6.0 IMPACT ASSESSMENT METHODS AND RESULTS

6.1 Overview of Impact Analysis

The ultimate objective of this instream flow study is to develop an impact assessment method for determining instream flow protection levels during the review of applications for surface water withdrawals. The method needs to include:

- Procedures to analyze the information to determine the protection level;
- Estimation of the effect of a proposed withdrawal; and
- Determination of the type and level of mitigation required.

To evaluate effects of changes in flow on habitat, a procedure was developed for combining the WUA versus flow relationships for each life stage into a single relationship of habitat to flow. The procedure is described in section 6.3. The resulting habitat variable is called renormalized minimum weighted usable area, or RMWUA.

It was decided to use the median monthly habitat as a measure of the habitat available with the natural flow regime. The rationale for using the median monthly habitat was the assumption that the fishery population had adjusted to the amount of habitat naturally available half the time. The median monthly habitat was considered as a benchmark for measuring the impacts of withdrawals and associated passby flows.

Both no-loss of habitat and no-net-loss of habitat at the median monthly flow were considered as possible criteria for determining the level of flow that would protect the median monthly habitat. Neither criterion specifically considers the impact of withdrawals. The no-loss of habitat criterion was determined to unduly restrict withdrawals (section 6.4). A preliminary study (section 6.5) of the no-net-loss of median monthly habitat criterion showed the criterion also severely restricted water withdrawals. Therefore, procedures were developed to estimate the impact of withdrawals and passby flows over the range of flows in different seasons.

The impact analysis procedures for water withdrawals provide information necessary to make decisions regarding:

- The magnitude of the impact associated with various combinations of withdrawal and passby flow;
- The passby requirement for a proposed withdrawal at a specified location; and
- The percent of time that withdrawals cannot be made because of passby requirements.

6.2 Definition of Median Monthly Habitat

The median monthly habitat can be defined as the median of all daily habitat values for a given month, or as the habitat available at the median monthly flow. Since the relationship between habitat and flow rate is generally nonlinear, it was expected these two definitions would produce different values of the median monthly habitat.

For the first definition, the median monthly habitat has to be derived from a statistical analysis of all the daily habitat values occurring in a given month at each study site. This method of computation requires:

- Estimation of daily flows at every study site;
- Computation of daily habitat values from the daily flows and the flow versus habitat table developed from the HABTAE analysis; and
- Statistical analysis of the daily habitat values to determine the median monthly habitat value.

Considering the amount of work involved in this analysis, and the concern that the two different definitions would produce different values, a pilot study was performed to compare the median monthly habitat for all species and life stages being analyzed, using both methods. The pilot study was performed at the same study sites used in the pilot study described in section 5.8.3.

In all cases, the median monthly habitat computed from the median monthly flow was within 2 percent of the value computed by statistical analysis of the daily habitat time series. Since the results were the same for all 12 sites, the median monthly habitat was defined as the habitat value associated with the median monthly flow in subsequent analyses.

6.3 WUA for Combinations of Life Stages

Analysis of habitat versus flow relationships for multiple fish species and multiple life stages is complex, because of different habitat preferences for different life stages, and the presence or absence of different life stages at particular times of year. The spawning and fry life stages of the study species prefer habitat with low depths and velocities, while adults and juveniles prefer higher depths and velocities. Since the different life stages have different habitat requirements, changes in flow that reduce habitat for one life stage may increase habitat for another life stage. Based on the periodicity chart (Table 3.4), the adult and juvenile life stages are present all year long, but the spawning and fry life stages are present only for about 5 months and 4 months, respectively.

One approach to analyzing habitat for multiple species and life stages is to combine the individual WUA curves for each life stage into a single curve that represents the WUA versus flow relationship for all life stages of a given species, and to use that curve to evaluate changes in WUA resulting from withdrawals. One such method for combining life stages is the maximum of the minimum habitat values at each discharge, as described by Orth and Leonard (1990). This method assumes the life stage with the lowest WUA at a given flow, relative to the maximum habitat for all life stages present at that time of year, is the most habitat-limited, and therefore the most critical life stage to be protected.

Different life stages are present at different times of year (Table 3.4), so combined WUA tables are needed for each possible combination of life stages, i.e., adult/juvenile/fry, adult/juvenile/spawning, and adult/juvenile. A sample computation of the combined WUA curves is shown in Table 6.1

The first step in combining the WUA relationships is to tabulate the WUA data for each life stage and each simulation flow, as shown in the columns headed Weighted Usable Area. Typically, the WUA has different magnitude for different life stages for a given flow. Also, the WUA data show different trends for different life stages. In this example, the WUA for the adult and juvenile life stages increases with increasing flow over the entire range of simulation flows. However, WUA for the spawning life stage has a maximum at a simulation flow of 4.91 cfs, and for the fry life stage, the WUA peaks at a simulation flow of 0.76 cfs.

The second step is to put all the WUA data on a comparable scale, by dividing the WUA for each life stage by the maximum value, shown at the bottom of the table, for that life stage. This results in rescaling all the data to the range from zero to unity, as shown in the columns headed Normalized Weighted Usable Area.

Table 6.1 Example Computation of Combined Habitat, Green Creek, Segment 1, Brook Trout

Drainage area at site: 2.6 square miles
Average daily flow: 4.4 cfs
Annual median flow: 2.5 cfs

Simulated Flow (cfs)	Weighted Usable Area (square feet per thousand feet of stream)				Normalized Weighted Usable Area			
	Adult	**Juvenile**	**Spawning**	**Fry**	**Adult**	**Juvenile**	**Spawning**	**Fry**
0.42	664.72	1,766.67	1,001.39	1,726.70	0.359	0.472	0.571	0.990
0.53	721.55	1,878.57	1,066.90	1,710.23	0.390	0.502	0.608	0.981
0.65	796.02	2,031.52	1,155.62	1,723.81	0.430	0.543	0.659	0.989
0.76	849.33	2,158.53	1,236.56	1,743.60	0.459	0.577	0.705	1.000
0.86	892.00	2,234.56	1,290.77	1,716.47	0.482	0.597	0.736	0.984
0.97	939.83	2,318.00	1,328.13	1,683.01	0.508	0.619	0.757	0.965
1.07	990.77	2,428.81	1,379.91	1,685.53	0.536	0.649	0.786	0.967
1.18	1,018.35	2,496.07	1,412.77	1,662.13	0.551	0.667	0.805	0.953
1.28	1,060.61	2,578.90	1,450.34	1,637.70	0.574	0.689	0.827	0.939
1.80	1,205.83	2,909.19	1,551.68	1,553.12	0.652	0.777	0.884	0.891
2.32	1,336.82	3,175.69	1,635.44	1,511.73	0.723	0.849	0.932	0.867
2.84	1,433.29	3,356.81	1,672.94	1,392.18	0.775	0.897	0.953	0.798
3.10	1,456.89	3,400.47	1,676.07	1,360.04	0.788	0.909	0.955	0.780
3.37	1,505.50	3,484.10	1,692.68	1,329.86	0.814	0.931	0.965	0.763
3.63	1,536.59	3,547.27	1,706.22	1,302.04	0.831	0.948	0.972	0.747
4.91	1,656.49	3,640.53	1,754.76	1,234.77	0.896	0.973	1.000	0.708
6.18	1,740.94	3,680.77	1,693.78	1,203.68	0.942	0.984	0.965	0.690
7.42	1,849.11	3,742.42	1,643.97	1,143.86	1.000	1.000	0.937	0.656
Maximum	**1,849.11**	**3,742.42**	**1,754.76**	**1,743.60**				

Table 6.1. Example Computation of Combined Habitat, Green Creek, Segment 1, Brook Trout —Continued

Simulated	Minimum Normalized Weighted Usable Area			Flow			Renormalized Minimum Weighted Usable Area		
Flow (cfs)	Adult/Juvenile/ Fry	Adult/Juvenile/ Spawning	Adult/ Juvenile	csm	% average daily flow	% annual median	Adult/Juvenile/ Fry	Adult/Juvenile/ Spawning	Adult/ Juvenile
0.42	0.359	0.359	0.359	0.165	9.46	16.67	0.461	0.382	0.359
0.53	0.390	0.390	0.390	0.208	11.94	21.03	0.500	0.414	0.390
0.65	0.430	0.430	0.430	0.255	14.64	25.79	0.552	0.457	0.430
0.76	0.459	0.459	0.459	0.298	17.12	30.16	0.589	0.488	0.459
0.86	0.482	0.482	0.482	0.337	19.37	34.13	0.618	0.512	0.482
0.97	0.508	0.508	0.508	0.380	21.85	38.49	0.652	0.540	0.508
1.07	0.536	0.536	0.536	0.420	24.10	42.46	0.687	0.569	0.536
1.18	0.551	0.551	0.551	0.463	26.58	46.83	0.706	0.585	0.551
1.28	0.574	0.574	0.574	0.502	28.83	50.79	0.735	0.609	0.574
1.80	0.652	0.652	0.652	0.706	40.54	71.43	0.836	0.693	0.652
2.32	0.723	0.723	0.723	0.910	52.25	92.06	0.927	0.768	0.723
2.84	0.775	0.775	0.775	1.114	63.96	112.70	0.994	0.823	0.775
3.10	0.780	0.788	0.788	1.216	69.82	123.02	1.000	0.837	0.788
3.37	0.763	0.814	0.814	1.322	75.90	133.73	0.978	0.865	0.814
3.63	0.747	0.831	0.831	1.424	81.76	144.05	0.957	0.883	0.831
4.91	0.708	0.896	0.896	1.925	110.59	194.84	0.908	0.951	0.896
6.18	0.690	0.942	0.942	2.424	139.19	245.24	0.885	1.000	0.942
7.42	0.656	0.937	1.000	2.910	167.12	294.44	0.841	0.995	1.000
Maximum	**0.780**	**0.942**	**1.000**						

Next, for each combination of life stages, compare the normalized WUA for each simulation flow, across those life stages, and determine the minimum value. Tabulate these minimums, as shown in the columns headed Minimum Normalized Weighted Usable Area, for the appropriate combination of life stages. For the first combination of life stages (adult/juvenile/fry) shown in the example, the normalized WUA for the adult life stage is less than the normalized WUA for the juvenile life stage over the entire range of flows. However, the normalized WUA for the adult life stage is less than the normalized WUA for the fry life stage over the simulation flow range less than 3.1 cfs. Therefore, in this example, the adult life stage is the most limited up to a simulation flow of 3.1 cfs, and the fry life stage is the most limited for greater flows. The minimum normalized WUA values are equal to the normalized adult values over the range of simulation flows less than 3.1 cfs, and are equal to the nomalized fry values for higher flows. A similar process is used to compute minimum normalized WUA for the combined adult, juvenile, and spawning life stages, and for combined adult and juvenile life stages, with the results shown in the corresponding columns of the table.

The next step is to renormalize the minimum normalized WUA values to span the range from zero to unity. First find the maximum value for each combination of life stages (column), and tabulate as shown at the bottom of the column. Then divide the minimum normalized WUA in each column by the maximum value in the column, and tabulate as shown in the last three columns of the table. The result is called the RMWUA. Finally, the simulated flows are converted to unit values (csm), percent ADF, and percent annual median flow, as shown in the columns headed Flow.

The computation of the combined life stages were made for brook trout, brown trout, and combined brook trout and brown trout at each of the 97 study sites.

6.4 Habitat Loss Criteria

Two 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 WUA, using the appropriate relationships for WUA versus flow. No-net-loss of habitat was defined as no reduction of WUA at the median monthly flow. A given quantity of habitat was assumed to have the same value for every life stage.

The WUA versus flow relationships have different shapes, as illustrated in Figure 6.1. These curves can be classified as follows:

- Class 1: WUA always increasing with increasing flows;
- Class 2: WUA always decreasing with increasing flows;
- Class 3: WUA rising and then declining; and
- Class 4: Constant WUA with increasing flow.

The difference between no-loss and no-net-loss criteria depends on the type of curve. For class 2 and class 4, there are no differences between the two types of criteria. For the other two classes, the difference between habitat loss criteria depends on the relative magnitude of the flow corresponding to the peak of the curve (Q_p), the median monthly flow (Q_M), and the flow actually occurring at any given time (Q_A). Four different combinations of Q_p, Q_M, and Q_A, and the amount of flow that can be withdrawn for each criterion for each case are shown in Figure 6.2. (Some combinations are not shown.)

The no-loss of habitat criterion allows withdrawals at a given flow only if the amount of habitat increases or remains the same with decreased flow. The no-net-loss of median monthly habitat criterion allows withdrawals if the habitat does not decline below that which is present at the median monthly flow.

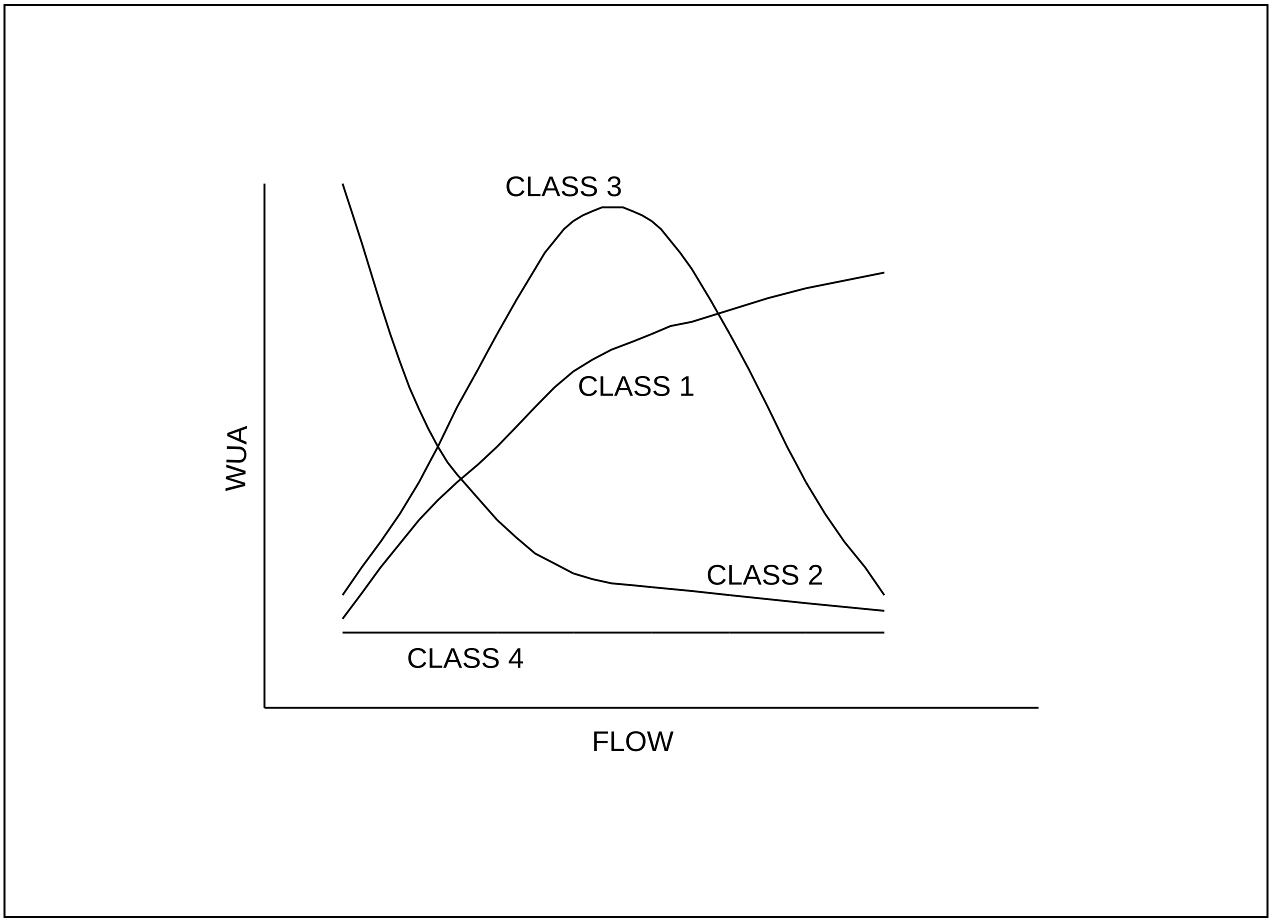

Figure 6.1.   Typical Shapes of Weighted Usable Area Versus Flow Relationships

If the actual flow and the median monthly flow both exceed the flow at the peak of the WUA curve (Figure 6.2, cases 3A and 3B), the no-loss of habitat criterion allows withdrawals to the flow less than Q_P, which has the same habitat as the actual flow; the no-net-loss-of median monthly habitat criterion allows withdrawals to the flow less than Q_P, which has the same amount of habitat as the median monthly flow. If the actual flow and the median monthly flow are both less than the flow at the peak of the WUA curve (Figure 6.2, cases 3C and 3D), the no-loss of habitat criterion allows no withdrawal, but the no-net-loss of median monthly habitat criterion allows withdrawals to the median monthly flow. Thus, the no-loss criterion restricts withdrawals at higher flows than the no-net-loss of median monthly habitat in cases 3A and 3C, and allows withdrawals to a lower flow only in case 3B.

