# INSTREAM FLOW STUDIES
# PENNSYLVANIA AND MARYLAND

## SUMMARY REPORT

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*Statutory *Citations: Federal - Pub. L. 91-575, 84 Stat. 1509 (December 1970); Maryland - Natural Resources Sec. 8-301 (Michie 1974); New York - ECL Sec. 21-1301 (McKinney 1973); and Pennsylvania - 32 P.S. 820.1 (Supp. 1976).*

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This study was conducted under contract ME94002 between Pennsylvania Department of Environmental Protection and Susquehanna River Basin Commission.  Pennsylvania Fish and Boat Commission, the Baltimore District U.S. Army Corps of Engineers, and the U.S. Environmental Protection Agency, Chesapeake Bay Program also provided funding for the study.

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# Instream Flow Studies
# Pennsylvania and Maryland

# Summary Report

## EXECUTIVE SUMMARY

Existing procedures for determining instream flow protection levels have certain deficiencies, which result in conflicts between agencies that regulate water supply withdrawals and agencies that manage fisheries. To overcome these deficiencies, the Pennsylvania Department of Environmental Protection, the Susquehanna River Basin Commission, Pennsylvania Fish and Boat Commission, U.S. Army Corps of Engineers, Maryland Department of the Environment, and the Biological Resources Division of the U.S. Geological Survey cooperatively conducted an instream flow needs assessment study. The goal of the study is 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 applications for surface water allocations.

The basic approach to the development of the procedure is to conduct instream flow needs assessments at sites selected to be representative of a study region, and then regionalize the results of the site-specific assessments to develop the procedure. Only sites with reproducing trout populations and drainage area less than 100 square miles were included in the study.

Physical habitat components of the Instream Flow Incremental Methodology were applied to selected study sites in the Ridge and Valley Freestone, Ridge and Valley Limestone, Unglaciated Plateaus, and Piedmont Upland study regions in Pennsylvania and Maryland. The evaluation species are brook and brown trout. Habitat suitability criteria were selected from the literature, and tested to see if they adequately represented habitat usage on Pennsylvania streams. These criteria were found not to be applicable to Pennsylvania. New criteria were developed from the data collected for the transferability study.

Study streams were selected from available information, and divided into segments based on length of the stream. Study sites were selected near the midpoint of each segment. All study sites had good access, reproducing trout populations, and good water quality. Field data and hydraulic modeling provided estimates of the amount of habitat available within a specified range of flows. The amount of habitat available for all life stages present in a defined season of the year was determined for that range of flows.

A computer program was developed to estimate the effects of withdrawals and passby flows on physical microhabitat and availability of flow for withdrawals. The program estimates a number of statistics of the impact for various combinations of withdrawal and passby flow for any project site in the study regions, including the long-term (average annual) impact. This computer program was run with many combinations of species, withdrawal and passby flow for selected study sites within a given class of study sites (study region, segment class) to estimate the average annual reduction in habitat resulting from

each combination. These results were used to prepare graphs of constant habitat impact, and the percent of time that water supply is unavailable, for different levels of impact.

These impact curves can be used to develop statewide policies regarding which impact curve(s) should be used to establish passby flows. They also can be used to determine impact of a proposed withdrawal at any site in these study regions. These curves also can be used by water purveyors to analyze stream intake alternatives that meet state fishery protection levels on cold water streams having drainage areas less than 100 square miles. The determination of which impact curve(s) to use will have to consider costs both to the environment and to withdrawal users. Obviously, the curve with the lowest habitat impact provides the greatest protection to the fishery habitat. However, as the degree of habitat protection increases, so does the percent of time that withdrawals cannot be made because of flow limitations or passby flow requirements

Although regional criteria have been developed, the computer program also can be used to evaluate conditions not considered in the development of the regional criteria. A regional hydrology procedure has been developed to provide hydrology for the computer program.

A detailed description of the methodology developed and applied in this study, and recommendations for additional studies, are presented.

# 1.0 INTRODUCTION

This report is a summary of Instream Flow Studies— Pennsylvania and Maryland (Denslinger and others, 1998). It is intended to summarize the procedures and the results of the instream flow needs assessment study conducted in Pennsylvania and Maryland. The purpose of the study is to develop a regional procedure for estimating the effects of withdrawals and passby flows on fishery habitat, and to develop regional criteria for determining passby flows for use during the administrative review of applications for water supply allocations.

The complete report is available from the Susquehanna River Basin Commission (SRBC).

# 2.0 STUDY SUMMARY

## 2.1 Study Need

Historically, the Pennsylvania Department of Environmental Protection (Pa. DEP) has used several different procedures to determine mandated conservation releases from major water supply reservoirs, or mandated passby flows at smaller dams and intake structures, to reduce impacts on fishery resources. These procedures do not directly consider the effects of withdrawals on fishery resources, and the conservation flows are derived from hydrologic records utilizing a statistical low flow. In 1992, Pa. DEP and the Pennsylvania Fish and Boat Commission (PFBC) agreed to use, to the extent practicable, a procedure based upon the Tennant method (Tennant, 1976). The method attempts to incorporate aquatic resource needs, but has questionable application to Pennsylvania streams, and may unnecessarily reduce the yield that can be obtained from water supply sources, while providing more than adequate protection to aquatic resources.

To correct the deficiencies of existing methods, Pa. DEP, Susquehanna River Basin Commission (SRBC), PFBC, U.S. Army Corps of Engineers (US COE), Maryland Department of Environment (MDE), Chesapeake Bay Program (CBP), and U.S. Geological Survey Biological Resources Division (GSBRD) conducted this study 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 applications for surface water allocations.

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.

The State of Maryland also is interested in the development of new procedures for determining flows that protect the biota and also allow water supply withdrawals. The Maryland water supply allocation program uses the Maryland Most Common Flow Method to establish conservation flow requirements for water supply withdrawals and reservoir projects.

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

- The effects 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.

The issue of the effect of withdrawals and consumptive uses on aquatic biota in cold water streams is considered the most important because of existing critical conflicts between withdrawals and instream uses on those streams.

## 2.2 Study Purpose and Approach

The purpose of this study is to develop a procedure for determining instream flow needs for streams with naturally reproducing trout populations (reproducing trout streams) in portions of Pennsylvania and Maryland, that does not require a stream-specific impact analysis study. The procedure must be based on fishery habitat, and instream flow needs must be derived from hydrologic data and the 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 procedure. Because of existing critical conflicts between instream and withdrawal uses on small trout streams in the Ridge and Valley, and unglaciated parts of the Appalachian Plateaus, physiographic provinces, this study focuses on those areas. Some streams in the Piedmont Upland physiographic section in Maryland also were studied. Only reproducing trout streams with drainage areas less than 100 square miles are included in this study, because most reproducing trout streams in Pennsylvania and Maryland are in that size range, and because the effects of withdrawals on instream uses are most critical on those streams. Therefore, the procedure applies only to those streams at this time.

## 2.3 Instream Flow Needs Assessment Methodologies

The Instream Flow Incremental Methodology (IFIM) (Bovee, 1982) and the wetted perimeter method (Collings, 1974; Nelson, 1984; Leathe and Nelson, 1989) were both applied to selected streams in this study. IFIM is the most sophisticated method available for determining instream flow needs, and is specifically designed to assess effects of man-made changes in flow on the habitat available for fish. The wetted perimeter method has been used by other investigators to establish instream flow protection levels.

The IFIM methodology includes physical microhabitat components shown in Figure 2.1, which were used in this study to estimate impacts of different combinations of natural flows and withdrawals. The Physical Habitat Simulation (PHABSIM) computer programs were used to evaluate physical microhabitat. The methodology uses evaluation species selected for recreational, economic, or ecological importance to evaluate impacts of withdrawals on stream ecology. Habitat suitability criteria (HSC) are used to describe the usability of depth, velocity, substrate, and cover for each life history stage (adult, juvenile, fry and spawning) for each evaluation species. Depth measurements are made at different flows for a number of measurement points across one or more transects at a study site. Velocity, substrate and cover measurements are made at the same measurement points at one flow. The depth and velocity measurements are used to calibrate hydraulic models for each measurement point. The calibrated models are used to simulate depth and velocity at a number of flows within a specified range, for each transect and measurement point. The simulated depth and velocity values are combined with substrate and cover measurements, and with the HSC, to generate a relationship between habitat and flow for each transect, species and life stage. Habitat is defined as weighted usable area (WUA). The difference between WUA available at different flows with and without a proposed project is the impact of the project on the habitat available.

The wetted perimeter of a transect generally increases rapidly with flow for flows less than some amount, and increases less rapidly for higher flows. Wetted perimeter is plotted versus flow, and the flow value at the point where the graph changes slope (inflection point) is assumed to be the amount of flow necessary to protect the biota. The wetted perimeter method is usually applied to the riffle area(s) of streams, because those are 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).

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 adequate food 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.

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

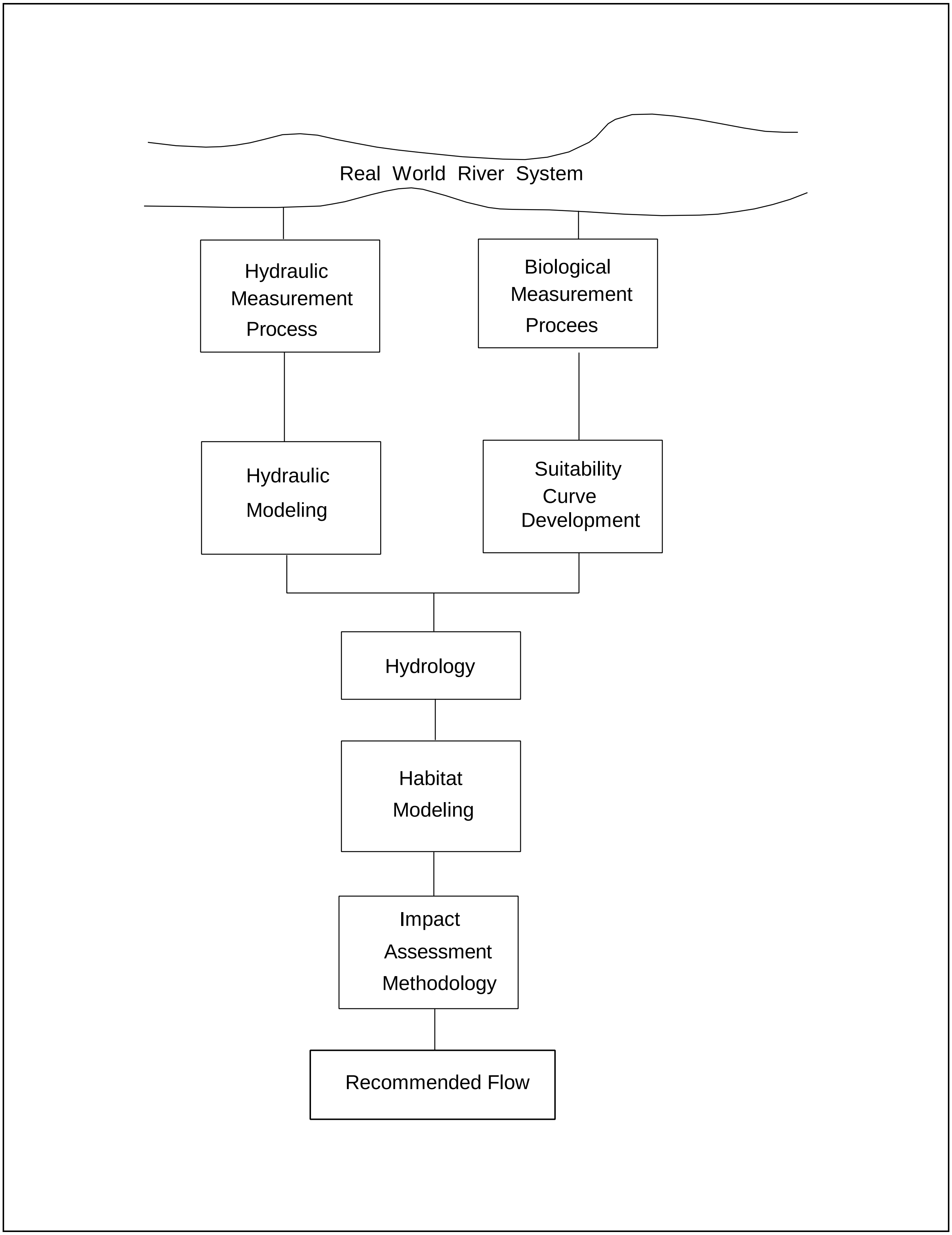


***Figure 2.1. Components of Instream Flow Incremental Methodology***

when a simple method is needed to develop basinwide standards for use in preliminary watershed planning (Leathe and Nelson, 1989).

## 2.4 Evaluation Species and Habitat Suitability Criteria

Brook and brown trout were selected as representative species for the evaluation of habitat availability and the impact of withdrawals. These species were selected because they are the most important economically and recreationally in the study regions. The periods when the different life stages of these species are present were determined and used to define seasons for impact analysis.

