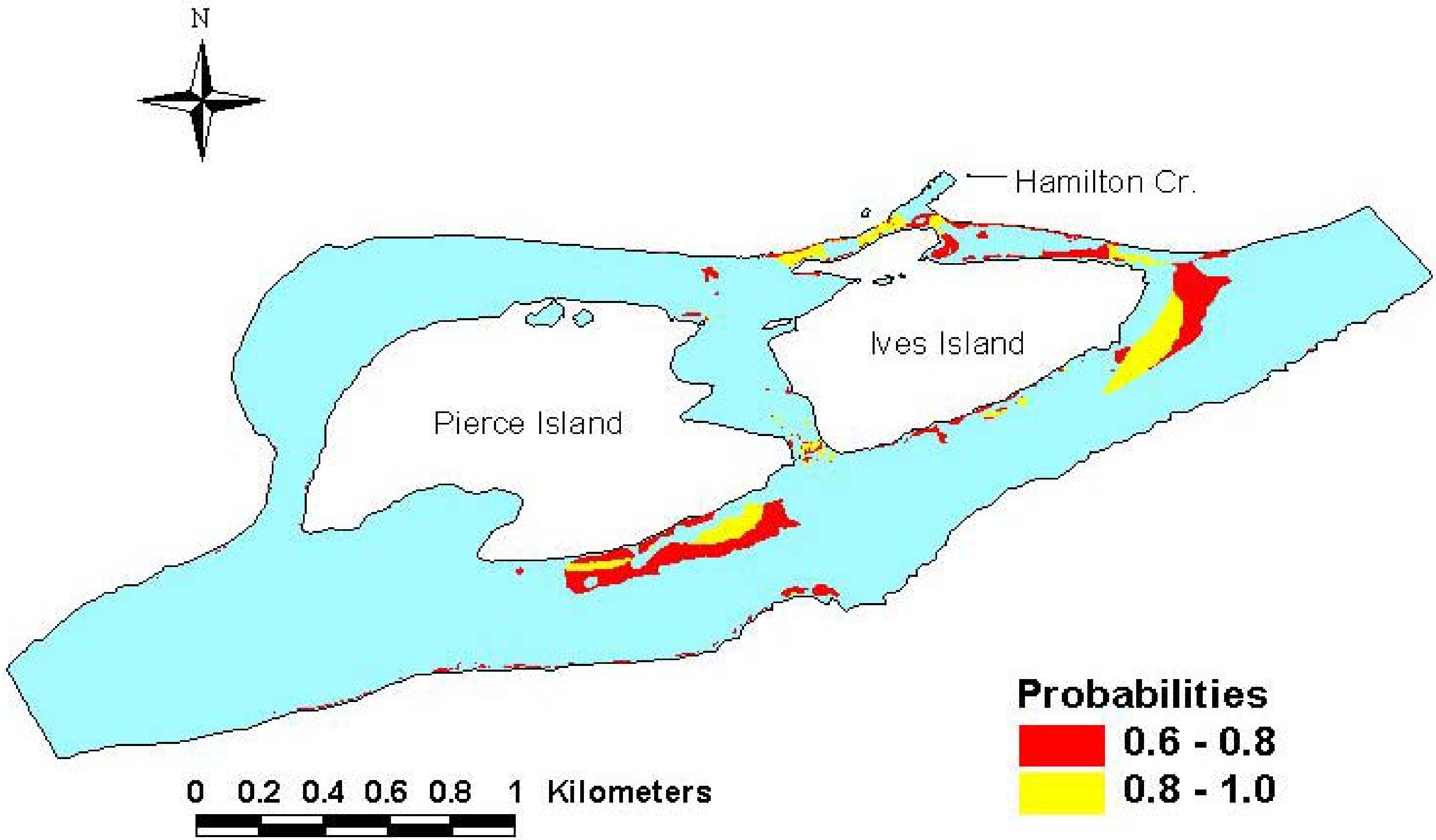
Appendix D.12 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 125 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.6 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



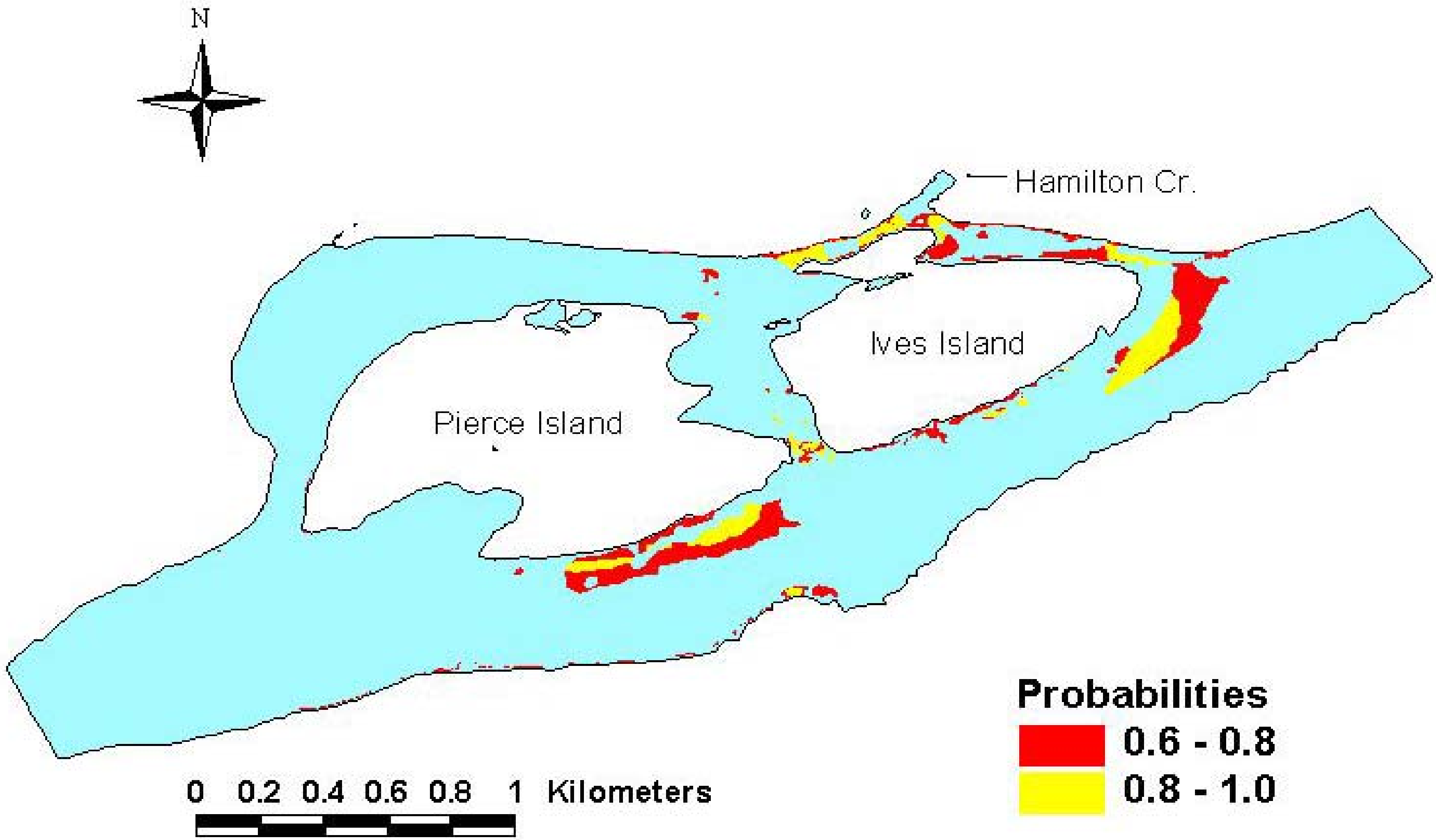
Appendix D.13 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 130 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.3 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



