Guidelines to the Application and Use of the Physical Habitat Simulation System

The Instream Flow Incremental Methodology (IFIM) is used to assess aquatic and riparian instream needs in California's streams and rivers. IFIM is a comprehensive framework of analytical techniques and approaches. It provides a considered and incremental approach to instream evaluations, and related decision making processes. The Physical Habitat Simulation system (PHABSIM) is one assessment methodology available within the suite of IFIM methodologies. PHABSIM was specifically developed as a component of IFIM. PHABSIM includes three major analytical components, river hydraulics, species life stage microhabitat suitability, and physical habitat modeling. PHABSIM was designed to incorporate these components to develop information on species life stages' microhabitat, in terms of weighted usable area (WUA) and flow relationships in specific streams and rivers.

Applicability, utility, and defensiblility of PHABSIM WUA/discharge models and relationships and resultant water allocation decisions are dependent upon many factors. Among these are:

1. Adequately and effectively sampling a range of river flows, mesohabitats (e.g., run, riffle, pool, etc.) present within river reaches, and the hydraulic and physical conditions (i.e., microhabitat) within those mesohabitats.
2. Development of well calibrated hydraulic and physical models.
3. Use of appropriate fish species life stage habitat suitability criteria as model input.
4. Development of biologically based habitat models (i.e., how hydraulics and suitability criteria are aggregated to estimate physical habitat quality and quantity).
5. Procedures followed to evaluate and develop aquatic and riparian habitat flow regimes.
6. Verification/validation of model output (spatial distribution of suitable and unsuitable habitat areas).

The following describes the Department of Fish and Game's (Department) guidelines regarding application and use of PHABSIM in California. This is a living document, and will be revised in as needed in the future, to reflect advancements in stream assessment techniques. These guidelines do not constitute a standard, specification, or regulation.

It is virtually impossible to measure a vast array of river discharges, and 100% of the distribution of hydraulic and physical variables available at each specific discharge, to develop WUA/flow relationships. Therefore, it is often necessary to sample subsets of these and other variables. For one-dimensional hydraulic analyses, physical conditions (e.g., water depth and velocity, cover, and substrate or channel index) within mesohabitat units are generally measured along cross-sectional transects established within the mesohabitat units. Two-dimensional hydraulic analyses typically employ mesohabitat sampling designs similar to the representative reach sample design. Physical variables within each two-dimensional sample site, however, are measured throughout the site, rather than along discrete transects. An extensive, variable shaped (i.e., polygons), sample grid includes representatives of all available mesohabitat types under consideration. Care must be taken during development and implementation of two-dimensional study designs, however, to insure sufficient data are collected for specific mesohabitats to allow extrapolation to represent the larger river segment. For either approach, adequate habitat mapping at the reach level is required to ensure implementation of effective and defensible sample designs, appropriate cross section placement in specific mesohabitat types or representative reaches (one-dimensional), inclusion of representative meso- and microhabitats (two-dimensional), and to allow appropriate scaling of results from the study site(s) to the reach level.

The following applies to one- and two-dimensional analyses' mesohabitat delineation and representative reach sample designs.

BASIC SAMPLING DESIGN AND PROCEDURES PROTOCOL

A statistical approach to determining sample designs to evaluate riverine needs is an effective means of ensuring macro-, meso-, and microhabitat variability are adequately considered and included in riverine evaluations, and resultant conclusions, recommendations, and management decisions. A statistical approach, however, may be lengthy and costly, due to the complexity, frequency, and distribution of various hydraulic and habitat parameters incorporated into PHABSIM habitat/river flow modeling; the variability within and between these parameters for similar meso- and microhabitats; and to the general requirement that preliminary estimates of population variances and means be determined to form the foundation of sample needs.

The number and range of river flows, mesohabitats, reaches, and transects sampled within river segments influence the extrapolation range, representativeness, applicability, reliability, and utility of any PHABSIM model. It is critical that river flows, mesohabitats, and microhabitats be effectively sampled in order to develop applicable and usable PHABSIM simulations. To that end, it is the Department's position that proposed PHABSIM analyses initially include: a) sampling three distinct river flows; b) three units of each significant mesohabitat type within each generally homologous river segment; and c) for one-dimensional simulations, at least three transects within each mesohabitat unit. The actual number of flows, mesohabitats, or transects actually sampled is dependent upon complexity in riverine conditions and investigation objectives. This is defined as the Basic Sampling Design and Procedures Protocol (protocol).

The protocol is a systematic decision tree that provides stepwise decisions to determine flow, mesohabitat, and microhabitat sample size requirements. It is designed to ensure simulation applicability and utility over the full range of historical and anticipated future hydrologic conditions for the stream segments under consideration. The various parties involved should apply the protocol in a collaborative manner.