For these species, depth and velocity suitability criteria were selected from the literature (Bovee, 1978; Bovee, oral communication, 1994; Aceituno and others, 1985; Raleigh and others, 1986; Jirka and Homa, 1990; Harris and others, 1992; Normandeau Associates Inc., 1992; and Gary Whelan, Michigan Department of Natural Resources, oral communication, 1994) for use in the IFIM methodology. The Normandeau (1992) criteria for adult and juvenile life stages, the Bovee (1978) criteria for the fry life stage, and the Whelan (oral communication, 1994) criteria for the spawning life stage were selected for testing. A substrate/cover classification scheme and corresponding suitability criteria were developed for use in the study, based on professional judgement.

In accordance with GSBRD recommendations, these suitability criteria were tested to determine whether they could be transferred to Pennsylvania. Four streams were selected for transferability testing, one brook trout stream, and one brown trout stream, in both the Ridge and Valley Freestone and the Unglaciated Plateau study regions, respectively. The transferability study generally followed the methodology described by Thomas and Bovee (1993). Depth, velocity, substrate and cover were recorded at locations occupied by the various life stages of the evaluation species, and at locations not occupied by fish. Statistical analyses of these data showed that the selected criteria were not suitable for use in Pennsylvania. New suitability criteria were developed using the data collected for the transferability study, and used in the subsequent PHABSIM studies.

## 2.5 Study Regions and Study Stream Selection

To develop a regional method, reproducing trout streams were classified according to key physical features that have a direct influence on the physical variables and stream attributes used to quantify fishery habitat. Streams were classified according to study region, species, and segment number.

Study regions were based on physiographic provinces and sections (Fenneman, 1938; Pennsylvania Dept. of Environmental Resources, 1989). In the Ridge and Valley physiographic province, streams were classified into study regions based on limestone (including dolomite) or freestone (e.g., sandstone, shale, conglomerate) geology, rather than physiographic sections. In the Appalachian Plateaus physiographic province, streams were classified into glaciated and unglaciated study regions, based on the location of the glacial boundary (Pennsylvania Dept. of Environmental Resources, 1989). Streams in the unglaciated physiographic sections were combined into one study region called the Unglaciated Plateau. Trout streams in the Piedmont Province were classified based on physiographic section and limestone/freestone geology. Physiographic regions and sections, and parts of the Ridge and Valley Province underlain by limestone, are shown in Plate 1.

In Pennsylvania, the conflicts between withdrawal and instream uses are most critical on cold water streams in the Ridge and Valley physiographic province, and the unglaciated part of the Appalachian Plateaus Province. The Piedmont Upland physiographic section was selected because there are more trout streams in that section than other sections in Maryland. For these reasons, and because of time and cost constraints, only the Ridge and Valley Limestone, Ridge and Valley Freestone, Unglaciated Plateau, and Piedmont Upland (freestone) study regions were included in this study.

Parts of five counties in the southwestern corner of Pennsylvania were deleted from the study because the streams have very low yield, and there are few reproducing trout streams in the area. For these reasons, there are few water supply withdrawals from reproducing trout streams in that area. The counties deleted are Beaver, Allegheny, Washington, Greene, and part of Fayette.

Lists of streams with naturally reproducing trout populations (reproducing trout streams) in each study region in Pennsylvania were developed from existing PFBC and Pa. DEP data. The list of trout streams in Maryland was developed from a report prepared by Steinfelt (1991). The presence of reproducing trout populations on certain study streams selected in Pennsylvania was verified in the field because the PFBC records were incomplete. Potential study streams were selected from these lists by stratified random sampling. The actual study streams were selected in the field from the list of potential streams, also using stratified random sampling. All study streams had good access, reproducing trout populations, good water quality, and no significant human influences.

Study streams were divided into segments based on stream length, which was used as a surrogate for stream slope. The maximum allowable length of stream segments was set at five miles, based on statistical analysis of stream length data. The actual segment length depended on the total length of stream.

The final selected study sites are shown in Plate 1.

A key assumption is that a total of 30 study segments is adequate to represent the variability in hydrology and habitat response to withdrawals in each study region. Approximately 30 segments of various size were studied in each of the three study regions in Pennsylvania (Ridge and Valley Limestone, Ridge and Valley Freestone, Unglaciated Plateau), but due to time and cost constraints, only 12 segments were studied in the Piedmont Upland study region. The proportion of streams in each segment class was approximately equal to the proportion of streams in that class in the entire number of reproducing trout streams in the respective region.

## 2.6 Field Data Collection

Once the study streams were chosen, a study site was selected near the midpoint of each segment. Then the relative amount of each different mesohabitat type (riffle, run, pool) was estimated for each study site. A representative occurrence of each mesohabitat type was selected, and transects were located near the midpoint of the respective mesohabitat type.

Flow rate and water surface elevation were measured at each transect, at a sufficient number of flows to allow calibration of a hydraulic model. The range of measurement flows was specified to satisfy extrapolation criteria for hydraulic calibration (U.S. Geological Survey, Biological Resources Division, 1994), and simulate flows over the range between maximum and minimum median monthly flows at each site. Velocity distribution, substrate and cover were measured at a number of points across each transect, generally at only one flow. The measurement points were selected to represent changes in habitat or velocity across the transect. Field data collection followed standard procedures (Bovee, undated; Buchanan and Somers, 1969).

Data were collected to show the location of trout redds (nests) within each mesohabitat type, to evaluate whether transects located near the midpoint of a mesohabitat type adequately represented spawning habitat. For each mesohabitat type, a large proportion ofthe redds were found in the central half of that type. Therefore, it was concluded that transects located near the midpoint of each mesohabitat type adequately represented spawning habitat.

The following problems were encountered during the study site selection and field data collection phases of the study. In limestone regions, aquatic vegetation frequently caused difficulty in obtaining valid velocity and flow measurements. Seasonal changes in vegetation resulted in changes in depth, velocity and roughness for different measurements, which made hydraulic calibration difficult, and in some cases impossible. For some streams, changes in transect geometry between measurements, usually as a result of high flows, also caused inconsistencies between measurements and required collection of additional data, or in some cases, deletion of a study site. Streams in the Piedmont Upland in Maryland showed signs of unstable bed and banks. Future hydraulic and habitat conditions for these streams may be different from current conditions, so the habitat analyses should be used with caution.

## 2.7 Hydrology and Habitat Modeling

Hydrology was developed from flow data collected at stream gages selected to be representative of the study streams. The following hydrology was developed for the study sites:

- Average daily flow (ADF);
- Median flow for the entire period of record;
- Median monthly flows for each month for the entire period of record;
- Time series of median monthly flows; and
- Annual and seasonal flow duration.

The hydrology for each study site was generally developed from the corresponding hydrology for a selected stream gage, by multiplying flows at the gage by the ratio of drainage area at the site to drainage area at the gage. Stream gages were selected, based on drainage area size, proximity to the study site, similar geology and topography, and judgment. For study streams or gages with mixed limestone and freestone geology, significant springs, withdrawals, or wastewater treatment plant flows, more complex procedures were used to derive the hydrology.

Hydraulic models, based on Manning's equation (Chow, 1959; Bovee, 1982), were calibrated for each transect and measurement point at each study site. The calibrated hydraulic model was used to simulate velocity and depth for 18 flows in the range between maximum and minimum median monthly flows, in accordance with established extrapolation criteria (U.S. Geological Survey, Biological Resources Division, 1994). The simulated depth and velocity data were combined with the substrate and cover data, and the HSC, to develop WUA versus flow relationships for each evaluation species, life stage, and transect. The percentages of each mesohabitat type for each study site were used to compute a weighted average WUA versus flow relationship for each study site, species, and life stage.

A pilot study was conducted to determine whether binary HSC should be used instead of univariate HSC, as recommended by Bovee and others (1994). Univariate criteria can have values over the entire range from 1 to 0, but binary criteria can only have a value of either 1 or 0. In effect, binary criteria discard habitat that may be usable by the fish species, but that is not optimal for those species. The univariate criteria developed from the transferability study data were modified to binary form.

WUA versus flow relationships for each type of criteria were computed and plotted. The univariate criteria resulted in smooth WUA plots for all streams considered. The binary criteria resulted in highly variable, sometimes saw-tooth WUA plots, with much lower amounts of habitat, which made interpretation of these plots difficult. The WUA curves based on univariate criteria appeared more realistic and consistent with expected relationships for the study streams, which support good trout populations. The marginal habitat, which is not considered in the binary criteria, may be very important to the trout populations. For that reason, univariate criteria were used to develop the WUA relationships used in the impact analysis.

### 2.8 Wetted Perimeter Analysis

Wetted perimeter versus flow plots were prepared using the output from the hydraulic simulations, for the riffle transects only. This procedure effectively assumes the inflection point (change of slope) of the plot occurs in the range between maximum and minimum median monthly flow. The flow rates at the inflection points of the curves were tabulated for each study region, and converted to flow rates per unit area and to percent of ADF. These tabulations showed a lot of variability of the flow rates at the inflection points within each region.

The plots were extrapolated to zero wettedperimeter at zero flow. The extrapolation substantially changed many graphs, and usually introduced a lower inflection point. The resulting inflection points also were tabulated for the three study regions in Pennsylvania, and were generally lower than the inflection points determined from the simulation flows alone. The conclusion is the wetted perimeter data developed from the limited range of simulation flows are not adequate to allow selection of inflection points. Therefore, comparisons with the results of the IFIM method are not possible without collecting additional extreme low flow data.

### 2.9. Impact Assessment Methods and Results

The median monthly habitat was assumed to be the best measure of the amount of habitat typically available. A pilot study showed that the habitat available at the median monthly flow is essentially the same as the median of the daily habitat determined from daily flows. Therefore, the median monthly habitat was defined as the habitat value associated with the median monthly flow for subsequent analyses.

To obtain WUA versus flow relationships for each study site, each species, and each season, the life stage present in that season with the least habitat at any flow was assumed to be the most critical life stage to be protected at that flow (Orth and Leonard, 1990). A procedure was developed and implemented to compute these relationships, which are called renormalized minimum weighted usable area (RMWUA).

To determine a conservation flow that would protect the habitat available, two alternative definitions of habitat loss were considered, no-loss of habitat, and no-net-loss of median monthly habitat. For this study, no-loss of habitat was defined as no reduction in RMWUA at any flow. No-net-loss of habitat was defined as no reduction of RMWUA at the median monthly flow. The no-loss criterion unnecessarily limits the withdrawals under a wide range of conditions, considering that natural flow and available habitat fluctuate within months, and years, and among years. Analysis of the no-net-loss criterion for 11 study sites, for both brook trout and brown trout, for three months of the summer season, showed that the no-net-loss flow was equal to the median monthly flow for virtually all cases. The conclusion was this criterion severely limits the withdrawals during the summer season. Therefore, more detailed procedures were developed to assess the impact of water withdrawals on the habitat available.

The purpose of impact analysis is to determine the magnitude of the impact of withdrawals on habitat over a full range of flows, and to use that information to establish criteria for passby flows. The impact is defined as the percentage difference between habitat (RMWUA) available without the withdrawal, and the habitat available with the withdrawal in place.

Two alternative procedures were developed to estimate the impact of withdrawals on available habitat. The first procedure analyzes the effect of withdrawals on time series of median monthly flow and habitat. The second procedure analyzes the effect of withdrawals on flow and associated habitat duration.

The time series impact analysis procedure is designed to estimate the long-term effect of withdrawals, for a specific project site and a specific combination of withdrawal and passby flow using median monthly flow time series. A time series is simply a set of values arranged in chronological order. The method also can be used with other time steps such as daily, but for shorter periods of record. The procedure estimates the average regional impact at a project site, in a given segment class, of a combination of withdrawal and passby flow (both expressed as percentage of ADF) by determining impacts on each study site in that class. Then the impacts are averaged across the study sites in that class.

A computer program has been developed in Microsoft Excel 7.0 format, to estimate the impact of withdrawals for any location within a study region. There are two separate, but related, computer programs included in the package. The first, called the "detailed analysis" program, provides detailed estimates of the average impacts of any combination of withdrawal and passby flow on the flow and habitat at a project site, and can analyze a number of different combinations of species and trout management procedures. This program also allows determination of the percent of time the withdrawal is not available for the given combination of withdrawal and passby flow. The second program, called the "preliminary analysis" program, provides general estimates of the effect of withdrawals and passby flows. The results of the preliminary analysis program can serve as a starting point for more complete analysis using the detailed analysis program.