The no-net-loss of habitat criterion was used because the median monthly habitat is considered the appropriate measure of the amount of habitat typically available. The no-net-loss criterion was further examined, as discussed in section 6.5. The no-loss criterion was not used because it 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.

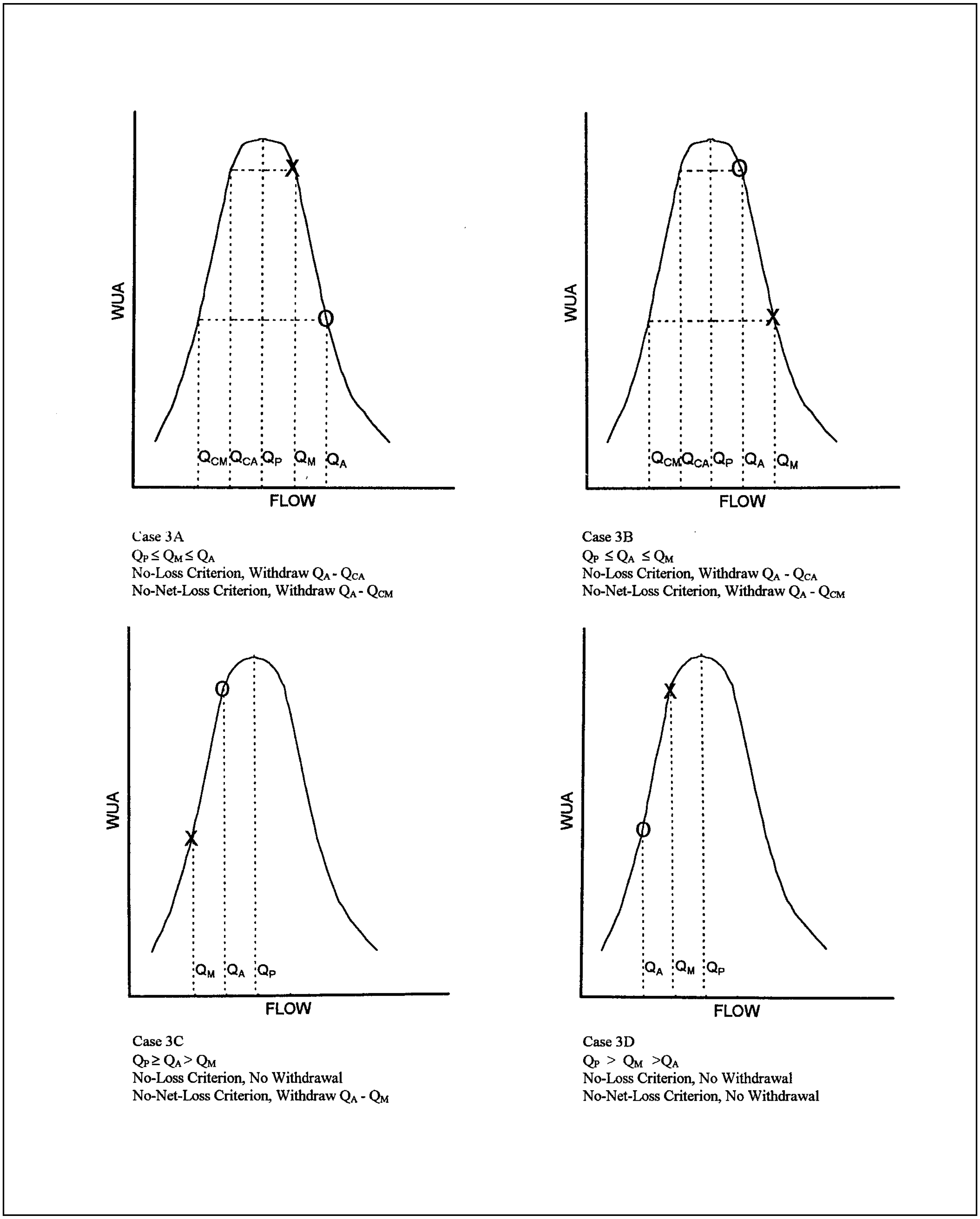

Figure 6.2. Illustration of Effects of Different Habitat Loss Criteria on Withdrawals for Different Flow Relationships

6.5 Evaluation of No-Net-Loss Criterion

Utilizing the procedure for combining habitat values for different life stages (section 6.3), the no-net-loss flow is equal to the smaller of the median monthly flow, or, if the median monthly flow exceeds the flow at the peak of the RMWUA curve, the flow less than the peak at the same RMWUA.

The no-net-loss flow was computed for brook and brown trout, for the summer season (adult and juvenile life stages), for 11 randomly-selected study sites. The flow corresponding to the maximum RMWUA was tabulated for each month. This peak RMWUA flow was then compared to the median monthly flow at the study site to determine the no-net-loss flow. The results of this analysis are summarized in Table 6.2.

In the 66 situations that were analyzed (11 streams x 3 months x 2 species), the no-net-loss flow was equivalent to the median monthly flow, except for brook trout for Monocacy Creek Segment 3. For that stream, the no-net-loss flow could not be determined, because the lowest flow simulated was not low enough to allow interpolation for the habitat at a flow less than the flow at the maximum RMWUA (Q_{CM} in Figure 6.2, case 3B).

This test of the no-net-loss of habitat criterion showed the peak RMWUA flow was greater than the median monthly flow for the summer months, for most streams (Figure 6.2, case 3D). That result implies the ability to withdraw water would be severely limited for that season.

This initial application of the no-net-loss of habitat procedure suggested more detailed procedures were needed to assess the impact of water withdrawals. These procedures will be described in sections 6.6.2 and 6.6.4.

6.6 Impact Analysis

6.6.1 Impact analysis concepts

The purpose of the impact analysis is to determine the magnitude of impact of withdrawals and passby flows on habitat, over the full range of flows and passbys, and to use that information to establish criteria for passby flows. Passby flow is defined as the flow rate below which no water withdrawal may be taken. The impact is defined as the percentage difference between habitat available without the withdrawal and habitat available with the withdrawal and passby in place. A percent reduction in habitat can be compared to an acceptable level.

As described previously, RMWUA versus flow relationships have been developed for study sites on study streams randomly selected to be representative of all the streams within each segment class of streams evaluated in each study area. Reproducing trout streams were classified by study region and segment number.

For each study stream, RMWUA represents a measure of the habitat available at a given flow relative to the peak habitat available over the entire range of possible flows on that stream. It can be used to compare relative habitat values between streams that may vary significantly, in terms of absolute size or absolute amount of habitat. For that reason, it was used as the measure of habitat in the impact analyses.

Table 6.2. Comparison of Median Monthly Flows, No-Net-Loss Flows, and Flow at Maximum Renormalized Minimum Weighted Usable Area for Adult/Juvenile Brook Trout

Stream Name	Flow at Peak of A/J RMWUA Curve	July		August		September	
		Median Monthly Flow	No-Net-Loss Flow	Median Monthly Flow	No-Net-Loss Flow	Median Monthly Flow	No-Net-Loss Flow
	cfs						
R&V Limestone							
Bushkill Creek–Seg. 2	152.4	48.1	48.1	46.3	46.3	41.3	41.3
Cedar Run (Cumb)	9.6	4.6	4.6	4.2	4.2	3.2	3.2
Monocacy Creek–Seg. 3	20.8	31.8	—	30.3	—	26.9	—
Spring Creek (Centre)–Seg. 1	44.6	17.8	17.8	15.1	15.1	14.2	14.2
R&V Freestone							
Fowler Hollow Run–Seg. 2	6.8	1.7	1.7	1.2	1.2	1.0	1.0
Green Creek–Seg. 3	43.9	14.8	14.8	11.2	11.2	9.8	9.8
Mile Run	4.4	0.9	0.9	0.6	0.6	0.6	0.6
Unglaciated Plateau							
Bloomster Hollow	1.8	0.7	0.7	0.5	0.5	0.5	0.5
Cherry Run	10.7	1.8	1.8	1.3	1.3	1.1	1.1
Fall Creek–Seg. 2	24.1	2.5	2.5	2.0	2.0	1.6	1.6
E. Br. Spring Creek	36.1	33.0	33.0	24.0	24.0	21.0	21.0

Impact analysis can be performed using either flow and habitat time series or flow and habitat duration analysis to evaluate effects of the withdrawal on the available habitat (Bovee, 1982). A time series is simply a record of any variable of interest such as flow or habitat in chronological order. Duration analysis generally involves ranking the appropriate variable (e.g., flow or habitat) in order of magnitude, and then determining the probability of exceedance of that variable. Habitat duration can be determined either by ranking habitat values for probability analysis, or by converting ranked flow values to habitat and assigning the probability of the flow values to the habitat values. The latter method will be called associated habitat duration analysis in this report. Because the habitat available at any time is related to the flow value at that time, the probability of that flow also is the probability of the associated habitat. Both methods of evaluating impact are described in the following sections.

The impact analyses are performed on a monthly, seasonal, or annual basis. Seasons are defined by changes in trout life stage combinations during the year, as shown in the periodicity chart (Table 3.4). Thus, spring (adult, juvenile, and fry life stages) is defined as March, April, May, and June; summer (adult and juvenile life stages) is defined as July, August, and September; and fall/winter (adult, juvenile, and spawning/incubation life stages) is defined as October, November, December, January, and February.

6.6.2 Flow and habitat time series impact analysis

6.6.2.1 General discussion

The following method was developed to utilize the RMWUA versus flow relationships for the study streams to estimate the impact of withdrawals and passby flows on habitat for any other stream in the same class of streams, for which a withdrawal is proposed. Streams from which withdrawals are proposed will be called "project streams."

Time series analysis of flows can use any time step such as the flow recorded every hour, or median or average flows during each month or year. This method uses a monthly time step and median monthly flows. A monthly time step represents a reasonable level of effort from an analytical and practical standpoint, and median flows are typically considered the best measure of central tendency in flow analyses.

The first step in this method is to develop ADF and time series of median monthly flows for a selected period of record for the project stream. These flows should be derived from the flow records at a nearby stream gage. A method for developing median monthly flows for ungaged locations within the Ridge and Valley Freestone, Ridge and Valley Limestone, and Unglaciated Plateau study regions is described in section 6.6.3.

Once the median monthly flow time series has been determined, a set of RMWUA time series is developed, using the RMWUA versus flow relationships (section 6.3**)** for each of the study streams in a class. The time series of median monthly habitat for the project stream is developed by averaging the median monthly habitat values for the study streams in the appropriate segment class.

Although the programs were developed using median monthly flows, other flow statistics and/or time steps can also be used. For example, minimum monthly flow time series, or up to 2.5 years of daily flow time series can be evaluated.

Two closely-related computer programs were written in Microsoft Excel 7.0 spreadsheet format to estimate impacts of withdrawals. The first program, called the "detailed analysis program," estimates the effect of any combination of withdrawal and passby flow on the flow and habitat of a project stream, and presents these effects in several different ways. The second program, called the "preliminary analysis program," was designed to provide general estimates of impacts from a proposed withdrawal, while reducing the run time necessary to analyze the same number of passby flows with the detailed analysis program. The outputs from the preliminary analysis program are less detailed than those of the detailed analysis program**.** The two programs are described and compared further in the following sections.

The detailed and preliminary analysis programs can be used for the Unglaciated Appalachian Plateau, the Ridge and Valley Limestone, and the Ridge and Valley Freestone study regions. The programs cannot be used for the Piedmont Upland region because field data has been collected for only 12 of the 30 segments considered necessary to provide an appropriate level of accuracy for this region. The RMWUA versus flow data for these 12 sites have been entered into the program.

For the regions that have been completed, both programs can analyze the following cases: wild brook, brown, or combined trout; stocked adult brook, brown, or combined trout; and stocked fingerling brook, brown, or combined trout. The main difference between wild, stocked adult, and stocked fingerling cases is that different life stages are used in the various habitat analyses. For wild trout, all life stages present in a given season are included in the analyses. For stocked adult trout, only the adult life stage is considered for the entire year. For stocked fingerling trout, only the adult and juvenile life stages are included for all seasons.

The time series analysis programs, at present, address only diversions of water from a stream. The program does not address changes in natural flows caused by releases from instream reservoirs, at this time. A reservoir operations model would have to be linked to this program to make such analyses possible. It is recommended this be the next step in development of the computer program.

Detailed descriptions of computations and procedures for use of detailed and preliminary analysis programs are given in Appendix E.

6.6.2.2 The detailed analysis program

The ADF and a table of median monthly flows for each year in the available flow record is developed for the project stream, using the regional hydrology method discussed in section 6.6.3. These flows are expected to occur on the stream under existing conditions, unimpacted by the proposed withdrawal. The program converts the flow values to percent ADF to make comparisons of flow and habitat among streams possible. Then the unimpacted flows from the project stream are used to develop time series of unimpacted habitat for each study stream by using the flow time series for the project stream and RMWUA versus flow relationships for each study stream.

The proposed withdrawal from the project stream and a proposed passby flow are then entered into the Excel program. Both the withdrawals and the passby flows can vary seasonally. The unimpacted flow time series is adjusted by the program to produce a time series of impacted flows, and corresponding tables of habitat are developed for the study streams. The flow and habitat available for unimpacted and impacted conditions are compared to determine the absolute and percentage change in flow and habitat.

After the tables of monthly unimpacted and impacted RMWUA values have been developed, the corresponding monthly habitat values from the tables are averaged for each condition. Because the use of RMWUA as the measure of habitat allows comparison of habitat available across different streams, habitat versus flow relationships for each study stream are weighted equally to develop average habitat estimates for a class of streams. Summary statistics such as average monthly, seasonal, or annual RMWUA and flow values are calculated from the tables for each condition, and confidence intervals (95 percent) for the summary statistics derived. In addition to these measures of flow and habitat, the program develops duration analyses of both median monthly flow and RMWUA for both the unimpacted and impacted conditions. These analyses are presented in both tabular and graphical form. The summary statistics and the duration analyses are compared to determine the impact of the withdrawal. These comparisons can be made on a monthly, seasonal, or annual basis.

The computer program is described in more detail in Appendix E.

6.6.2.3 The preliminary analysis program

The preliminary analysis program also uses the median monthly flow time series for the study site, but it does not require the entry of passby flows. During each run, it automatically computes the habitat values that result from a range of possible passby flows between 0 and 60 percent ADF, at 5 percent increments. The passby flows are held constant throughout the year, rather than varying seasonally, as in the detailed analysis program. Impacts are expressed in terms of percent change in average seasonal and average annual RMWUA, and absolute and percentage change in median seasonal and median annual RMWUA.

The output from the preliminary analysis program does not provide any comparisons of flow, monthly RMWUA, confidence intervals, or duration analyses, as does the detailed analysis program.

Also, the preliminary analysis program uses a different algorithm than the detailed analysis program to estimate impacts to seasonal average and median RMWUA. The differences are explained in Appendix E. Consequently, the results will be similar, but probably not identical, for the two programs.

