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SACRAMENTO FISH AND WILDLIFE OFFICE STANDARDS FOR PHYSICAL HABITAT SIMULATION STUDIES

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SFWO Standards For Physical Habitat Simulation Studies

1. Study Segment Delineation - Study segments should be delineated based on differences in flow. Bovee (1995) recommends that the cumulative change in flow within a segment be less than ten percent.

2. Mesohabitat Mapping – Mesohabitats for alluvial channels should be delineated using the following geomorphically-based habitat mapping system. This habitat mapping system uses 12 mesohabitat types: bar complex glides, bar complex pools, bar complex riffles, bar complex runs, flatwater glides, flatwater pools, flatwater riffles, flatwater runs, side channel glides, side channel pools, side channel riffles, and side channel runs (Snider et al 1992). Definitions of the habitat types are given in Table 1. Aerial photos should be used in conjunction with direct observations to determine the aerial extent of each habitat unit. The location of the upstream and downstream end of each habitat unit should be recorded with a Global Positioning System (GPS) unit. The habitat units should be also delineated on the aerial photos. Following the completion of the mesohabitat mapping, the mesohabitat types and number of each habitat type in each segment should be enumerated, and shapefiles of the mesohabitat units should be created in a Geographic Information System (GIS) using the GPS data and the aerial photos. The area of each mesohabitat unit should be computed in GIS from the above shapefiles.

3. Field Reconnaissance and Study Site Selection – Study sites for modeling spawning should be placed in high spawning use areas and study sites for rearing should be selected to adequately represent the mesohabitat types present in each segment. Using a mesohabitat-based approach for modeling spawning habitat fails to take into account salmonids' preference for spawning in areas with high gravel permeability (Vyverberg et al 1996), while having sites only in high-use spawning areas indirectly takes into account characteristics of spawning habitat, such as permeability and upwelling, which are key characteristics of spawning habitat and are not captured by depth, velocity and substrate (Gallagher and Gard 1999). The assumption is that high-use spawning areas have high gravel permeability since salmonids are selecting these areas for spawning. For spawning, the study segment should be surveyed, with the location of the upstream and downstream ends of spawning areas recorded with a GPS unit and the numbers of redds in each spawning area recorded. The spawning study sites selected should be those with the highest number of redds observed during the above survey. The upstream and downstream end of each spawning study site should be selected to correspond to the upstream and downstream ends of spawning areas recorded with the GPS unit. There should be at least five spawning study sites per study segment.

Study sites for rearing should be randomly selected to ensure unbiased selection of the study sites. The upstream and downstream end of each rearing study site should be selected to correspond to the upstream and downstream ends of the mesohabitat units selected. The rearing study sites should have a total length of four percent of the river segment length. The rearing study sites should include, in total, at least three mesohabitat

Table 1. Habitat type definitions.

Habitat Type	Definition
Bar Complex	Submerged and emergent bars are the primary feature, sloping cross-sectional channel profile.
Flatwater	Primary channel is uniform, simple and without gravel bars or channel controls, fairly uniform depth across channel.
Side Channel	Less than 20% of total flow.
Pool	Primary determinant is downstream control - thalweg gets deeper as go upstream from bottom of pool. Fine and uniform substrate, below average water velocity, above average depth, tranquil water surface.
Glide	Primary determinants are no turbulence (surface smooth, slow and laminar) and no downstream control. Low gradient, substrate uniform across channel width and composed of small gravel and/or sand/silt, depth below average and similar across channel width (but depth not similar across channel width for Bar Complex Glide), below average water velocities, generally associated with tails of pools or heads of riffles, width of channel tends to spread out, thalweg has relatively uniform slope going downstream.
Run	Primary determinants are moderately turbulent and average depth. Moderate gradient, substrate a mix of particle sizes and composed of small cobble and gravel, with some large cobble and boulders, above average water velocities, usually slight gradient change from top to bottom, generally associated with downstream extent of riffles, thalweg has relatively uniform slope going downstream.
Riffle	Primary determinants are high gradient and turbulence. Below average depth, above average velocity, thalweg has relatively uniform slope going downstream, substrate of uniform size and composed of large gravel and/or cobble, change in gradient noticeable.

units of each of the following mesohabitat types: pool, run, riffle, and glide. The proportion of habitat types in the rearing sites should roughly correspond to the proportion of habitat types in each study segment.

