1.0 NEED FOR STUDY

Historically, instream flows downstream of public water supply sources in Pennsylvania have been protected through mandated conservation releases from major water supply reservoirs or mandated passby flows at smaller dams and intake structures. These conservation flows were first imposed through the surface water allocation program under the auspices of the Pennsylvania Water Rights Act of 1939.

The procedures for determining conservation flows have changed over the years. Prior to the mid-1970s, instream flow protection levels were based on an assumed average low flow of 0.15 cubic feet per second per square mile (csm) of drainage area above the dam or intake structure. In the mid-1970s, the Pennsylvania Department of Environmental Resources (Pa. DER), now Department of Environmental Protection (Pa. DEP), developed a new procedure through the State Water Plan Program. This procedure established instream flow protection levels based upon the 7-day, 10-year low flow ($Q_{7\text{-}10}$), adjusted by a factor related to the magnitude of the withdrawal per square mile. This procedure was later refined to account for seasonal variability in low flows on High Quality and Exceptional Value streams (Pennsylvania Code, Title 25, Chapter 93).

These procedures are considered standard-setting, because they do not address the effect of withdrawals on the habitat or population of the fishery resources, and because the conservation flows are derived from hydrologic records, utilizing a statistical low flow. The $Q_{7\text{-}10}$ flow was originally developed to ensure that violations of water quality standards occurred very infrequently (less than 1 percent of the time).

In 1992, discussions regarding the validity of the procedure based on the $Q_{7\text{-}10}$ flow, resulted in an informal agreement between Pa. DEP and the Pennsylvania Fish and Boat Commission (PFBC) to use, to the extent practicable, a procedure based upon the Tennant Method (Tennant, 1976). That method, which determines conservation flows as a percentage of average daily flow (ADF), also is a standard-setting procedure, but attempts to incorporate aquatic resource needs, based upon field data and observations.

Pa. DEP agreed to use the Tennant-based method, despite the agency's posture that the method does not directly apply to Pennsylvania streams, and the percentages of ADF that are applied may be higher than necessary. Consequently, the conservation flows may unnecessarily reduce the yield that can be obtained from water supply sources, while providing more than adequate protection to the aquatic resources.

Pa. DEP and other interested agencies, including the Susquehanna River Basin Commission (SRBC), recognized the deficiencies of the existing procedures. They wanted to conduct appropriate investigations in Pennsylvania to develop a procedure for determining instream flow protection levels that: (1) is based on fishery resource protection; (2) is clearly applicable to Pennsylvania streams; (3) does not require expensive, site-specific studies; and (4) can be easily applied during the administrative review of each application for a surface water allocation.

SRBC's responsibilities for managing the water resources of the Susquehanna basin include protecting instream flows through the regulation of: (1) certain water withdrawals where signatories to the Susquehanna Compact (Susquehanna River Basin Commission, 1972) do not have the authority; and (2) consumptive use of water.

SRBC adopted a consumptive water use regulation (18CFR §803.42) that requires new consumptive users to compensate for their consumptive use to protect instream water uses. Although the reservoir releases and other consumptive use actions are currently triggered when flows drop to the $Q_{7,10}$ level, the commission intends to conduct an instream flow study on the main river system to determine whether the trigger level should be modified.

The State of Maryland is interested in the development of new methodology for determining flows that protect biota and also allow water supply withdrawals. The state also is concerned about the implementation of any regulations developed as a result of the study.

The State of Maryland, through its water allocation program, uses the Maryland Most Common Flow Method (letter from R. C. Lucas, Md. Dept. of the Environment, to D. R. Jackson, November 18, 1991) to establish conservation flow requirements for water supply withdrawals and reservoir projects. The method assumes that for any stream and any specified time period flows in the range between 85 percent and 50 percent probability of exceedance on a monthly basis are naturally most common, and that those flows are within the tolerance range of the biota in the stream. The conservation flow is selected in that range, and flows vary with different time periods, depending on the natural flows. Flows near the lower end of the range provide more instream flow protection, while flows near the upper end of the range provide more periods when withdrawals can be made.

There are many important instream flow protection issues. Among the priority issues are:

- The effect of withdrawals and consumptive uses on aquatic biota in cold water trout streams;
- The effects of withdrawals and consumptive uses on aquatic biota in tributary streams with warm water fisheries;
- The effect of withdrawals and consumptive uses on the aquatic biota in major rivers; and
- The effect of consumptive uses on the receiving waters of the Chesapeake Bay.