The results of the preliminary analysis program are simply meant as a general overview of impacts, and can serve as a starting point for more complete analyses using the detailed analysis program.

6.6.2.4 Habitat impact curves: development

The detailed analysis program has been used to develop sets of habitat impact curves for the Unglaciated Plateau, Ridge and Valley Freestone and Ridge and Valley Limestone study regions.

The detailed analysis program computes impact of a given withdrawal and passby for each median monthly flow value for the period of record, and calculates various measures of habitat impact, including maximum, average annual, and 90 percent probability of exceedance. The relationships between these three measures of impact are shown in Figure 6.3. The median monthly flow duration plots, with and without the withdrawal, are illustrated in Figure 6.3A. Note that the maximum impact in percent flow reduction occurs when the natural flow is equal to the sum of the passby flow plus the withdrawal. At this flow level, the reduction in habitat also is the greatest. As natural flows decrease from the maximum impact flow, withdrawals are reduced to maintain the passby flow. When flows become less than the passby flow, no withdrawals may be made; therefore, no impacts to flow or habitat occur at flows less than the passby flow. For natural flows greater than the flow at maximum impact, the impacts to habitat generally decrease, until at some higher flow, the withdrawals produce

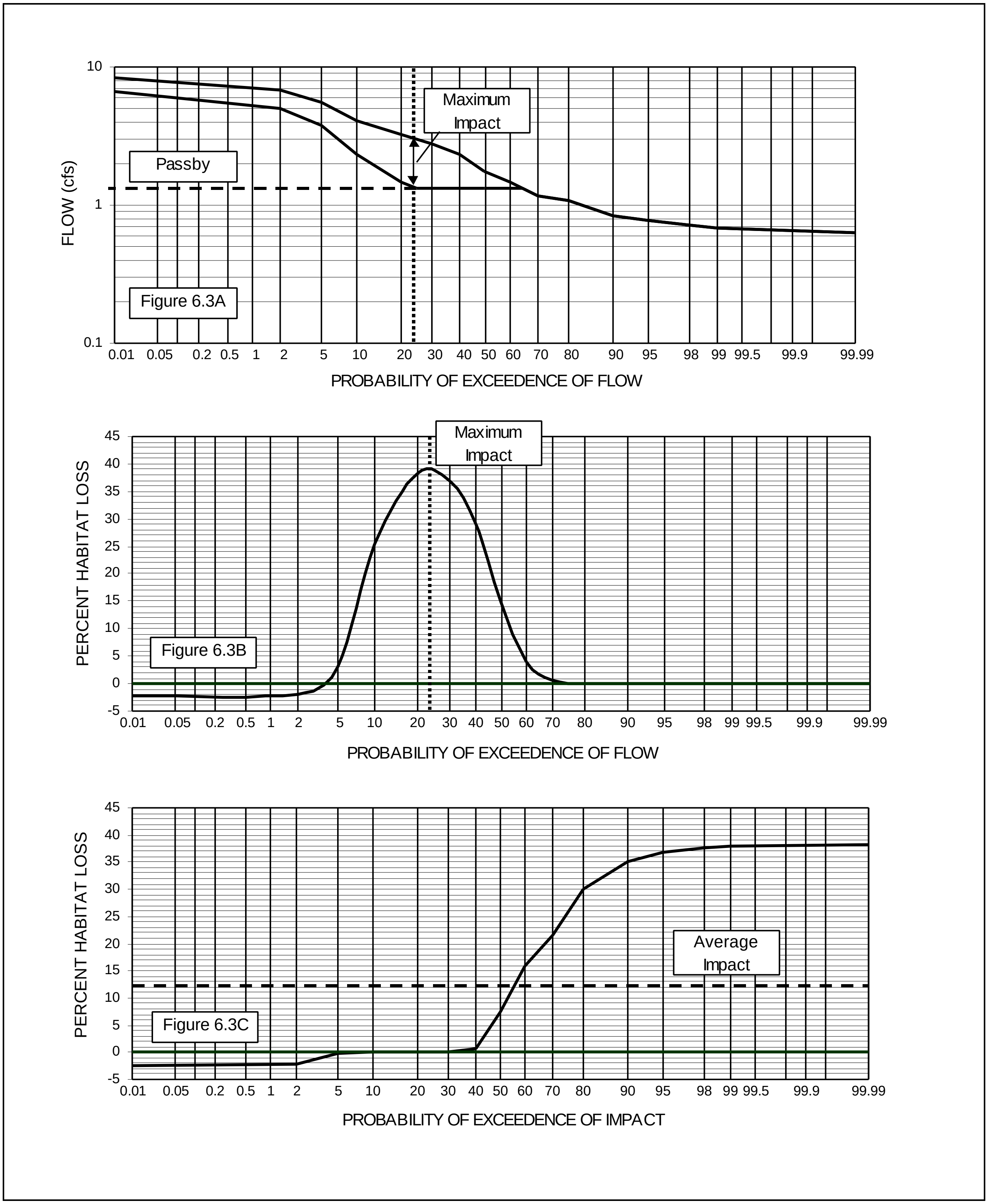

Figure 6.3. Illustrations of Impact on Flow and Habitat at Green Creek, Ridge and Valley Freestone Region (NOTE: Results depict impacts for a 40 percent withdrawal and a 30 percent passby.)

depths and velocities that improve fish habitat. These habitat impacts are illustrated as a percent loss in habitat on the same probability scale in Figure 6.3B. Habitat gains are shown as negative habitat losses.

If all of the habitat impacts in Figure 6.3B are ranked from highest to lowest, the habitat impact duration curve will have the general shape shown in Figure 6.3C. The maximum impact always occurs at the 100 percent probability level, but also may occur at lower probabilities. In the example, the maximum impact (38 percent reduction) occurs over the range from 98 to 100 percent probability. The 90 percent impact is the impact that is exceeded 90 percent of the time (35 percent habitat reduction). The average impact is simply the algebraic average of all the individual values.

The purpose of instream flow protection is to protect fish populations against significant short-term and long-term impacts of a withdrawal. The various impact values between average and 100 percent probability of exceedance could be used to evaluate the full range of withdrawals and passby combinations. The average impact value gives a measure of the long-term impact of the withdrawal, while the maximum impact measure defines the worst possible impact in a short-term period. In the absence of a passby flow, the maximum impact measure defines the fishery impacts in the worst year of record. For withdrawals less than the lowest flow on record, the maximum impact generally occurs very infrequently. As withdrawals increase, passby flows become essential as the withdrawal approaches the record low flow. When the withdrawal equals or exceeds the record low flow, the impact approaches 100 percent, and may occur fairly frequently depending on the magnitude of the withdrawal. Such a large impact is considered unacceptable. Passby flow protection is required before that occurs, and low flows are fully protected at both the median and daily low flow levels. The introduction of a passby flow reduces the maximum impact substantially and shifts its probability of occurrence to a more frequent flow level.

Three measures of impact were examined more closely, the maximum, average, and the 90 percent probability of exceedance. The average impacts were felt to be useful because they showed the long-term impacts to the fishery habitat, provided there is sufficient passby flow protection to guard against severe short-term habitat losses. The maximum impact curves likewise are important because they depict the worst possible short-term impacts.

In considering maximum habitat impacts, the fact that median monthly flows were used becomes a concern, since 50 percent of the flow values in a month are less than the median. The flow duration curves for median monthly flows and daily flows are almost identical between the 5 percent and 95 percent exceedance levels. Therefore, the concern for maximum impacts will be eliminated if the passby flow is selected to protect median monthly flows at approximately the 95 percent probability of exceedance level, as shown in Figure 6.3A. Flows greater than 5 percent probability can be considered flood flows, and flows less than 95 percent probability can be considered drought flows.

The detailed analysis program was run repeatedly for 27 combinations of withdrawal and passby flows (e.g., 10 percent ADF withdrawal and 5 percent ADF passby). The average annual impacts were determined for each representative stream gage in the region. The maximum, minimum, and average values across streams were tabulated. For example, in the Ridge and Valley Freestone region, six gages were used to represent the hydrology of the 21 segment class 1 sites. Therefore, six streams were chosen to represent the six contributing gages, and the withdrawal/passby combinations were run for only those six streams, rather than all 21. The study streams used in the impact analysis are shown in Table 6.3. The model was run using the hydrology for each of the six streams. The average annual impacts from the six representative streams were averaged and tabulated along with the maximum and minimum values of the average impacts across the six representative streams.

Table 6.3. Study Streams Used in Habitat Impact Analysis

Region	Gage	Representative Study Stream	Segment 1	Segment 2	Segment 3	Segment 4
Ridge and Valley Limestone Group 1	Letort Spring Run near Carlisle	Letort Spring Run	X	X		
	Spring Creek at Houserville	Spring Creek	X	X	X	X
		Penns Creek	X	X	X	
	Yellow Breeches Cr. near Camp Hill	Cedar Creek, Cumberland Co.	X			
Ridge and Valley Limestone Group 2	Bixler Run near Loysville	Long Hollow Run	X			
	Kishacoquillas Creek at Reedsville	Honey Creek	X			
	Monocacy Creek at Bethlehem	Monocacy Creek	X	X	X	X
		Bushkill Creek		X		
Ridge and Valley Freestone	Wapwallopen Cr. near Wapwallopen	Wapwallopen Creek	X	X	X	X
		Mugser Run		X		
	Fishing Creek near Bloomsburg	Green Creek	X	X	X	
	Sherman Creek at Shermans Dale	Big Run	X			
		Fowler Hollow		X		
	Sand Spring Run near White Deer	Sand Spring Run	X			
		Rapid Run		X	X	
	Bald Eagle Creek at Tyrone	Big Fill Run	X	X		
	Aughwick Creek near Three Springs	Laurel Run, Huntingdon Co.	X			
Unglaciated Plateau	W. Branch Susquehanna R. at Bower	Dunlap Run	X			
		Cush Creek		X		
	Laurel Hill Creek at Ursina	Whites Creek	X	X		
		Falls Creek		X		
	Mahoning Creek at Punxsutawney	Beech Run	X			
	S. Fork Beech Creek near Snow Shoe	Benner Run	X			
	Oil Creek at Rouseville	Lower Two Mile Run	X	X		
	Potato Creek at Smethport	Strange Hollow	X			
	Blacklick Creek at Josephine	Findley Run	X			
	W. Branch Clarion River at Wilcox	Cherry Run	X			
		E. Branch Spring Creek Segment 2		X		
	Driftwood Branch Sinnemahoning Creek at Sterling Run	Tannery Hollow	X			

The mean impact percentages, for each combination of withdrawal, and passby flow, were used to plot curves of constant impact such as a curve where there is a constant habitat loss of 25 percent. These curves of constant habitat impacts were developed for each segment in all three study regions, and have been developed for the average annual impact measure for all three study regions, and for the maximum impact measure for the Ridge and Valley Freestone study region.

6.6.2.5 Habitat impact curves: results and discussion

Ten different constant impact curves based on the average impact measure are shown in Figure 6.4 through 6.13. All life stages present in a given season were used in this analysis so these curves apply only to the wild trout cases (section 6.6.2.1). There are two curves for the Ridge and Valley Freestone study region, four for the Ridge and Valley Limestone study region, and four for the Unglaciated Plateau study region. In these graphs, for a constant level of withdrawal, the impact increases from right to left.

For the Ridge and Valley Freestone study region, the curves for segment classes 1, 2 and 3, for each level of impact, were close to each other. For a given level of impact, the range of passby flows for different segments was always within about +/- 4 percent ADF. Therefore, those curves were averaged, and the average curve for each level of impact is shown in Figures 6.3 and 6.4. The constant impact curve for segment class 4 sites plots to the left of the corresponding curves for segments 1 through 3. However, the segment class 4 curve is based on only 1 site, Wapwallopen Creek (Table 6.3). Because of the small number of study sites, the constant habitat impact curves for segment class 4 sites are not shown.

Habitat impact plots for all the Ridge and Valley Limestone study streams showed significant scatter for different study streams. For withdrawals less than about 20 percent ADF, streams with more than 50 percent limestone showed little or no change in impact to RMWUA with increasing passby flows. Streams with less than 50 percent limestone showed decreasing percentage reductions in habitat with increasing passby flow over essentially the entire range of passby flows and withdrawals. Therefore, each representative study site was classified according to whether the part of the watershed underlain by limestone is greater or less than 50 percent. In the first case, the base flows are relatively high, and the withdrawal has little impact up to about 20 percent ADF withdrawal, and passby flows have little effect within that range. For the second case, the base flows are relatively low, so that low levels of withdrawal cause impacts on habitat for those study sites.

For study sites included in the first group, the constant habitat impact curves for segment class 2 and 3 sites are much higher (shifted to the left) than either the segment class 1 or 4 curves. The constant impact curves for sites included in the second group showed similar, but less extreme, behavior. This erratic behavior is believed to be due to a combination of hydrology and small sample size for segment class 2, 3, and 4 study sites. Several of these streams have higher flows per unit area or as a percentage of ADF in segment 2 or segment 3 compared to segment 1, because of springs, underflow, or WWTP return flows. As shown in Table 6.3, there are only a few segment class 2 and segment class 3 sites in each subregion included in the impact analysis, and there is only one segment class 4 site (Spring Creek, Centre County). Also, the Honey Creek study site is classified as segment class 1 because it is a short distance downstream from the upstream limit of the limestone rock. However, it is probably not a typical segment class 1 site, because there is a large watershed (about 90 square miles) upstream of the site, most of which is underlain by freestone.

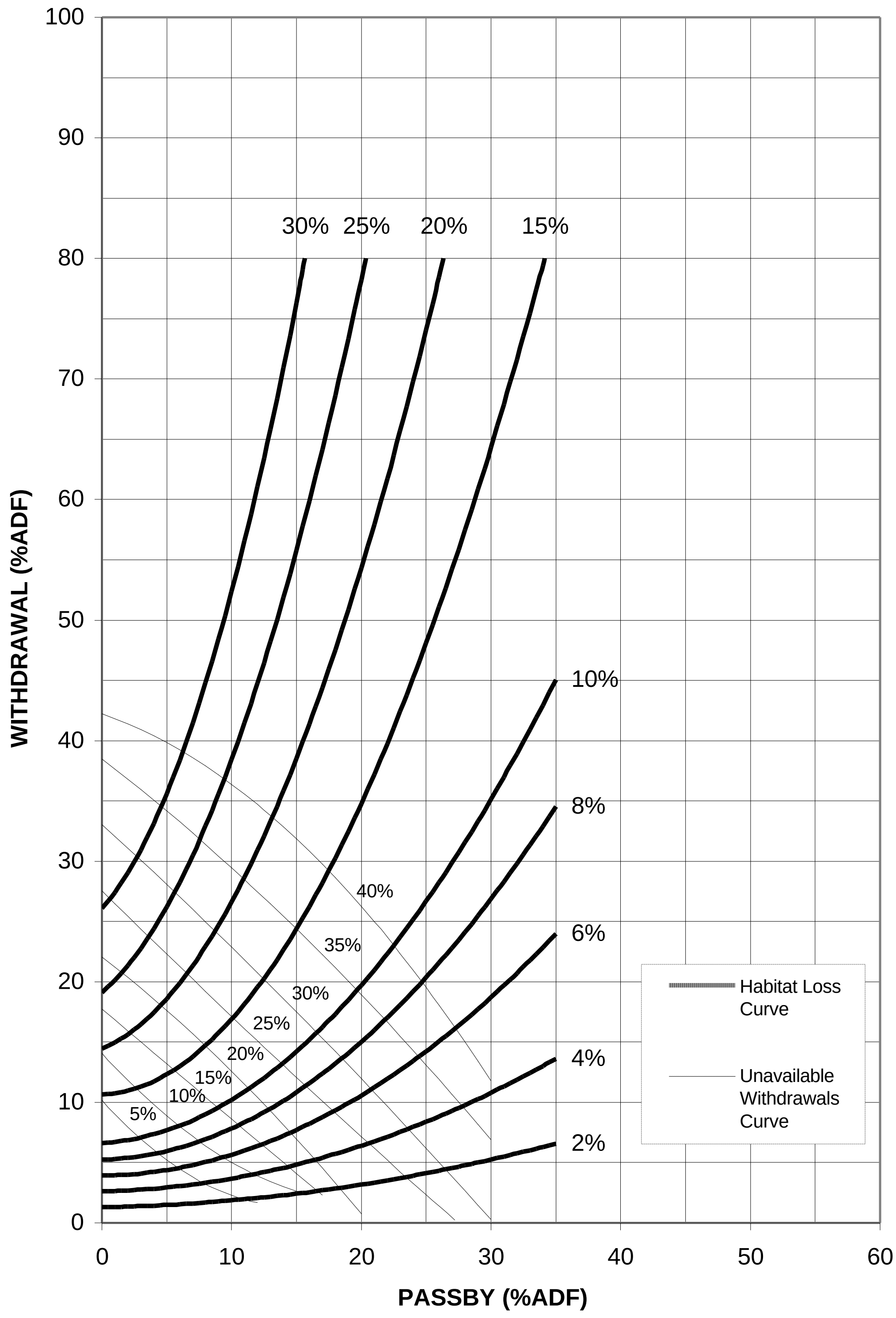

Figure 6.4. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Freestone, Wild Brown and Combined Species