4. Habitat Modeling – Habitat modeling should be conducted using a two-dimensional (2-D) model rather than 1-D PHABSIM. 2-D model inputs include the bed topography and bed roughness, and the water surface elevation at the downstream end of the site. The amount of habitat present in the site is computed using the depths and velocities predicted by the 2-D model, and the substrate and cover present in the site. The 2-D model avoids problems of transect placement, since data is collected uniformly across the entire site (Gard 2009a). The 2-D model also has the potential to model depths and velocities over a range of flows more accurately than 1-D PHABSIM because it takes into account upstream and downstream bed topography and bed roughness, and explicitly uses mechanistic processes (conservation of mass and momentum), rather than Manning's Equation and a velocity adjustment factor (Leclerc et al. 1995). Other advantages of 2-D modeling are that it can explicitly handle complex hydraulics, including transverse flows, across-channel variation in water surface elevations, and flow contractions/expansions (Ghanem et al. 1996, Crowder and Diplas 2000, Pasternack et al. 2004). With appropriate bathymetry data, the model scale is small enough to correspond to the scale of microhabitat use data with depths and velocities produced on a continuous basis, rather than in discrete cells. The 2-D model, with compact cells, should be more accurate than 1-D PHABSIM, with long rectangular cells, in capturing longitudinal variation in depth, velocity and substrate. The 2-D model should do a better job of representing patchy microhabitat features, such as gravel patches. The data can be collected with a stratified sampling scheme, with higher intensity sampling in areas with more complex or more quickly varying microhabitat features, and lower intensity sampling in areas with uniformly varying bed topography and uniform substrate. Bed topography and substrate mapping data can be collected at a very low flow, with the only data needed at high flow being water surface elevations at the up- and downstream ends of the site and flow, and edge velocities for validation purposes. In addition, alternative habitat suitability criteria, such as measures of habitat diversity, can be used.

A. 2-D Model Quality Assurance/Quality Control (QA/QC)

A PHABSIM transect should be placed at the upstream and downstream end of each site. See PHABSIM section for standards for developing stage/discharge relationships for upstream and downstream end of sites.

Data collected between the upstream and downstream transects should include: 1) bed elevation; 2) northing and easting (horizontal location); 3) substrate; and 4) cover. These parameters should be collected at enough points to characterize the bed topography, substrate and cover of the sites. Bed topography points need to be collected at a minimum density of 40 points/100 m^2 in all areas of the selected study sites. Data should be collected at least up to the location of the water's edge at the highest flow to be simulated. Bed topography data should be collected at a higher density of points in areas with rapidly varying topography and patchy substrate and cover, and lower densities of points in areas with more uniform topography, substrate and cover. The accuracy of the bed elevations should be 0.1 foot, while the accuracy of the northings and eastings should be at least 1.0 foot[1]. The bed topography data can be collected with a total station, a survey-grade Real-time Kinematic (RTK) GPS, or for deeper areas, a combination of

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[1] All bed topography points will need to be accurate to within 0.1 foot. An accuracy level of 0.1 foot is the scientific standard for modeling salmonid habitat (Gard 2006, 2009a). While Light Detection and Ranging (LiDAR) and other methods may have their uses for coarse scale hydraulic modeling, we believe that the amount of vertical error involved with LiDAR makes it unacceptable for use in juvenile salmonid habitat modeling.

Acoustic Doppler Current Profiler (ADCP) traverses across the channel and total station to record the initial and final northing and easting of each traverse, or a combination of depth sounder and RTK GPS. Substrate and cover data should be collected using the categories in Tables 2 and 3. The northings and eastings of the transect headpins and tailpins should be determined with the total station or RTK GPS so that the topography for the transects can be incorporated into the bed topography of the sites. Additional topography data should be collected for one channel width upstream of the upstream transect to improve the accuracy of the flow distribution at the upstream end of the sites.

At least 50 velocity measurements, with the northing and easting of each velocity measurement determined with the total station or RTK GPS, should be collected (in addition to the velocities measured at the upstream and downstream transects and measured by the ADCP, if used) to validate the hydraulic predictions of the 2-D model. The locations of these velocity measurements should be distributed throughout the site. Velocities should be measured to the nearest 0.01 ft/s at 0.6 of the depth for 20 seconds using either a Price AA or Marsh-McBirney velocity meter. The flow present during validation velocity data collection should be detemined from gauge readings, if available. If gauge data is not available, the flow present during validation velocity data collection should be measured.

The topographic data described above should be combined with the bed topography from the upstream and downstream transects to create the initial bed file. The bed file contains the horizontal location (northing and easting), bed elevation and initial bed roughness value for each point. The initial bed roughness values should be determined from the substrate and cover data using the values in Table 4. If the topography data collected upstream of the upstream transect does not extend at least one channel width upstream of the top of the site, a one-channel-width artificial extension should be added upstream of the measured topography data to enable the flow to be distributed by the model when it reaches the study area, thus minimizing boundary conditions influencing the flow distribution at the upstream transect and within the study site. A utility program, R2D_BED (Steffler 2002), should be used to define the study area boundary and to refine the raw topographical data triangulated irregular network (TIN) by defining breaklines[2] going up the channel along features such as thalwegs, tops of bars and bottoms of banks. Breaklines should also be added along lines of constant elevation.