The detailed analysis program has been used with the hydrology and RMWUA data for selected study sites to develop habitat impact curves for the Unglaciated Plateau, Ridge and Valley Freestone, and Ridge and Valley Limestone study regions. One study site was selected for impact analysis to represent each stream gage used to develop hydrology for each segment class and study region. The data for the curves were obtained by systematically varying withdrawals and passby flows. For each segment class in each region, twenty-seven combinations of withdrawal and passby flows (e.g., 10 percent ADF withdrawal and 5 percent ADF passby flow) were run for each of the stream gages represented, and for each species considered. Three species were analyzed; wild brook trout, wild brown trout, and combined wild brook and brown trout.

For each study site, the average annual percent reduction in RMWUA across the period of record was used as the measure of impact. Curves of constant impact (e.g., 25 percent reduction of habitat) were developed for each region, species, withdrawal, and passby flow. The Ridge and Valley Limestone region was split into two groups, based on whether the amount of limestone on the watershed was greater or less than 50 percent, and different curves were developed for each group.

Comparison of the average annual impacts for the selected study streams within each region showed little variability between the average impacts across streams and the maximum and minimum values of those impacts. This comparison indicated that, while hydrology and stream characteristics were highly variable, habitat impacts were fairly consistent within each region. However, impacts for a given combination of species, withdrawal, and passby flow were very different among regions. This supported the basic study concept that streams would react similarly within regions, but differently among regions.

For the Ridge and Valley Freestone study region, the impact curves for segment classes 1, 2, and 3 were close together, so these curves were averaged. Because segment class 4 included only one stream, no impact curves were provided for that class.

For the Ridge and Valley Limestone study region, the average annual impacts showed significant scatter among streams. These study sites were further classified based on the percentage of limestone in the watershed, which significantly reduced the scatter, but also reduced the sample size, especially for segment classes 2, 3, and 4. Because of limited sample size and the effect of existing withdrawals, WWTP flows, and springs (or caves) on the hydrology at these study sites, impact curves were developed only for segment class 1 sites in this study region.

A partial list of limestone streams has been provided. This list may be incomplete and should be used with caution. Streams not included in the list should be classified as limestone on case-by-case basis.

In the Unglaciated Plateau study region Comparison of the impact curves showed a difference between segment class 1 and class 2 sites. There were no segment class 3 or 4 study sites in that region.

The final constant habitat impact curves are shown in Figures 2.2 through 2.11. The habitat impact curves for Ridge and Valley Limestone Group 1 should be used for project streams and sites where more than 50 percent of the watershed upstream from the study site is underlain by limestone, and the curves for Group 2 should be used where less than 50 percent of the watershed is underlain by limestone. For all three study regions, the impact curves for brown trout and combined brown and brook trout are similar. For that reason, only one set of curves is shown for those species for each study region. There are significant differences between impacts on brook and brown trout, as well as between brook trout and combined brook and brown trout.

The maximum and the 90 percent probability of exceedance measures of habitat impact also were considered. The average impact curves show the long-term effect, and maximum impact curves show the short-term effect. The impact curves based on the average impact are included in this report, based on the assumption that long-term average impacts to habitat may result in average impacts to fish biomass of similar magnitude. However, since short-term maximum impacts to habitat may have more acute effects, both long-term and short-term impacts should be considered when making decisions regarding habitat protection. The impacts at the 90 percent probability of exceedance were found to be very close to the maximum impacts, and thus provided no advantage.

The constant-habitat-impact graphs (Figures 2.2 through 2.11) also show theimpact of a given passby flow on the percentage of time that a given withdrawal is not available. Obviously, the curve with the lowest habitat impact provides the greatest protection to the fishery habitat. However, as the degree of protection increases, so does the percent of time that withdrawals cannot be made because of passby requirements. The graphs show that, as the withdrawal increases to a level above 20 percent ADF, the percent of time that withdrawals cannot be made, either because of natural flow limitations or passby requirements, or both, will be between 60 and 150 days per year. Streams underlain by large amounts of limestone are exceptions because they have very substantial base flows.

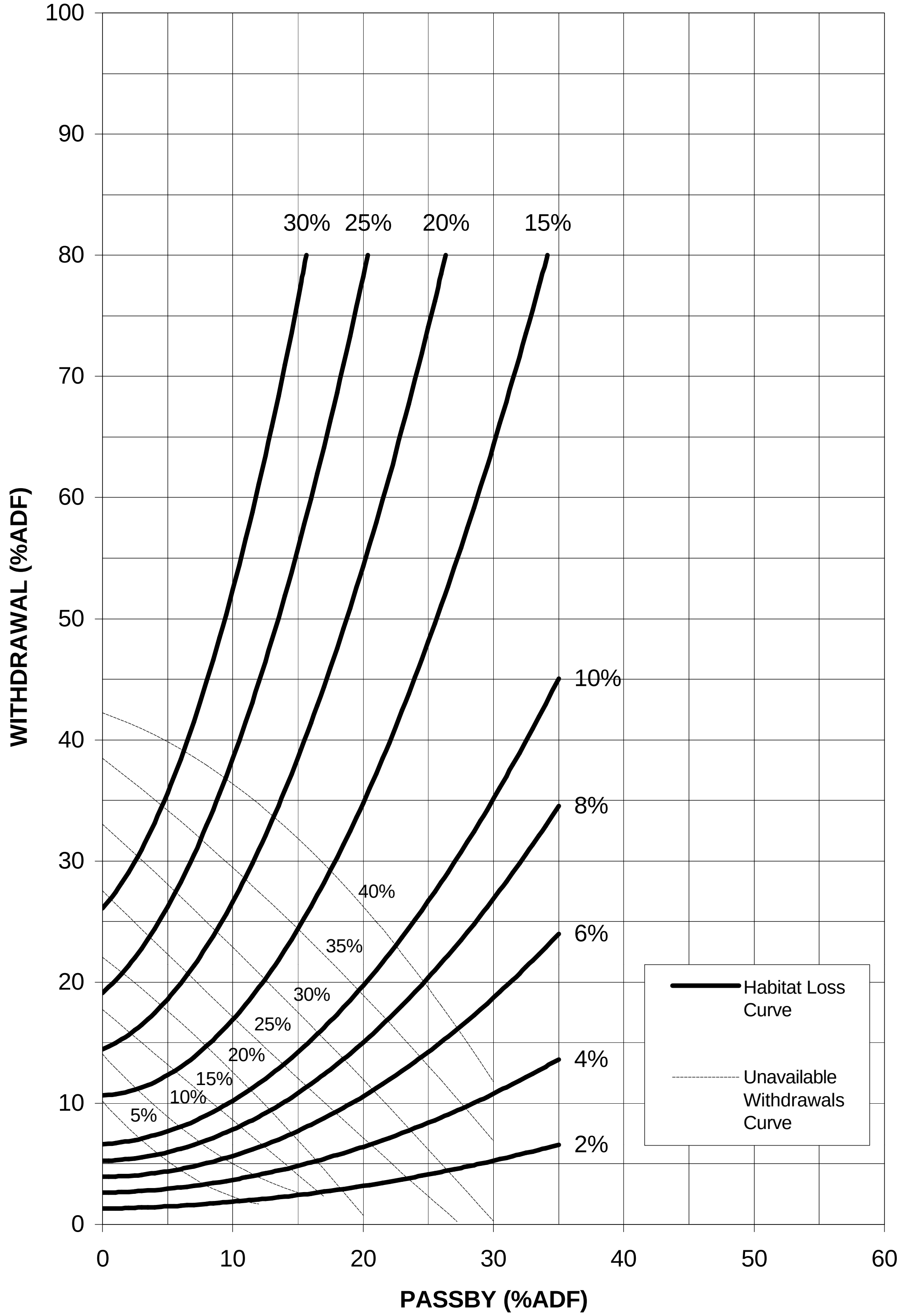


*Figure 2.2. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Freestone, Wild Brown and Combined Species*