Existing conflicts between instream and withdrawal uses demonstrate the need for answers to these issues. Prior to this study, there was no usable information available to resolve these issues.

The interested parties determined the first issue to be the most important, because of existing critical conflicts between withdrawals and instream uses on cold water streams. This study will focus on that issue, but the remaining issues should be addressed in additional studies in the near future.

2.0 STUDY CONCEPTS AND PROCEDURES

2.1 Overall Study Plan for Determining Instream Flow Needs

The purpose of this study is to develop a procedure for determining instream flow needs for streams with naturally reproducing trout populations, in portions of Pennsylvania and Maryland, that does not require a stream-specific impact analysis study.

The two study requirements are: (1) the procedure must be habitat-based; and (2) instream flow needs must be easily derived from hydrologic records and data developed in the study.

The basic approach to the problem is to conduct instream flow needs assessment studies at selected representative sites and then regionalize the results of the site-specific assessments to develop the generalized procedure.

Only reproducing trout streams (streams with naturally reproducing trout populations) are included in this study, because the effects of withdrawals on instream uses are most critical on those streams.

A number of methods for determining instream flow needs are found in the literature. The two methods applied in this study are the Instream Flow Incremental Methodology (IFIM) (Bovee, 1982) and the wetted perimeter method (Collings, 1974; Nelson, 1984; Leathe and Nelson, 1989). The IFIM method was selected because it is the most sophisticated method presently available for determining instream flow needs, and because it is specifically designed to assess effects of man-made changes in flows such as water supply withdrawals on the habitat available for fish. The wetted perimeter method was selected because it has frequently been used by other investigators to establish instream flow protection levels.

The results of the wetted perimeter method can be compared to the results of the IFIM analysis, especially for effects of changes in flow on riffle transects.

The overall study plan to develop the procedure included the following steps:

- Classification of trout streams based on common characteristics;
- Development and selection of study regions;
- Application of the IFIM methodology to selected study streams within each study region; and
- Application of the wetted perimeter method to determine whether the method furnished information useful for determining instream flow protection levels.

Application of the IFIM methodology included:

- Selection of evaluation species;
- Selection and testing of habitat suitability criteria (HSC) obtained from the literature;
- Development of new HSC;
- Selection of study streams within study regions;
- Selection of representative study sites on the study streams;
- Development of habitat versus flow relationships for the study sites;
- Development and application of impact assessment methodologies utilizing these habitat versus flow relationships to assess impacts on the study streams; and
- Development and application of an impact assessment methodology for the study regions, based on the impact assessment for the study streams.

Each of these steps will be described in detail in subsequent sections.

2.1.1 Methods for evaluating instream flow needs

2.1.1.1 Description of IFIM methodology

The IFIM methodology was originally developed to determine man-made impacts on fishery habitat in a specific reach of a single stream. To the authors' knowledge, IFIM has not been used previously to develop regional or general criteria for determining the impacts of withdrawals for a number of streams classified into similar groups.

Certain components of the IFIM methodology were used in this study to estimate impacts of different combinations of natural flow and withdrawal on physical microhabitat. The methodology used in the study includes the following steps, as shown in the flow chart in Figure 2.1:

- Fish species that are important recreationally, economically, or ecologically are selected and used to evaluate impacts of changes in flow.
- HSC are developed to describe the usability of depth, velocity, substrate, and cover for each life history stage (adult, juvenile, fry, spawning) for each evaluation species.
- Depth, velocity, substrate and cover are used to represent the habitat available for fish species present in the stream.
- Water surface elevation is measured for different flow conditions at each study site.
- Velocity distribution, substrate and cover are measured at one flow.
- The depth and velocity measurements are used to calibrate a hydraulic model.
- The hydraulic model is used to simulate the depth and velocity for a range of flows.
- The simulated depth and velocity values, and the substrate and cover measurements are combined with HSC for each evaluation species and life stage to determine the habitat available over a range of flows. Habitat is defined as weighted usable area (WUA), expressed in units of square feet per thousand feet of stream.
- The amount of habitat available for natural conditions is compared to the habitat available for modified conditions to evaluate the impact of the modifications on habitat.