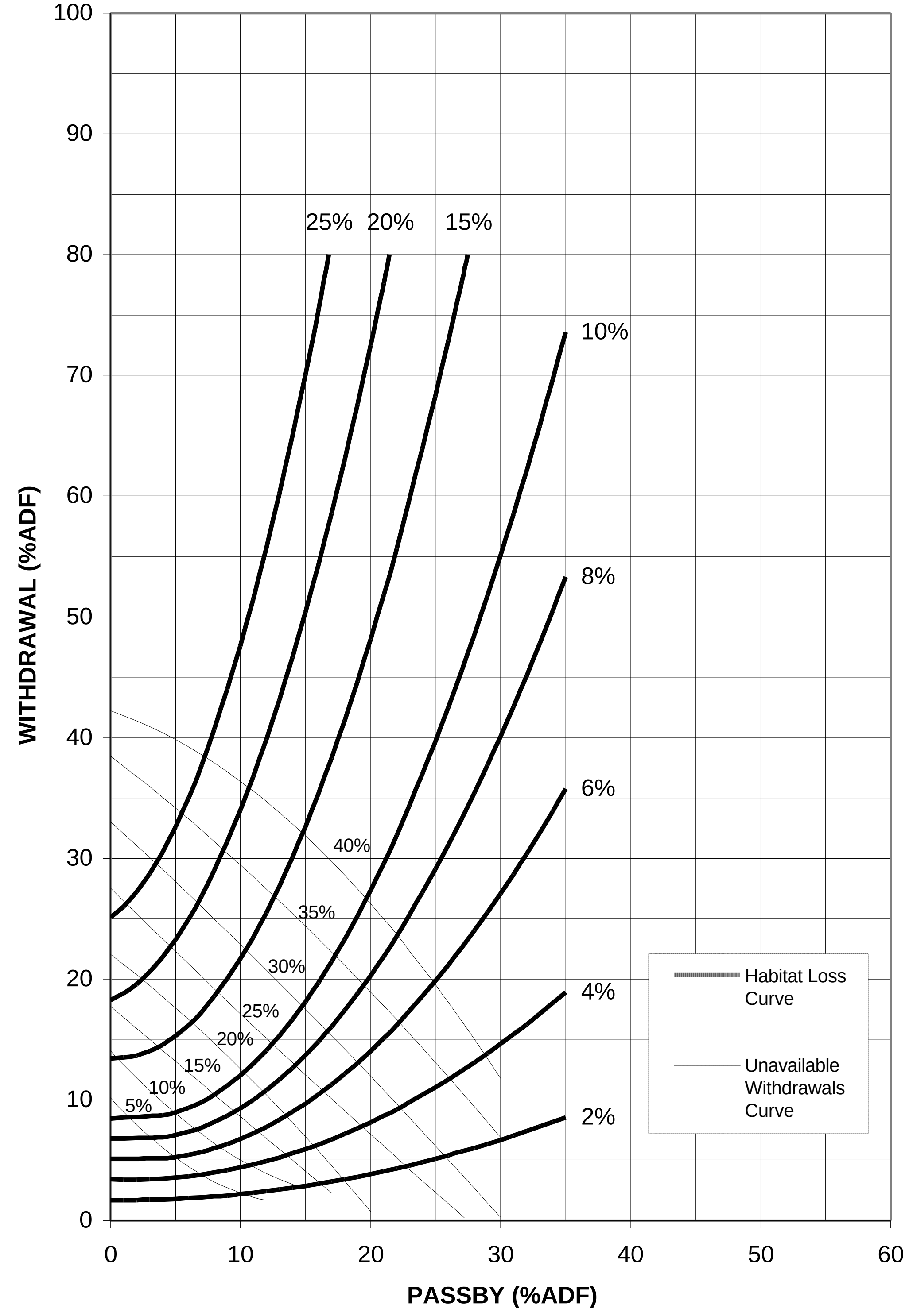

Figure 6.5. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Freestone, Wild Brook Trout

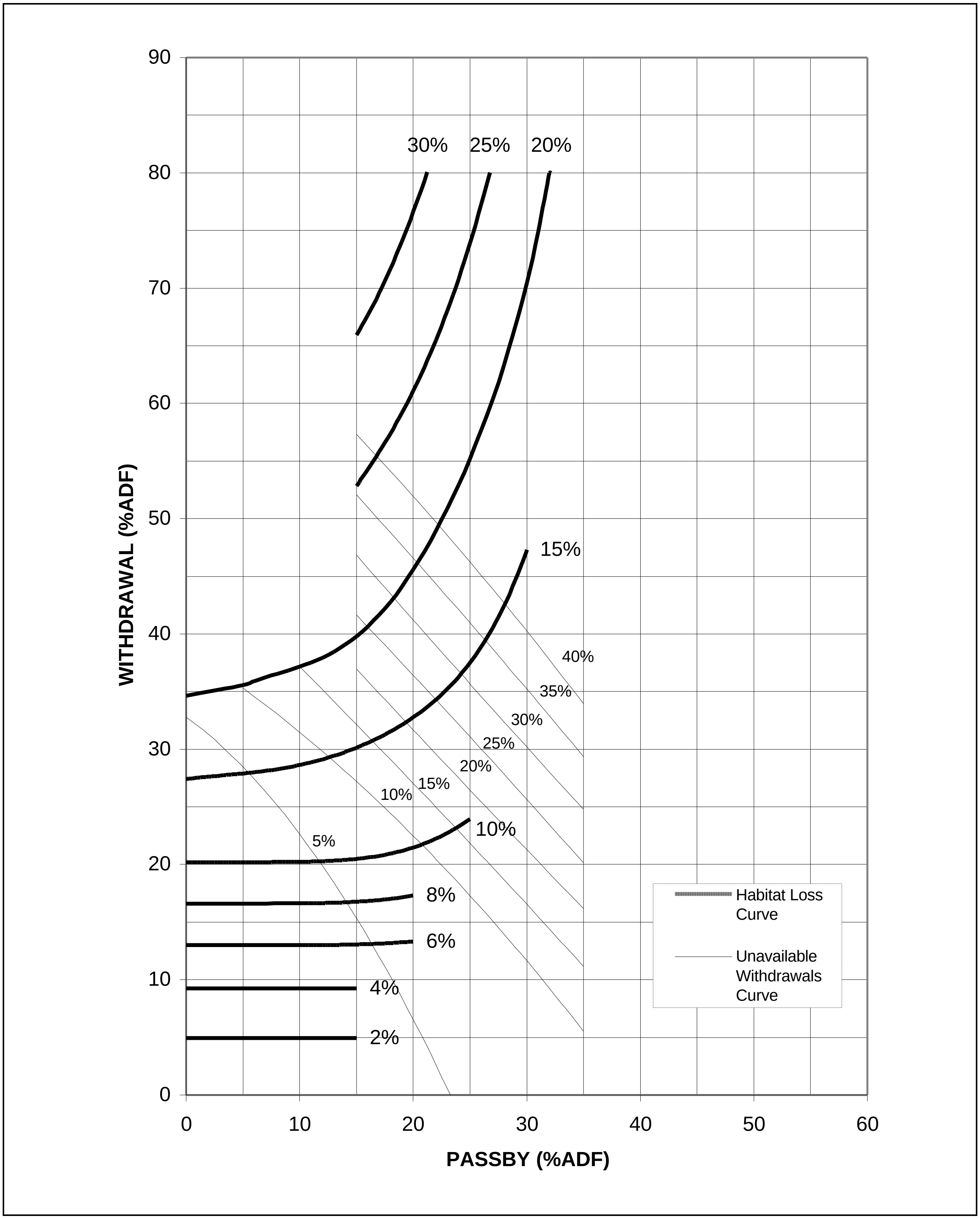

Figure 6.6. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 1, Wild Brown and Combined Species

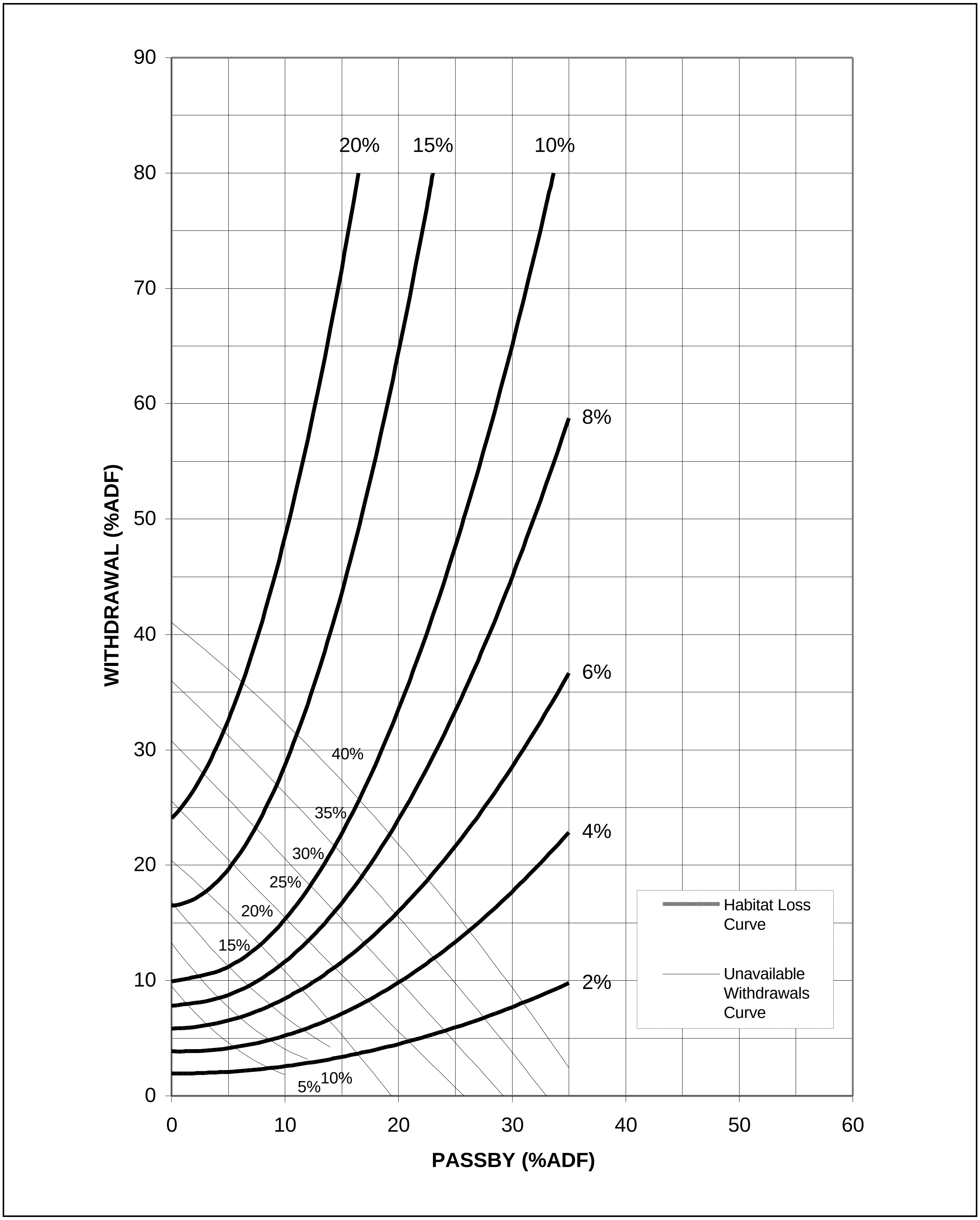

Figure 6.7. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 2, Wild Brown and Combined Species

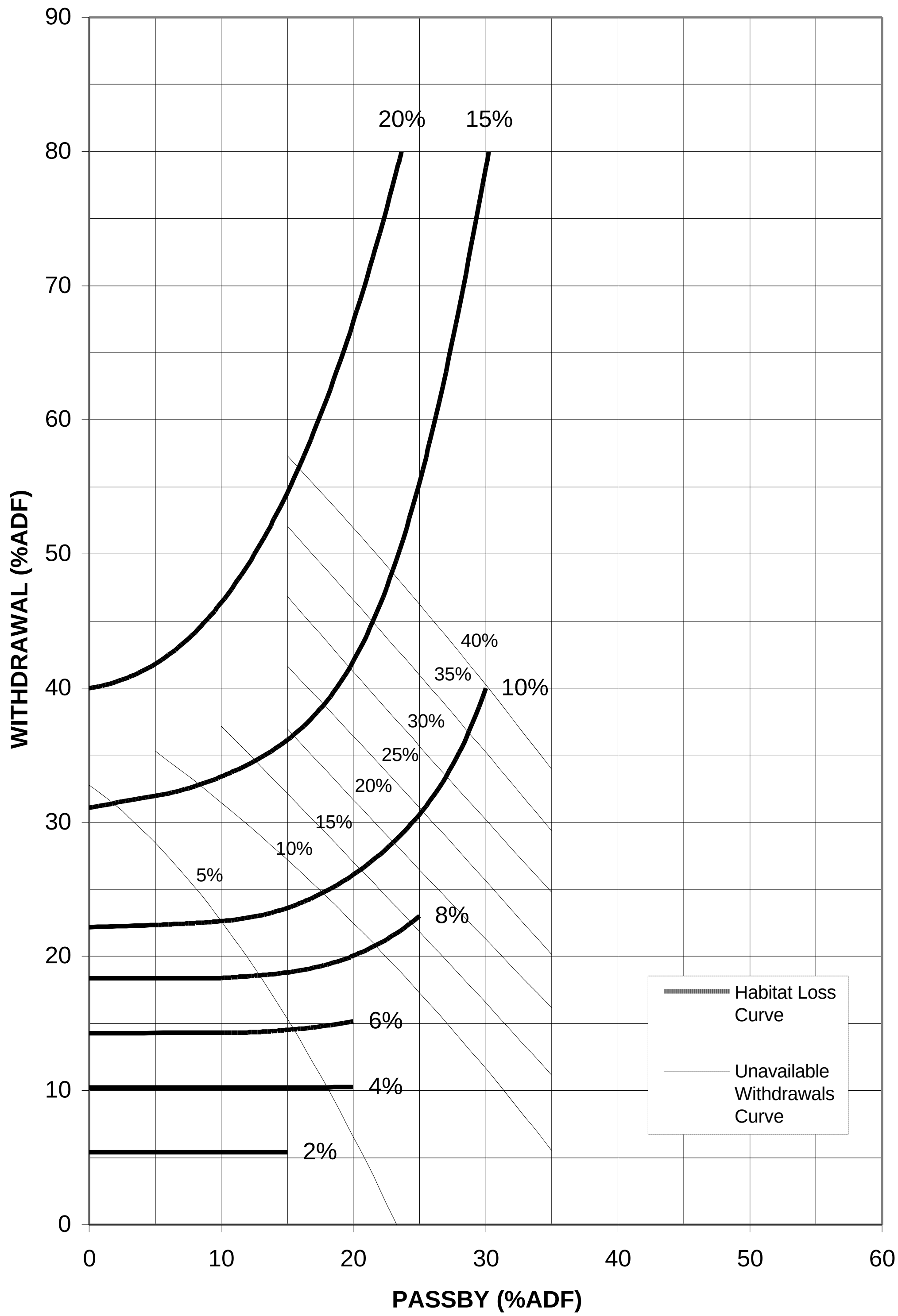

Figure 6.8. Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 1, Wild Brook Trout