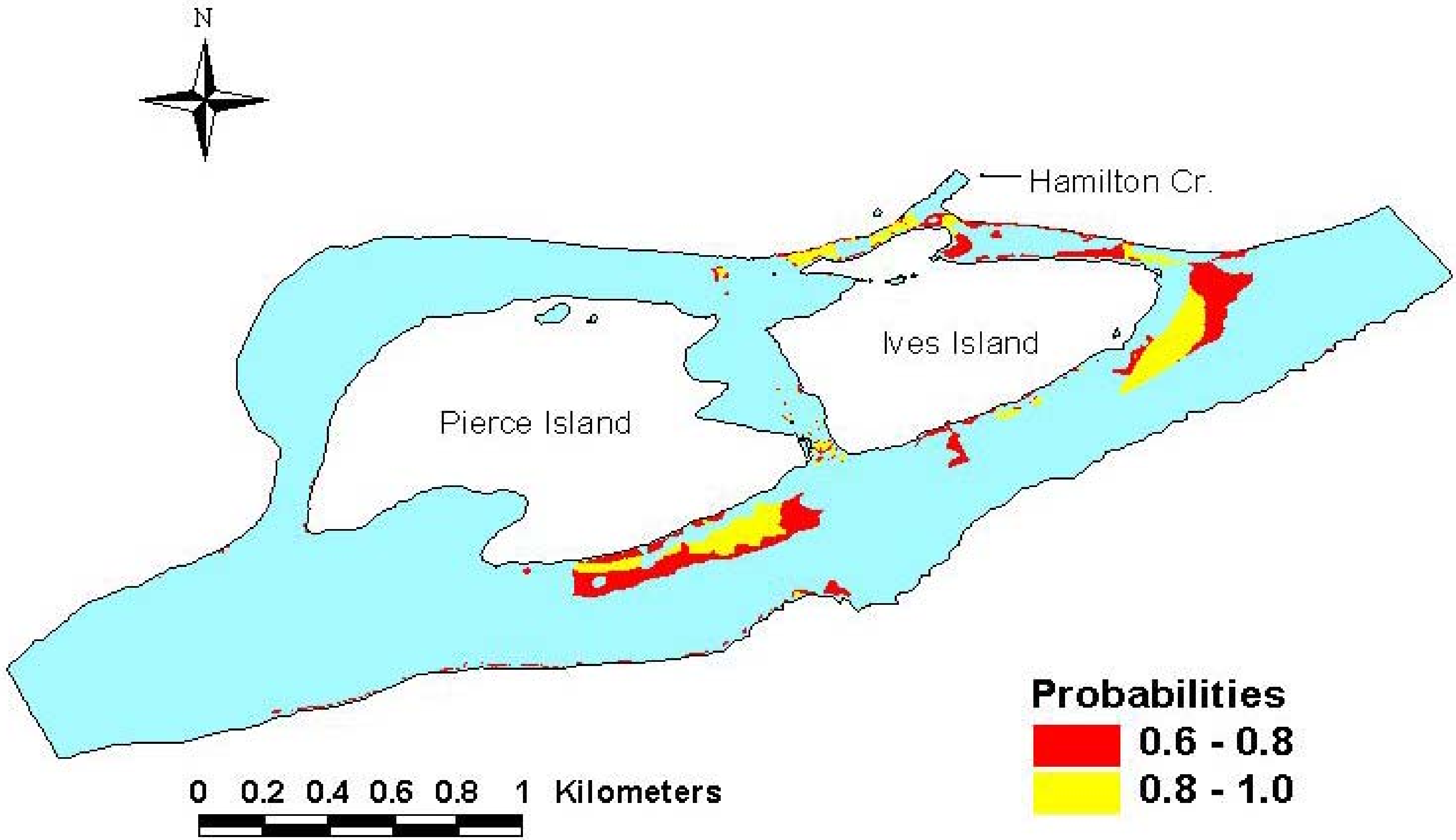
Appendix D.14 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 130 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.6 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



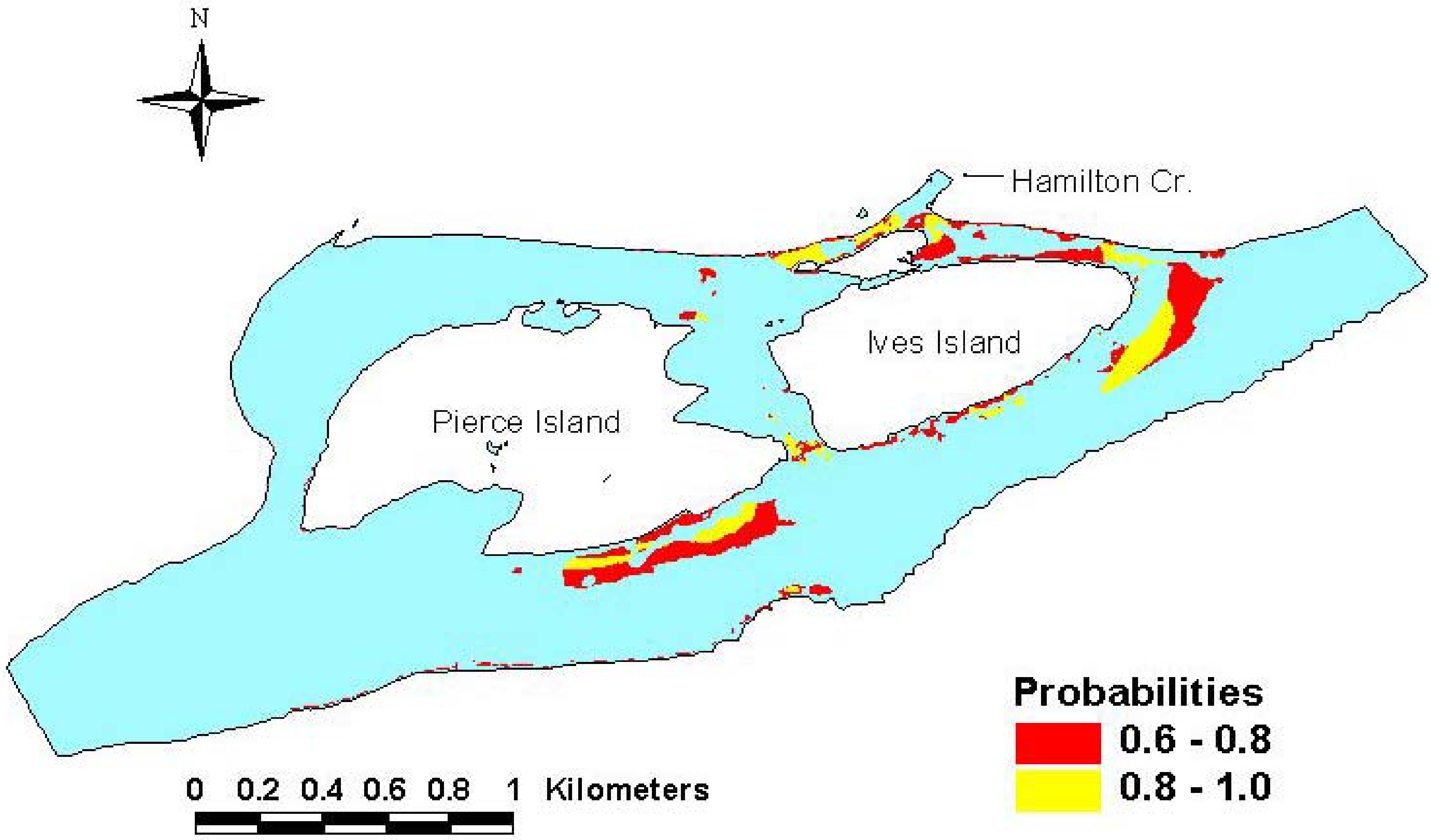
Appendix D.15 – Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 135 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.8 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