In the methodology, one or more transects are established for each site. Then numerous measurement points are selected across each transect at points where the depth, velocity, substrate, or cover change. In effect, the transects and measurement points collectively describe the stream as a series of quasi-rectangular areas or cells, each centered on a transect.

The methodology uses the Physical Habitat Simulation (PHABSIM) computer program for hydraulic model calibration and physical habitat simulation. The hydraulic model is calibrated for each cell, and the calibrated model(s) is (are) used to estimate depth and velocity for other flow conditions.

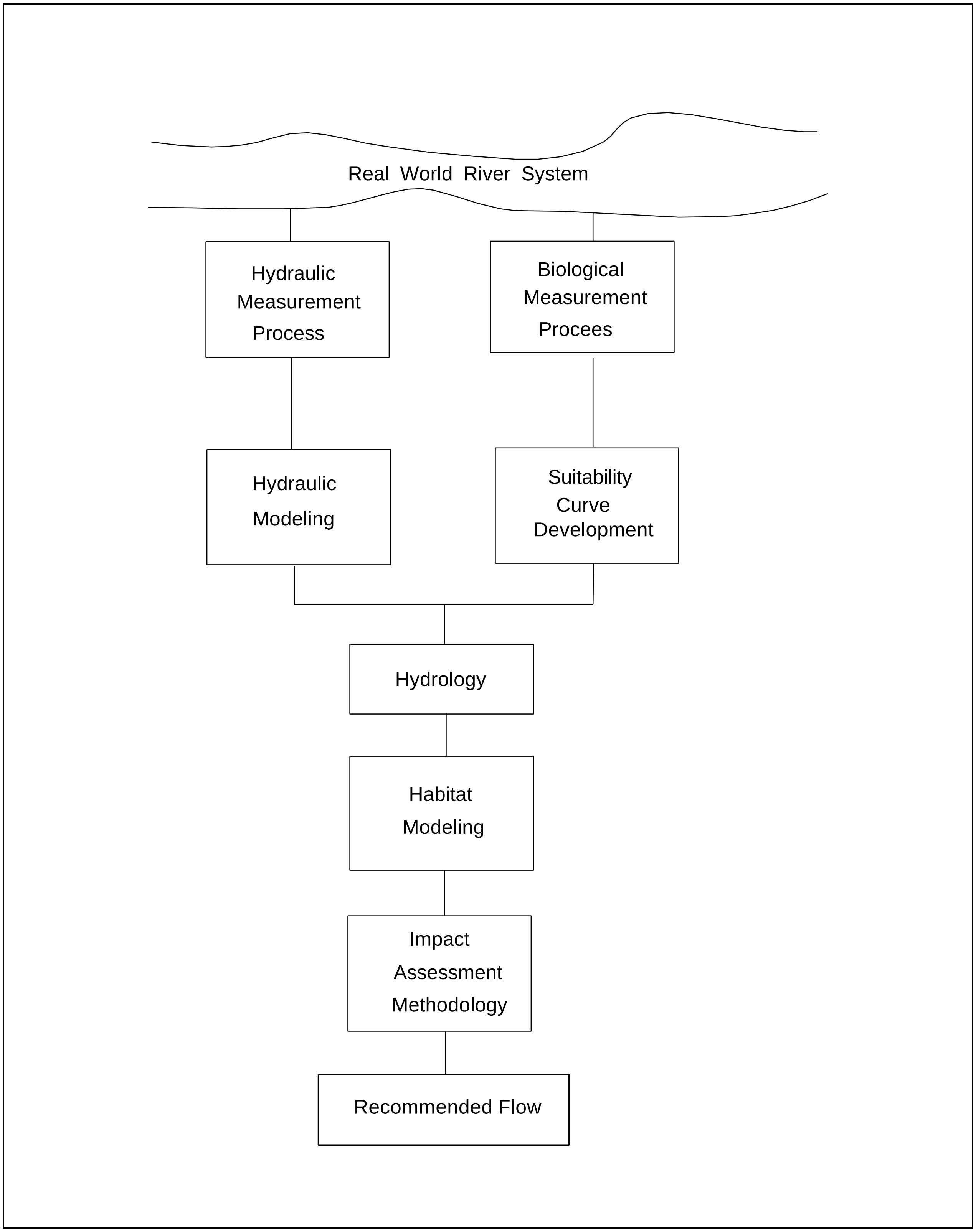

Figure 2.1. Components of Instream Flow Incremental Methodology

2.1.1.2 Description of wetted perimeter method

The wetted perimeter method uses field measurements or hydraulic modeling to determine how the wetted perimeter of a study stream changes with flow. Wetted perimeter generally increases rapidly with flow for flows less than some amount, and then increases less rapidly for higher flows. Wetted perimeter is plotted versus flow, and the flow value at the change in slope of the curve (inflection point) is assumed to be the amount of flow needed to protect the biota.