An additional utility program, R2D_MESH (Waddle and Steffler 2002), should be used to define the inflow and outflow boundaries and create the finite element computational mesh for the RIVER2D model. R2D_MESH uses the final bed file as an input. Mesh

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[2] Breaklines are a feature of the R2D_Bed program which force the TIN of the bed nodes to linearly interpolate bed elevation and bed roughness values between the nodes on each breakline and force the TIN to fall on the breaklines (Steffler 2002).

Table 2. Substrate codes, descriptors and particle sizes.

Code	Type	Particle Size (inches)
0.1	Sand/Silt	< 0.1
1	Small Gravel	0.1 – 1
1.2	Medium Gravel	1 – 2
1.3	Medium/Large Gravel	1 – 3
2.3	Large Gravel	2 – 3
2.4	Gravel/Cobble	2 – 4
3.4	Small Cobble	3 – 4
3.5	Small Cobble	3 – 5
4.6	Medium Cobble	4 – 6
6.8	Large Cobble	6 – 8
8	Large Cobble	8 – 10
9	Boulder/Bedrock	> 12
10	Large Cobble	10 – 12

breaklines[3] should be defined which coincide with the final bed file breaklines. Additional mesh breaklines should then be added between the initial mesh breaklines, and then additional nodes should be added as needed to improve the fit between the mesh and the final bed file and to improve the quality of the mesh, as measured by the Quality Index (QI) value. A QI value of at least 0.2 is considered acceptable (Waddle and Steffler 2002).

The computational mesh should be run to steady state at the highest flow to be simulated, and the water surface elevations (WSELs) predicted by RIVER2D at the upstream end of the site should be compared to the WSELs predicted by PHABSIM at the upstream transect. A stable solution will generally have a solution change (Sol Δ) of less than 0.00001 and a net flow (Net Q) of less than one percent (Steffler and Blackburn 2002).

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[3] Mesh breaklines are a feature of the R2D_MESH program which force edges of the computation mesh elements to fall on the mesh breaklines and force the TIN of the computational mesh to linearly interpolate the bed elevation and bed roughness values of mesh nodes between the nodes at the end of each breakline segment (Waddle and Steffler 2002). A better fit between the bed and mesh TINs is achieved by having the mesh and bed breaklines coincide.

Table 3. Cover coding system.

Cover Category	Cover Code
No cover	0
Cobble	1
Boulder	2
Fine woody vegetation (< 1" diameter)	3
Fine woody vegetation + overhead	3.7
Branches	4
Branches + overhead	4.7
Log (> 1' diameter)	5
Log + overhead	5.7
Overhead cover (> 2' above substrate)	7
Undercut bank	8
Aquatic vegetation	9
Aquatic vegetation + overhead	9.7
Rip-rap	10

In addition, solutions for low gradient streams should usually have a maximum Froude Number (Max F) of less than one. Calibration is considered to have been achieved when the WSELs predicted by RIVER2D at the upstream transect is within 0.1 foot of the WSEL predicted by PHABSIM. In cases where the simulated WSELs at the highest simulation flow varies across the channel by more than 0.1 foot, the highest measured flow within the range of simulated flows should be used for RIVER2D calibration. The bed roughnesses of the computational mesh elements should then be modified by multiplying them by a constant bed roughness multiplier (BR Mult) until the WSELs predicted by RIVER2D at the upstream end of the site matched the WSELs predicted by PHABSIM at the top transect. BR Mult values should lie within the range of 0.3 to 3.0. The minimum groundwater depth should be adjusted to a value of 0.05 to increase the stability of the model. The values of all other RIVER2D hydraulic parameters should be left at their default values (upwinding coefficient = 0.5, groundwater transmissivity = 0.1, groundwater storativity = 1, and eddy viscosity parameters $\varepsilon_1 = 0.01$, $\varepsilon_2 = 0.5$ and $\varepsilon_3 = 0.1$).

Table 4. Initial bed roughness values. For substrate code 9, use bed roughnesses of 0.71 and 1.95, respectively, for cover codes 1 and 2. Bed roughnesses of zero should be used for cover codes 1 and 2 for all other substrate codes, since the roughness associated with the cover is included in the substrate roughness.