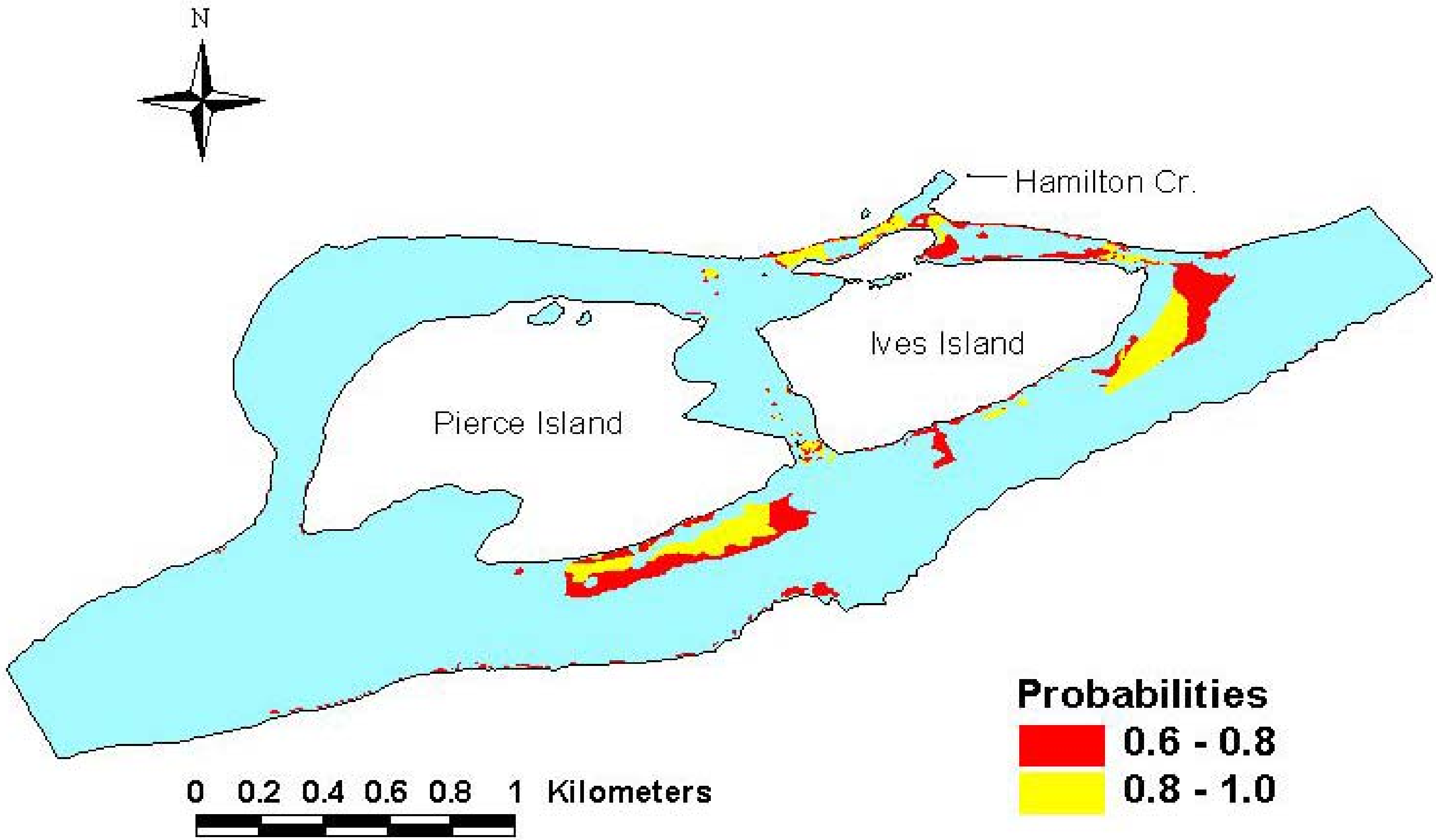
Appendix D.16 – Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 140 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.4 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