Typically, the wetted perimeter method is applied to riffle area(s) of the stream channel, because riffles are known to be the most productive areas for aquatic invertebrates, which are the food base for certain species of fish (Collings, 1974; Nelson, 1984; Leathe and Nelson, 1989). Sufficient riffle habitat is necessary to produce this food (Leathe and Nelson, 1989).

One of the problems with the wetted perimeter method is the difficulty and subjectivity of determining inflection points. Wetted perimeter curves frequently have two or more inflection points, as described by Leathe and Nelson (1989). Those authors define the upper inflection point as the optimal habitat (and corresponding flow), because almost all the available riffle area is wetted. They also define the lower inflection point as the minimum acceptable flow, because the rate of loss of habitat for lesser flows is unacceptable. They then select a flow in the range between the upper and lower inflection points as the instream flow requirement.

The wetted perimeter method has the advantage of being quick and inexpensive to apply. However, the method has a number of questionable assumptions and limitations (Leonard and others, 1986; Mohrhardt, 1987). The major assumption is that the flow at the inflection point needs to be maintained to ensure an adequatefood supply for the fish, but this assumption has not been verified. The method does not allow evaluation of the effects of withdrawals on the biota.

2.1.1.3 Comparison of IFIM and wetted perimeter methods

Leathe and Nelson (1989) list five major factors(Hall and Knight, 1981) that control fish abundance in streams: streamflow; habitat quality; food abundance; predation; and movement and migration. Any of these may be the limiting factor for any given stream. Standard setting methods such as the wetted perimeter method identify minimum flow standards, while incremental methods such as IFIM quantify tradeoffs between withdrawals and instream uses by examining the response of fish habitat to changes in flow (Leathe and Nelson, 1989).

Where man-made changes in streamflow such as withdrawals limit the amount of habitat available, a method that evaluates the effects of incremental changes in streamflow such as IFIM is probably most appropriate. The wetted perimeter method may be appropriate where food supply is the limiting factor, or when a simple method is needed to develop basinwide standards for use in preliminary watershed planning (Leathe and Nelson, 1989).

2.1.2 <u>Evaluation species</u>

Selecting appropriate evaluation species for IFIM studies is important because all interpretations of environmental impacts are based on the effects on the habitat used by the evaluation species (Bovee, 1995).

Originally, brook trout, brown trout, white sucker, blacknose dace, and slimy sculpin were considered as possible evaluation species for the cold water streams included in this study. To focus on the species that are most important economically and recreationally, and reduce the amount of work required, only brook trout and brown trout were used in the study. The months when each life stage is expected to be present also was determined.

2.1.3 Habitat suitability criteria selection, testing, and development

Habitat suitability criteria can be developed based on field observations for a specific stream, or group of streams, or can be obtained from the literature. Prior to this study, HSC had not been developed for streams in Pennsylvania or Maryland. The criteria in the literature have been developed by various investigators for streams in other parts of the country. The National Biological Service (now Biological Resources Division, U.S. Geological Survey) recommends that HSC obtained from the literature be tested to determine whether they are applicable to other areas.

Procedures for developing HSC are described by Bovee (1986) and Bovee and Zuboy (1988), but they are very resource-intensive and expensive, and beyond the resources available for this study. For that reason, HSC were selected from the literature for depth and velocity for all four life stages of each evaluation species. Criteria for substrate and cover were developed based on professional judgement. These steps are described in section 3.1. Then the transferability of the criteria to Pennsylvania was evaluated, by collecting and analyzing habitat usage data for four streams in two study regions in Pennsylvania, as described in sections 3.2 through 3.6. The evaluation showed the criteria obtained from the literature are not satisfactory for use in habitat modeling for Pennsylvania streams. New criteria were developed from the data collected during the transferability study, as described in section 3.7.