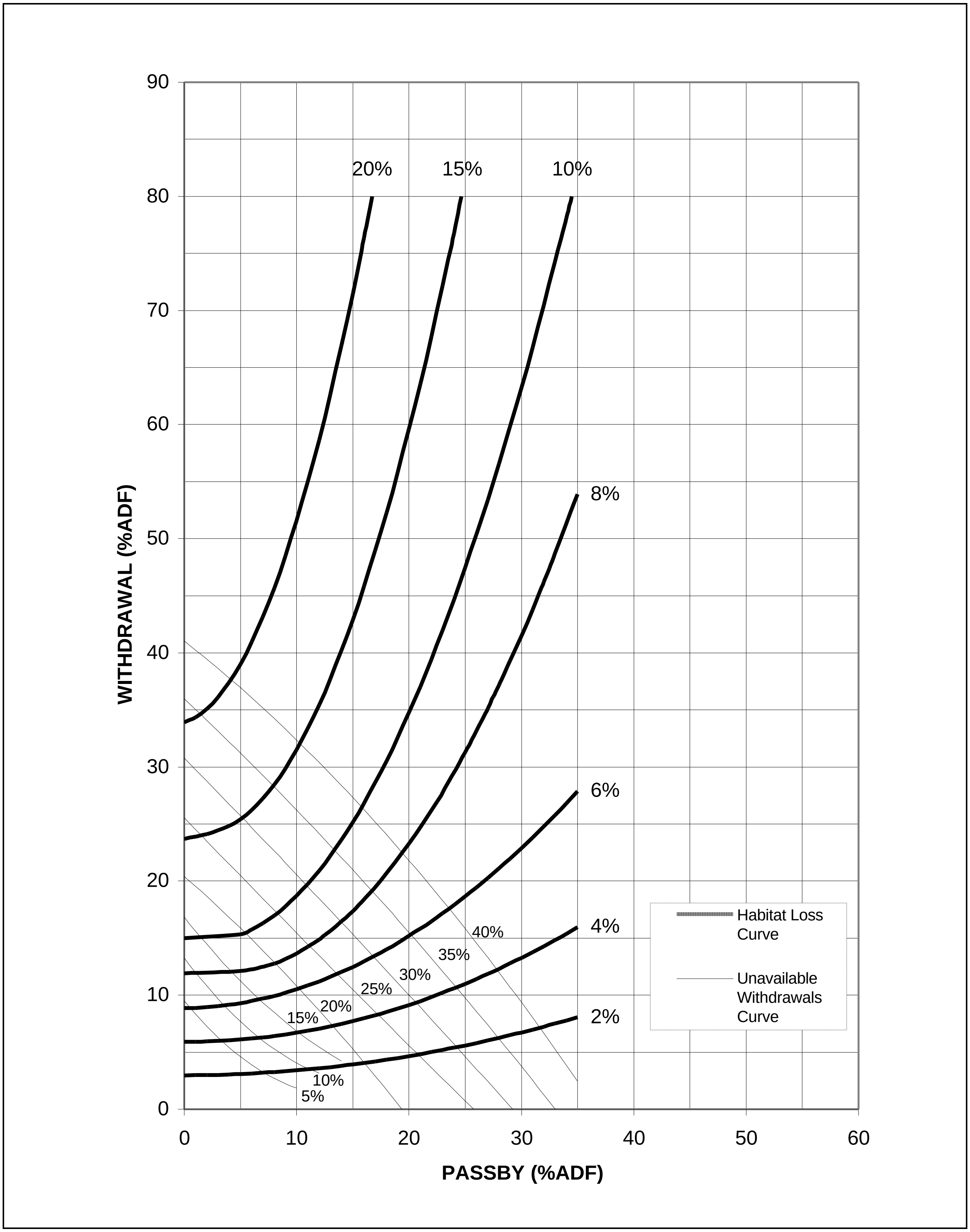

Figure 6.9. ***Impact of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Limestone Group 2, Wild Brook Trout***

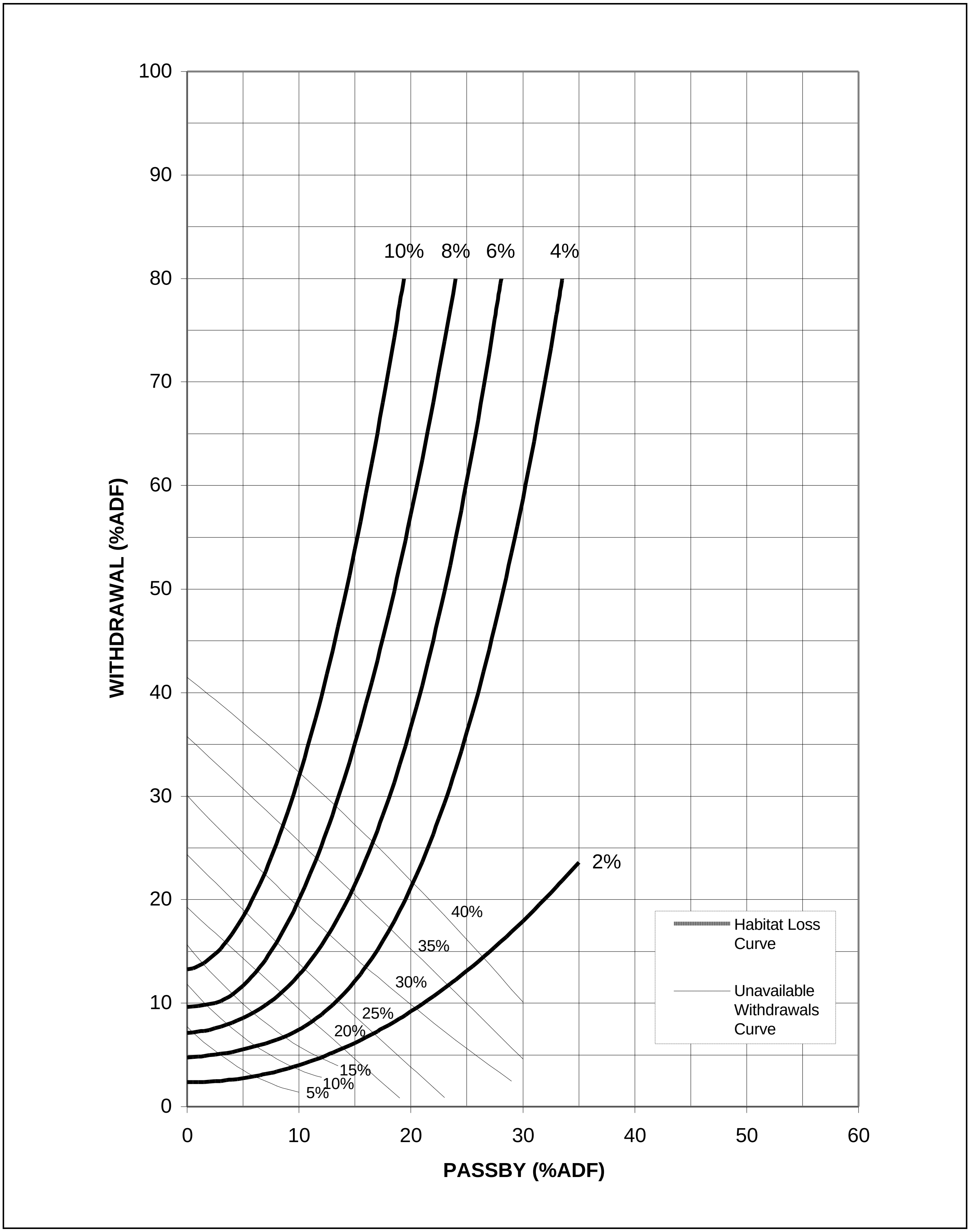

Figure 6.10. Impact of Selected Withdrawal and Passby Combinations, Unglaciated Plateau Segment Class 1 Streams, Wild Brook Trout

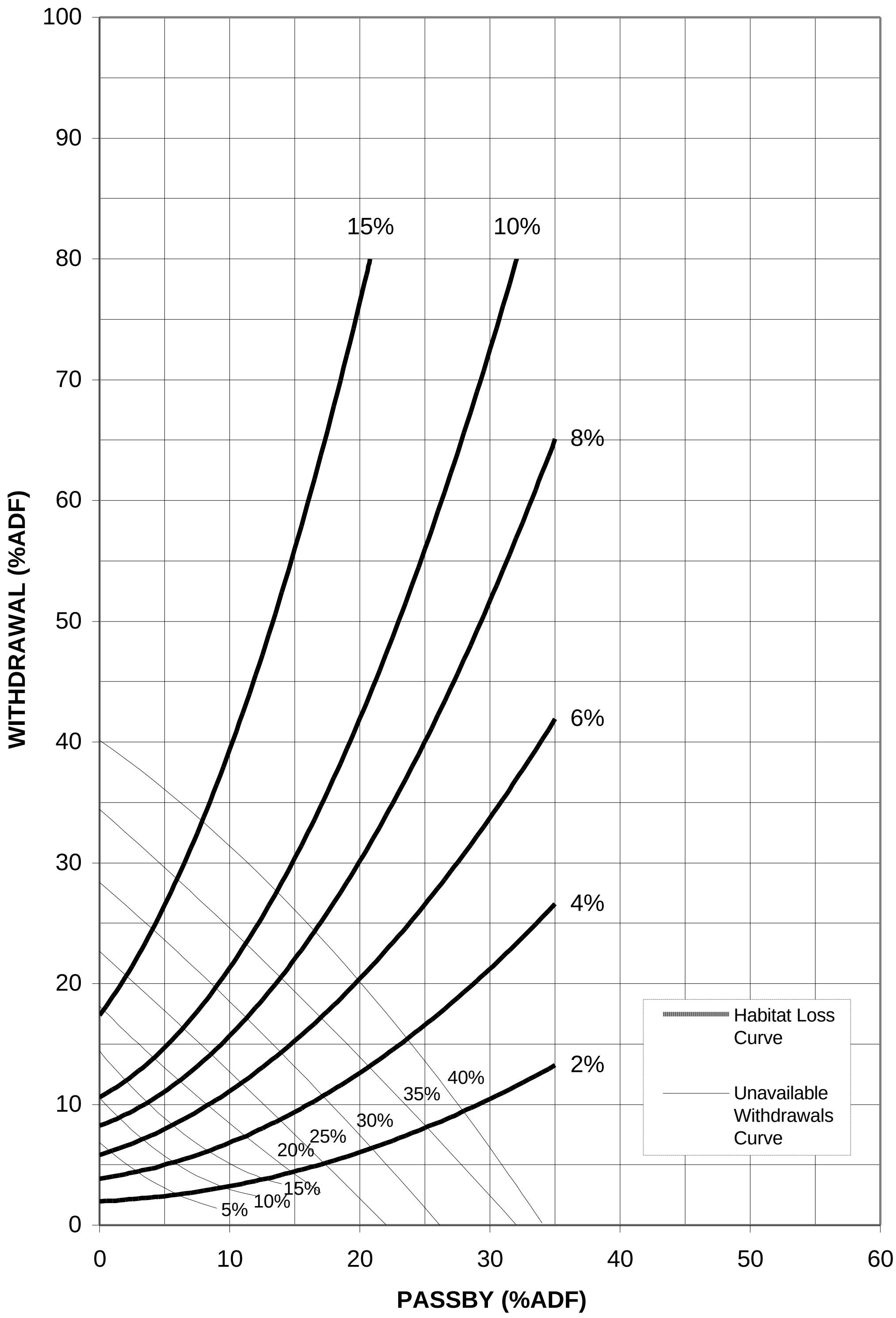

Figure 6.11. Impact of Selected Withdrawal and Passby Combinations, Unglaciated Plateau Segment Class 2 Streams, Wild Brook Trout

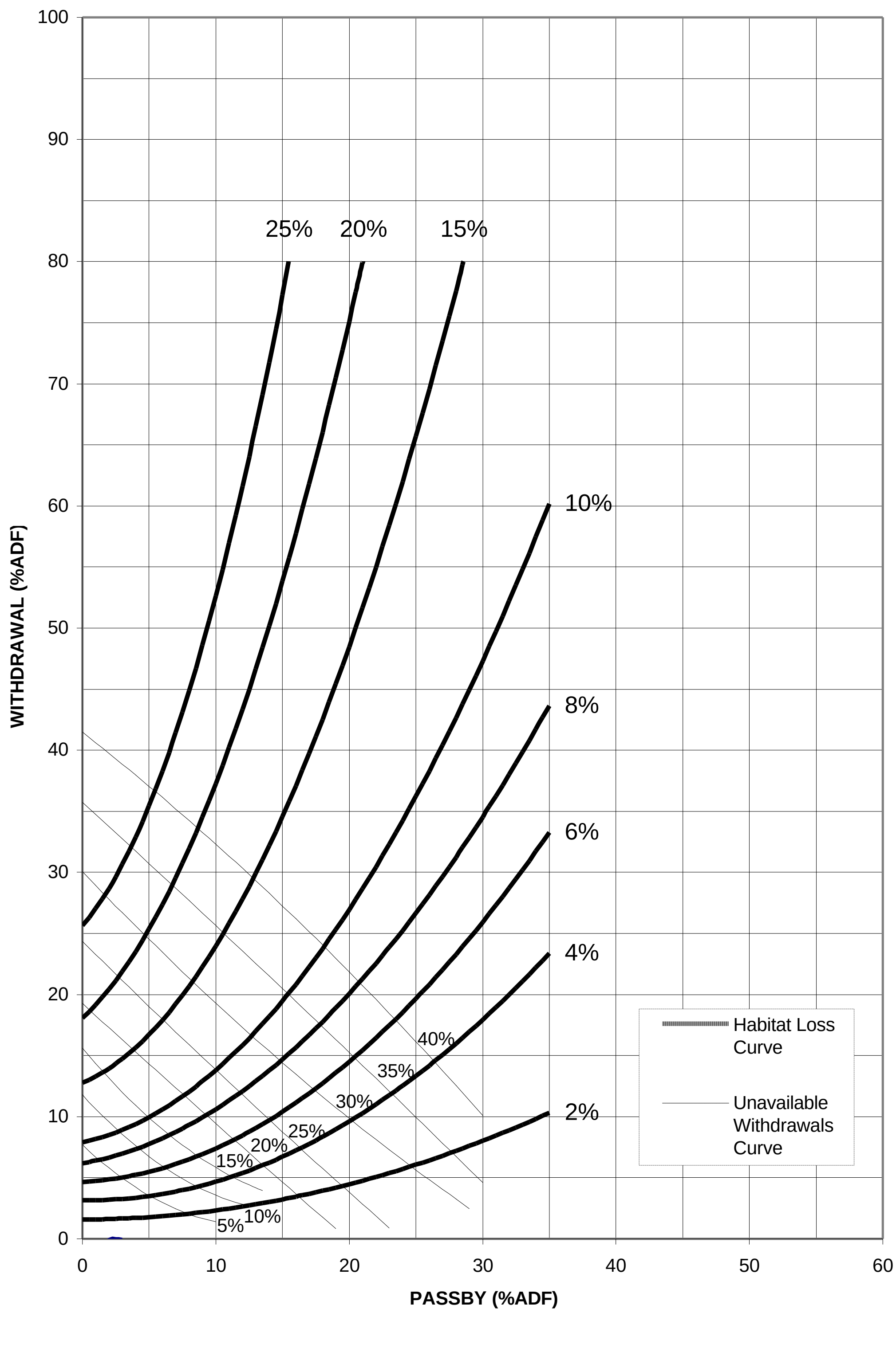

Figure 6.12. Impact of Selected Withdrawal and Passby Flow Combinations, Unglaciated Plateau Segment Class 1 Streams, Wild Brown and Combined Species