Substrate Code	Bed Roughness (m)	Cover Code	Bed Roughness (m)
0.1	0.05	0.1	0
1	0.1	1	0
1.2	0.2	2	0
1.3	0.25	3	0.11
2.3	0.3	3.7	0.2
2.4	0.4	4	0.62
3.4	0.45	4.7	0.96
3.5	0.5	5	1.93
4.6	0.65	5.7	2.59
6.8	0.9	7	0.28
8	1.25	8	2.97
9	0.05	9	0.29
10	1.4	9.7	0.57
		10	3.05

Velocities predicted by RIVER2D should be compared with measured velocities on the transects and 50 validation velocities to determine the accuracy of the model's predictions of mean water column velocities. The criterion used to determine whether the model is validated is whether the correlation between measured and simulated velocities is greater than 0.6. The model would be in question if the simulated velocities deviated from the measured velocities to the extent that the correlation between measured and simulated velocities fell below 0.6.

After the RIVER2D model is calibrated, the flow and downstream WSEL in the calibrated cdg file should be changed to simulate the hydraulics of the site at the simulation flows. The cdg file for each flow contains the WSEL predicted by PHABSIM at the downstream transect at that flow. Each cdg file should be run in RIVER2D to steady state. Again, a stable solution will generally have a Sol Δ of less than 0.00001 and a Net Q of less than 1%. In addition, solutions should usually have a Max F of less than one.

B. 1-D PHABSIM QA/QC

If juvenile habitat is going to be simulated, at least 40 transects should be placed in each study segment to keep the 95% confidence limits for the flow associated with the highest juvenile WUA at or below 25% (Gard 2005). If only adult habitat is going to be simulated, the number of transects per study segment can be reduced to 20, which will keep the 95% confidence limits for the flow associated with the highest adult WUA at or below 13% (Gard 2005). The number of transects placed in each mesohabitat type should be proportional to the percentage of that mesohabitat type in the study segment. In addition, more transects (3-4) should be placed in more complex habitat units (i.e. pocket waters and pools) than in simpler habitat units (i.e. runs and riffles), which can be represented with 2 transects (SPECS 1995). For each mesohabitat unit selected for placing transects, a transect should be placed in each strata of the mesohabitat unit (i.e. pool head, middle and tail), with the location of the transect in each strata randomly selected. Transects should be placed so that the various features found within the habitat unit (i.e. bars, differences in substrate size, islands, etc.) are represented. A minimum of 2 replicates of each habitat type found within a study segment is required. If islands or divided channels comprise 15% or more of the segment, transects should be established in one or more of these divided habitats. Side channels and backwaters provide calmer backwater areas and are preferred by some life stages of fish (i.e. young of the year fish). To exclude these areas would be to miss an extremely important mesohabitat type.

Ideally, a transect should be placed across the hydraulic control. Hydraulic controls (constriction in the channel vertically or laterally that creates a backwater effect in the upstream direction) need to be defined, particularly for pools. The crest of a riffle is a familiar type of hydraulic control. Water surface elevations can be predicted more accurately at hydraulic controls. The *WSP* model in PHABSIM uses the WSELs at the hydraulic controls to estimate the WSELs further upstream, particularly in pool habitats. The second important function of a hydraulic control is that its lowest elevation determines how deep the water will be in the upstream pool at zero discharge. This elevation is known as the "stage of zero flow" and is an important input to the IFG4 hydraulic simulation model.

Transects should be placed in locations where there is no more than a 0.1 foot difference in WSEL across the transect and where the velocity profile across the transect is entirely perpendicular to the transect. Transects generally cannot be placed in areas with transverse flows, across-channel variation in water surface elevations, or flow contractions/expansions. Vertical benchmarks should be established for each transect to serve as the reference elevations to which all elevations (streambed and water surface) are tied. Vertical benchmarks should consist of items that will not change elevation over time, such as lag bolts driven into trees or painted bedrock points. Vertical benchmarks should be tied together for all transects located within three channel widths of each other, so that water surface elevations at different transects can be compared to ensure that water is not running uphill.

The data collected at each transect should include: 1) WSELs measured to the nearest 0.01 foot at a minimum of three significantly different stream discharges using standard surveying techniques (differential leveling); 2) wetted streambed elevations determined by subtracting the measured depth from the surveyed WSEL at a measured flow; 3) dry ground elevations to points above bankfull discharge surveyed to the nearest 0.1 foot; 4) mean water column velocities measured at the points where bed elevations were taken; and 5) substrate and cover classification at these same locations (Tables 2 and 3) and also where dry ground elevations were surveyed. When conditions allow, WSELs should be measured along both banks and in the middle of each transect. Otherwise, the WSELs should be measured along both banks. If the WSELs measured for a transect are within 0.1 foot of each other, the WSELs at each transect should be derived by averaging the two to three values. If the WSEL differ by greater than 0.1 foot, the WSEL for the transect should be selected based on which side of the transect was considered most representative of the flow conditions. If there is a hydraulic control downstream of a given transect, the stage of zero flow in the thalweg downstream of that transect should be surveyed in using differential leveling.