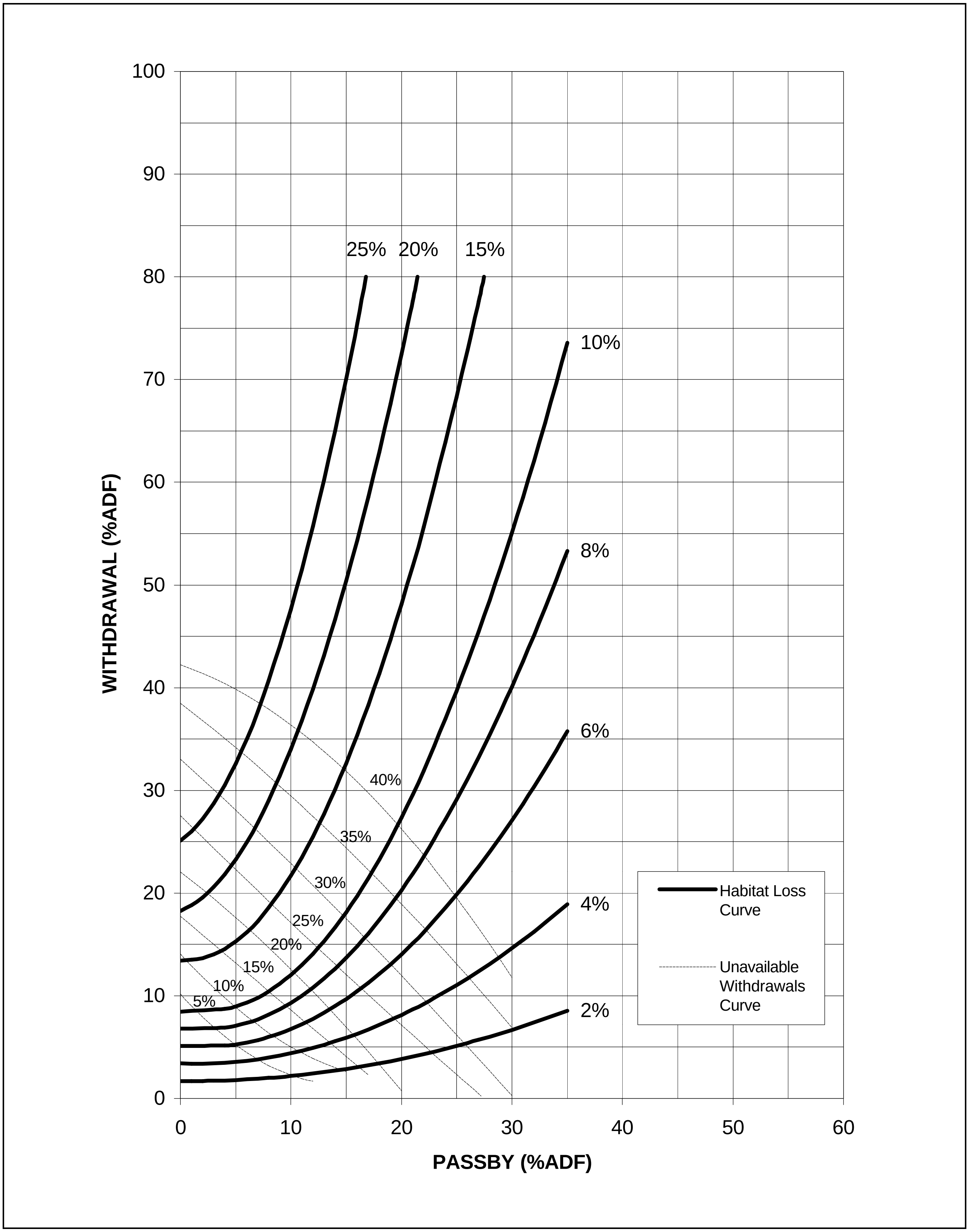


***Figure 2.3. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Freestone, Wild Brook Trout***

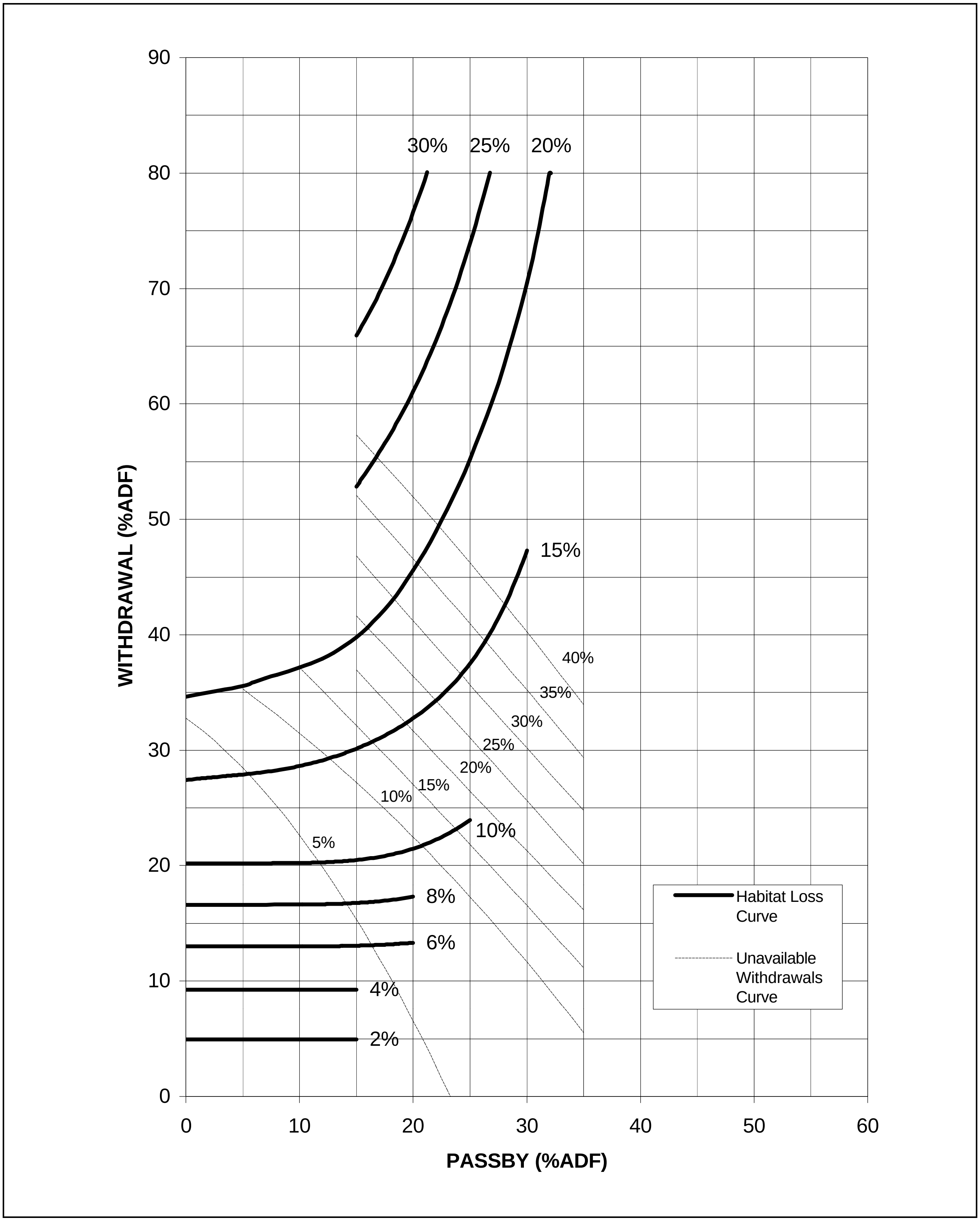


*Figure 2.4. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 1, Wild Brown and Combined Species*