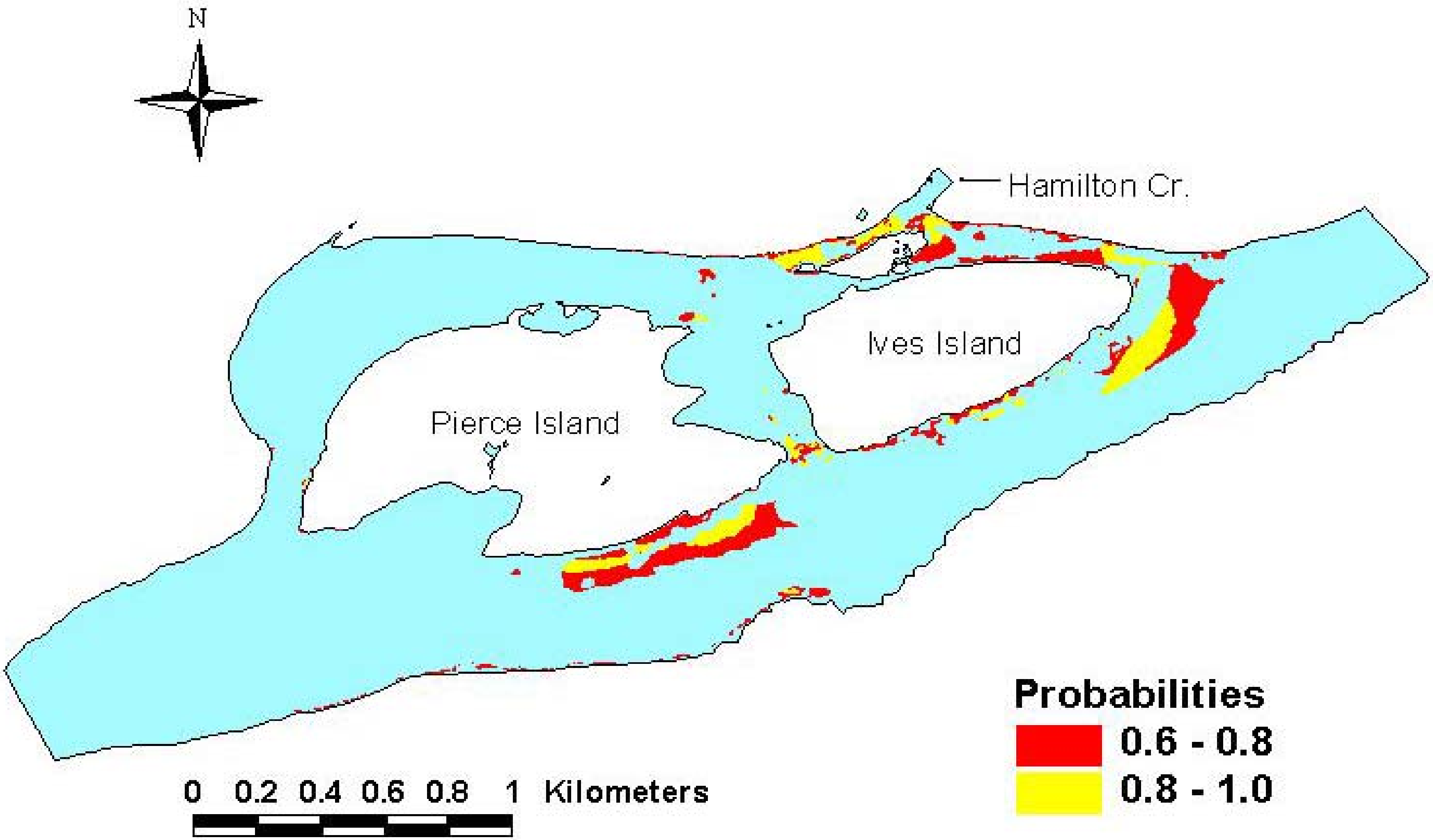
Appendix D.17 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 140 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 2.9 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



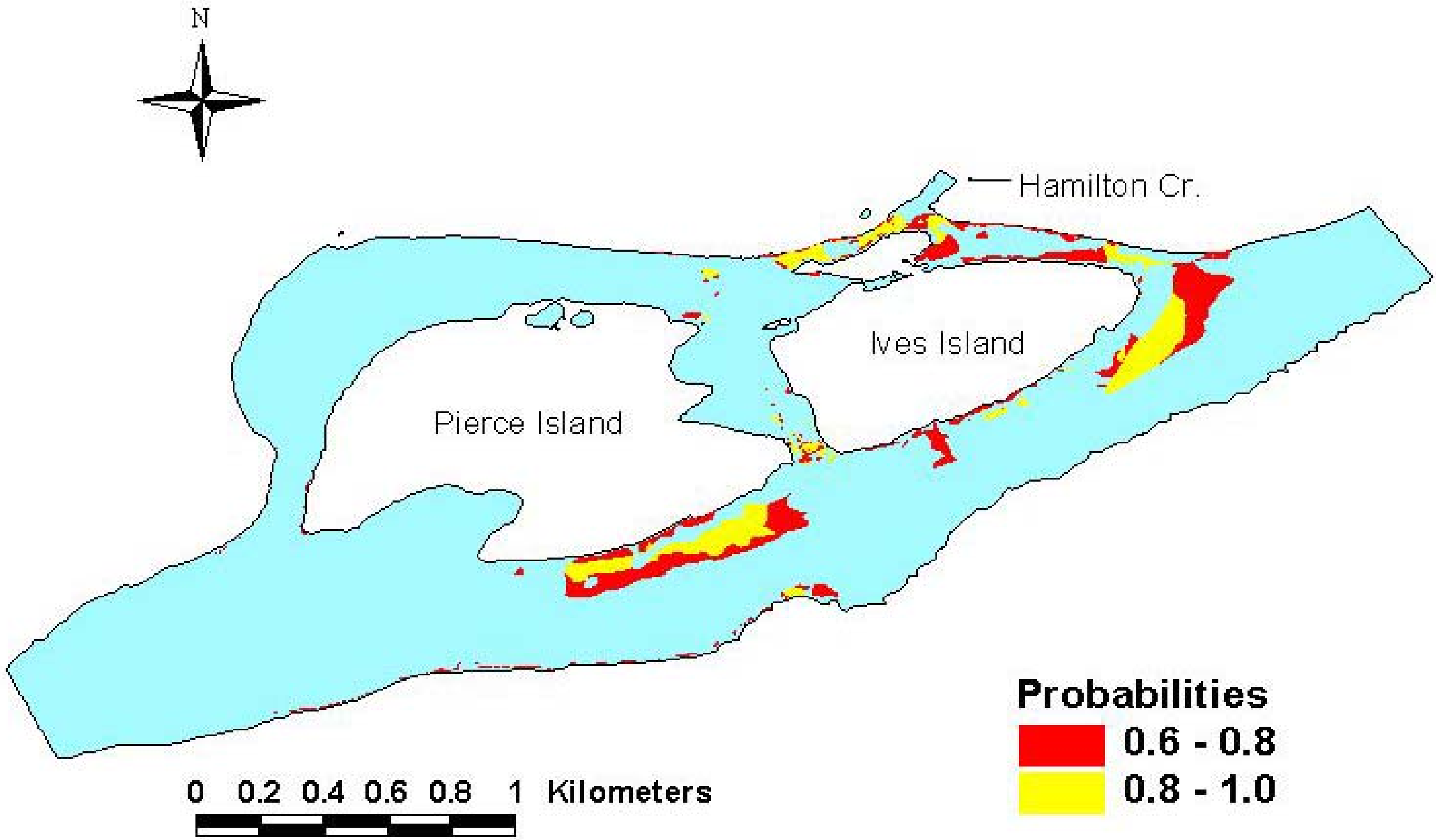
Appendix D.18 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 145 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.4 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