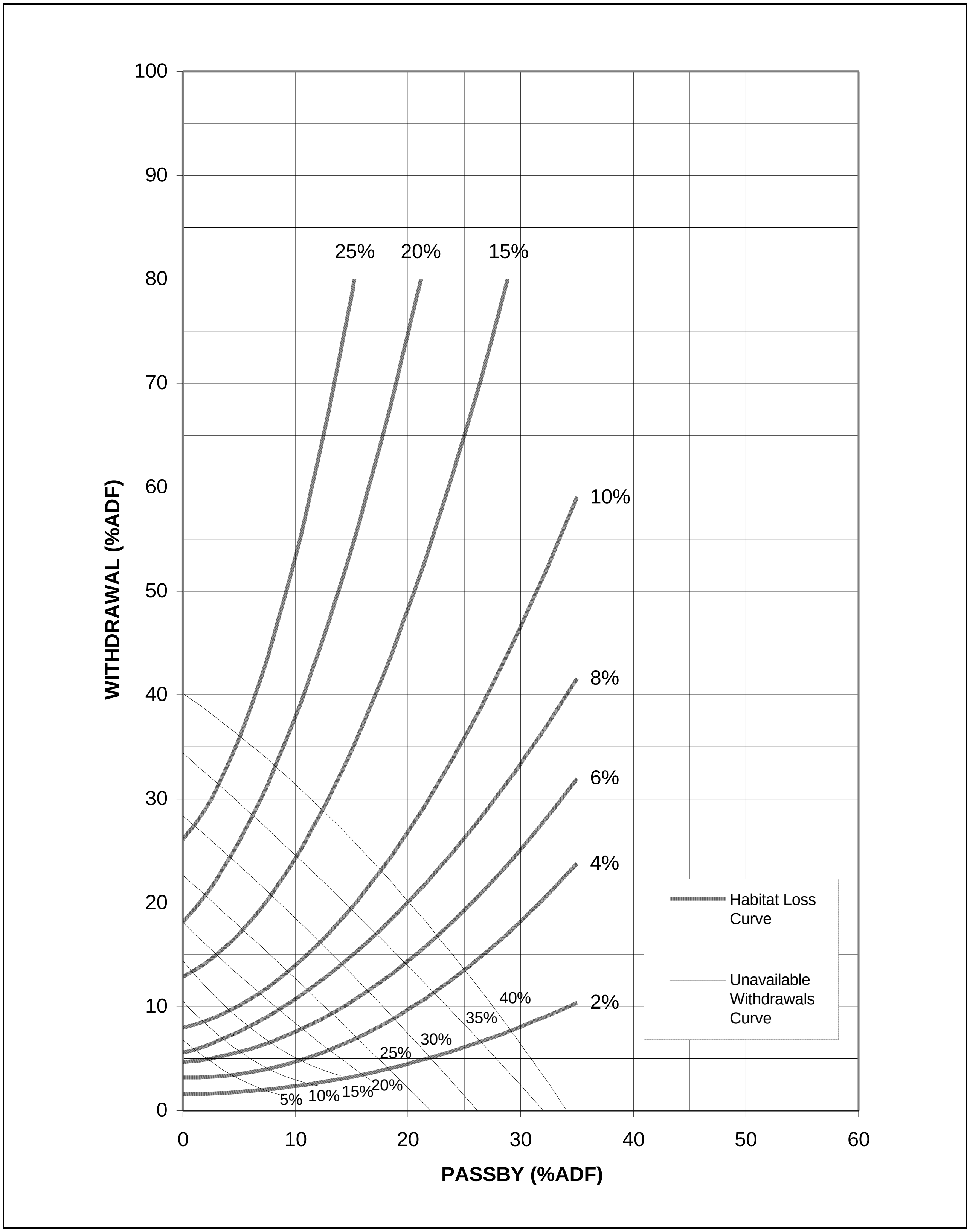

Figure 6.13. Impact of Selected Withdrawal and Passby Flow Combinations, Unglaciated Plateau Segment Class 2 Streams, Wild Brown and Combined Species

Because of this erratic behavior of the constant habitat impact curves for segment class 2 and 3 sites, only the curves for segment class 1 sites are shown in Figures 6.6 through 6.9. The segment class 2, 3, and 4 study sites should be classified according to prominent physical features, and considered representative of other streams with similar physical features. For example, Penns Creek is characterized by a large cave immediately upstream of the segment class 1 site; Spring Creek (Centre County) is characterized by springs, and a WWTP return flow, which significantly increase the amount of flow in segments 3 and 4; Monocacy Creek and Bushkill Creek are characterized by large amounts of shale in the watershed; Monocacy Creek also has significant underflow at the segment class 2 and 3 study sites. The availability of additional segment class 2, 3, or 4 streams in this region should be determined, and any streams found should be similarly classified by physical features. These streams should be studied and compared to the streams already included.

For the Unglaciated Plateau study region, the curves for segment 1 and 2 were clearly different. Both sets of curves are shown in Figures 6.10 through 6.13.

The effect of the fish species variable on the impact also was investigated. For the Unglaciated Plateau study region, changing the species from brook to brown trout increased the impact from withdrawals by between 2 and 4 percentage points for each combination of withdrawal and passby flow. In the Ridge and Valley Limestone study region, changing brook to brown trout increased the impact by about the same amount. In the Ridge and Valley Freestone study region, the difference between brown trout and combined brown and brook trout is much less than 1 percentage point. In other words, there is so little difference between brown trout and combined brook and brown trout, the two can be used interchangeably. However, in that study region, the difference between brook trout and combined brook and brown trout again was between 2 and 4 percentage points.

A sample summary of the average annual impacts, and the maximum and minimum values of the average impacts, across six representative streams in the Unglaciated Plateau is shown in Table 6.4. This table shows that the range of these values, for each withdrawal and passby flow combination, is small, and similar results were found for most of the representative streams in the respective study regions. In other words, the variation in impact across the region from one stream to another was small, indicating that, while hydrology and stream characteristics were highly variable, impacts to the habitat were fairly consistent within the region. While there is a small range of variation for each of the points plotted on any impact matrix, the habitat impact curves for each study region are very different from the other regions. This supported the basic concept that streams would react similarly within study regions, but differently from one region to another.

Table 6.4. Sample Summary of Range of Impacts, Unglaciated Plateau, Wild Brook Trout

Habitat Impact	10% ADF Withdrawal, 5% ADF Passby	40% ADF Withdrawal, 20% ADF Passby
Maximum	6.95	7.09
Average	6.45	6.49
Minimum	5.97	5.73

An example of the constant habitat impact curves based on the maximum impact measure is shown in Figure 6.14. Comparison of this figure with Figure 6.4 shows the maximum impact for a given withdrawal and passby flow is about 2.5 to 4 times the average impact. The average habitat curves are provided in this report based on the assumption that the long-term average impacts to habitat may result in average impacts to fish biomass of similar magnitude. However, since short-term

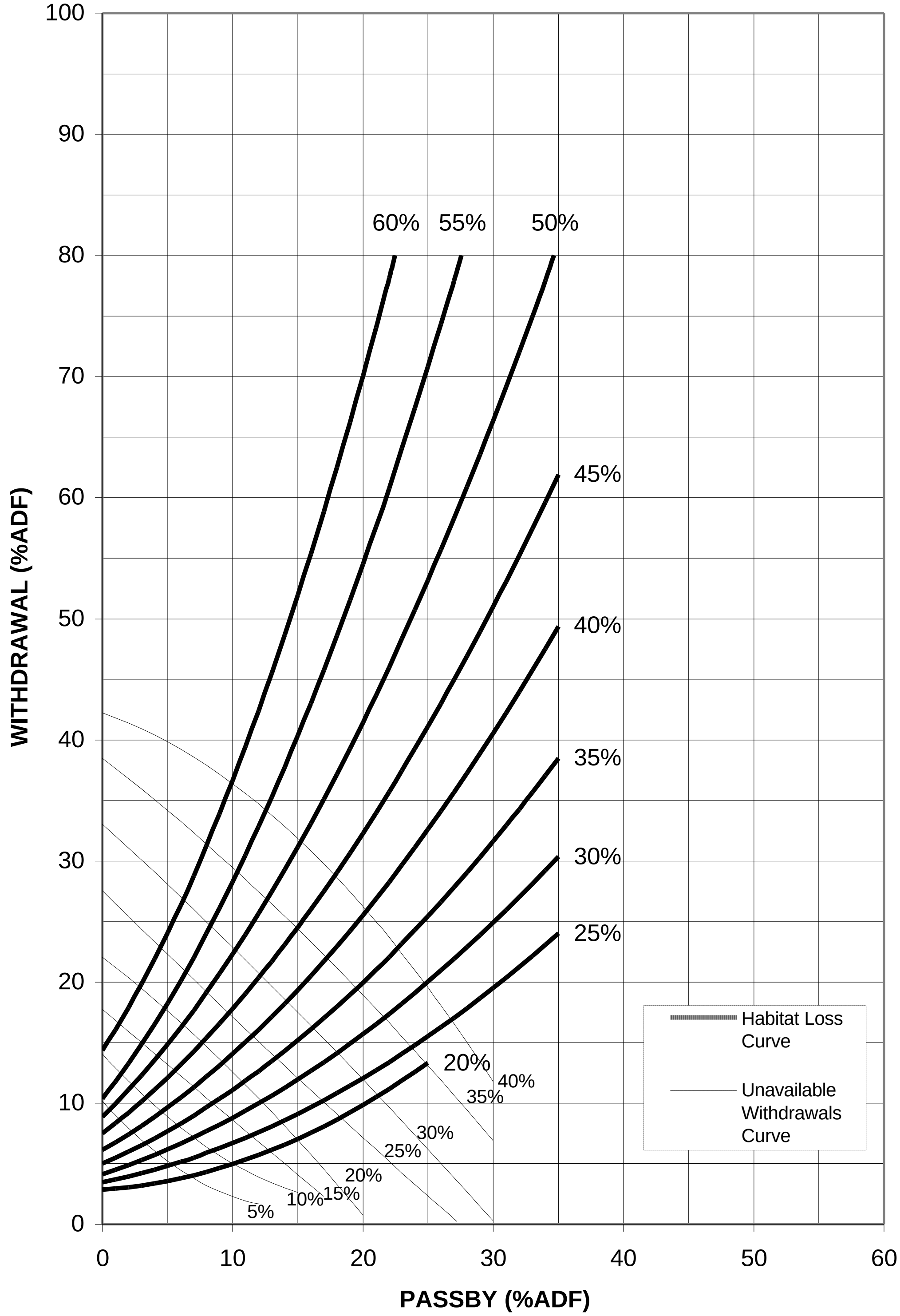

Figure 6.14. Example of Maximum Impact Measure of Selected Withdrawal and Passby Flow Combinations, Ridge and Valley Freestone Streams, Wild Brown and Combined Species

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**.** Corresponding curves could be developed for the 90 percent probability of exceedance impacts on habitat. However, the example of impacts of withdrawals on an individual stream shown in Figure 6.3 shows that the 90 percent probability impact is about three percentage points less than the maximum impact. Other streams showed similar small differences between maximum impact and the 90 percent probability impact. Therefore, there was no advantage in using the 90 percent exceedance impacts rather than the maximum impact curves. The average impact curves show the long-term effect, and the maximum impact curves show the short-term effect.

A project site in the Ridge and Valley study regions should be classified as freestone unless it meets the criteria for limestone. A partial list of limestone streams in Pennsylvania is shown in Table 6.5. Streams were included in this table if they were included in the list of limestone streams prepared by Shaffer (1991), or if they had a total alkalinity greater than 70 mg/L, as shown by PFBC (1994). However, some streams on the list are in the Piedmont Province and these streams should not be used with the Ridge and Valley Limestone impact curves. Some streams shown by PFBC (1994) as having total alkalinity greater than 70 mg/L were not included in this list, because geologic maps showed no limestone rocks in the watershed. Armstrong (1992) lists a large number of trout streams in Pennsylvania, which needs further evaluation before being used for instream flow purposes. Sites on streams not included in Table 6.4 should be classified as limestone on a case-by-case basis, considering the presence of limestone in the upstream watershed, alkalinity, and stream biological characteristics.

In the impact assessment, results showed that the passby flow needed to increase as withdrawals increase, to maintain constant impact. If withdrawals are small, little, if any, passby is required, and the maximum habitat impacts occur during the very low flows. However, as the withdrawals become a larger portion of the flow, passby flows are needed, both to prevent the total depletion of the stream at the lower flows, and to conserve habitat during medium flows. The time when maximum impacts occur shifts from the late summer and fall for small withdrawals to early summer and the winter period, for large withdrawals. Finally, when withdrawals become very large, say over 50 percent of the average daily flow, the passby flows have to be even larger to maintain the same magnitude of impacts, and the most critical periods occur in the winter and spring seasons.

Having developed the family of habitat impact curves, there is the question of which curve to use. Obviously, the curve with the lower percentage impact gives the higher degree of habitat protection. However, as the degree of protection increases, so does the percent of time that withdrawals cannot be made because of passby requirements. The detailed analysis program computes these percentages of time when the full withdrawal cannot be made. These results were plotted on the same graphs (Figures 6.4 through 6.13) with the habitat impact curves. The graphs show that, as the withdrawal increases to levels above 20 percent of the average daily flow, the amount of time that withdrawals will not be possible, either because of flow limitations, or passby requirements, or both, will be 60 to 150 days per year. The exception to this condition is limestone streams included in group 1, which have very substantial low flows.

The determination of which impact curve(s) to use will have to take into account the costs both to the environment and to the withdrawal users. The curves clearly indicate the impact of a specific withdrawal will be less on a larger stream, because the percentage withdrawal is less. However, large streams are generally not available in headwater areas. But, with these curves, the passby flow can be determined for any magnitude of withdrawal at a specific location, to minimize unacceptable impacts on fishery habitat. These curves will allow water purveyors to analyze stream intake alternatives

Table 6.5. Limestone Trout Streams in Pennsylvania

Name of Stream	County	Name of Stream	County
Ott Town Run	Bedford	Buck Run	Franklin
Potter Creek	Bedford	Falling Spring Branch	Franklin
Yellow Creek	Bedford		
		Spring Run	Fulton
Moselem Creek	Berks		
Peters Creek	Berks	Willow Run	Juniata
Spring Creek	Berks	Unnamed Tributary to	
Willow Creek	Berks	Willow Run, nr. Peru Mills	Juniata
Wyomissing Creek	Berks		
		Donegal Creek	Lancaster
Boiling Spring Run	Blair	Eshleman Run	Lancaster
Clover Creek	Blair	Indian Run	Lancaster
		Londonland Run	Lancaster
Cooks Creek	Bucks	Swarr Run	Lancaster
Buffalo Run	Centre	East Branch Mill Creek	Lebanon
Cedar Run	Centre	Mill Creek	Lebanon
Elk Creek	Centre		
Lick Run	Centre	Catasaqua Creek	Lehigh
Little Fishing Creek	Centre	Cedar Creek	Lehigh
Logan Branch	Centre	Coplay Creek	Lehigh
Penns Creek	Centre/Union	Little Lehigh Creek	Lehigh
Pine Creek	Centre	South Branch Saucon Creek	Lehigh
Sinking Creek	Centre	Spring Creek	Lehigh
Slab Cabin Run	Centre	Trout Creek	Lehigh
Spring Creek	Centre		
Spruce Creek	Centre	Antes Creek	Lycoming
Unnamed Tributary to			
Spring Cr., nr. Lemont	Centre	Honey Creek	Mifflin
		Kishacoquillas Creek	Mifflin
Little Valley Creek	Chester	Long Hollow Run	Mifflin
Valley Creek	Chester	Tea Creek	Mifflin
		Penns Creek	Mifflin/Union
Bald Eagle Creek	Clinton		
Cedar Run	Clinton	Allegheny Creek	Northampton
Fishing Creek	Clinton	Bushkill Creek	Northampton
		E. Branch Monocacy Creek	Northampton
Big Spring Creek	Cumberland	Frya Run	Northampton
Cedar Run	Cumberland	Jacoby Creek	Northampton
Green Spring Creek	Cumberland	Monocacy Creek	Northampton
Hogestown Run	Cumberland	Nancy Run	Northampton
Letort Spring Run	Cumberland	Saucon Creek	Northampton
Trindle Spring Run	Cumberland	Shoeneck Creek	Northampton

Sources: Shaffer (1991)
PFBC (1994); Streams with total alkalinity greater than 70 mg/L

NOTE: A few of these streams are located outside the Ridge and Valley Limestone study region.

that meet state fishery protection levels on cold water streams having less than 100 square miles of drainage area. Likewise, the curves will allow the administrative agency to regulate fishery protection on an equitable basis among all applicants requesting water withdrawals.