The protocol considers PHABSIM sampling needs related to simulating a river's hydraulic, physical, and habitat variability *in lieu* of a statistical approach. The protocol was developed to provide an effective approach to PHABSIM streamflow assessments, while minimizing assessment costs. The protocol is intended to ensure that within and between river flows, mesohabitats, and microhabitat variability are considered and adequately sampled and simulated. It avoids high costs associated with purely statistical approaches (e.g., basing sample needs on preliminary estimates of variance and other population information).

The protocol approaches sample size needs from the perspective that a sample of one does not allow within or between mesohabitat, microhabitat (e.g., water depth and velocity, substrate, cover, etc.), or flow variability to be introduced into a model. A sample size of two would allow some variability to be introduced, but results could be biased and/or misleading if a sample data were somehow not representative of the overall reach. A sample size of two would not provide verification of presence or absence of bias. A minimum sample size of three is required to develop an estimate of variance, and is a first step to minimize the potential effects of including biased/misleading samples within the model. Therefore, a sample of at least three units of each target mesohabitat type present per each homologous river reach, at least three microhabitat transects per each mesohabitat unit, and at least three water depth and velocity calibration flows is the initial starting point. Target species and life stage physical habitat needs should be carefully considered when defining necessary target mesohabitat types to be included. For example, a mesohabitat type may be rare (e.g., less than 5%), but represent the only known spawning habitat for a target species, and, therefore, should be included as a target mesohabitat. The actual number of mesohabitat units, microhabitat transects per unit, and river flows necessarily sampled for PHABSIM model development and aquatic habitat simulation is dependent upon river reach heterogeneity; mesohabitat and microhabitat frequency, distribution, and variability; and flow characteristics' variability. In specific cases, it may be appropriate to sample less or more than three replicates of each mesohabitat unit, three microhabitat transects per unit, and water depth and velocity characteristics at three flows. Collaborating parties should evaluate sampling design and needs in the field, and document the decision making process.

Complexities and variability inherent in river flows, mesohabitats, and microhabitat sub-units generally require several transects be sampled within each mesohabitat. Microhabitat sub-unit distribution, complexity, and variability within each mesohabitat dictate the number of transects necessary per each mesohabitat. The more microhabitat sub-units, the more transects required. In some cases, mesohabitats may be very homologous and less than three transects may be required.

Each specific microhabitat sub-unit should be delineated by an up- and downstream boundary depicting a row of cells, within which the physical variables are assumed to be uniform. The variables across each transect will vary, and the number of cells across each transect is dictated by this variability. As channel geometry, substrate, and/or cover complexity and distribution increases within a given microhabitat unit, the number of transects necessary to capture the linear microhabitat variation within a mesohabitat also increases. It is not unusual for 10 or more transects to be used to describe a riffle-pool sequence in a small stream that has a diversity of physical features (e.g., boulders, broken ledge rock, gravel, cobbles, areas of fine deposition, large woody debris, etc.). For larger alluvial streams, several transects may be required to capture the features of a relatively simple pool-crossing bar sequence due to the significant change in river depth in the linear dimension and edge effects where features such as root wads, undercut banks, eddies, etc. are common and are critically important fish habitat features. Sample sizes smaller than three must be documented with written explanation/justification.

Sampling Design and Procedures

HYDROLOGY

1. Develop unimpaired [i.e., natural, without project(s)] annual flow time series and exceedance information for the period of record, and extend this hydrological information from the point of measurement (e.g., gaging station) to the stream segments under consideration. In some cases, simulation models may be used where adequate gauge data cannot be extended.
2. Identify three discharges that, if each were sampled for depth/velocity characteristics, the resultant data and calibrated hydraulic models would allow for PHABSIM WUA/discharge information to be extrapolated to flows ranging between 90 and 10% unimpaired flow exceedance values. Typically, well calibrated hydraulic models provide for a PHABSIM extrapolation range from approximately 40% of the lowest flow to approximately 250% of the highest flow sampled. However, valid ranges of extrapolation in the hydraulics must be evaluated as part of the hydraulic model calibration/simulation process. Evaluate the three flows identified prior to sampling. Determine if sampling water depth and velocity characteristics at fewer or more flows would be necessary to adequately simulate the range of characteristics present. This determination shall be based on the hydraulic and physical microhabitat variability present within each mesohabitat at the three flows, and is to be made collaboratively. If all parties cannot agree whether fewer or more than three flows should be sampled, three flows remains the default sample size. Regardless of the number of river flows sampled, those sampled must be of a sufficient magnitude to allow development of habitat time series for flows ranging from the 90 to 10% exceedance flows, applicable and reliable habitat duration values for these exceedance flows, and the 50% exceedance habitat duration metric for various runoff or water year types. The 50% habitat duration metric serves as a stream's natural flow benchmark. In specific cases, the actual flow range evaluated may be limited by water availability due to legal, and sometimes, operational constraints. The actual range of flows sampled should be evaluated and agreed upon cooperatively. In the event agreement cannot be reached, the Department shall identify the flows to be sampled and data extrapolation range.