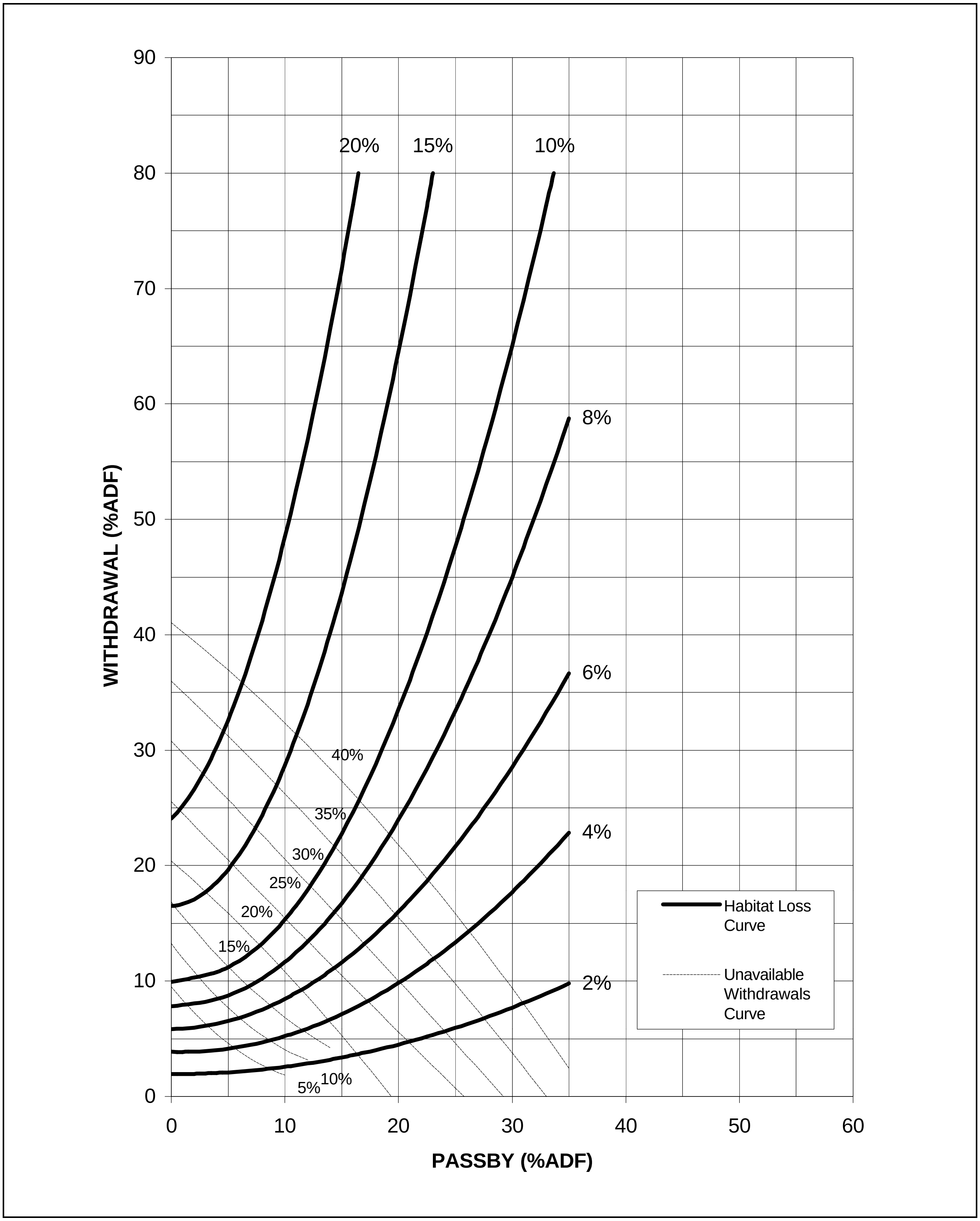


***Figure 2.5. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 2, Wild Brown and Combined Species***

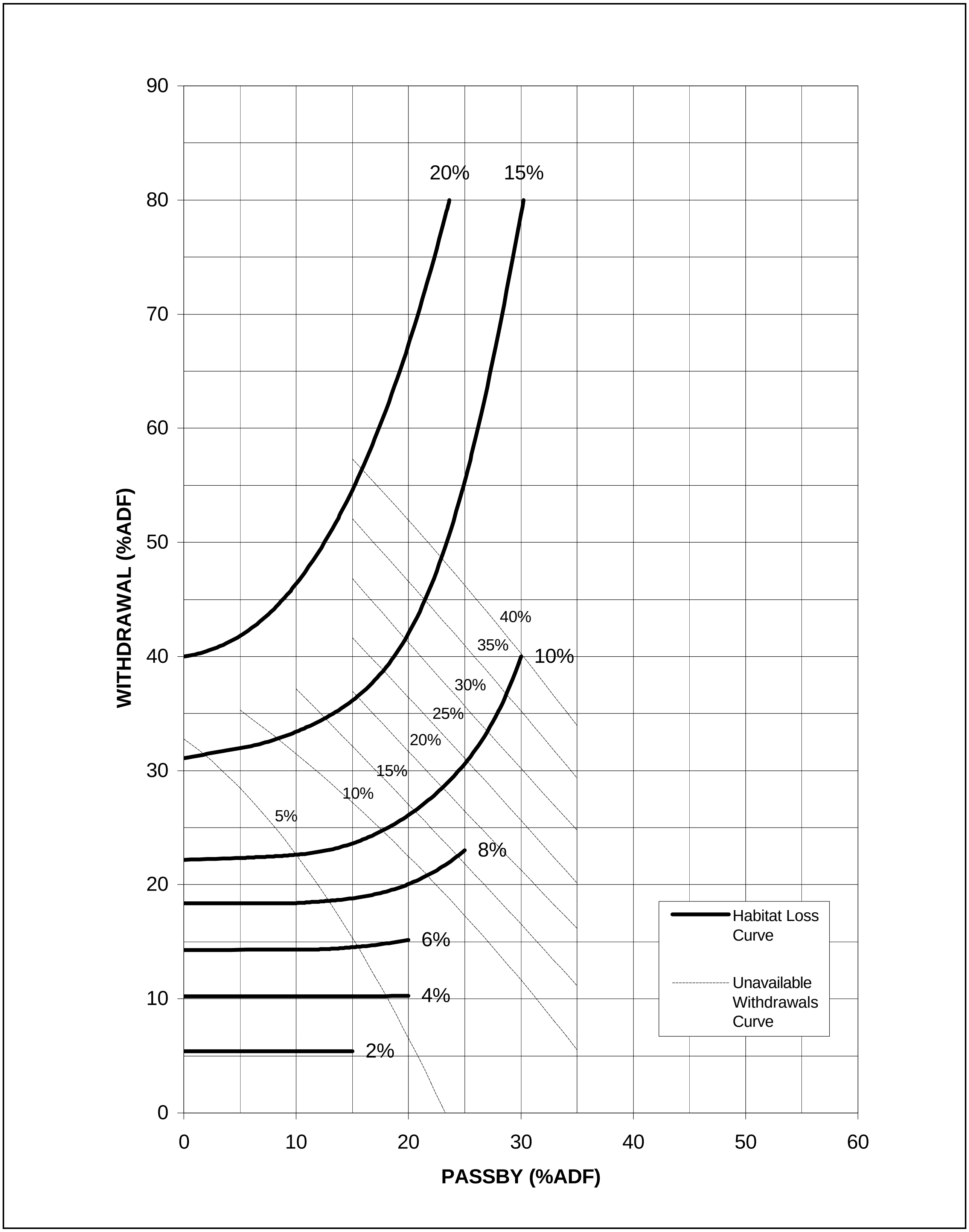


***Figure 2.6. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 1, Wild Brook Trout***

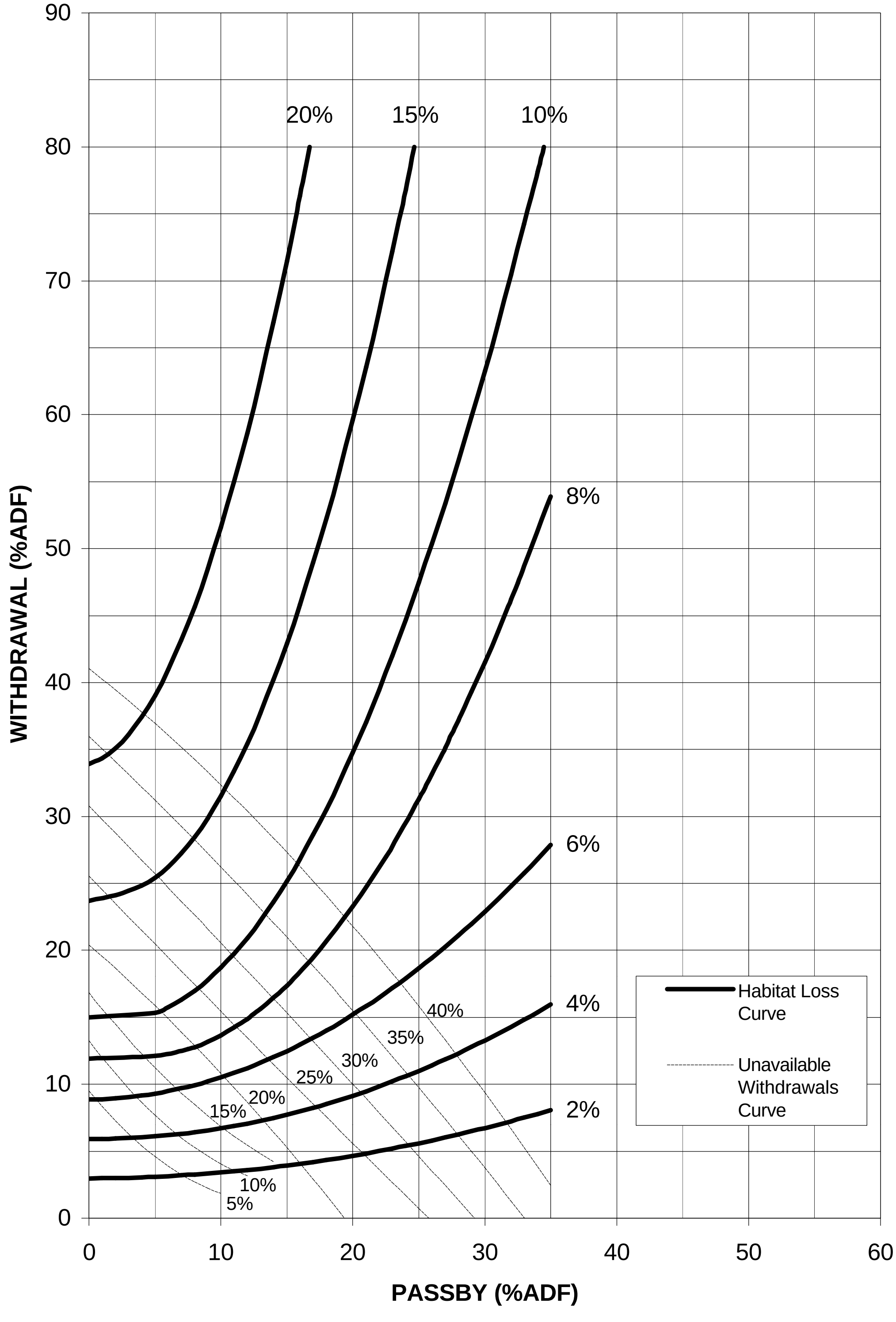


***Figure 2.7. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 2, Wild Brook Trout***

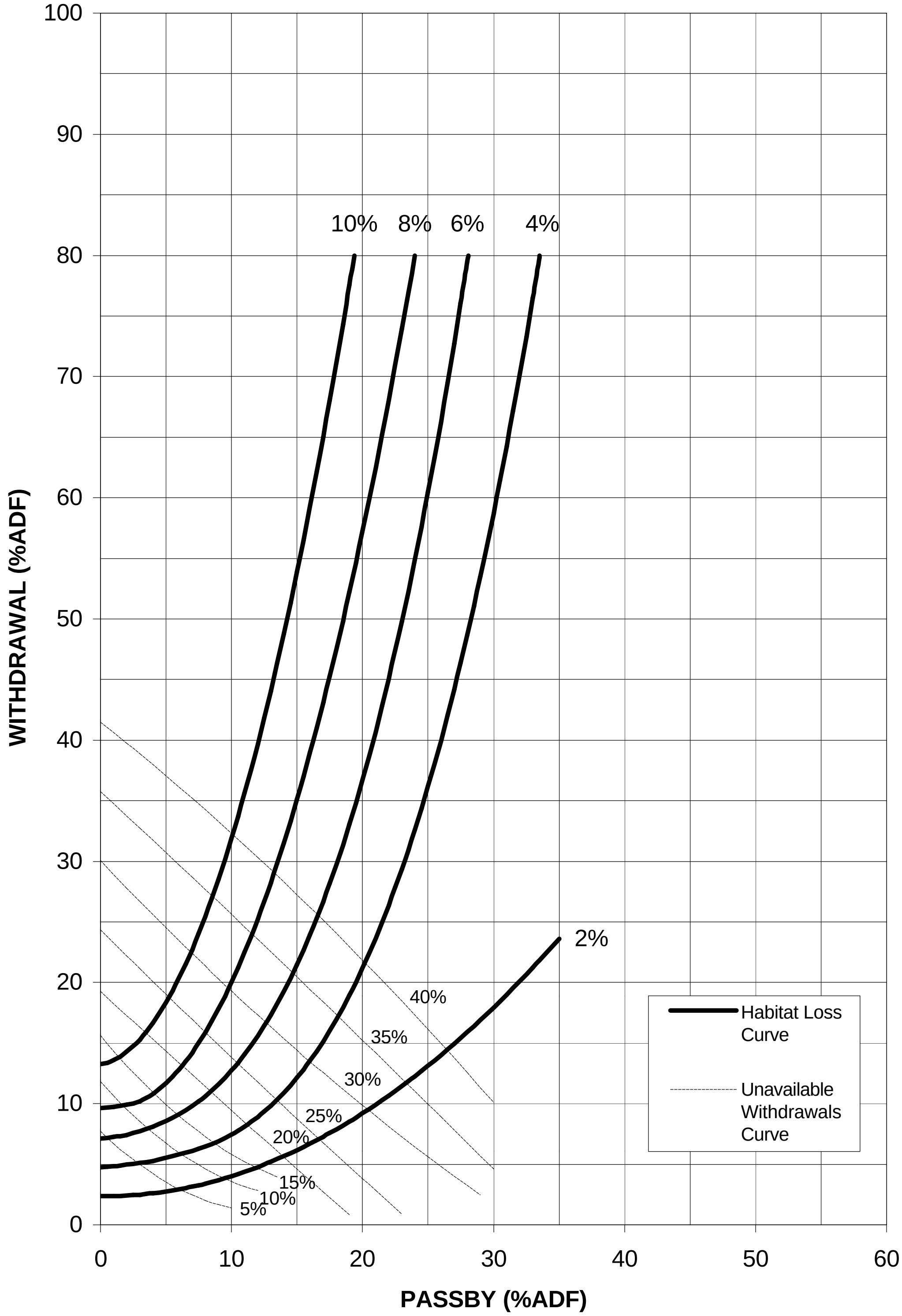


*Figure 2.8. Impact of Selected Withdrawal and Passby Combinations, Unglaciated Plateau Segment Class 1 Streams, Wild Brook Trout*

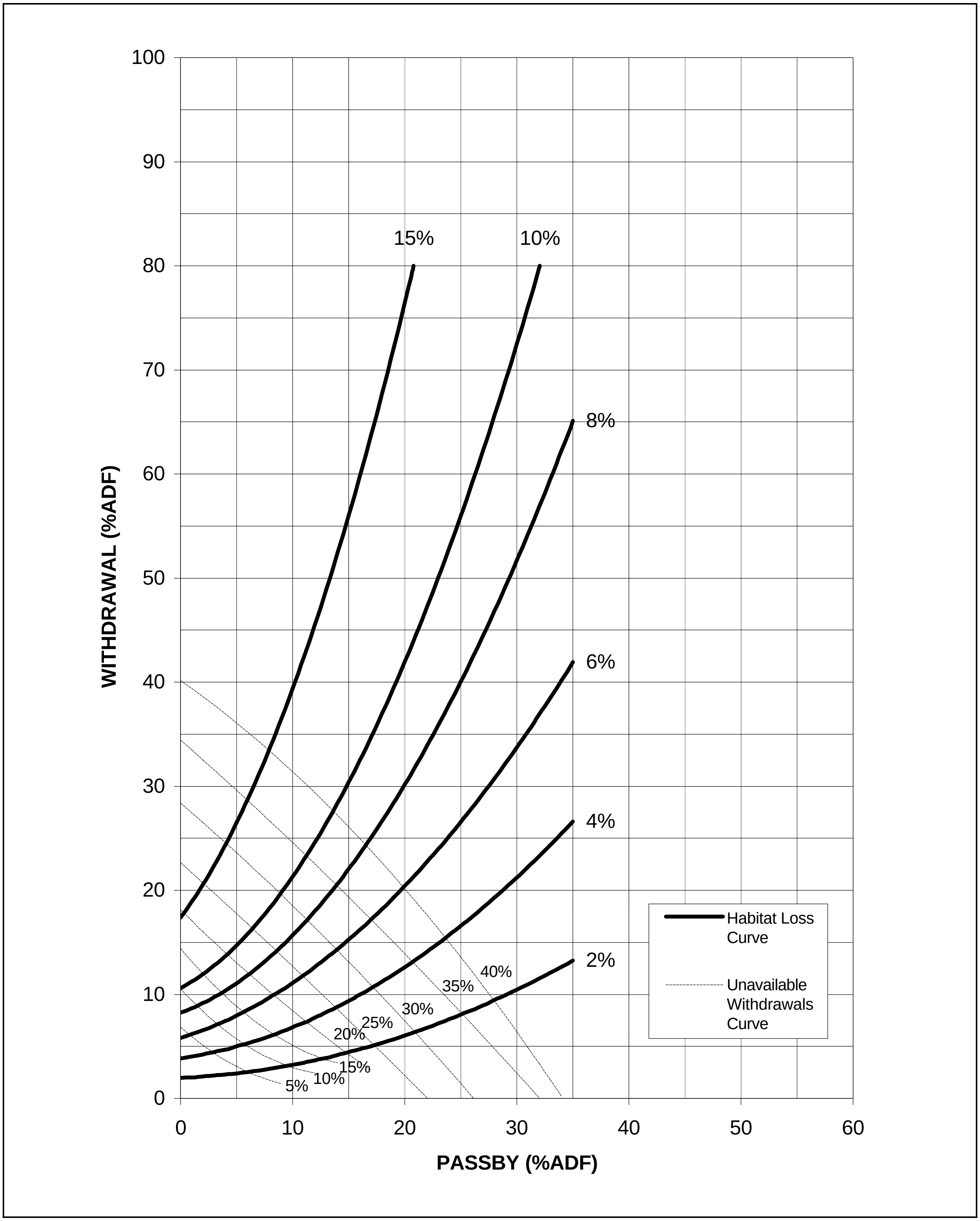


***Figure 2.9. Impact of Selected Withdrawal and Passby Combinations, Unglaciated Plateau Segment Class 2 Streams, Wild Brook Trout***

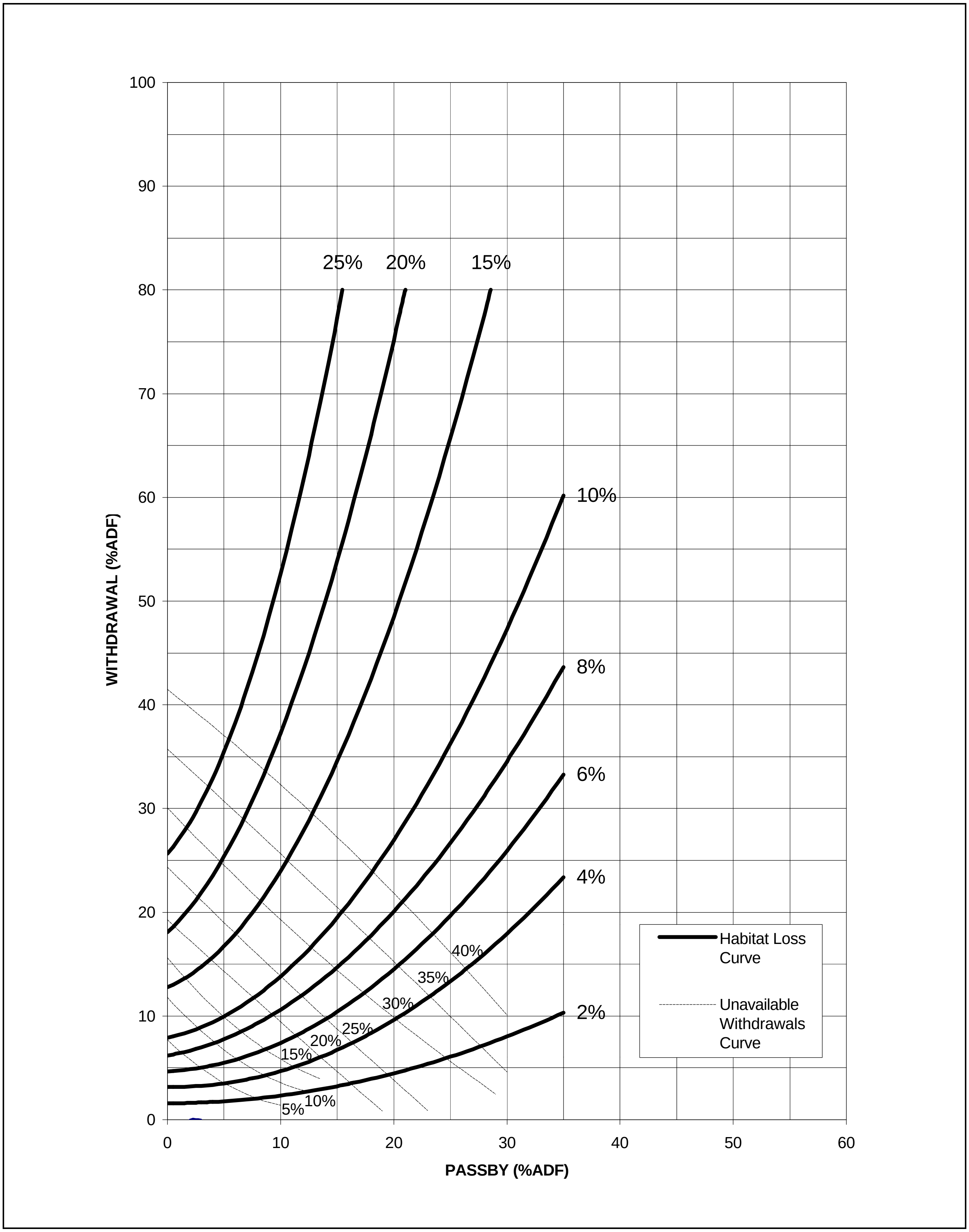


***Figure 2.10. Impact of Selected Withdrawal and Passby Flow Combinations, Unglaciated Plateau Segment Class 1 Streams, Wild Brown and Combined Species***