The range of flows to be simulated should go up to the mean unimpaired flow in the highest flow month. Water surface elevations should be collected at a minimum of three relatively evenly spaced calibration flows, spanning approximately an order of magnitude. The calibration flows should be selected so that the lowest simulated flow is no less than 0.4 of the lowest calibration flow and the highest simulated flow is at most 2.5 times the highest calibration flow. Velocity sets should be measured at the highest calibration flow, since it is generally more accurate to simulate down than up. If velocity sets cannot be measured at the highest calibration flow, edge cell velocities and depths should be measured at the highest calibration flow for cells that would be shallow or dry at the velocity set flow. These measurements should be used to calculate Manning's n values to put into these cells in the PHABSIM deck.

For the *IFG4* model to be considered to have worked well, the following standards must be met: 1) the beta value (a measure of the change in channel roughness with changes in streamflow) is between 2.0 and 4.5; 2) the mean error in calculated versus given discharges is less than 10%; 3) there is no more than a 25% difference for any calculated versus given discharge; and 4) there is no more than a 0.1 foot difference between measured and simulated WSELs. A beta value greater than 4.5 generally indicates that a hydraulic control downstream of the transect was not surveyed in, resulting in an erroneously low stage of zero flow value. *MANSQ* is considered to have worked well if the second through fourth of the above criteria are met, and if the beta value parameter used by *MANSQ* is within the range of 0 to 0.5. The first *IFG4* criterion is not applicable to *MANSQ*. *WSP* is considered to have worked well if the following criteria are met: 1) the Manning's n value used falls within the range of 0.04 - 0.07; 2) there is a negative log-log relationship between the reach multiplier and flow; and 3) there is no more than a

0.1 foot difference between measured and simulated WSELs. The first three *IFG4* criteria are not applicable to *WSP*. An additional QA/QC measure for *IFG4* or *MANSQ* is to check and see if water is flowing uphill at any of the simulated flows – if this is present, it usually indicates that the extrapolation of WSELs beyond the range of measured WSELs has broken down, and in such cases *WSP* should be used to develop the stage-discharge relationship for the upstream transect. The Froude numbers should be <1.0. The acceptable range of VAF values is 0.2 to 5.0 and the expected pattern for VAFs is a monotonic increase with an increase in flows.

5. Habitat Suitability Criteria (HSC) – Cover and adjacent velocity will be needed for all HSC observations, in addition to depth and mean water column velocity at the fish location (Service 2005). The Service measures average water column velocities when collecting HSC data. Average water column velocity data need to be collected for all HSC velocity and adjacent velocity measurements. There needs to be a minimum of 150 observations for each life stage and species (Bovee 1986).

Most existing habitat suitability criteria should not be used since they are likely biased towards low depths and velocities. The criteria used should use the recent advances in techniques for developing habitat suitability criteria for instream flow studies (adjustment of depth habitat suitability criteria for spawning to account for low availability of deep waters with suitable velocity and substrate, use of logistic regression to develop criteria, use of cover and adjacent velocity criteria for rearing). Criteria should be developed on the stream in question or the criteria in Service (2010a and b) should be used.

Most habitat utilization curves for salmonid spawning suggest that spawning salmonids, such as Chinook salmon and steelhead, prefer shallow conditions (typically depths of one to two feet). However, such curves may simply reflect that there is very little deeper areas present in streams which have suitable (good) velocities and substrates. Gard (1998) presents a method to adjust depth habitat utilization curves for spawning to account for low availability of deep waters with suitable velocity and substrate. To modify the depth curve to account for the low availability of deep water having suitable velocities and substrates, a sequence of linear regressions (Gard 1998) is used to determine the relative rate of decline of use versus availability with increasing depth. The depth correction methodology has been published in a peer-reviewed journal (Gard 1998) and has been applied on six streams (Merced River, American River, Sacramento River, Butte Creek, Yuba River and Clear Creek). The methodology has consistently shown that most of the decline in spawning habitat use with increasing depth is due to the low availability of deeper waters with suitable velocities and substrates, and not because salmonids will select only shallow depths for spawning.