SAMPLING

1. Partition the river in question into generally homologous segments.
2. Delineate all mesohabitat types (e.g., run, riffle, pool, etc.) throughout each segment at a moderate, unimpaired discharge. In diverted systems, this may require release of water into the study reach. In undiverted systems, this may require careful consideration of natural flow(s) timing and characteristics. Mesohabitat definitions included in the Third Edition of the Department's "California Salmonid Stream Habitat Restoration Manual "

(1998), Level III and potentially Level IV definitions, should be used when delineating mesohabitats. Extremely low and high flows should be avoided for mesohabitat delineation. If the range of natural and/or simulation flows is large and/or there is substantial variability in hydraulic characteristics, habitat delineation at more than one flow may be necessary. Each mesohabitat distribution should be used for its respective habitat simulation flow range. Ground survey habitat delineation techniques are the preferred techniques. Mesohabitat delineation via aerial or photogrammetric techniques, may be acceptable, and, if used, must be verified by ground surveys. A frequency distribution of available habitat types and distribution per river segment shall be the basis for subsequent sample design development for cross section selection or representative reaches. The Department's concurrence with mesohabitat types definitions should be obtained prior to habitat delineation.

3. Evaluate specific mesohabitat types that may be hazardous to sample, and/or that may be virtually impossible to model hydraulically. If all interested parties agree that specific mesohabitats may be deleted from subsequent PHABSIM sampling and modeling, determine how such mesohabitat types will be considered during the assessment(s). Alternatives include interested parties agreeing upon: a) different assessment methods if the mesohabitat type comprises a significant portion of a river reach, and/or if the mesohabitat includes an important function for target species; b) deleting these mesohabitat types from sampling, model development, and stream needs assessment(s); and c) assuming that results of assessment valuations for other mesohabitats will be applicable to mesohabitats that may be hazardous and/or may not be modeled.
4. Evaluate the biological importance of each mesohabitat that comprises less than 5% of the total linear distance of the homologous reach. Include all biologically significant mesohabitat types in subsequent sampling, WUA/discharge development, and streamflow needs assessment(s).
5. One Dimensional Hydraulic Analyses:
    a. *Mesohabitat Selection for Mesohabitat Delineation Analyses* - Prepare a sample design including each mesohabitat type that may be sampled, and that comprises 5% or greater of the total linear distance of each homologous reach, and for any biologically important mesohabitat type comprising less than 5% of the total linear distance. Randomly select three representative units of each mesohabitat type identified (e.g., three runs, three riffles, etc.) within each homologous river segment. There are various procedures to introduce randomness into mesohabitat selection. The method selected shall be determined in a collaborative manner. If an acceptable approach cannot be agreed upon by all interested parties, then complete random selection is the default. Document the decision making process and random approach selection. In cases where a representative reach approach is determined acceptable to all parties, the sample reach must include all mesohabitat types comprising 5% or greater of the total linear distance of each homologous river segment and/or any biologically important mesohabitat types comprising less than 5% of the total linear distance.

       Determine if it would be appropriate to sample fewer than three units of each mesohabitat. This determination shall be based on the number of units of a specific mesohabitat type within a single reach, the hydraulic and physical microhabitat variability present in the specific mesohabitat type, and on a mesohabitat's biological significance. This determination shall be made collaboratively. If all parties cannot agree whether less than three units should be sampled, three units remains the default sample size. Often only a single unit of a unique mesohabitat type may be present within an entire stream segment (e.g., an island complex or backwater area at the mouth of a small intermittent tributary). In such cases, one or two mesohabitat units captures 100% of the variability present in the segment.

Ground truth each mesohabitat unit selected for sampling to verify that the reach and unit indeed does represent the appropriate mesohabitat type and can be sampled/modeled. Randomly select additional units as needed, or adjust the upstream and downstream spatial extant of the representative reach boundaries to incorporate needed mesohabitat types.

b Mesohabitat Selection for Representative Reach Analyses - Select a representative reach, or reaches, that include(s) at least three units of each mesohabitat type that comprises at least 5% of the total linear distance of each homologous reach, and any biologically important mesohabitat type comprising less than 5% of the total linear distance. Document the selection process. Two or more representative reaches my be needed to capture three units of each mesohabitat type. Fewer than three units of each mesohabitat type may be acceptable in relatively short stream segments where only one or two units of a particular mesohabitat type are present within the segment.

Determine if it would be appropriate to sample fewer than three units of each samplable mesohabitat per reach that can be sampled. This determination shall be based on the number of units of a specific mesohabitat type within a single reach, the hydraulic and physical microhabitat variability present in the specific mesohabitat type, and on a mesohabitat unit's biological significance. This determination shall be made collaboratively. If all parties cannot agree whether less than three units should be sampled, three units per representative reach remains the default sample size. Often only a single unit of a unique mesohabitat type may be present within an entire stream segment (e.g., an island complex or backwater area at the mouth of a small intermittent tributary). In such cases, one or two mesohabitat units captures 100% of the variability present in the segment.