2.1.4 Classification of trout streams

2.1.4.1 Stream classification purpose

To develop a regional procedure for assessing impacts of withdrawals on any stream in a region, the streams need to be classified according to important characteristics related to fishery habitat. Once the streams have been classified, typical streams can be selected from each class. The results of instream flow assessments for these typical streams can be used to estimate the effects of withdrawals on other streams within the region. Since trout streams are found in all parts of Pennsylvania, the classification scheme needs to apply to the entire state.

The purpose of the stream classification system was to identify classes of streams that have similar key physical features. Key physical features are those that have a direct influence on the physical variables (depth and velocity) and stream attributes (substrate and cover) used to quantify fish habitat. Similar, in this case, means that all the sampled streams within a class are expected to have a comparable WUA versus discharge relationship, if the flow variable is normalized to minimize the effects of watershed size. Similarity of the streams implies the WUA versus discharge relationships, aggregated across the sampled streams within a class, should be representative of any stream within the class.

2.1.4.2 Stream classification scheme

Streams with cold water fisheries were classified according to study regions, which were selected to represent different geology and topography. Within each study region, streams were further classified according to slope. Because slope was difficult to determine for such a large number of streams within the time constraints for this study, length was used as a surrogate for slope, as described in section 4.3. Streams were divided into an appropriate number of segments, based on an appropriate length of segment. The length of segment was based on statistical analysis of stream length data, as described in section 4.3. Segments were numbered from 1 to 4, and streams with the same segment number in a study region were assumed to be similar.

Most of the trout streams in Pennsylvania have drainage areas less than 100 square miles. Larger streams are generally too warm during the summer months to allow trout reproduction. Smaller streams present the greatest concern, because of the large number of water supply withdrawals located on them, and the potential impacts of the withdrawals on trout species. All the study segments had drainage areas less than 100square miles; therefore, the study results are applicable only to such streams.

2.1.4.3 Development and selection of study regions

Topographic and geologic classfication of streams could be based on physiographic provinces and sections, as described by Fenneman (1938), or on ecoregions (Omernik, 1987a, b). The physiographic provinces and sections have been mapped by Pa. DER (now Pa. DEP) (1989), and revised by Sevon (1995). The ecoregion boundaries for Pennsylvania were being remapped at the time the study began (R. Shertzer, Pa. DEP, oral communication), and the boundaries proposed by Omernik (1987b) were not considered satisfactory for this study. Because the ecoregion boundaries developed by Omernik (1987b) are related to the physiographic region boundaries, and the physiographic regions are based on similar geologic and topographic conditions, streams were classified using physiographic provinces and sections, rather than ecoregions.

The physiographic provinces and sections in Pennsylvania are shown in Table 2.1, beginning in the southeastern corner of the commonwealth, and proceeding north and west. These physiographic provinces and sections are shown on the map in Plate 1.

Table 2.1. Physiographic Provinces, Sections, and Study Regions

Province	Section	Study Region
Coastal Plain		
Piedmont	Piedmont Upland Piedmont Lowland Gettysburg-Newark Lowland	Piedmont Upland (freestone)
New England Province	Reading Prong	
Blue Ridge Province	South Mountain	
Ridge and Valley	Great Valley Appalachian Mountain	Ridge and Valley Freestone/Limestone Ridge and Valley Freestone/Limestone
Appalachian Plateaus	Glaciated Low Plateau Glaciated Pocono Plateau Glaciated High Plateau Deep Valleys Allegheny Plateau Allegheny Mountain High Plateau Pittsburgh Low Plateau Glaciated Pittsburgh Plateau	 Unglaciated Plateau Unglaciated Plateau Unglaciated Plateau Unglaciated Plateau Unglaciated Plateau
Lakes	Eastern Lake	

The stream classification based on physiographic sections was modified, as described below.

The Ridge and Valley Province includes the Great Valley and the Appalachian Mountain sections. Both sections include important trout streams that are underlain by limestone and dolomite rocks (limestone streams), and trout streams that are underlain by freestone (e.g., sandstone, shale, conglomerate) rocks (freestone streams). Limestone streams are known to have different hydrology, are expected to have different habitat characteristics, and to respond differently to water supply withdrawals, than the freestone streams. Therefore, the trout streams in the Ridge and Valley Province were classified into study regions based on limestone/freestone geology, rather than physiographic sections.