Traditionally, habitat suitability criteria are created from observations of fish use by fitting a nonlinear function to the frequency of habitat use for each variable (depth, velocity, and substrate or cover). One concern with this technique is the effect of availability of habitat on the observed frequency of habitat use. For example, if a cover type is relatively rare in a stream, fish will be found primarily not using that cover type simply because of the rarity of that cover type, rather than because they are selecting areas without that cover type. Guay et al. (2000) proposed a modification of the above technique where depth, velocity, and cover data are collected both in locations where fish are present and in locations where fish are absent, and a logistic regression is used to develop the criteria. Logistic regressions tend to produce criteria that are shifted towards higher depths and velocities, as compared to criteria based solely on habitat use data, as a result of the limited availability of faster and deeper conditions (Service 2010a, b).

Unoccupied observations need to be collected to be used for developing logistic regression criteria (Manly et al. 2002). There needs to be a minimum of 300 unoccupied observations for each life stage and species. In general, logistic regression is an appropriate statistical technique to use when data are binary (e.g., when a fish is either present or absent in a particular habitat type) and result in proportions that need to be analyzed (e.g., when 10, 20, and 70 percent of fish are found respectively in habitats with three different sizes of gravel; Pampel 2000). It is well-established in the literature (Knapp and Preisler 1999, Parasiewicz 1999, Geist et al. 2000, Guay et al. 2000, Pearce and Ferrier 2000, Filipe et al. 2002, Tiffan et al. 2002, McHugh and Budy 2004, Tirelli et al. 2009) that logistic regressions are appropriate for developing habitat suitability criteria. For example, McHugh and Budy (2004) state:

> "More recently, and based on the early recommendations of Thielke (1985), many researchers have adopted a multivariate logistic regression approach to habitat suitability modeling (Knapp and Preisler 1999; Geist et al. 2000; Guay et al. 2000)."

Adjacent velocity can be an important habitat variable as fish, particularly fry and juveniles, frequently reside in slow-water habitats adjacent to faster water where invertebrate drift is conveyed (Fausch and White 1981). Both the residence and adjacent velocity variables are important for fish to minimize the energy expenditure/food intake ratio and maintain growth. The concept of adjacent velocity criteria was included in the original PHABSIM software, through the Adjacent Velocity Habitat Analysis (HABTAV) program (Milhous et al. 1989, pages v.69-78), but has rarely been implemented, and has been envisioned as primarily applying to adult salmonids, where the fish reside in low-velocity areas, but briefly venture into adjacent fast-velocity areas to feed on invertebrate drift. In studies for both the Yuba and Sacramento Rivers, the adjacent velocity criteria has been developed based on an entirely different mechanism, namely the transport of invertebrate drift from fast-water areas to adjacent slow-water areas where fry and juvenile salmonids reside via turbulent mixing (Service 2010b). Adjacent velocity is an important aspect of anadromous juvenile salmonid rearing habitat that has been overlooked in previous studies. Fry and juvenile anadromous salmonid rearing criteria show a consistent preference for composite cover (instream woody plus overhead) (Service 2010b). Composite cover likely is an important aspect of juvenile salmonid habitat because it reduces the risk of both piscivorous and avian predation. While cover is frequently used for anadromous juvenile salmonid rearing, the simplicity of the cover categories (typically no cover, object cover, overhead cover and object plus overhead cover) misses the importance of woody composite cover for anadromous juvenile salmonid rearing.

6. Biological Verification – Biological verification data should be collected to test the hypothesis that the compound suitability predicted by the River2D model is higher at locations where redds, fry or juveniles were present than in locations where redds, fry or juveniles were absent. The collected biological verification data are the horizontal locations of redds, fry and juveniles. The horizontal locations of redds, fry and juveniles found during surveys should be recorded with a total station or RTK GPS. For redds, depth, velocity, and substrate should also be measured. For fry and juveniles, depth, velocity, adjacent velocity, and cover should also be measured. The horizontal locations of where redds, fry or juveniles were not present (unoccupied locations) should also be recorded with a total station or RTK GPS. The hypothesis that the compound suitability predicted by the River2D model is higher at locations where redds, fry and juveniles were present than in locations where redds, fry and juveniles were absent should be statistically tested with a Mann-Whitney U test (Zar 1984). The combined habitat suitability predicted by River2D should be determined at each fry and juvenile observation location in the sites where redds, fry and juvenile locations were recorded with a total station or RTK GPS. The River2D cdg files should be run at the flows present in the study sites for the dates that the biological verification data was collected. The horizontal location measured for each observation should be used to determine the location of each observation in the River2D sites. The horizontal locations recorded with a total station or RTK GPS where redds, fry or juveniles were not present should be used for the unoccupied points. Mann-Whitney U tests (Zar 1984) should be used to determine whether the combined suitability predicted by River2D was higher at locations where redds, fry or juveniles were present versus locations where redds, fry or juveniles were absent. Biological verification needs to be conducted at the microhabitat scale (1 ft^2 grid) to determine if the combined suitability of occupied locations is greater than the combined suitability of unoccupied locations. This data is needed to verify the accuracy of the model's predictions regarding habitat availability and use (Gard 2006).