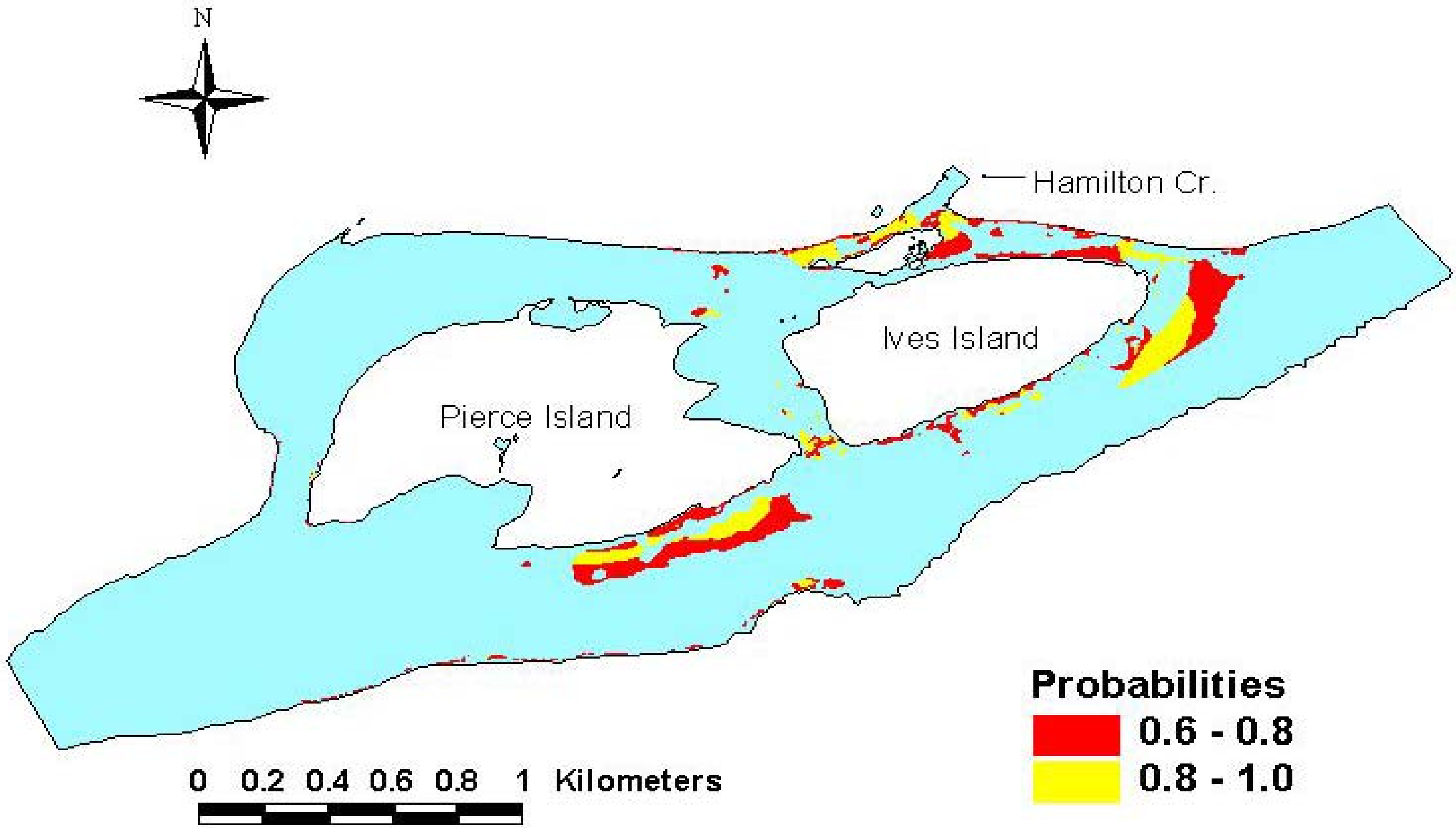
Appendix D.19 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 145 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 3.0 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



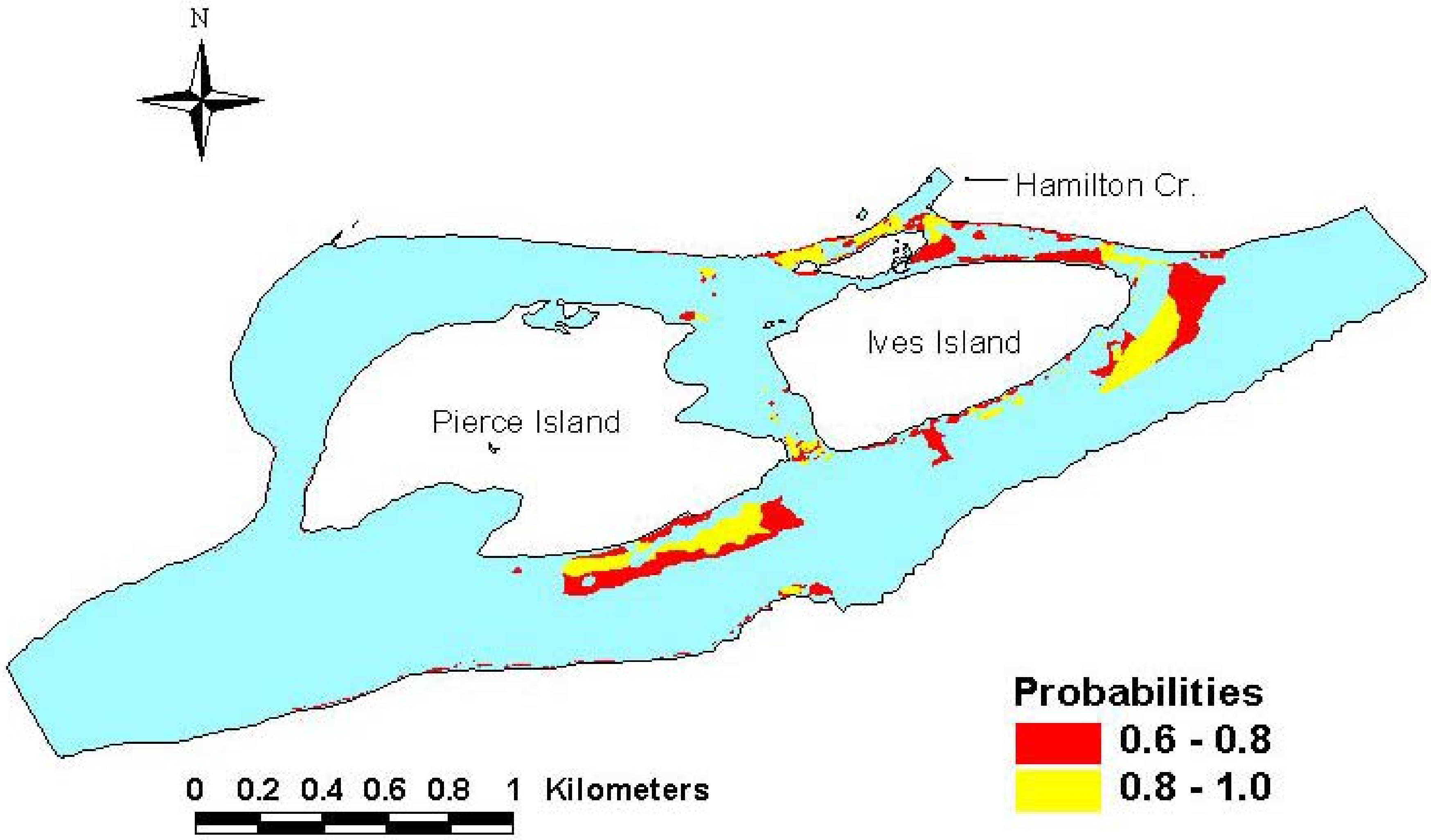
Appendix D.20 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 150 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.6 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