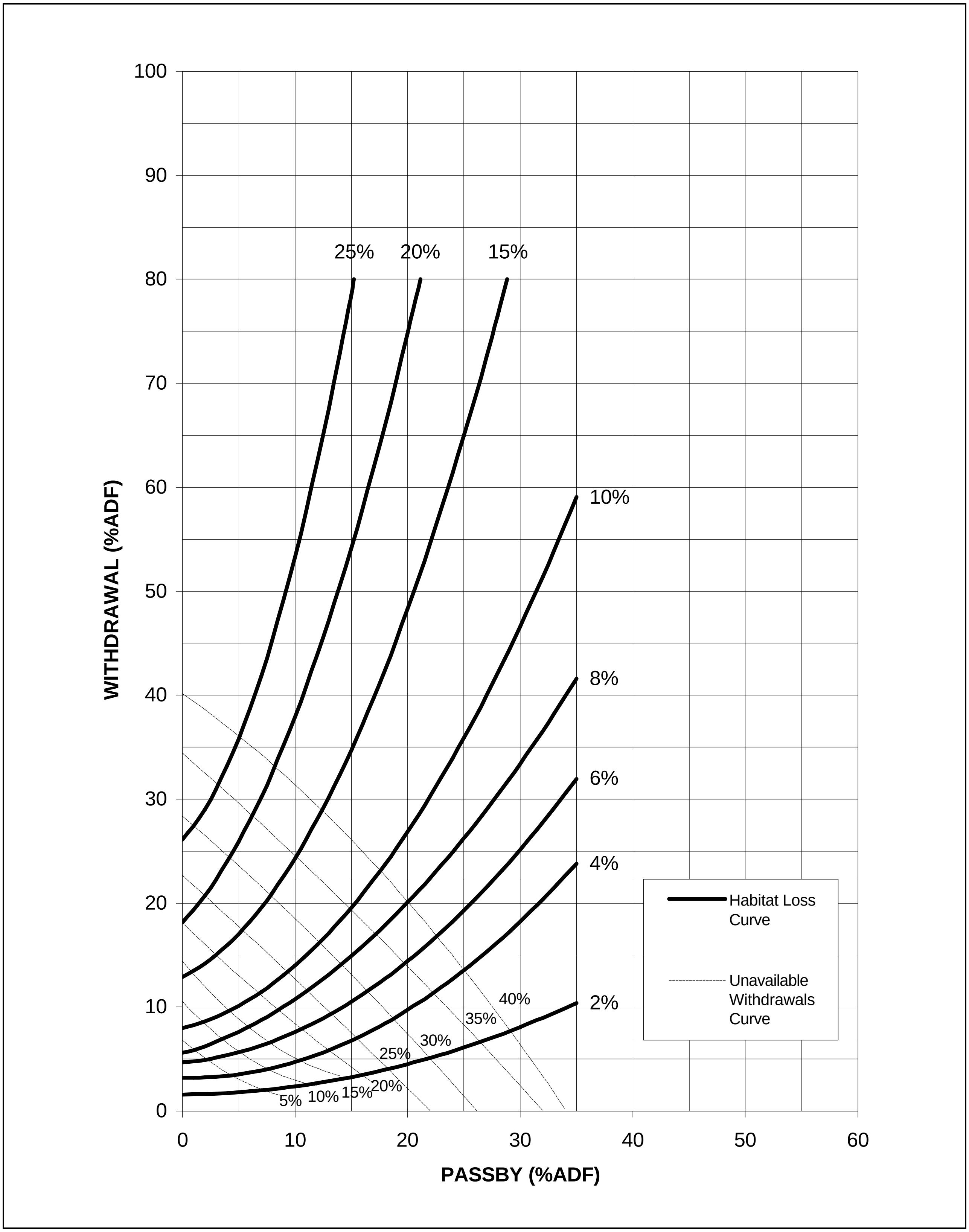


*Figure 2.11. Impact of Selected Withdrawal and Passby Flow Combinations, Unglaciated Plateau Segment Class 2 Streams, Wild Brown and Combined Species*

These impact graphs can be used to develop statewide policies regarding which impact curve should be used to establish passby flows. These graphs also can be used to determine impact of a proposed withdrawal at any site within these study regions. These graphs also can be used by water purveyors to analyze stream intake alternatives that meet state fishery protection levels on cold water streams having used by water purveyors to analyze stream intake alternatives that meet state fishery protection levels on cold water streams having drainage areas less than 100 square miles. The determination of which impact curve(s) to use will have to consider costs both to the environment and to withdrawal users.

Although regional criteria have been developed, the computer program(s) can be used to investigate alternatives or special situations that have not been considered in developing the regional criteria. Additional runs will require hydrology for the study site(s), or for a stream where a withdrawal is proposed. A regional hydrology procedure has been developed for use in developing ADF and median monthly flow time series for any location within these study regions in Pennsylvania.

The regional hydrology procedure uses data for one or more selected U.S. Geological Survey stream gages. The hydrologic regions are shown in Plate 2. The gage(s) recommended for each hydrologic region are shown in Table 2.1. The hydrology for a specific site is generally derived by multiplying the gage data by the ratio of drainage area at the site to drainage area at the gage. More complex procedures are necessary for sites with mixed or unusual geology. Adjustments for special conditions such as springs, withdrawals, and wastewater treatment plant return flows are included in the procedures.

An alternative procedure, called the associated habitat duration impact analysis procedure, is designed to estimate the effect of withdrawals on the study streams within a study region or group. The concept is that impacts of a given level of withdrawal on a given study species should be similar within a study region or group. The procedure combines daily flow duration analyses for each season with the RMWUA versus flow relationship for each study stream to obtain the habitat probability relationship for each stream and season. The habitat probability relationships are derived for unimpacted and impacted conditions and used to develop the relationship between percentage change in habitat and flow for different levels of withdrawal. For a given level of withdrawal, the passby flow equals the lowest level of flow for which habitat reduction is equal to an acceptable level. Flows, withdrawals, and passby flows are expressed as percentages of ADF, so that levels of impact for different passby flows can be compared across streams within a study region.

These relationships can be used to evaluate the effect of alternative withdrawals and passby flows on habitat over the entire range of daily flows for each season. The effect of passby flows on water supply availability can be evaluated in a tradeoff analysis. This information can be used to determine allowable levels of withdrawal, and the required passby flows, to prevent unacceptable impacts on the evaluation species. The results can be used to develop regional criteria for required passby flows. If this procedure were used, it could allow evaluation of the existing regional classes, which may lead to modification of those classes. The procedure is incomplete due to time and cost constraints and the decision to use the time series impact analysis procedure instead.

*Table 2.1. Hydrology Regions and Gages*

| Region Designation | Region Description | Stream Gage Number | Stream Gage Name |
|---|---|---|---|
| GP-1 | Glaciated Appalachian Plateau Section in Wayne and Wyoming and eastern Lackawanna Counties, Lackawanna River drainage only | 01429500 | Dyberry Creek near Honesdale |
| GP-2 | Glaciated Appalachian Plateau Section in Pike County, south flowing streams only | 01440400 | Brodhead Creek near Analomink |
| GP-3 | Glaciated Pocono Plateau Section | 01447500 | Lehigh River at Stoddartsville |
| GP-4 | Glaciated Appalachian Plateau Section in Susquehanna, Lackawanna, Luzerne, and Columbia Counties, streams flowing into Ridge and Valley physiographic province only | 01533950 | South Branch Tunkhannock Creek near Montdale |
| GP-5 | Glaciated High Plateau Section, Muncy Creek and Loyalsock Creek drainages | 01552500 | Muncy Creek near Sonestown |
| GP-6 | Glaciated Appalachian Plateau Section, Lycoming Creek, Pine Creek and Oswayo Creek drainages | 01518862 | Cowanesque River at Westfield |
| GP-7 | Glaciated Pittsburgh Plateau Section in Erie, Warren, Crawford, Venango, Mercer, Butler and Lawrence Counties | 03022540 | Woodcock Creek at Blooming Valley |
| RV-1 | Appalachian Mountain Section (Glaciated), Susquehanna River drainage north of glacial boundary (Berwick) | 01538000 | Wapwallopen Creek near Wapwallopen (modified) |
| RV-2 | Appalachian Mountain Section in Monroe County, east of glacial boundary | 01449360 | Pohopoco Creek at Kresgeville |
| RV-3 | Great Valley Section east of glacial boundary in Northampton County | 01446600 | Martins Creek near East Bangor |
| RV-4 | Appalachian Mountain Section, Lehigh River drainage | 01449360 | Pohopoco Creek at Kresgeville |
| RV-5 | Great Valley Section, Delaware and Lehigh drainage | 01452500<br><br>01451800 | Limestone sections: Monocacy Creek at Bethlehem (modified)<br>Freestone sections: Jordan Creek near Schnecksville |
| RV-6 | Appalachian Mountain Section, Susquehanna River drainage north of Susquehanna River, west to West Branch Susquehanna River and including Loyalsock Cr. drainage; and south of Susquehanna River to crest of Little Mountain and west to Susquehanna River, including Fishing Creek, Mahoning Creek, Chillisquaque Creek, Muncy Creek and part of Shamokin Creek drainage downstream from Weigh Scale | 01539000<br>01567500 | Freestone: Fishing Creek near Bloomsburg<br>Limestone: Bixler Run near Loysville |
| RV-7 | Appalachian Mountain Section, Susquehanna River drainage, south of glacial boundary, north of Susquehanna River including Briar Creek drainage; South of Susquehanna River including Nescopeck Creek, Catawissa Creek, Roaring Brook, Mahanoy Creek, and Shamokin Creek drainage upstream from Weigh Scale | 01538000 | Wapwallopen Creek near Wapwallopen (modified) |
| RV-8 | Appalachian Mountain Section, Schuylkill River drainage | 01469500 | Little Schuylkill River at Tamaqua |
| RV-9 | Great Valley Section, Schuylkill River drainage | 01470779<br>01470720 | Limestone: Tulpehocken Creek near Bernville<br>Freestone: Maiden Creek Tributary at Lenhartsville |

***Table 2.1. Hydrology Regions and Gages—Continued***

| Region Designation | Region Description | Stream Gage Number | Stream Gage Name |
|---|---|---|---|
| RV-10 | Appalachian Mountain Section, Susquehanna River drainage, south of Line Mountain, and east of Susquehanna River, including Schwaben Creek, Mahantango Creek, Wiconisco Creek, and Powell Creek | 01555500 | East Mahantango Creek near Dalmatia |
| RV-11 | Great Valley Section, Susquehanna River drainage east of Susquehanna River, including part of Swatara Creek drainage | 01573086<br>01470720 | Limestone: Beck Creek near Cleona<br>Freestone: Maiden Creek Tributary at Lenhartsville |
| RV-12 | Appalachian Mountain Section, north of West Branch Susquehanna River and west of Bald Eagle Creek, south and east of crest of Allegheny Front, including parts of Lycoming Creek, Pine Creek, West Branch Susquehanna River and Bald Eagle Creek drainages | 01547700 | Freestone: Marsh Creek at Blanchard |
| RV-13 | Appalachian Mountain Section, west and south of West Branch Susquehanna River, east of Bald Eagle Creek, north of Juniata River divide, including White Deer Creek, White Deer Hole Creek, Buffalo Creek (Union County), Penns Creek, Middle Creek, West Mahantango Creek, Fishing Creek (Centre and Clinton Counties), and Spring Creek (Centre County) drainages | 01546400<br>01555000<br>01553130 | Limestone: Spring Creek at Houserville<br>Freestone valley: Penns Creek at Penns Creek<br>Freestone mountainous: Sand Spring Run near White Deer |
| RV-14 | Appalachian Mountain Section, Kishacoquillas Creek upstream from Reedsville, and Saddler Run drainages | 01565000<br>01568000<br>01553130 | Limestone: Kishacoquillas Creek at Reedsville (modified)<br>Freestone valley: Sherman Creek at Shermans Dale<br>Freestone mountainous: Sand Spring Run near White Deer |
| RV-15 | Appalachian Mountain Section, Sherman Creek, Buffalo Creek, Little Juniata Creek, Tuscarora Creek (downstream from McCoysville), Cocolamus Creek, Jacks Creek, Kishacoquillas Creek (downstream from Reedsville), and headwaters of Conodoguinet Creek, drainages | 01567500<br>01568000 | Limestone: Bixler Run near Loysville<br>Freestone: Sherman Creek at Shermans Dale |
| RV-16 | Great Valley Section, Cumberland and Franklin counties | 01569800<br>01571500<br>01568000 | Limestone with significant springs (Flippo, 1974): Letort Spring Run near Carlisle, (modified), and add spring flow;<br>Limestone, no significant springs: Yellow Breeches Creek near Camp Hill<br>Freestone: Sherman Creek at Shermans Dale |
| RV-17 | Appalachian Mountain Section, north of Juniata River from Granville (Mifflin County) to crest of Tussey Mountain (except Saddler Run); south of Juniata River, to Potomac River divide, west of RV-14 and RV-15 to crest of Tussey Mountain and Evitts Mountain; including Buffalo Creek (Perry County), Tuscarora Creek (upstream from McCoysville), Aughwick Creek, Raystown Branch Juniata River (downstream from Everett), Standing Stone Creek and Shaver Creek drainages | 01564500<br>01567500 | Freestone: Aughwick Creek near Three Springs<br>Limestone: Bixler Run near Loysville |