The Appalachian Plateaus Province includes nine sections that have different geologic and topographic characteristics. Of these nine sections, four have been glaciated, based on the location of the glacial boundary (Sevon, 1995), as shown in Plate 1. The glaciated streams are known to have different hydrology than the unglaciated streams, and are expected to have different habitat characteristics and response to water withdrawals. For that reason, the difference between glaciated and unglaciated sections is expected to be an important factor affecting habitat. The glaciated and unglaciated physiographic sections were combined into Glaciated and Unglaciated Plateau study regions.

In Pennsylvania, the conflicts between withdrawal and instream uses are most critical on cold water streams in the Ridge and Valley Province, and in the unglaciated parts of the Appalachian Plateaus Province. Accordingly, those parts of the commonwealth were included in the study. Parts of five counties in the Unglaciated Plateau study region were subsequently deleted, because the low yield of surface streams results in few water supply withdrawals from small streams. The areas eliminated included all of Beaver, Allegheny, Washington, and Greene Counties, and a portion of Fayette County in the Pittsburgh Low Plateau physiographic section.

The Piedmont Physiographic Province includes three sections, as shown in Table 2.1. Limestone streams are present in all three Piedmont study regions, and in some cases, limestone has been metamorphosed into marble, which may behave differently. Since there are more reproducing trout streams in the Piedmont Upland freestone region, the Piedmont study streams were selected from that study region.

In summary, this study includes three study regions in Pennsylvania; Ridge and Valley Limestone; Ridge and Valley Freestone; and Unglaciated Plateau; and one study region, the Piedmont Upland (freestone), in Maryland. The relationship between study regions used in this study and physiographic sections is shown in Table 2.1.

2.1.5 Selection of study streams

Lists of reproducing trout streams were developed for each study region from PFBC files, and from an inventory of Maryland cold water fisheries (Steinfelt, 1991). Study streams and segments were selected from these lists in three stages. First, potential study streams were selected by stratified random sampling from the lists of reproducing trout streams in each study region, as described in section 4.4. Second, the study streams and segments were selected in the field from the list of potential study streams, again using a stratified random sampling process, as described in section 4.4. The list of study streams selected in the field is shown in Tables 5.1 through 5.4, and summarized in Table 5.5. Third, certain streams or segments were deleted from this list because of modeling problems, as described in section 5.6.2.

A basic assumption was that 30 stream segments in each study region provided an appropriate level of accuracy for development of the regional procedure. Thirty segments were selected in each study region for data collection and modeling, except for the Piedmont Upland study region.

For the Piedmont Upland study region, sufficient potential study streams were identified to select 30 stream segments in the field. However, funding limitations only allowed 12 stream segments (all in Maryland) to be studied. Additional Piedmont streams should be studied in the future to develop instream flow guidelines for all three Piedmont study regions.

2.1.6 Selection of study sites

Study sites were selected in the field at an accessible location as close as possible to the midpoint of a segment. Crews observed several occurrences of each mesohabitat type (riffle, run, pool), if present, and selected one representative of each type. Then transects were established at the midpoint of each representative mesohabitat type. The procedure is described in detail in section 5.2.

2.1.7 Development of habitat versus flow relationships

Habitat versus flow relationships were developed for each transect, utilizing field data, hydrology, and modeling. During field data collection, water surface elevation was measured at each transect at several different flows, as described in section 5.3. Velocity distribution, substrate, and cover were determined at one flow Substrate and cover were determined using a classification scheme developed for this study, which is described in section 3.1.2.

Stream gage data were used to develop hydrology for the study sites, as described in section 5.5. Procedures were developed for determining when to dispatch field crews, as described in section 5.5.4.

Hydraulic models were calibrated using the field data for each measurement point, as described in section 5.6. The calibrated hydraulic models and the hydrology were used to determine the velocity and depth values for each cell, each study site, and a large range of flows, as described in section 5.7. These data were combined with the HSC for each life stage of each species to compute WUA versus flow relationships for each transect, species and life stage (section 5.7). The relationships for each transect were combined to produce a composite WUA versus flow relationship for each species and life stage for each study site, as described in section 5.7.

2.1.8 Impact assessment

The IFIM procedure (Figure 2.1) includes assessment of impacts. Procedures were developed to combine the WUA versus flow relationships, produced by the habitat modeling, into composite normalized minimum WUA versus flow relationships for each species and each study site (section 6.3). The resulting relationships were used in three different impact assessment procedures.