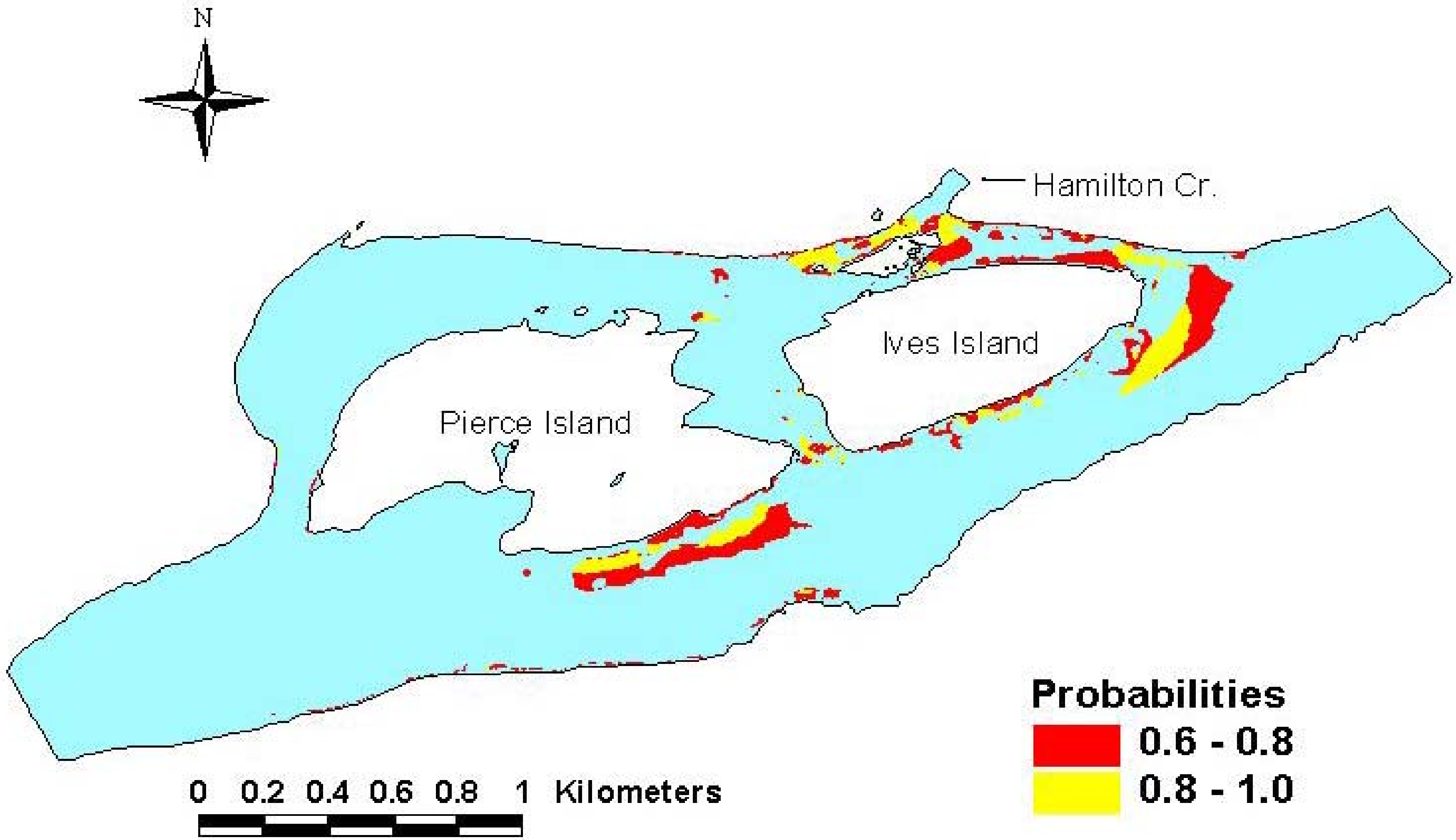
Appendix D.21 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 150 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 3.0 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



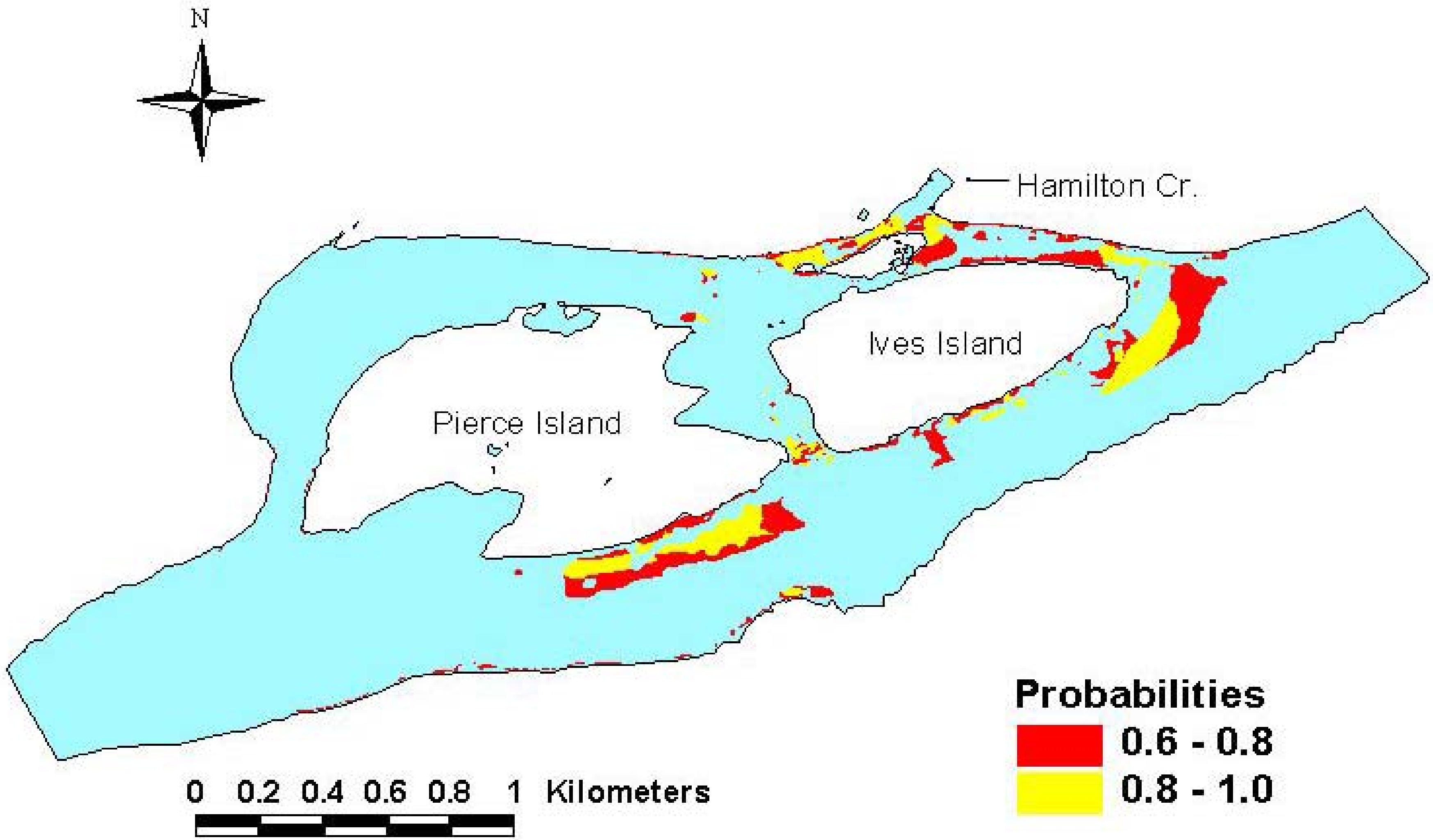
Appendix D.22 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 155 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.7 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