C. Demonstration Flow Assessment QA/QC

Depth and velocities should be measured to verify the location of polygon boundaries. Polygon boundaries should be delineated using tablet computers, high accuracy GPS transceivers, and high resolution aerial photographs (Gard 2009b). The minimum polygon size selected for use in a Demonstration Flow Assessment should correspond to the relevant scale for the smallest life stage/species assessed by a Demonstration Flow Assessment, for example, on the order of one square foot for trout fry. Binary criteria should be developed from continuous criteria that were developed in accordance with the standards identified above under Habitat Suitability Criteria.

References:

Bovee, K.D. 1986. Development and evaluation of habitat suitability criteria for use in the Instream Flow Incremental Methodology. Instream Flow Information Paper 21. U. S. Fish and Wildlife Service Biological Report 86(7). 235 pp.

Bovee, K.D., editor. 1995. Data collection procedures for the physical habitat simulation system. National Biological Service, Fort Collins, CO. 322 pp.

Crowder, DW and Diplas P. 2000. Using two-dimensional hydrodynamic models at scales of ecological importance. Journal of Hydrology. 230: 172-191.

Fausch, K.D. and R.J. White. 1981. Competition between brook trout (*Salvelinus fontinalis*) and brown trout (*Salmo trutta*) for positions in a Michigan stream. Canadian Journal of Fisheries and Aquatic Sciences 38: 1220-1227.

Filipe, A., I. Cowx and M. Collares-pereira. 2002. Spatial modeling of freshwater fish in semi-arid river systems: a tool for conservation. River Research and Applications 18: 123-136.

Gallagher, S. P. and M. F. Gard. 1999. Relation between chinook salmon (Oncorhynchus tshawtscha) redd densities and PHABSIM predicted habitat in the Merced and Lower American Rivers, CA. Canadian Journal of Fisheries and Aquatic Sciences 56: 570-577.

Gard, M. 1998. Technique for adjusting spawning depth habitat utilization curves for availability. Rivers: 6: 94-102.

Gard, M.F. 2005. Variability in flow-habitat relationships as a function of transect number for PHABSIM modeling. River Research and Applications 21: 1013-1019.

Gard, M. 2006. Changes in salmon spawning and rearing habitat associated with river channel restoration. International Journal of River Basin Management 4: 201-211.

Gard, M. 2009a. Comparison of spawning habitat predictions of PHABSIM and River2D models. International Journal of River Basin Management 7:55-71.

Gard, M. 2009b. Demonstration flow assessment and 2-D modeling: perspectives based on instream flow studies and evaluation of restoration projects. Fisheries 34(7): 320-329.

Geist, D.R., J. Jones, C.J. Murray and D.D. Dauble. 2000. Suitability criteria analyzed at the spatial scale of redd clusters improved estimates of fall Chinook salmon (*Oncorhynchus tshawytscha*) spawning habitat use in the Hanford Reach, Columbia River. Canadian Journal of Fisheries and Aquatic Sciences 57: 1636-1646.

Ghanem, A., P. Steffler, F. Hicks and C. Katopodis. 1996. Two-dimensional hydraulic simulation of physical habitat conditions in flowing streams. *Regulated Rivers: Research and Management.* **12**: 185-200.

Guay, J.C., D. Boisclair, D. Rioux, M. Leclerc, M. Lapointe and P. Legendre. 2000. Development and validation of numerical habitat models for juveniles of Atlantic salmon (*Salmo salar*). Canadian Journal of Fisheries and Aquatic Sciences 57: 2065-2075.

Knapp, R.A. and H.K. Preisler. 1999. Is it possible to predict habitat use by spawning salmonids? A test using California golden trout (*Oncorhynchus mykiss aguabonita*). Canadian Journal of Fisheries and Aquatic Sciences 56: 1576-1584.

Leclerc M, Boudreault A, Bechara JA and Corfa G. 1995. Two-dimensional hydrodynamic modeling: a neglected tool in the instream flow incremental methodology. *Transactions of the American Fisheries Society.* **124**(5): 645-662.

McHugh, P. and P. Budy. 2004. Patterns of spawning habitat selection and suitability for two populations of spring chinook salmon, with an evaluation of generic verses site-specific suitability criteria. Transactions of the American Fisheries Society 133: 89-97.