Ground truth each represent reach and sample mesohabitat unit selected to verify that the reach and units represent the appropriate river and mesohabitat types. Randomly select additional reaches or units as needed.

It is recognized that in many instances, site access, property ownership and related logistical considerations must be considered.

c. *Transect Selection for Mesohabitat Delineation and Representative Reach*

Analyses - The preferred approach is to sub-divide each mesohabitat into relatively homogeneous microhabitat sub-units, each delineated by an upstream and downstream boundary. Randomly place a transect within each microhabitat sub-unit, and then ground truth all transects to verify that the significant microhabitat features of each mesohabitat are captured by the transects and associated habitat cells. If ground truthing indicates a transect is not effectively placed and/or does not transect reflect all of the hydraulic and physical characteristics present, adjust transect placement and/or add additional transects as necessary. Any adjustments should be carefully documented.

Evaluate each mesohabitat sample unit to determine how many transects are needed to describe the microhabitat features and variability within each mesohabitat unit. Determine the number of acceptable transects and document the decision making process. Transect(s) sample size decision making process shall be based on the hydraulic and physical microhabitat variability present within the specific mesohabitat type, and shall be made collaboratively. In specific, limited cases, such as hydraulically uniform or extremely simple mesohabitat units, it may be appropriate to use fewer than three habitat transects. If all parties cannot agree whether less than three habitat transects should be sampled, three transects for habitat simulation is the default sample size.

Pools shall have at least three transects. At least one transect shall be placed in the head, one in the body, and one in the tail section of each pool sampled. Large and/or complex pools may require additional transects. Pool tail-outs and transition zones upstream of the next downstream habitat type shall be considered components of pool tails. Unusual circumstances (e.g., very small pools and low habitat variability) may justify evaluation of whether three habitat transects are necessary. If all parties cannot agree whether fewer or more than three habitat transects should be sampled, three habitat transects is the default sample size.

Ground truth each transect selected for sampling within each mesohabitat sample unit to determine whether the transect represents the mesohabitat unit, and samples the hydraulic and physical microhabitats available within the unit. Select additional transects (using the agreed upon selection technique) within the mesohabitat unit as needed, with ground truthing.

To allow extrapolation over the full range of historic flows, and use of the several options in the PHABSIM library, the downstream hydraulic control for each mesohabitat must be identified, and included with the sample design in a addition to microhabitat representation transects. The hydraulic control transect is used in the step back water sub-program to simulate water surface elevations for the full range of flows under consideration. The hydraulic control transect generally is not included in habitat simulations. The thalweg elevation of each control should be identified and surveyed.

d. *Transect Microhabitat Measurements* - Measure hydraulic and physical microhabitat conditions (e.g., water depth and velocity, substrate, cover, etc.) along each transect at three distinct river discharges (e.g., low, moderate, and high). Transects shall be extended up the bank to allow for simulations over the full range of flows in the hydrological time series. Hydraulic and physical conditions along each transect shall determine measurement cell width. Transect stations should be established at the mesohabitat delineation flow to ensure characteristic changes will be incorporated, and not disruptive to overall study, or necessitate establishing new transects or stations at lower or higher flows. A minimum of 20 cells shall be required for each transect, unless collaborating parties agree fewer cells would be appropriate. No more than 5% of the flow should be within a single cell. Cell boundaries shall be placed at changes in physical and/or hydraulic characteristics. Cells should not include conflicting hydraulic or physical features, such as up- and down- stream water currents within a single cell, eddies, shear zones, substrate differences, etc. Cell widths and boundaries shall be sufficiently sized and spaced (i.e., the more complex the microhabitat, the narrower the cells) to capture all important habitat variables, and to permit application of the habitat suitability function selected.

e. *Model Development* - Proceed with hydraulic and physical habitat sampling, PHABSIM model development, and streamflow needs assessment(s). Data collected should be compatible with habitat components generally described within the Habitat Suitability Criteria Section, below. Predicted river discharge, water surface elevations, and calibrated water velocities should be compared with measured values to validate predicted velocities and model calibration. Make appropriate adjustments to water surface elevations to improve calibration(s). Final calibration results, including validation comparisons should be carefully documented and agreed upon.

6. Two Dimensional Hydraulic Analyses:

a. Mesohabitat and Sample Area Selection - Select a reach, or reaches, that include(s) at least three units of each samplable mesohabitat type that comprises at least 5% of the total linear distance of each homologous reach, and any biologically important mesohabitat type comprising less than 5% of the total linear distance. Delineate location and distribution of mesohabitats within the representative reach. Maintain records based on this delineation.

Two or more representative reaches my be needed to capture three units of each mesohabitat type. In some cases, it may be necessary to establish more than one sample reach within a stream segment in order to describe all mesohabitats present. In other cases, a river segment may be relatively short (e.g., 100 yards) and may be included in its entirety for habitat sampling. If all collaborators agree, fewer than three units of each mesohabitat type may be acceptable in relatively short stream segments where only one or two units of a particular mesohabitat type are present within the segment.