***Table-2.1. Hydrology Regions and Gages—Continued***

| Region Designation | Region Description | Stream Gage Number | Stream Gage Name |
|---|---|---|---|
| RV-18 | Appalachian Mountain Section, Potomac basin divide south to Maryland line, east of Town Mountain, including Licking Creek, Tonoloway Creek and Bear Creek drainages | 01613050<br>01546400 | Freestone: Tonoloway Creek at Needmore<br>Limestone: Bixler Run near Loysville |
| RV-19 | Appalachian Mountain section, parts of Little Juniata River, and Frankstown Branch and Raystown Branch Juniata River drainages; west of crest of Tussey Mountain, east of crest of Bald Eagle Mountain, Canoe Mountain, Lock Mountain, Dunning Mountain, and Evitts Mountain; south of West Branch Susquehanna River divide; north of Raystown Branch Juniata River; including Spruce Creek, Sinking Run, Clover Creek, Piney Creek, Snakespring Valley Run, and part of Yellow Creek (Bedford County) drainages | 01556000 | Limestone: Spring Creek at Houserville<br>Freestone: Dunning Creek at Belden |
| RV-20 | Appalachian Mountain Section, parts of Little Juniata River and Frankstown Branch Juniata River drainages; west of crest of Bald Eagle Mountain, Canoe Mountain, Lock Mountain and Dunning Mountain; and east of crest of Allegheny Front | 01546400<br>01560000 | Limestone: Bixler Run near Loysville<br>Freestone: Bald Eagle Creek at Tyrone |
| RV-21 | Appalachian Mountain Section, west of crest of Dunning Mountain, Evitts Mountain, and Tussey Mountain, east of crest of Allegheny Front, south of Frankstown Branch divide, north of Potomac basin divide, including all of Raystown Branch Juniata River drainage upstream of Bedford, and Shover's Run and Cove Creek drainages | 01546400<br>01560000 | Limestone: Bixler Run near Loysville<br>Freestone: Dunning Creek at Belden |
| RV-22 | Appalachian Mountain Section, Potomac basin divide south to Maryland line, west of Town Mountain to boundary of Ridge and Valley Province, including Sideling Hill Creek, Town Creek, Flintstone Creek, Evitts Creek, and part of Wills Creek drainages | 01601000<br>01567500 | Freestone: Wills Creek below Hyndman<br>Limestone: Bixler Run near Loysville |
| RP-1 | Reading Prong Section, Lehigh, Northampton, and Berks Counties | 01470853 | Furnace Creek at Robesonia (modified) |
| GNL-1 | Gettysburg-Newark Lowland Section in northern Bucks County, Durham Creek drainage | 01472198 | Perkiomen Creek at East Greenville |
| GNL-2 | Gettysburg-Newark Lowland Section in Lebanon, Dauphin, and York Counties, north flowing streams only, including parts of Swatara Creek and Yellow Breeches Creek drainages | 01574000 | West Conewago Creek near Manchester |
| SM-1 | South Mountain Section in Cumberland, York, Adams, and Franklin Counties | 01568000 | Sherman Creek at Shermans Dale |

***Table 2.1. Hydrology Regions and Gages—Continued***

| Region Designation | Region Description | Stream Gage Number | Stream Gage Name |
|---|---|---|---|
| UP-1 | Deep Valley Section, in Susquehanna drainage, including parts of Lycoming, Pine Creek and Kettle Creek drainage | 01545600 | Young Womans Creek near Renovo |
| UP-2 | Deep Valley Section as defined by Sevon (in preparation), Allegheny River drainage, south of glacial boundary and New York state line; excluding Potato Creek drainage upstream from Farmers Valley, and part of Allegheny River drainage upstream from Port Allegany and west of Allegheny River | 03007800 | Allegheny River at Port Allegany |
| UP-3 | Deep Valleys Section as defined by Sevon (in preparation), Potato Creek drainage upstream from Farmers Valley, and part of Allegheny River drainage upstream from Port Allegany and west of the Allegheny River | 03009680 | Potato Creek at Smethport |
| UP-4 | Deep Valley Section, Sinnemahoning Creek drainage | 01543000 | Driftwood Branch Sinnemahoning Creek at Sterling Run |
| UP-5 | Allegheny Plateau Section, including West Branch Susquehanna River, Beech Creek, and Black Moshannon Creek drainages | 01547800 | South Fork Beech Creek near Snow Shoe |
| UP-6 | Pittsburgh Low Plateau Section, West Branch Susquehanna River, parts of Moshannon Creek and Bennett Branch Sinnemahoning Creek drainages | 01541000 | West Branch Susquehanna River at Bower, except for main stem of Clearfield Creek downstream from Glendale Lake |
| UP-7 | Allegheny Mountain Section, Conemaugh River drainage | 03042000 | Freestone and limestone: Blacklick Creek at Josephine |
| UP-8 | Allegheny Mountain Section, Wills Creek drainage | 01601000 | Wills Creek below Hyndman |
| UP-9 | Allegheny Mountain Section, Youghiogheny River and Monongahela River drainages | 03080000 | Freestone and limestone: Laurel Hill Creek at Ursina |
| UP-10 | High Plateau Section as defined by Sevon (in preparation), Allegheny River (downstream from Kinzua Dam) and Tionesta Creek drainage in southwestern McKean, Warren, Elk and Forest Counties | 03017500 | Tionesta Creek at Lynch |
| UP-11 | High Plateau Section, part of Clarion River and Redbank Creek drainages, (Pa. DEP subbasins 17A, parts of 17B and 17C) | 03028000 | West Branch Clarion River at Wilcox |
| UP-12 | High Plateau Section, Oil Creek, parts of Sugar Creek and Pithole Creek drainages (Pa. DEP Subbasin 16E, part of 16D and 16G) | 03020500 | Freestone and limestone: Oil Creek at Rouseville |
| UP-13 | Pittsburgh Low Plateau Section, including Mahoning Creek, Crooked Creek, parts of Redbank Creek and Clarion River drainages | 03034000 | Freestone and limestone: Mahoning Creek at Punxsutawney |
| UP-14 | Pittsburgh Low Plateau Section, including Slippery Rock Creek, Connoquenessing Creek, Buffalo Creek, Conemaugh River, Sewickley Creek, and part of Youghiogheny River drainages (Pa. DEP subbasins 18B, 18F, 19A, 19D, 20C) | 03049000 | Freestone and Limestone: Buffalo Creek near Freeport |

## 3.0 STUDY CONCLUSIONS

A procedure has been developed for determining instream flow needs and passby flows for small reproducing trout streams in Pennsylvania and Maryland. The procedure is based on available habitat, is easily derived from hydrologic records, and does not require stream-specific impact analysis studies. At present, the procedure can be applied to sites with drainage areas less than 100 square miles in the Ridge and Valley, and unglaciated parts of the Appalachian Plateaus, physiographic provinces. The procedure includes computer program(s) that estimate the impact on fishery habitat available, resulting from various combinations of withdrawal and passby flow, for project sites in those study regions. The effects of imposing passby flows on the availability of water supply also is estimated. This information can be used to evaluate tradeoffs between impacts on fishery habitat and impacts on the water supply.

The computer program has been used to develop a set of graphs relating withdrawal, passby flow, and impact on habitat for brook, brown, and combined brook and brown trout. The impact of passby flows on water supply availability has been superimposed on the habitat impact graph to facilitate tradeoff analysis and development of regional criteria for passby flows. The computer program(s) also may be used to study special situations not considered in development of the impact curves. The procedures can be extended to the remaining parts of Pennsylvania, Maryland, and the Susquehanna basin by collecting and analyzing additional field data for each remaining study region.

The PHABSIM components of IFIM can be applied to selected study streams to develop the WUA relationships necessary to estimate the impact of withdrawals for streams in a defined study region, and to develop regional habitat impact curves.

The computer program developed as part of this study can be used to determine the impacts of withdrawals for the study sites, and the results can be used to develop regional relationships between withdrawal, passby flow, and impact on fishery habitat. These relationships can be used to develop regional and statewide passby flow criteria.

The original concept of classifying streams based on differences in key physical characteristics that affect the availability of habitat at different flows is satisfactory for developing a regional procedure for determining instream flow needs.

The stream classification scheme, based on physiographic provinces and sections, type of geology, and stream segment number, appears to represent the differences in the key physical features that affect the availability of habitat. However, the impact curves show that there are differences in impact between brook and brown trout, and between brook trout and combined brook and brown trout. This result indicates that the trout species present is an important variable in determining statewide policy regarding passby flows.

The classification by segment number is useful for separating the impacts of withdrawals on small, steep streams from those that are larger and less steep. It also is useful in ensuring that streams of different size are sampled.

The impact analysis results show differences in impacts between study sites in different segment classes in all study regions. These differences are considered insignificant for the Ridge and Valley Freestone study region, and impact curves for segment classes 1, 2, and 3 were combined. Streams in the Ridge and Valley Limestone study region need to be further classified based on amount of limestone. The habitat impact curves for different segment classes behave erratically, probably due to site-specific differences in hydrology, and small sample size for segment classes 2 through 4. For the Unglaciated Plateau study region, the habitat impact curves are different for sites in segment classes 1 and 2.

## 4.0 STUDY RECOMMENDATIONS

The habitat and withdrawal impact curves developed in this study should be used by the participating agencies to develop regional or statewide procedures for determining withdrawal limits and passby flows. In particular, decisions need to be made regarding acceptable levels of impact on both uses.

This procedure also should be extended to trout streams in the Piedmont Province. Based on present knowledge, it is recommended that the province be divided into the Piedmont Upland, Piedmont Lowland and Gettysburg-Newark Lowland sections, and that both limestone and freestone subdivisions of these sections be considered. Alternatively, the entire province could be classified as either limestone or freestone, regardless of the physiographic section.

The method should be developed for trout streams in the glaciated sections of the Appalachian Plateaus Province. Based on present knowledge, three study regions are recommended: Glaciated Low Plateau and Glaciated Pocono Plateau combined; Glaciated High Plateau; and Glaciated Pittsburgh Plateau. Also, the study design needs to consider the possibility that headwater streams formed on glacial till are much steeper and have different hydrology and habitat impact characteristics than streams formed on glacial fill materials in the valleys.

Studies of additional regions and types of streams should include evaluations of the transferability of HSC to these regions and types of streams.

It has been demonstrated that regional relationships for fishery habitat can be developed for Pennsylvania and the Susquehanna River Basin streams. It is appropriate to see if these concepts can be extended to larger cold water and warm water streams and rivers in the Susquehanna basin and Pennsylvania. These studies are needed because of existing conflicts between instream and withdrawal uses, and to facilitate evaluation of impacts of withdrawals on those streams.

The applicability of results of these studies to streams in the Ridge and Valley and Appalachian Plateaus study regions in Maryland should be considered.

## 5.0 AREAS FOR ADDITIONAL RESEARCH

The computer program should be further refined. In particular, the hydrology calculations that are presently made externally should be incorporated in the program. Also, a reservoir operations model should be added to the program to allow consideration of minimum releases from storage facilities.

The sampling scheme utilized to select study streams and segments generally provides satisfactory results. However, the assumptions used in selecting a sample of streams should be investigated further. The number of segment class 1 study sites sampled appears to be adequate in all study regions. The number of segment class 2 sites appears to be adequate in the Ridge and Valley Freestone and Unglaciated Plateau study regions, but appears inadequate in the Ridge and Valley Limestone study region. The number of segment class 3 and 4 sites appears to be inadequate in all study regions. There may be a need for additional segment class 3 and 4 study sites in all study regions, and additional segment class 2 sites in the Ridge and Valley Limestone region. Also, the relationship of the stream selection procedures to variations in hydrology within a study region should be evaluated to determine whether each hydrologic region should be sampled. Variations in hydrology among segment classes, due to both natural and man-made conditions, also should be considered.

Transects located near the midpoint of each mesohabitat type appear to provide satisfactory sampling of spawning habitat. In future studies, it may be desirable to collect data ata transect in the downstream part of pools to include the area with the highest proportion of redds.

The field measurement and model calibration problems encountered in this study should be considered and minimized in selecting streams for future studies.

The HSC developed in this study are based on the best field data obtainable with the resources available for the study. However, these criteria could be refined in future studies by: testing the HSC developed in this study against independent habitat usability data for streams in the same study regions; developing separate HSC for each study region; developing HSC for rainbow trout; or collecting additional data to allow evaluation of the effects of season, time of day, or other trout species present. Development of habitat suitability criteria for rainbow trout allows application of the procedures, including habitat impact curve development, to that species.