Manly, B.F.J., L.L. McDonald, D.L. Thomas, T.L. McDonald and W.P. Erickson. 2002. Resource Selection by Animals: Statistical Design and Analysis for Field Studies, Second Edition. Kluwer Academic Publishers, Dordrecht, The Netherlands.

Milhous, R.T., M.A. Updike and D.M. Schneider. 1989. Physical habitat simulation system reference manual - version II. Instream Flow Information Paper No. 26. U. S. Fish and Wildlife Service Biological Report 89(16).

Pampel, F.C. 2000. Logistic regression: a primer. Quantitative Applications in the Social Sciences 132.

Parasiewicz, P. 1999. A hybrid model – assessment of physical habitat conditions combining various modeling tools. In: Proceedings of the Third International Symposium on Ecohydraulics, Salt Lake City, Utah.

Pasternack GB, Wang CL and Merz JE. 2004. Application of a 2D hydrodynamic model to design of reach-scale spawning gravel replenishment on the Mokelumne River, California. *River Research and Applications.* 20(2): 202-225.

Pearce, J. and S. Ferrier. 2000. Evaluating the predictive performance of habitat models developed using logistic regression. Ecological Modelling 133(3): 225-245.

Snider, W.M., D.B. Christophel, B.L. Jackson and P.M. Bratovich. 1992. Habitat characterization of the Lower American River. California Department of Fish and Game, Sacramento, CA.

SPECS. 1995. Study Planning, Checking and Evaluation System: River Segment Evaluation. National Biological Service, Fort Collins, CO.

Steffler, P. 2002. River2D_Bed. Bed Topography File Editor. User=s manual. University of Alberta, Edmonton, Alberta. 32 pp. http://www.river2d.ualberta.ca/download.htm

Steffler, P. and J. Blackburn. 2002. River2D: Two-dimensional Depth Averaged Model of River Hydrodynamics and Fish Habitat. Introduction to Depth Averaged Modeling and User=s Manual. University of Alberta, Edmonton, Alberta. 120 pp. http://www.river2d.ualberta.ca/download.htm

Theurer, F.D., K.A. Voos, W.J. Miller. 1984. Instream Water Temperature Model. Instream Flow INF. PAP. 16. U.S. Fish and Wildlife Service FWS/OBS-84/15.

Thielke, J. 1985. A logistic regression approach for developing suitability-of-use functions for fish habitat. Pages 32-38 in F.W. Olson, R.G. White, and R.H. Hamre, editors. Proceedings of the symposium on small hydropower and fisheries. American Fisheries Society, Western Division and Bioengineering Section, Bethesda, Maryland.

Tiffan, K.E., R.D. Garland and D.W. Rondorf. 2002. Quantifying flow-dependent changes in subyearling fall Chinook salmon rearing habitat using two-dimensional spatially explicit modeling. North American Journal of Fisheries Management 22: 713-726.

Tirelli, T., L. Pozzi and D. Pessani. 2009. Use of different approaches to model presence/absence of salmon marmoratus in Piedmont (NorthWestern Italy). Ecological Informatics 4: 234-243.

U. S. Fish and Wildlife Service. 2005. Flow-habitat relationships for chinook salmon rearing in the Sacramento River between Keswick Dam and Battle Creek. Sacramento, CA: U.S. Fish and Wildlife Service. Sacramento, CA: U.S. Fish and Wildlife Service.

U. S. Fish and Wildlife Service. 2010a. Flow-habitat relationships for spring and fall-run Chinook salmon and steelhead/rainbow trout spawning in the Yuba River. U. S. Fish and Wildlife Service, Sacramento, California.

U. S. Fish and Wildlife Service. 2010b. Flow-habitat relationships for juvenile spring/fall-run Chinook salmon and steelhead/rainbow trout rearing in the Yuba River. U. S. Fish and Wildlife Service, Sacramento, California.

Vyverberg, K., B. Snider and R.G. Titus. 1996. Lower American river Chinook salmon spawning habitat evaluation October 1994. California Department of Fish and Game, Environmental Services Division, Stream Flow and Habitat Evaluation Program, Sacramento, CA. 120 pp.

Waddle, T. and P. Steffler. 2002. R2D_Mesh - Mesh Generation Program for River2D Two Dimensional Depth Averaged Finite Element. Introduction to Mesh Generation and User=s manual. U.S. Geological Survey, Fort Collins, CO. 32 pp. http://www.river2d.ualberta.ca/download.htm

Zar, J.H. 1984. Biostatistical Analysis, Second Edition. Prentice-Hall, Inc., Englewood Cliffs, NJ.