Ground truth each represent reach and sample mesohabitat unit selected to verify that the reach and units represent the appropriate river and mesohabitat type(s). Select additional reaches or units as needed per the agreed upon selection process.

b. Microhabitat Measurements - A stage discharge relationship in which at least three water surface elevations and discharge estimates are considered should be established at the downstream and upstream boundary of each reach to be modeled. In addition, the longitudinal profile of the water surface elevation, that includes all breaks in the slope of the water surface elevation should be collected at each calibration flow. Substrate and vegetation distributions should be mapped (via polygons) within the entire reach in order to assign the appropriate roughness within the computational mesh for hydraulic calibration and habitat modeling. Validation velocity sets should also be collected within the reach at one or more calibration flows. Sampling of calibration velocities should target capture of the complexity in the flow fields within the reach (i.e., re-circulation zones, shear zones, laminar flow areas, etc.). Channel topographies may be collected by a variety of survey techniques but should focus on obtaining an accurate three-dimensional representation of the channel topography. More field points should be obtained in area of complex geometries to ensure that the hydraulic computational mesh is adequate to represent the channel topography from these interpolated data. In construction of the computational meshes, care should be given to preserve measured field points, and to examining for spurious interpolated points.

   During the hydraulic model calibration process, mesh refinement may be required in regions where poor agreement is obtained between predicted and observed water surface elevations or velocities. Computational mesh density (i.e, grid spacing) should carefully consider the species and life stages being modeled, and the particular hydrodynamic model's computational efficiencies.

c. *Model Development* - Proceed with hydraulic and physical habitat sampling, PHABSIM model development, and streamflow needs assessment(s). Data collected should be compatible with habitat components generally described within the Habitat Suitability Criteria Section, below. Predicted river discharge, water surface elevations, and calibrated water velocities should be compared with measured values to validate predicted velocities and model calibration. Make appropriate adjustments to water surface elevations to improve calibration(s).

If agreement regarding mesohabitat or representative reach approaches; flows, mesohabitats, mesohabitat sampling needs, transect sampling needs, transect placement; and/or one or two dimensional techniques and analyses cannot be reached through the collaborative process, three river flows, three mesohabitat units within each homologous segment or representative reach, microhabitat transect placement, and/or grid size as described above for one or two dimensional hydraulic analyses continues to be the minimum sample size.

STATISTICAL APPROACH

If there is disagreement regarding the Department's IFIM/PHABSIM basic sampling design and procedures, use of a statistical approach to determine sample size needs and subsequent sampling is acceptable. The number of mesohabitats and transects necessary to develop representative WUA/discharge relationships within prescribed statistical limits may be statistically determined by developing preliminary estimates of population variance, and applying appropriate formulas.

To use a statistical approach effectively, it is necessary to identify sample size needs regarding the number of mesohabitats and types within each homologous reach, as well as the number of microhabitat units within each mesohabitat type. Mesohabitat parameters such as type, length, minimum and maximum width, water depth and velocity (e.g., range, average, etc.), slope, edge type. and physical habitat features (e.g., substrate size and distribution, cover, bank and vegetation edges and types), shall be considered in statistically analyses to determine the required mesohabitat sample size(s). Parameters such as water depth and velocity (e.g., range, average, etc.), substrate, vegetation, cover type, distance to escape cover, distance to shear zones, etc. at specific stations along transects within each mesohabitat type must also be considered to statistically determine transect sample size(s).

HABITAT SUITABILITY CRITERIA

Habitat suitability criteria (HSC) are functions that define the suitability (typically on a scale of 0.0 to 1.0) of environmental factors, such as water depth and velocity, substrate, cover, and other habitat components, for specific species life stages. Alternatives that may be considered for certain species life stages HSC are binary and variable quality suitability indices. Binary indices are indices that denote conditions are suitable (HSC = 1.0) or unsuitable (HSC = 0.0). Variable quality indices are indices that denote suitabilities in general, broad categories. Most, moderately, or not suitable (HSC = 1.0, 0.5, and 0.0, respectively) are examples of variable suitability indices.

Hydraulic and physical characteristics found within each evaluation cell for each evaluation flow typically are considered to develop WUA/discharge relationships. An evaluation cell's overall biological importance and, consequently, WUA contribution may be influenced by conditions in cells or areas adjacent to, or near a cell being evaluated. For example, fast water velocity zones adjacent to an evaluation cell with slow water velocity may be conditions that are particularly important to specific species life stages. Another example is the proximity of inundated riparian vegetation to an evaluation cell. An evaluation cell adjacent to the inundated riparian may be critically important, whereas evaluation cells adjacent to non-vegetated areas may be of little importance. In cases such as these examples, and for other factors identified during stream needs assessments, needed HSC should be developed and included in PHABSIM evaluations.