The regional hydrology procedures developed in this study are the besthat could be developed within the time and cost constraints of the study. As experience is gained with the procedures, refinements may become necessary or desirable.

The habitat data for the Maryland study streams should be used cautiously, becauseof evidence that some of the streams are not in dynamic equilibrium. The existing data should be verified through other sources, or collection of additional data. Also, the effect of changes in bed and banks on habitat estimation should be evaluated.

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# GLOSSARY

## A

| | |
|---|---|
| **Adult life stage** | Trout 6 or more inches long. |
| **Average daily flow** | The arithmetic mean of individual daily mean discharges during a period of record. |
| **ADF** | Average daily flow. |
| **Associated habitat duration analysis** | Development of habitat probability relationship by determining habitat corresponding to a flow and assigning the probability of the flow to the habitat. |

## B

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|---|---|
| **Binary suitability criteria** | Habitat suitability criteria that have values onlyof zero or unity. |

## C

| | |
|---|---|
| **Conservation flow** | Mandated flow expected to be maintained downstream from a water storage facility or water intake to protect instream uses, including fishery habitat. |
| **Conservation releases** | Releases made from a controlledwater storage facility to maintain some amount of flow in the stream downstream from the facility. |
| **Consumptive use** | Loss of water from ground-water or surface water source, through a man-made conveyance system, by a process that does not return the water to the basin. |
| **Cover** | Areas of shelter that provide resting places, visual isolation, or protection from predators for aquatic organisms. |

## D

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|---|---|
| **Daily flow** | Average of instantaneous discharges during a clock day. |
| **Duration analysis** | Categorization of events (eg., flow rates or habitat available) to determine the probability of exceedance by arranging the values in order of magnitude. |

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|---|---|
| **Detailed analysis program** | Computer program written in Microsoft Excel format for complete analysis of the impact of any combination of withdrawal and passby flows on the flow and habitat of a project stream; see preliminary analysis program. |

# E

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|---|---|
| **Evaluation species** | Species used to estimate effects of changes in flow on the aquatic ecosystem. |

# F

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|---|---|
| **Flow duration analysis** | Duration analysis of streamflow data of a selected time step (e.g., daily or monthly). |
| **Freestone** | A general term for the class of rocks that do not contain significant amounts of carbonate minerals. See limestone. |
| **Flow protection** | Maintenance of flows to prevent significant reductions in habitat for aquatic species, or other instream uses. |
| **Fry life stage** | Immature fish after emergence from gravel, assumed herein to be less than 2 inches long. |

# G

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|---|---|
| **Gaging station** | Point on a stream or water body where water surface elevations or flow are systematically measured. |
| **Glacial boundary** | Location of the terminal moraine of the late Wisconsin glacial advance, as defined by Sevon (1995). |

# H

| | |
|---|---|
| **Habitat** | The place where an organism or population lives and its surroundings, both living and nonliving; used herein to refer to the physical aspects of habitat represented as weighted usable area. |
| **Habitat suitability criteria** | Relationship(s) describing usability of different value physical habitat variable(s) (depth, velocity, substrate/cover) that compose the physical habitat of species. |

| | |
|---|---|
| **HSC** | Habitat suitability criteria. |
| **Hydrologic region** | A portion of a study region assumed to be hydrologically similar for computing ADF and median monthly flows for project streams. |
| **Habitat duration** | Duration analysis of habitat data of selected time step (e.g., daily or monthly). |

## I

| | |
|---|---|
| **Impact** | Absolute or percentage difference between the amount of habitat available without the withdrawal and the amount available with the withdrawal. |
| **Instream use** | Any use of water that does not require diversion or withdrawal from the natural watercourse. |
| **Instream Flow Incremental Methodology** | A method to quantify the effects of alterations of streamflow on the aquatic ecosystem. |
| **IFIM** | Instream Flow Incremental Methodology. |
| **Inflection point** | Point where the slope of a curve changes. |

## J

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|---|---|
| **Juvenile lifestage** | Immature fish larger than fry; assumed herein to be between 2 and 6 inches long. |

## L

| | |
|---|---|
| **Life stage** | An arbitrary age classification of an organism used in this study to describe adult, juvenile, fry and spawning periods in the life of selected species. |
| **Limestone** | A general term for the class of rocks that contain carbonate minerals (calcium carbonate or magnesium carbonate), as shown by Pa. DER (1990). |
| **Limestone streams** | Streams draining areas underlain by carbonate rocks, defined in this study as streams having total alkalinity greater than 70 mg/l, or identified as limestone streams by Shaffer (1991). |

## M

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|---|---|
| **Median monthly flow** | Median value of all the daily flows during a particular month for some period-of-record. |
| **Median monthly habitat** | Habitat available half the time during a particular month in the record; defined in this study as habitat available at the median monthly flow. |
| **Mesohabitat** | Collective term for different stream habitat types (e.g., riffle, run, pool). |
| **Microhabitat** | Small localized areas within a mesohabitat type, typically described by a combination of depth, velocity, substrate, or cover. |

## N

| | |
|---|---|
| **No-loss of habitat** | No reduction of weighted usable area at any flow. |
| **No-net-loss of habitat** | No reduction in weighted usable area at the median monthly flow. |
| **No-net-loss flow** | The flow that results in no-net-loss of habitat, computed as the smaller of the flow at the maximum renormalized minimum weighted usable area and the median monthly flow. |

## P

| | |
|---|---|
| **Passby flow** | The flow rate below which a withdrawal can not be allowed. |
| **PHABSIM** | Physical Habitat Simulation Program; a set of software and methods used to compute relationships between physical habitat and streamflow. |
| **Physiographic province** | Region with similar structural characteristics and a unified geomorphic history, as described by Fenneman (1938) and delineated by Pa. DER (1989) and Sevon (1995). |
| **Physiographic section** | A subdivision of a physiographic province, as delineated by Pa. DER (1989), Sevon (1995), or Sevon (in preparation). |
| **Pool** | Part of a stream where velocity is reduced, usually with deeper water than surrounding areas. |
| **Preliminary analysis program** | Computer program written in Microsoft Excel format for initial analysis of the impact of combinations of withdrawal and pre-specified passby flows on the flow and habitat of a project stream; see detailed analysis program. |

| | |
|---|---|
| **Protection** | Maintenance or protection of habitat. |

## R

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|---|---|
| **Redd** | A depression in the streambed created by trout or salmon for spawning purposes. |
| **Renormalized minimum weighted usable area** | The amount of weighted usable area available for the most limited life stage at each flow, rescaled to a range of zero to unity. |
| **Reproducing trout stream** | Stream with naturally reproducing trout population(s). |
| **Riffle** | Shallow rapids in a stream where obstructions create waves. |
| **RMWUA** | Renormalized minimum weighted usable area. |
| **Run** | A part of a stream characterized by rapid velocity and few waves over a significant length. |

## S

| | |
|---|---|
| **Season** | Period of time when the same life stages are present. |
| **Segment** | A certain length of a study stream. |
| **Simulation flow** | Any flow rate for which depth, velocity and weighted usable area have been computed. |
| **Spawning life stage** | Life stage defined herein as including redd construction, laying and incubation of eggs, and immature trout up to the time of emergence from the substrate in the spring of the year. |
| **Study region** | A part of a physiographic province or section assumed to have homogeneous topographic, geologic, hydrologic, and habitat characteristics. |
| **Study site** | A representative portion of a study segment selected for detailed data collection and modeling. |
| **Study stream** | A stream selected from lists of trout streams and assumed to be representative of other trout streams in the same study region. |
| **Substrate** | The material on the bottom of the stream channel such as rocks, gravel, or sand. |

**Summer season** Months of July through September, when only adult and juvenile life stages are present.

## T

**Time series** A set of values arranged in chronological order.

**Transect** A vertical cross section taken across the stream.

## U

**Univariate suitability criteria** Habitat suitability criteria that vary continuously over the range from zero to unity.

## W

**Weighted usable area** Unit of measurement of habitat used in Instream Flow Incremental Methodology; the wetted area of a stream weighted by its suitability for use by aquatic organisms or recreational activity (units of square feet per thousand feet of stream).

**Wetted perimeter** The length along the bottom and sides of a stream channel, perpendicular to the flow, that is in contact with the water at a particular flow rate.

**Wetted perimeter method** A method for determining flows that maintain the availability of food based on the relationship of wetted perimeter to flow.

**WUA** Weighted usable area.

**WWTP** Wastewater treatment plant.

*Key to Study Sites Shown on Plate 1*

| Stream Name | Number |
|---|---|
| Bear Run | 1 |
| Big Fill Run, Seg. 1 | 2 |
| Big Fill Run, Seg. 2 | 3 |
| Big Run | 4 |
| Fowler Hollow, Seg. 1 | 6 |
| Fowler Hollow, Seg.2 | 7 |
| Green Creek, Seg. 1 | 9 |
| Green Creek, Seg. 2 | 10 |
| Green Creek, Seg. 3 | 11 |
| Horning Run | 12 |
| Kansas Valley Run | 13 |
| Laurel Run (Juniata) | 15 |
| Mile Run | 16 |
| Mugser Run, Seg. 1 | 17 |
| Mugser Run, Seg.2 | 18 |
| Rapid Run, Seg. 1 | 19 |
| Rapid Run, Seg. 2 | 20 |
| Rapid Run, Seg. 3 | 21 |
| Salem Creek | 22 |
| Sand Spring Run | 23 |
| Swift Run | 24 |
| Vanscoyoc Run | 26 |
| Wapwallopen Creek, Seg. 1 | 27 |
| Wapwallopen Creek, Seg. 2 | 28 |
| Wapwallopen Creek, Seg. 3 | 29 |
| Wapwallopen Creek, Seg. 4 | 30 |
| Antes Creek | 31 |
| Big Spring Creek | 32 |
| Boiling Spring Run | 33 |
| Bushkill Creek, Seg. 1 | 34 |
| Bushkill Creek, Seg. 2 | 35 |
| Cedar Creek (Lehigh) | 36 |
| Cedar Run (Centre) | 37 |
| Cedar Run (Cumberland) | 38 |
| Falling Spring Run | 39 |
| Honey Creek | 40 |
| Letort Creek, Seg. 1 | 41 |
| Letort Creek, Seg. 2 | 42 |
| Lick Creek | 43 |
| Little Fishing Creek | 44 |
| Long Hollow Run | 45 |
| Monocacy Creek, Seg. 1 | 46 |
| Monocacy Creek, Seg. 2 | 47 |
| Monocacy Creek, Seg. 3 | 48 |
| Nancy Run | 49 |
| Penns Creek, Seg. 1 | 50 |
| Penns Creek, Seg. 2 | 51 |
| Penns Creek, Seg. 3 | 52 |
| Potter Creek | 53 |

| Stream Name | Number |
|---|---|
| Spring Creek (Berks) | 54 |
| Spring Creek, Seg. 1 | 55 |
| Spring Creek, Seg. 2 | 56 |
| Spring Creek, Seg. 3 | 57 |
| Spring Creek, Seg. 4 | 58 |
| Trindle Spring Run | 59 |
| Trout Creek | 60 |
| Beech Run | 61 |
| Benner Run | 62 |
| Bloomster Hollow | 63 |
| Cherry Run | 64 |
| Coke Oven Hollow | 65 |
| Cush Creek, Seg. 1 | 66 |
| Cush Creek, Seg. 2 | 67 |
| Dunlap Run | 68 |
| E. Br. Spring Creek, Seg.2 | 70 |
| Fall Creek, Seg. 1 | 71 |
| Fall Creek, Seg. 2 | 72 |
| Findley Run | 73 |
| Lower Two Mile Run, Seg. 1 | 74 |
| Lower Two Mile Run, Seg. 2 | 75 |
| Lyman Run | 76 |
| McClintock Run | 77 |
| McEwen Run | 78 |
| Meyers Run | 79 |
| Mill Run | 80 |
| Red Run | 82 |
| Seaton Run | 83 |
| Strange Hollow | 84 |
| Tannery Hollow | 85 |
| Warner Brook | 86 |
| Whites Creek, Seg. 1 | 88 |
| Whites Creek, Seg. 2 | 89 |
| E. Br. Raven Creek | 90 |
| Granville Run | 91 |
| Laurel Run (Huntingdon) | 92 |
| Baisman Run | 93 |
| Basin Run, Seg. 1 | 94 |
| Basin Run, Seg. 2 | 95 |
| Cooks Branch | 96 |
| First Mine Branch | 97 |
| Gillis Falls, Seg. 1 | 98 |
| Gillis Falls, Seg. 2 | 99 |
| Greene Branch | 100 |
| Norris Run | 101 |
| Piney Run | 102 |
| Third Mine Branch | 103 |
| Timber Run | 104 |