The first impact assessment procedure, described in sections 6.4 and 6.5, considered two definitions of habitat loss, no-loss of habitat, and no-net-loss of habitat at the median monthly flow, for establishing stream protection levels. Both criteria were found to significantly restrict withdrawals. For that reason, more detailed impact assessment procedures were developed.

The second impact assessment procedure, described in section 6.6, is designed to analyze time series of median monthly flows for each study site. Other flow statistics or time steps also can be analyzed. A computer program has been written to estimate the impact of withdrawals and passby flows on the monthly, seasonal, and annual habitat and flow available, and provides summary statistics and duration analyses of the impacts (section 6.6.2 and Appendix E). The program also estimates the impact of natural flows and passby flows on the percent of time the withdrawal can be made. Different combinations of withdrawal and passby flows can be analyzed to compare different scenarios for wild or stocked trout populations. A regional hydrology procedure (section 6.6.3) has been developed for use with the impact assessment program.

The computer program was used to develop a series of constant-habitat-impact graphs, for several levels of withdrawal and passby flow, both expressed as percentage of average daily flow, for the Ridge and Valley Freestone, Ridge and Valley Limestone, and Unglaciated Plateau study regions, as described in sections 6.6.2.4 and 6.6.2.5. The graphs show both the impact of withdrawals and passby flows on habitat, and the effect on the availability of water for withdrawal. These graphs can be used to develop regional or statewide policies regarding acceptable levels of impact on both uses, considering tradeoffs between habitat impact and impact on water users. The curves also can be used to evaluate engineering alternatives for meeting required fishery protection levels on cold water streams having drainage areas less than 100 square miles in Pennsylvania.

The third impact assessment procedure, which is described in section 6.6.4, utilizes flow and associated habitat duration analysis to evaluate impacts of withdrawals, and estimate the appropriate passby flow. The results of this method can be used in establishing regional or statewide passby flow requirements. The impact analysis for individual study streams in Pennsylvania has been completed, but the interpretation of the results has not been completed, due to time and cost constraints.

2.1.9 Wetted perimeter method

Output from the hydraulic model runs was used to plot graphs of wetted perimeter versus flow, as described in section 5.9. This procedure effectively assumes the inflection point occurs in the range of flows between maximum and minimum monthly flows. The inflection points of these graphs were tabulated, and are shown in the same section. Extrapolation of these plots to a point of zero wetted perimeter at zero flow showed that the limited range of simulation flows was not adequate to allow selection of inflection points. Additional field data would need to be collected at extreme low flows for application of the wetted perimeter method.

2.2 Study Organization

The following agencies participated in the study:

- Pennsylvania Department of Environmental Protection (Pa. DEP);
- Pennsylvania Fish and Boat Commission (PFBC);
- Susquehanna River Basin Commission (SRBC);
- Baltimore District, U.S. Army Corps of Engineers (COE);
- U.S. Geological Survey, Biological Resources Division (GSBRD);
- U.S. Fish and Wildlife Service (USFWS);
- Maryland Department of Natural Resources (MDNR).

Pa. DEP, SRBC, PFBC, COE, MDNR, and Environmental Protection Agency Chesapeake Bay Program (CBP) provided funding for the study.

Prior to beginning this study, SRBC established a Water Resources Management Advisory Committee (WRMAC), which identified instream flowneeds studies as a priority. WRMAC then established an Instream Flow Subcommittee (IFSC) to provide technical information regarding instream flow needs, and to develop a study plan. These activities, conducted under SRBC auspices, were integrated with Pa. DEP activities to satisfy their needs.

A Study Steering Committee provided general oversight to the study. The committee included representatives of both public and private interests. Also, a study team that included staff from Pa. DEP, SRBC, PFBC, COE, GSBRD, and MDNR developed the detailed study procedures and provided guidance for the study. SRBC, PFBC, COE, and MDNR staff conducted the field work. SRBC and PFBC staff performed HSC transferability testing and developed new HSC from field data. Hydrology and habitat modeling were provided by SRBC staff. PFBC staff developed the time series impact assessment methodology and computer program, and SRBC staff conducted the impact assessment using that methodology. SRBC staff developed and implemented the flow and associated habitat duration impact analysis methodology. GSBRD provided technical assistance.