HSC are critical input values to PHABSIM, and are key components to the applicability and utility of PHABSIM analyses. PHABSIM results can be sensitive to many input variables, but reliable HSC are one of the most important components. Biased HSC lead to biased results, and questionable decisions and flow regimes. For example, if habitat availability is not included in the basic study design, or accounted for in data compilation, biased criteria likely result. Hence, care must be used in selecting HSC to use during such analyses and evaluations. Emphasis should be placed on developing HSC that describe a species life stage's actual meso- and microhabitat selection/avoidance characteristics.

HSC should provide insight into a fish's actual habitat selection or preference. To avoid including unknown biases when developing HSC, it is necessary to sample a wide range of flows, mesohabitats, and hydraulic and physical conditions. HSC developed from data collected at a single flow, limited mesohabitats, limited conditions, etc., typically lead to PHABSIM analyses that return the conditions existing during data collection. This is particularly true if habitat availability is not considered in criteria development.

The Department's protocol for HSC selection, in order of priority, is:

1. Develop and use site specific HSC in PHABSIM analyses.
2. Develop and use of regional HSC.
3. Consider literature HSC if site-specific or regional species life stage of interest HSC are not available, or cannot be developed. Transferability and applicability of candidate HSC to the river or river section under consideration is evaluated, and confirmed or rejected. The first step to transfer HSC evaluation should be a visual evaluation of plotted fish observation from the test stream with the proposed transfer HSC. The second step should be statistical analyses to determine whether the transfer HSC "fit" the test stream. Unfortunately, tests commonly used often produce conflicting results. Therefore, unless a more suitable statistical test is used, results of statistically analyses should be considered in light of the visual examination of plotted data.
4. Professional judgement modification of literature same species and life stage HSC. The applicability of such modified HSC to the test stream is evaluated, statistically tested when possible, and confirmed or rejected.
5. Consider similar species and life stage(s) HSC from the river segment being evaluated, if same species life stage HSC are not available in the literature. Transferability and applicability of candidate HSC is evaluated as described in number 3, above.
6. Professional judgement modification of similar species and life stage(s) HSC from the river segment being evaluated may be considered. Transferability and applicability of candidate HSC is evaluated as described in number 3, above.
7. Consideration of similar species and life stage(s) literature HSC if same species life stage(s) literature HSC, or onsite similar species life stage(s) are not available. Transferability and applicability of candidate HSC should be evaluated as described in number 3, above.
8. Professional judgement modification of similar species and life stage(s) literature HSC. Applicability of such modified HSC is evaluated as described in number 3, above.
9. Consideration of professional judgement HSC. The applicability of professional judgement HSC is evaluated as described in number 3, above, and confirmed or rejected.
10. In the event site-specific HSC cannot be developed, existing HSC cannot be transferred, and/or agreement on professional judgement HSC cannot be reached, the Department, in consultation with interested parties will determine the HSC appropriate for use.

There are a number of field methods available to collect data to develop HSC. The preferred method is use of underwater, or, in certain circumstances, above water, direct observation techniques. If other methods are used (e.g., electrofishing, radio tagging, etc.), the validity and applicability of such technique(s) and resultant data must be compared with, and verified by, direct observation data.

The following procedures are designed to ensure collection of usable field data and HSC development. They were derived to address the matter of habitat availability in HSC development. These procedures focus on development of site-specific criteria. However, the general concepts apply to development of regional criteria as well.

1. Identify and evaluate at least three river flows (e.g., low, medium, and high) to sample. Extremely low and high flows should be avoided during data collection. Sampling fewer than three flow levels very likely would result in biased criteria, and should be avoided. Flows sampled shall be based on the hydraulic and physical microhabitat variability present within mesohabitat types, and shall be made collaboratively. Regardless of the number of flows sampled, flows sampled and data obtained must allow for development of HSC applicable to PHABSIM models that facilitate extrapolation of WUA/discharge relationships to flows ranging between 90% and 10% unimpaired (i.e., natural) exceedance flows. If all parties cannot agree whether fewer or more than three flows should be sampled, three flows remains the default sample size.
2. Partition the river in question into generally homologous segments. If regional HSC are being developed, riverine systems should be partitioned by stream type, elevation, gradient, and/or other appropriate characteristics.
3. Delineate all mesohabitat types (e.g., run, riffle, pool, etc.) at an unimpaired, moderate river discharge throughout each segment. Extremely low and high flows should be avoided for mesohabitat delineation. Identify each mesohabitat type comprising at least 5% of the total linear distance of each homologous reach, and all biologically important mesohabitat types comprising less than 5% of the total linear distance.
4. Evaluate specific mesohabitat types and/or river flows that may be hazardous to sample. If all interested parties agree that specific mesohabitats and/or flows should be deleted from subsequent HSC data collection, determine how deletion of such data may affect HSC development and utility. Incorporate appropriate measures to reduce identified impacts. Document the decision making process, and conclusions.
5. Prepare a sample design for each homologous stream segment. Randomly select three units of each mesohabitat type comprising 5% or greater of the total linear distance of each homologous segment, and those biologically important mesohabitat types comprising less than 5% of the total linear distance. There are various procedures to introduce randomness into mesohabitat selection. The method selected shall be determined in a collaborative manner. If an acceptable approach cannot be agreed upon by all interested parties, then complete random selection is the default. Document the decision making process and random approach selection.
6. Ground truth selected mesohabitat units to determine whether the unit represents the target mesohabitat type. Randomly select and ground truth additional units as needed.
7. Collect data within each mesohabitat unit. Data may be collected through 100% sampling of each unit, or by a Department approved sub-sampling technique (e.g., transects, grids, etc.). Ground truth sub-sampling units selected within each mesohabitat