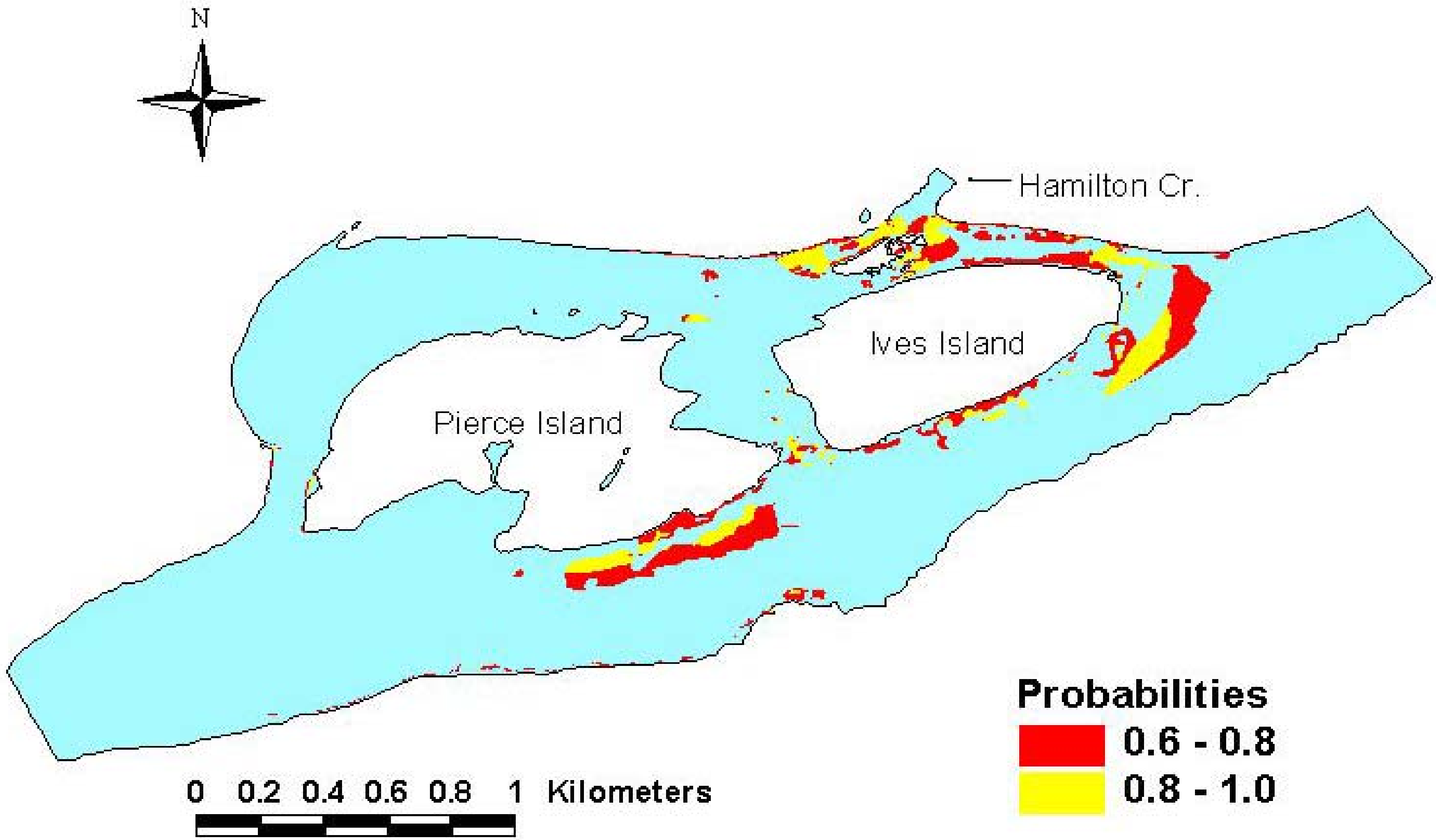
Appendix D.23 - Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 155 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 3.1 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



Appendix D.24 – Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 160 kcfs, Hamilton Creek discharge of 388 cfs, and a minimum Warrendale water surface elevation of 2.8 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



Appendix D.25 – Areas predicted to be suitable spawning habitat for fall chinook salmon at Ives Island at a Bonneville Dam discharge of 160 kcfs, Hamilton Creek discharge of 388 cfs, and an average Warrendale water surface elevation of 3.3 m above mean sea level. Areas in yellow have the highest probability of predicted fish use.



APPENDIX E

Appendix E.1 - Fall chinook salmon spawning total wetted area, total area of predicted fall chinook salmon spawning area with probabilities ≥0.6, and percentage of area suitable for spawning for each study section (SS), for different combinations of Columbia River discharges, Hamilton Creek discharges, and water surface elevations (WSE) elevations.