6.6.3 Regional hydrology

6.6.3.1 Overview

Regional hydrology was developed for three study regions, Ridge and Valley Limestone, Ridge and Valley Freestone, and Unglaciated Plateau, and adjacent areas, for use in the time series impact analysis programs, described in section 6.6.2. Regional hydrology has not been provided for the Piedmont Upland study region at this time, since the IFIM studies for that region are incomplete, and impact analyses for that region may be unreliable because of insufficient study streams. Regional hydrology for the Piedmont study regions can be added when IFIM studies for those areas are completed. Hydrology provided for adjacent areas should be used only for streams flowing into the study area.

The basic assumption in the regional hydrology is that differences in hydrology are related to differences in geology (limestone or freestone), geologic structure, climate, physiography, and topography, and those factors are related to physiographic province and section. While there may be other factors affecting hydrology, those factors are not well understood, and could not be incorporated in this analysis, due to time and cost constraints. The available data supports the assumption.

Development of the regional hydrology is complicated by the following conditions:

- The distribution of limestone, particularly in the Ridge and Valley Physiographic Province (Pa. DER, 1990);
- Limestone also occurs in parts of the Unglaciated Plateau study region in Armstrong, Clarion, and Butler Counties (Pa. DER, 1990);
- Part of the Ridge and Valley Physiographic Province in Lackawanna, Luzerne, Monroe, and Northampton Counties has been glaciated; and
- The Unglaciated Plateau study region encompasses five physiographic sections.

In the Ridge and Valley province, the distribution of limestone affects determination of hydrologic regions because many watersheds, including the gaged streams, have mixed limestone and freestone geology. Limestone valleys are often surrounded by freestone ridges, and some valleys include both limestone and freestone at the surface. For those reasons, the two Ridge and Valley study regions were combined for the purpose of developing regional hydrology procedures. The procedures account for the difference between limestone and freestone by recommending different gages for each rock type. Also, hydrologic regions were defined to account for the expected differences in hydrology between the glaciated and unglaciated parts of the Ridge and Valley Physiographic Province and sections, to the extent possible.

The Appalachian Plateaus Physiographic Province includes nine sections, as shown in Table 2.1 and Plate 1. Note that five sections are unglaciated, and four are glaciated. The Unglaciated Plateau study region includes the five unglaciated sections (section 2.1.3.3).

The procedure for developing regional hydrology included the following steps:

- Select appropriate representative gages for the study regions, and adjacent areas, requiring hydrology;
- Compare the seasonal flow duration curves for each gage within these regions to determine whether pairs of gages are similar;
- For pairs of gages that are hydrologically similar, compare physical data for each pair of gages (Shaw, 1984) to determine whether one gage can be eliminated; and
- Delineate boundaries of hydrologic regions.

6.6.3.2 Selection of gages to develop regional hydrology

The hydrology for the study sites was based on flow data for gages selected to best represent a specific study site (section 5.4). There was no attempt to select gages to represent entire study regions, and no gages were selected for hydrologic regions adjacent to the study regions. For that reason, additional gages were added to the original list (Table 5.8) to ensure that the hydrology of the entire study region was adequately represented.

To determine which gages to include, the USGS ADAPS header file for all gages in Pennsylvania was retrieved and printed out. From this list, a table was prepared that included the following information for all the gaging stations: begin and end date of the record; number of years of record; drainage area; latitude/longitude of the gage; use code; regulation code; and beginning date of the regulation. The use code showed whether the gage is active or inactive, and whether it had been used to develop hydrology for a study stream. The regulation code showed the type of regulation, if any, for each gage (e.g., water supply withdrawal, flood control operation, etc.).

From this list, gages were selected that had at least 10 years of continuous record since 1960, and a drainage area less than 600 square miles. The resulting list included about 220 gages in the entire state. Approximately 20 stations were removed from the list, due to regulation or urbanization, or location outside the study regions.

USGS prepared a map of the state, using a geographic information system (GIS), which included the remaining 200 gages, the physiographic province and section boundaries, and areas underlain by limestone. The physiographic boundaries were obtained from a computer file and a map developed by the Pa. Department of Conservation and Natural Resources (Pa. DCNR), Bureau of Topographic and Geologic Survey (Sevon, 1995). In the Appalachian Plateaus Province, these boundaries are significantly different than the boundaries shown by Pa. DER (1989).

The map prepared by USGS, and the list of gages, were used to further screen gages. This second stage screening produced a list of 56 gages considered to be most representative of each study area. In general, the criteria used in this screening were length and period-of-record, proximity, drainage area size, location, and absence of coal mining or regulation. In general, the gages deleted were those with shorter records, or are presently inactive, or have larger drainage areas. Gages were retained if they were considered representative of different major subbasins and could be easily classified according to geology and/or physiography. This list of gages is shown in Table 6.6.

The data for these gages were compared to see if they were similar, and whether some could be eliminated, and the corresponding hydrologic regions combined, to simplify the regional hydrology procedure. There are two considerations in the decision to combine hydrologic

Table 6.6. Gages Retained After Second Stage Screening

Station Number	Station Name	Begin Date		End Date		Total Years	Drainage Area (sq. mi.)
		Month	Year	Month	Year		
01429500	Dyberry Creek near Honesdale, Pa.	10	1943	7	1996	53	64.60
01440400	Brodhead Creek near Analomink, Pa.	10	1957	6	1996	39	65.90
01446600	Martins Creek near East Bangor, Pa.	9	1961	9	1978	18	10.40
01447680	Tunkhannock Creek near Long Pond, Pa.	4	1965	7	1996	32	18.00
01449360	Pohopoco Creek at Kresgeville, Pa.	10	1966	7	1996	30	49.90
01451800	Jordan Creek near Schnecksville, Pa.	2	1966	7	1996	31	53.00
01452500	Monocacy Creek at Bethlehem, Pa.	10	1948	7	1996	48	44.50
01467500	Schuylkill River at Pottsville, Pa.	10	1943	9	1969	26	53.40
01470779	Tulpehocken Creek near Bernville, Pa.	11	1974	7	1996	22	66.50
01470853	Furnace Creek at Robesonia, Pa.	10	1982	6	1996	14	4.18
01472198	Perkiomen Creek at East Greenville, Pa.	8	1981	7	1996	16	38.00
01518862	Cowanesque River at Westfield, Pa.	8	1983	5	1996	14	90.60
01533950	S. Br. Tunkhannock Creek near Montdale, Pa.	9	1960	9	1978	19	12.60
01538000	Wapwallopen Creek near Wapwallopen, Pa.	10	1919	9	1996	76	43.80
01539000	Fishing Creek near Bloomsburg, Pa.	6	1938	7	1996	59	274.00
01541000	West Branch Susquehanna River at Bower, Pa.	10	1913	7	1996	83	315.00
01541500	Clearfield Creek at Dimeling, Pa.	10	1913	7	1996	83	371.00
01543000	Driftwood Br. Sinnemahoning Creek, Sterling Run, Pa.	10	1913	7	1996	83	272.00
01545600	Young Womans Creek near Renovo, Pa.	12	1964	6	1996	32	46.20
01546400	Spring Creek at Houserville, Pa.	11	1984	7	1996	12	58.50
01547700	Marsh Creek at Blanchard, Pa.	10	1955	5	1996	41	44.10
01547800	South Fork Beech Creek near Snow Shoe, Pa.	5	1969	3	1981	13	12.20
01552500	Muncy Creek near Sonestown, Pa.	10	1940	5	1996	56	23.80
01553130	Sand Spring Run near White Deer, Pa.	1	1968	3	1981	14	4.93
01555000	Penns Creek at Penns Creek, Pa.	10	1929	7	1996	67	301.00
01555500	East Mahantango Creek near Dalmatia, Pa.	10	1929	7	1996	67	162.00
01556000	Frankstown Br. Juniata River at Williamsburg, Pa.	10	1916	7	1996	80	291.00
01557500	Bald Eagle Creek at Tyrone, Pa.	10	1944	7	1996	52	44.10
01560000	Dunning Creek at Belden, Pa.	10	1939	7	1996	57	172.00
01564500	Aughwick Creek near Three Springs, Pa.	6	1938	6	1996	59	205.00
01565000	Kishacoquillas Creek at Reedsville, Pa.	10 10 10	1939 1983 1991	9 9 9	1970 1985 1992	31 2 1	164.00
01565700	Little Lost Creek near Oakland Mills, Pa.	9	1963	3	1981	19	6.52
01567500	Bixler Run near Loysville, Pa.	2	1954	7	1996	43	15.00
01568000	Sherman Creek at Shermans Dale, Pa.	10	1929	7	1996	67	200.00
01569800	Letort Spring Run near Carlisle, Pa.	6	1976	7	1996	21	21.60
01570000	Conodoguinet Creek near Hogestown, Pa.	7	1967	7	1996	30	470.00
01571500	Yellow Breeches Creek near Camp Hill, Pa.	7	1954	7	1996	43	216.00
01573086	Beck Creek near Cleona, Pa.	8	1963	3	1981	19	7.87
01574000	W. Conewago Creek near Manchester, Pa.	10	1928	7	1996	68	510.00
01613050	Tonoloway Creek near Needmore, Pa.	10	1965	6	1996	31	10.70
03007800	Allegheny River at Port Allegany, Pa.	10	1974	7	1996	22	248.00
03009680	Potato Creek at Smethport, Pa.	10	1974	7	1996	22	160.00
03015280	Jackson Run near North Warren, Pa.	10	1962	9	1978	16	12.80

Table 6.6. Gages Retained After Second Stage Screening — Continued

Station Number	Station Name	Begin Date		End Date		Total Years	Drainage Area (sq. mi.)
		Month	Year	Month	Year		
03015500	Brokenstraw Creek at Youngsville, Pa.	10	1909	7	1996	87	321.00
03017500	Tionesta Creek at Lynch, Pa.	3	1938	10	1979	43	233.00
03020500	Oil Creek at Rouseville, Pa.	10	1932	7	1996	64	300.00
03022540	Woodcock Creek at Blooming Valley, Pa.	9	1974	7	1996	23	31.10
03025000	Sugar Creek at Sugarcreek, Pa.	10	1932	11	1979	48	166.00
03028000	West Branch Clarion River at Wilcox, Pa.	10	1953	7	1996	43	63.00
03034000	Mahoning Creek at Punxsutawney, Pa.	10	1938	7	1996	58	158.00
03042000	Blacklick Creek at Josephine, Pa.	2	1952	7	1996	45	192.00
03042200	Little Yellow Creek near Strongstown, Pa.	9	1960	12	1978	20	7.36
		10	1986	10	1988	3	
03049000	Buffalo Creek near Freeport, Pa.	10	1940	6	1996	56	137.00
03080000	Laurel Hill Creek at Ursina, Pa.	10	1918	7	1996	78	121.00
03104760	Harthegig Run near Greenfield, Pa.	10	1968	4	1981	13	2.26
03106000	Connoquenessing Creek near Zelienople, Pa.	10	1919	7	1996	77	356.00

regions: whether the gages are sufficiently similar, and whether it is reasonable to use one gage to represent the other.

There is no established procedure for comparing two or more gages. However, following a brief review of the literature, and several telephone calls to other hydrologists, the following list of potential approaches to the problem was developed:

- Compare the normalized (csm) flow duration curves graphically, using an assumed acceptable difference between pairs of curves;
- Determine the statistics (mean, standard deviation, skewness) of the daily flow data for each gage, and compare pairs of gages using standard statistical tests (adjustments for serial correlation of the daily flow data are necessary to apply the tests);
- Array the unit flow rates (csm) at selected percentile levels from each probability curve, and analyze the array using a nonparametric test; the Wilcoxon Rank Sum Test and the Kruskal-Wallis Test were considered (Gilbert, 1987), and believed to be inappropriate for this purpose, so this concept was not developed further;
- Perform regional regression analysis of flow values using drainage area, precipitation, and relief (average basin slope) as predictors (R. Vogel, Tufts University, oral communication, June 11, 1996; Helsel and Hirsch, 1992, pp. 52-55);
- Fit an appropriate probability distribution function to each frequency curve, and compare using appropriate statistical tests (R. Vogel, Tufts University, oral communication, June 11, 1996);
- Plot statistics of flow duration curves against drainage area and relief (R. Vogel, Tufts University, oral communication, June 11, 1996); and
- Use a flow duration model developed by Fennessey (1994; R. Vogel, Tufts University, oral communication, June 11, 1996).

Because of time and cost constraints, the first method was used to evaluate similarities among the selected gages. The procedure included the following steps:

- Plot the seasonal flow duration curves for the entire period-of-record for each gage on log-normal probability paper;
- Determine graphically whether pairs of curves are similar, based on whether they differ by less than 20 percent or 30 percent over the entire range of the curve for each season;
- Tabulate whether the curves are similar or dissimilar for each season and each pair of gages; and
- Summarize the table to show which pairs are similar across all seasons.

The following pairs of gages were determined to have similar seasonal flow duration curves:

- Wapwallopen Creek near Wapwallopen and Bald Eagle Creek near Tyrone;
- Pohopoco Creek at Kresgeville and Schuylkill River at Pottsville;

- Young Womans Creek near Renovo and Laurel Hill Creek near Ursina; and
- Connoquenessing Creek near Zelienople and Buffalo Creek near Freeport.

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Wapwallopen Creek near Wapwallopen and Bald Eagle Creek near Tyrone are about 110 miles apart, and have different relief ratio, stream length and pattern, and topography, although the channel slopes are similar (Shaw, 1984). The hydrologic similarity appears to be coincidental, so both gages were retained, due to the distance between them.

Pohopoco Creek at Kresgeville and Schuylkill River at Pottsville are about 40 miles apart and in the Ridge and Valley Appalachian Mountain Section. Shaw (1984) includes data for the West Branch Schuylkill River at Cressona and for the Little Schuylkill River above Port Clinton. Both locations are on other branches of the Schuylkill River, and the data may not be representative of the watershed above the Pottsville gage. The West Branch Schuylkill River above Cressona was considered more representative of the watershed upstream from Pottsville. Comparison of the data for that location with data for Pohopoco Creek at Perryville shows the former has a much higher relief ratio and much greater channel slope. There also are differences in channel pattern, geology, and main channel physiography. The topographic relief maps (U.S. Army Corps of Engineers, undated) showed major topographic differences between the two watersheds, so both gages were retained.

Young Womans Creek near Renovo and Laurel Hill Creek near Ursina are about 130 miles apart and have different physiographic and topographic settings. The channel length, relief ratio, channel slope, drainage pattern and main channel characteristics (Shaw, 1984) are all dissimilar. Again, the similarity in hydrology appears coincidental, so both gages were retained.

Buffalo Creek near Freeport and Connoquenessing Creek near Zelienople are both in the Pittsburgh Low Plateau physiographic section and drain adjacent areas. The two watersheds seem to have similar characteristics (Shaw, 1984). Although either gage could be used, Buffalo Creek was retained, since it is more centrally located within the hydrologic region.

A pilot study was conducted to evaluate whether more gages would be similar, based on seasonal flow duration curves, if data for a coincident period-of-record were used in the comparison.