sample unit to determine whether they represent the mesohabitat unit, the hydraulic conditions, and the physical microhabitats available within the unit. Select additional sub-sampling units within the mesohabitat unit(s) needed, with ground truthing. This item does not apply to two dimensional data collection.

8. Partition data collection by riverine type, flow, and meso- and microhabitat type. Data should be partitioned diurnally and seasonally whenever possible. Data from different categories should be compared, and data for significant individual categories included, as appropriate, within PHABSIM analyses and water allocation decisions.
9. Sample all sample periods/conditions/components/flows/etc. equally. If not sampled equally, appropriate steps (e.g., mathematically adjust sample sizes to attain equality) should be taken to address and minimize potential biases. These steps should be developed collaboratively. However, the Department reserves the option of determining the acceptable technique.
10. The target sample size is at least 150 observations per species life stage per river flow, homologous reach, season, and diurnal period sampled. A single fish or group of fish in the same location is considered an observation. More than 150 observations may be needed to develop HSC. Actual sample sizes and partitioning components are dependent upon specific circumstances, and should be determined in a collaborative manner. Identify and account for influencing factors. Sampling should not be discontinued once 150 observations is reached if doing so would compromise equal sampling design needs (e.g., effort, area, etc.). Each condition is a specific requirement. For example, if 150 observations have been collected, but equal area sampling requirements have not been met, sampling must continue until the sample area requirements have also been met.
11. Address habitat availability for each river flow, mesohabitat, and/or representative reach, season, diurnal period, etc. sampled, and account for habitat availability in HSC development. Habitat availability may be accounted for in the basic fish observation sample design (e.g., sample a wide range of flows, hydraulic conditions, physical conditions, seasons, etc.), or in data compilation (e.g., proportional habitat use divided by proportional habitat availability). If habitat availability data are not included in HSC development, resultant HSC are suitable for habitat analyses only for the limited conditions existing during data collection.
12. Collect hydraulic and physical data. These data include:
    a. Total water depth and average velocity.
    b. Fish focal point velocity.
    c. Stream margin edge type.
    d. Cover type components.
    e. Substrate components.
    f. Vegetative components
    j. Distance to and type of nearest components described above.
    k. Other factors as appropriate.
13. Compile observation and habitat availability data in such a way that unequal sizes do not bias resultant HSC. For example, individual data sets may be normalized or equalized prior to data compilation. The procedures used should be developed collaboratively. However, the Department reserves the option of determining the acceptable technique.
14. Address anomalies in HSC distributions. Determine if additional data are required to

address the anomalies, or if the effect of the anomalies should be minimized and/or included in analyses. An example of minimizing anomaly effects is by smoothing or curve fitting techniques, and/or professional judgment. Smoothing and curve fitting techniques are preferred. Procedures used should be developed collaboratively. The Department reserves the option of determining the acceptable technique.

15. Determined whether the above procedures provide sufficient sample sizes and/or do not account for habitat availability. Evaluate and select alternative procedures through a collaborative process. The Department reserves the option of approving appropriate methods.

PHABSIM COMPILATION

PHABSIM data compilation procedures, hydraulic model calibration, and model validation requirements are considered elsewhere.

PHABSIM EVALUATION AND FLOW RECOMMENDATIONS

Use PHABSIM WUA/discharge relationships with hydrological time series to identify river flow regimes that address intra- and inter-annual riverine needs, and for evaluating project impacts and potential tradeoffs. To fully incorporate the abilities and utility of PHABSIM into water allocation procedures, WUA/discharge relationships must be combined with river flow hydrologic time series to develop a time series of total habitat across hydrologic year types and time. This enables evaluation of inter- and intra-annual hydrologic habitat availability and riverine resource and habitat needs, and development of flow regimes that closely resemble habitat conditions available under natural flow conditions

Care must be taken in compiling PHABSIM models and simulations to contribute to meaningful water allocation decisions. Failure to consider potential biases results in misrepresentations and misinterpretations. The following describes the Department’s position regarding assessment of riverine flow needs and project evaluation:

1. Develop total WUA/discharge relationships per homologous river segment. Proportionally weight species life stage individual transect WUA/discharge relationships, which are produced as WUA/1,000 linear ft, per the specific transect’s contribution to the specific mesohabitat sampled. For example, if a transect represents 15% of a specific mesohabitat’s total length, the transects contribution to the mesohabitat’s total WUA for each flow simulated should 15%. Extrapolate individual transect simulations to simulate the total WUA/discharge relationship per individual mesohabitat. Proportionally weight each mesohabitat simulation, and extrapolated each simulation to attain each mesohabitat type’s contribution to total WUA/discharge relationship within each stream segment. For example, if a mesohabitat comprises 30% of a stream reach, it should comprise 30% of the reach’s total WUA for each flow simulated. Sum the total mesohabitat WUA/discharge relationships to produce the segment-wide total WUA/discharge relationship.
2. Partition the unimpaired [i.e., natural, without project(s)] annual flow exceedance information into critically dry, dry, below median, above median, wet, and extremely wet

water or runoff year (collectively water year) categories (100-90, 90-70, 70-50, 50-30, 30-10, 10-0% annual flow exceedance ranges, respectively).

3. Develop species life stage daily habitat time step series in monthly increments for each water year category. This effort uses total stream segment WUA/discharge habitat relationships from a hydrologic record that includes at least three representative years within each water year type category (unless the flow record is long, there may not be three years within some water year categories) to develop daily flow time series as input variables. If it is collaboratively determined that time steps other than monthly increments and daily discharges are appropriate, such time steps should be considered. The Department reserves the option of determining the appropriate time step.
4. Develop species life stage monthly habitat exceedance, or duration, information for each year type, based on the habitat time series.
5. Identify species life stage monthly 50% exceedance habitat duration value for each water year type. Determine the flow in the total stream segment necessary to provide the respective 50% exceedance habitat duration values on a monthly and year type basis. The 50% exceedance habitat duration metric is based on the biological significance of the median representing a measure of central tendency. This flow is defined as the flow needed to maintain the riverine species life stages under consideration. This flow regime does not address the need for channel/riparian flows and dynamics. These latter flows should be considered, and included within final flow regimes.
6. Develop overall year type flow regime recommendations for fish and other aquatic/riparian species by evaluating species life stage tradeoffs. Species and species life stages of special concern should receive priority consideration during such evaluations. However, other species and life stages should not necessarily be placed at risk. Such an evaluation process should emphasize multi-species and life stages needs, and should be developed collaboratively. The Department reserves the option of determining the appropriate process.
7. Conduct an impact analysis by developing total stream segment habitat time series, and then comparing this time series with habitat time series values developed for unimpaired conditions, the above described flow regime (item 6), and the existing (i.e., with project) flow regime. Several analytical approaches are available, and should be developed collaboratively. If agreement cannot be reached on the analytical approach, the Department reserves the option of determining the appropriate process.

PHABSIM MODEL OUTPUT VERIFICATION/VALIDATION

Verifying that suitable versus unsuitable stream habitat cells as simulated with PHABSIM are in agreement with actual fish distribution in the mesohabitats and stream is an important verification/validation step for IFIM applications. Unless previous habitat suitability criteria have been tested for transferability to the stream under consideration, or PHABSIM model output has been validated for the species in similar streams in the region, a field test must be conducted onsite.

The following describes the Department’s position regarding field testing of PHABSIM model output.

1. Select a sample of each mesohabitat (or representative reach) that was sampled for PHABSIM modeling as described above.
2. Prepare a map of the mesohabitats (or reaches) showing water's edge at the discharge to be tested. This should not be at the discharge that was used as input for the PHABSIM model.
3. Flag the transects at water edge and generally delineate the habitat cells using field markers (e.g., weights with flagging placed on the stream bed, buoys, etc.) across the stream.
4. Use direct observations techniques as described for developing HSC, above, to identify habitat cells that are occupied and those that are not. To assure a constant flow rate, determine the discharge before and after the observations are made.
5. Determine whether observed fish are in suitable or unsuitable cells. If all fish observations are within cells that were predicted to be suitable (and with more in the cells with the highest suitability values), the model may be considered valid for use for habitat simulations for the stream under consideration.
6. If some fish observations fall within the model's predicted unsuitable cells, determine and evaluate possible causes, and potential remedies. Acceptance or rejection of use of unsuitable and suitable cells shall be based on the results of statistically analyses such as Chi-square observed versus expected analyses. The habitat simulation model may be further "calibrated" by developing additional onsite HSC, or, in the event of use of literature based or professional judgement HSC, evaluation of the HSC, and potential adjustment until all observed fish fall within suitable cells. When literature or professional judgement HSC are modified, it is necessary that the validation test be conducted again at a different flow and with additional fish observations. This process is repeated until there is agreement that the model output is a good fit to the field observations, or the model is rejected for use on the stream under consideration. This process should be conducted collaboratively. However, in the event agreement is not attained, the Department reserves the decision.
7. Randomly partition fish observation data into two data sets when HSC are developed onsite as described above for the preferred option. Use one data set to develop HSC, while reserving the second set for model output testing.