			SS 1			SS 2			SS 3			SS 4			SS 5			SS 6		
Columbia River Discharge (m^3/s)	Hamilton Creek Discharge (m^3/s)	Down-Stream WSE (m)	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6
115	388	2.5	5.1	0.9	18.0	6.0	1.1	18.4	0.0	0.0	0.0	165.5	12.3	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	353	2.5	5.0	0.9	17.5	5.9	1.1	18.0	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	318	2.5	4.9	0.8	17.0	5.9	1.0	17.7	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	282	2.5	4.9	0.8	16.6	5.8	1.0	17.3	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	247	2.5	4.8	0.8	16.2	5.7	1.0	16.9	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	212	2.5	4.7	0.7	15.9	5.7	0.9	16.4	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	177	2.5	4.6	0.7	15.5	5.6	0.9	15.7	0.0	0.0	0.0	165.5	12.3	7.4	14.9	0.4	2.5	38.9	0.1	0.1
115	141	2.5	4.6	0.7	15.2	5.5	0.8	15.1	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	106	2.5	4.5	0.7	15.3	5.4	0.8	14.3	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	71	2.5	4.4	0.7	15.1	5.3	0.7	13.5	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	35	2.5	4.6	0.7	15.6	5.6	0.9	15.7	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	0	2.5	4.4	0.7	15.0	4.4	0.6	13.3	0.0	0.0	0.0	165.5	12.2	7.4	14.9	0.4	2.6	38.9	0.1	0.1
115	388	2.1	5.0	0.9	17.5	5.3	1.1	20.7	0.0	0.0	0.0	159.1	14.5	9.1	12.1	0.2	1.3	32.9	0.0	0.1
115	353	2.1	4.9	0.9	17.5	5.3	1.1	20.2	0.0	0.0	0.0	159.1	14.5	9.1	12.1	0.2	1.3	32.8	0.0	0.1
115	318	2.1	4.8	0.8	17.1	5.2	1.0	19.6	0.0	0.0	0.0	159.1	14.5	9.1	12.1	0.2	1.2	32.8	0.0	0.1
115	282	2.1	4.7	0.8	16.9	5.1	1.0	18.9	0.0	0.0	0.0	159.1	14.5	9.1	12.1	0.1	1.2	32.8	0.0	0.1
115	247	2.1	4.5	0.8	16.8	5.1	0.9	18.1	0.0	0.0	0.0	159.1	14.5	9.1	12.1	0.1	1.2	32.8	0.0	0.1
115	212	2.1	4.4	0.7	16.5	5.0	0.9	17.2	0.0	0.0	0.0	159.1	14.5	9.1	12.1	0.1	1.2	32.8	0.0	0.1
115	177	2.1	4.3	0.7	16.1	4.9	0.8	16.1	0.0	0.0	0.0	159.1	14.5	9.1	12.1	0.1	1.2	32.8	0.0	0.1
115	141	2.1	4.2	0.7	16.0	4.8	0.7	15.0	0.0	0.0	0.0	159.0	14.5	9.1	12.1	0.1	1.2	32.8	0.0	0.1
115	106	2.1	4.1	0.7	16.0	4.7	0.6	13.6	0.0	0.0	0.0	159.2	14.6	9.2	12.1	0.1	1.2	32.8	0.0	0.1
115	71	2.1	3.9	0.6	16.3	4.6	0.5	12.0	0.0	0.0	0.0	159.1	14.5	9.1	12.0	0.1	1.2	32.8	0.0	0.1
115	35	2.1	3.7	0.6	17.5	4.3	0.5	10.5	0.0	0.0	0.0	159.1	14.5	9.1	12.0	0.1	1.2	32.8	0.0	0.1
120	388	2.6	5.7	1.2	21.7	6.2	1.2	19.7	0.0	0.0	0.0	169.0	12.2	7.2	15.9	0.5	3.0	40.5	0.1	0.1
120	388	2.2	5.0	0.9	18.1	5.6	1.0	18.2	0.0	0.0	0.0	164.8	13.5	8.2	14.1	0.3	2.4	37.1	0.0	0.1
120	353	2.2	4.9	0.9	17.4	5.5	1.0	18.4	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.2	0.0	0.1
120	318	2.2	4.9	0.8	17.1	5.6	1.0	17.8	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.2	0.0	0.1

Appendix E.1 - Continued.

Columbia River Discharge (m^3/s)	Hamilton Creek Discharge (m^3/s)	Down-Stream WSE (m)	SS 1			SS 2			SS 3			SS 4			SS 5			SS 6		
			Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6	Total Area (ha)	Total Area ≥0.6 (ha)	Percent ≥0.6
120	282	2.2	4.8	0.8	16.7	5.5	0.9	17.3	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.2	0.0	0.1
120	247	2.2	4.8	0.8	16.3	5.4	0.9	16.6	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.2	0.0	0.1
120	212	2.2	4.7	0.8	15.9	5.4	0.9	16.1	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.2	0.0	0.1
120	177	2.2	4.7	0.7	15.6	5.3	0.8	15.2	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.2	0.0	0.1
120	141	2.2	4.6	0.7	15.3	5.2	0.8	14.4	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.2	0.0	0.1
120	106	2.2	4.6	0.7	15.1	5.1	0.7	13.6	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.1	0.0	0.1
120	71	2.2	4.6	0.7	15.0	5.0	0.6	12.6	0.0	0.0	0.0	164.7	13.5	8.2	14.1	0.3	2.4	37.1	0.0	0.1
120	35	2.2	4.6	0.7	15.0	4.9	0.6	11.5	0.0	0.0	0.0	164.7	13.5	8.2	14.0	0.3	2.4	37.1	0.0	0.1
120	0	2.2	4.6	0.7	15.0	4.5	0.5	10.1	0.0	0.0	0.0	164.7	13.5	8.2	14.0	0.3	2.4	37.1	0.0	0.1
125	388	2.7	6.0	1.5	25.1	6.4	1.3	20.9	0.0	0.0	0.0	170.2	12.5	7.4	16.6	0.5	3.3	41.2	0.1	0.2
125	388	2.1	4.8	0.8	16.3	5.3	0.8	15.8	0.0	0.0	0.0	164.6	14.2	8.6	13.9	0.3	2.4	36.8	0.0	0.1
125	177	2.1	4.7	0.8	16.0	4.6	0.5	11.1	0.0	0.0	0.0	164.6	14.2	8.6	13.9	0.3	2.4	36.8	0.0	0.1
125	0	2.7	6.3	1.8	29.4	6.6	1.5	22.4	0.0	0.0	0.0	171.1	13.0	7.6	17.0	0.6	3.8	42.1	0.1	0.2
130	388	2.4	5.8	1.3	22.8	6.1	1.2	20.0	0.0	0.0	0.0	168.2	13.8	8.2	15.2	0.4	2.8	39.1	0.1	0.1
130	388	2.8	6.8	2.2	32.6	7.0	1.7	23.6	0.01	0.0	0.0	173.1	13.1	7.5	17.7	0.8	4.6	43.6	0.1	0.2
135	388	3.0	7.3	2.5	34.7	7.6	1.9	24.5	0.05	0.012	26.1	175.3	12.9	7.4	18.6	0.9	4.8	45.2	0.1	0.2
140	388	2.4	6.4	1.9	30.2	6.3	1.4	22.8	0.0	0.0	0.0	169.3	14.9	8.8	15.7	0.5	3.2	39.8	0.1	0.1
140	388	3.0	7.5	2.7	36.0	7.8	2.0	25.1	0.5	0.04	6.9	176.0	13.3	7.6	18.9	0.9	4.8	45.7	0.1	0.3
145	388	2.5	6.7	2.1	31.2	6.6	1.6	24.2	0.05	0.01	28.3	170.2	15.2	8.9	16.2	0.6	3.6	40.6	0.1	0.1
145	388	3.0	7.6	2.8	37.3	7.9	2.0	25.7	0.8	0.06	7.2	176.3	13.9	7.9	19.0	0.9	4.8	45.8	0.1	0.3
150	388	2.6	7.2	2.5	34.6	7.0	1.8	25.2	0.1	0.03	28.5	172.5	15.4	8.9	17.3	0.8	4.6	42.3	0.1	0.2
150	388	3.2	7.9	3.2	40.6	8.4	2.3	26.8	1.0	0.08	8.1	178.3	13.7	7.7	19.9	0.9	4.8	47.4	0.1	0.3
155	388	2.8	7.5	2.8	36.6	7.6	2.0	26.3	0.8	0.1	7.4	174.4	15.4	8.8	18.1	0.9	5.1	44.2	0.1	0.2
155	388	3.3	8.2	3.6	43.8	8.9	2.5	28.0	1.2	0.3	21.1	180.1	13.6	7.6	20.6	0.9	4.5	48.7	0.2	0.4
160	388	2.8	7.7	3.0	38.7	7.9	2.1	27.0	1.1	0.1	12.8	175.7	15.6	8.9	18.7	1.0	5.2	45.1	0.1	0.2