This pilot study used 18 gages selected from Table 6.6 to represent the Ridge and Valley Freestone study region. A plot of the periods-of-record for these 18 gages showed that the maximum number of gages could be included in the comparison if the calendar years 1968-1980 were selected as the period-of-record. Shorter periods-of-record would have questionable hydrologic validity, and would not increase the number of gages. Longer periods-of-record would eliminate gages, and alternative periods-of-record would exchange gages without increasing the total number being compared.

The gages included in these comparisons are:

- Pohopoco Creek at Kresgeville;
- East Mahantango Creek near Dalmatia;
- Frankstown Branch Juniata River at Williamsburg;
- Marsh Creek at Blanchard;
- Jordan Creek at Schnecksville;
- Dunning Creek at Belden;
- Tonoloway Creek near Needmore;
- Maiden Creek Tributary at Lenhartsville;

- Sand Spring Run near White Deer;
- Wapwallopen Creek near Wapwallopen;
- Bald Eagle Creek at Tyrone;
- Sherman Creek at Shermans Dale;
- Fishing Creek near Bloomsburg;
- Aughwick Creek near Three Springs; and
- Penns Creek at Penns Creek.

The following three gages were not included:

- Martins Creek near East Bangor;
- Schuylkill River at Pottsville; and
- Wills Creek below Hyndman.

The comparisons were made, as described previously, except that only summer and fall seasons were considered, and only the 30 percent difference was analyzed. The results showed no pairs of gages were similar across all seasons.

The comparison of flow duration curves using the full period-of-record for each gage showed the following pairs of Ridge and Valley Freestone gages were similar.

- Pohopoco Creek and Schuylkill River; and
- Wapwallopen Creek and Bald Eagle Creek.

The similarity of Pohopoco Creek and Schuylkill River could not be evaluated in this analysis, because the Schuylkill River gage was not in operation for most of the assumed period of record. The other pair of gages are not similar for this period of record, which tends to confirm the previous conclusion that the apparent similarity was coincidence.

The effect of alternative criteria was investigated by making the same comparisons using only the range between 10 percent and 90 percent probability of exceedance. Using this criteria, the following gages are similar across both seasons:

- East Mahantango Creek and Bald Eagle Creek;
- East Mahantango Creek and Sherman Creek;
- Frankstown Branch and Penns Creek;
- Jordan Creek and Maiden Creek Tributary;
- Dunning Creek and Sherman Creek; and
- Wapwallopen Creek and Fishing Creek.

There are at least two criteria for evaluating whether it is reasonable to substitute one gage for the other in each of these six pairs: whether the two regions are adjacent; and whether the geology is similar. The respective regions are adjacent for three pairs of gages:

- East Mahantango Creek and Sherman Creek;
- Jordan Creek and Maiden Creek Tributary; and
- Wapwallopen Creek and Fishing Creek.

The regions represented by each of the other three pairs of gages are separated by one or more intervening regions. Therefore, using one gage to represent both regions will reduce the number of gages, but will not reduce the number of regions. For these cases, the regional hydrology procedure is simplified only by reducing the number of gages included in the database, which is considered insignificant.

The following conclusions can be drawn from this analysis:

- For the Ridge and Valley Freestone region, use of the assumed coincident period-of-record, rather than the full period-of-record for each gage, does not increase the number of gages that appear to be hydrologically similar, utilizing the assumed criteria for similarity.
- If the rules for determining similarity of gages are modified to include only the range of flows greater than 90 percent probability of exceedance, six pairs of gages are similar, out of a possible 196 pairs. Preliminary analysis shows there is a minor reduction in complexity of the regional hydrology procedure.

Similar analyses of the gages used in the Unglaciated Plateau study region also are expected to show that only a few pairs of gages can be considered similar, and only minor simplification of the regional hydrology procedure is possible. Considering the complexity of the hydrology of the Ridge and Valley Limestone study streams and gages, it is doubtful that the number of gages used in the regional hydrology procedure can be reduced.

The finding that very few pairs of gages are similar implies significant hydrologic variability among hydrologic regions.

6.6.3.3 Delineation of hydrologic regions

To delineate regions, the physiographic province and section boundaries were plotted on the Pennsylvania stream map (Ings and Simmons, 1991). Then the hydrologic region boundaries were delineated on an overlay to the map, based on judgment. Watershed boundaries, physiographic section boundaries, topography, geology, mountain ridges, topographic divides, and streams were used in the delineation of hydrologic boundaries. The topographic relief maps (U.S. Army Corps of Engineers, undated) were used to determine areas with similar topography, and differences in topography were used to delineate appropriate boundaries. The location of limestone was determined from the map prepared by USGS. The map and computer file prepared by Sevon (1995) were used to delineate physiographic boundaries. The boundaries of the Appalachian Plateau Deep Valleys section are being modified (Sevon, in preparation), and those modifications were incorporated (W. D. Sevon, oral communication, April 1997).

Hydrologic regions are designated by a region code, followed by a number. The region codes are based on physiographic province or section, and are shown in Table 6.7. The hydrologic regions were numbered consecutively within each physiographic section. The numbering begins in the northeast corner of the state and proceeds south and west.

The map of the regions is shown in Plate 2. A description of the regions and the gages used for each region are shown in Table 6.8. The final list of gages is shown in Table 6.9.

Table 6.7. Hydrologic Region Designation and Description

Hydrologic Region Designation	Physiographic Province	Comments
GP	Appalachian Plateaus (glaciated)	Includes only streams draining into Ridge and Valley or Unglaciated Appalachian Plateau study regions.
RV	Ridge and Valley	Includes both Appalachian Mountain and Great Valley sections, and glaciated parts of those sections.
RP	New England Province, Reading Prong Section	Includes only streams draining into Ridge and Valley province.
GNL	Piedmont Province, Gettysburg-Newark Lowland Section	Includes only streams draining into Ridge and Valley province.
UP	Appalachian Plateaus (unglaciated)	Includes Deep Valleys, Allegheny Plateau, Allegheny Mountain, High Plateau, and Pittsburgh Low Plateau sections.
SM	Blue Ridge Province South Mountain Section	Includes only streams draining into Ridge and Valley province.

Table 6.8 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 01451800	Limestone sections: Monocacy Creek at Bethlehem (modified) 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 01567500	Freestone: Fishing Creek near Bloomsburg 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 01470720	Limestone: Tulpehocken Creek near Bernville Freestone: Maiden Creek Tributary at Lenhartsville

Table 6.8. 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 01470720	Limestone: Beck Creek near Cleona 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 01555000 01553130	Limestone: Spring Creek at Houserville Freestone valley: Penns Creek at Penns Creek Freestone mountainous: Sand Spring Run near White Deer
RV-14	Appalachian Mountain Section, Kishacoquillas Creek upstream from Reedsville, and Saddler Run drainages	01565000 01568000 01553130	Limestone: Kishacoquillas Creek at Reedsville (modified) Freestone valley: Sherman Creek at Shermans Dale 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 01568000	Limestone: Bixler Run near Loysville Freestone: Sherman Creek at Shermans Dale
RV-16	Great Valley Section, Cumberland and Franklin counties	01569800 01571500 01568000	Limestone with significant springs (Flippo, 1974): Letort Spring Run near Carlisle, (modified), and add spring flow; Limestone, no significant springs: Yellow Breeches Creek near Camp Hill 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 01567500	Freestone: Aughwick Creek near Three Springs Limestone: Bixler Run near Loysville

Table-6.8. 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 01546400	Freestone: Tonoloway Creek at Needmore 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 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 01560000	Limestone: Bixler Run near Loysville 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 01560000	Limestone: Bixler Run near Loysville 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 01567500	Freestone: Wills Creek below Hyndman 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 6.8. 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

Table 6.9. Final List of Gages Used in Regional Hydrology

Station Number	Station Name	Begin Date		End Date		Total Years	Drainage Area (sq. mi.)
		Month	Year	Month	Year		
01429500	Dyberry Creek near Honesdale, Pa.	10	1943	7	1996	53	64.60
01440400	Brodhead Creek near Analomink, Pa.	10	1957	6	1996	39	65.90
01446600	Martins Creek near East Bangor, Pa.	9	1961	9	1978	18	10.40
01447500	Lehigh River at Stoddartsville, Pa.	10	1943	7	1996	53	91.70
01449360	Pohopoco Creek at Kresgeville, Pa.	10	1966	7	1996	30	49.90
01451800	Jordan Creek near Schnecksville, Pa.	2	1966	7	1996	31	53.00
01452500	Monocacy Creek at Bethlehem, Pa.	10	1948	7	1996	48	44.50
01469500	Little Schuylkill River at Tamaqua, Pa.	10	1919	7	1996	77	42.90
01470720	Maiden Creek Tributary at Lenhartsville, Pa.	10	1965	4	1981	16	7.46
01470779	Tulpehocken Creek near Bernville, Pa.	11	1974	7	1996	22	66.50
01470853	Furnace Creek at Robesonia, Pa.	10	1982	6	1996	14	4.18
01472198	Perkiomen Creek at East Greenville, Pa.	8	1981	7	1996	16	38.00
01518862	Cowanesque River at Westfield, Pa.	8	1983	5	1996	14	90.60
01533950	S. Br. Tunkhannock Creek near Montdale, Pa.	9	1960	9	1978	19	12.60
01538000	Wapwallopen Creek near Wapwallopen, Pa.	10	1919	12	1978	78	43.80
01539000	Fishing Creek near Bloomsburg, Pa.	6	1938	7	1996	59	274.00
01541000	West Branch Susquehanna River at Bower, Pa.	10	1913	7	1996	83	315.00
01543000	Driftwood Br. Sinnemahoning Creek, Sterling Run, Pa.	10	1913	7	1996	83	272.00
01545600	Young Womans Creek near Renovo, Pa.	12	1964	6	1996	32	46.20
01546400	Spring Creek at Houserville, Pa.	11	1984	7	1996	12	58.50
01547700	Marsh Creek at Blanchard, Pa.	10	1955	5	1996	41	44.10
01547800	South Fork Beech Creek near Snow Shoe, Pa.	5	1969	3	1981	13	12.20
01552500	Muncy Creek near Sonestown, Pa.	10	1940	5	1996	56	23.80
01553130	Sand Spring Run near White Deer, Pa.	1	1968	3	1981	14	4.93
01555000	Penns Creek at Penns Creek, Pa.	10	1929	7	1996	67	301.00
01555500	East Mahantango Creek near Dalmatia, Pa.	10	1929	7	1996	67	162.00
01557500	Bald Eagle Creek at Tyrone, Pa.	10	1944	7	1996	53	44.10
01560000	Dunning Creek at Belden, Pa.	10	1939	7	1996	57	172.00
01564500	Aughwick Creek near Three Springs, Pa.	6	1938	6	1996	59	205.00
01565000	Kishacoquillas Creek at Reedsville, Pa.	10 10 10	1939 1983 1991	9 9 9	1970 1985 1992	31 2 1	164.00
01567500	Bixler Run near Loysville, Pa.	2	1954	7	1996	43	15.00
01568000	Sherman Creek at Shermans Dale, Pa.	10	1929	7	1996	67	200.00
01569800	Letort Spring Run near Carlisle, Pa.	6	1976	7	1996	21	21.60
01571500	Yellow Breeches Creek near Camp Hill, Pa.	7	1954	7	1996	43	216.00
01573086	Beck Creek near Cleona, Pa.	8	1963	3	1981	19	7.87
01574000	W. Conewago Creek near Manchester, Pa.	10	1928	7	1996	68	510.00

Table 6.9. Final List of Gages Used in Regional Hydrology— Continued

Station Number	Station Name	Begin Date		End Date		Total Years	Drainage Area (sq. mi.)
		Month	Year	Month	Year		
01601000	Wills Creek below Hyndman, Pa.	6	1951	9	1967	17	146.00
01613050	Tonoloway Creek near Needmore, Pa.	10	1965	6	1996	31	10.70
03007800	Allegheny River at Port Allegany, Pa.	10	1974	7	1996	22	248.00
03009680	Potato Creek at Smethport, Pa.	10	1974	7	1996	22	160.00
03017500	Tionesta Creek at Lynch, Pa.	3	1938	10	1979	43	233.00
03020500	Oil Creek at Rouseville, Pa.	10	1932	7	1996	64	300.00
03022540	Woodcock Creek at Blooming Valley, Pa.	9	1974	7	1996	23	31.10
03028000	West Branch Clarion River at Wilcox, Pa.	10	1953	7	1996	43	63.00
03034000	Mahoning Creek at Punxsutawney, Pa.	10	1938	7	1996	58	158.00
03042000	Blacklick Creek at Josephine, Pa.	2	1952	7	1996	45	192.00
03049000	Buffalo Creek near Freeport, Pa.	10	1940	6	1996	56	137.00
03080000	Laurel Hill Creek at Ursina, Pa.	10	1918	7	1996	78	121.00

During the delineation of boundaries, two gages (Wills Creek below Hyndman, and Maiden Creek Tributary at Lenhartsville) were added to the list, shown in Table 6.5, to represent certain hydrologic regions. Also, Tunkhannock Creek near Long Pond was replaced by Lehigh River at Stoddartsville, and Little Schuylkill River at Tamaqua was substituted for Schuylkill River at Pottsville in region RV-8. Eleven gages included in Table 6.6 were not used in the final determination of regions.

The delineation of boundaries considered the location of study streams and gages used to develop hydrology for those study streams. In most cases, the study streams are within a hydrologic region where the same gage was used for determining study site hydrology as described in section 5.4. For a few study streams, shown in Table 6.10, a different gage is recommended. In those cases, the hydrology of the study stream(s) was recomputed. For study streams where the revised hydrology was significantly different, the hydraulic simulations and RMWUA versus flow relationships were revised in accordance with the simulation criteria described in section 5.7. The revised hydrology and RMWUA relationships were used in the impact analysis studies described in section 6.6.2.4.

Table 6.10. Study Streams Revised for Regional Hydrology

Region	Study Stream	New Gage
Ridge and Valley Limestone, Group 1	Penns Creek	Spring Creek at Houserville with Penns Creek at Penns Creek
Ridge and Valley Limestone, Group 2	Boiling Spring Run Long Hollow Run	Bixler Run near Loysville Bixler Run near Loysville
Unglaciated Plateau	Benner Run Dunlap Run Meyers Run Mill Run	South Fork Beech Creek near Snow Shoe West Branch Susquehanna at Bower South Fork Beech Creek near Snow Shoe Driftwood Branch Sinnemahoning Creek at Sterling Run

No gages are available to represent the watersheds underlain by the Vanport limestone in Armstrong, Clarion, and Butler Counties. This limestone is not expected to affect the hydrology, because of its characteristics (L. Taylor, SRBC, oral communication; S. Runkle, Pa. DEP, oral communication). For that reason, it should be ignored in determining hydrology for study streams in these counties.

In Table 6.8, the region description provides guidance for determining the appropriate region. The hydrologic region includes the watersheds shown in the description, and may include other streams not specifically noted. Also, the description may imply overlap among regions that is not intended. Because of the difficulty of describing complex regional boundaries, the appropriate regions should be determined by locating the actual stream on the map in Plate 2.

Some of the gage data were modified, because of unusual conditions, as described in section 5.4 and Appendix D, for use in the regional hydrology procedure. Those cases are designated as "modified" in the last column of Table 6.8.

6.6.3.4 Regional hydrology application

For most streams, the ADF and median monthly flows are computed from the unit flow rates (csm) for the appropriate gage by multiplying by an appropriate drainage area at the project location. The gage data for some gages may need to be modified, as described in section 5.4 and Appendix E, to compute hydrology for project streams. If the watershed at the project site is underlain by only one type of geology, the hydrology can be computed using only one gage, and the drainage area at the project site. If the watershed includes significant amounts of different geology (for example, limestone and freestone, or different physiographic sections), the drainage area underlain by each type of geology or each physiographic type must be determined. Then the ADF and median monthly flows can be computed by multiplying the unit flow rate (csm) for each appropriate gage by the appropriate drainage area above the project site, and summing the resulting values for each type of geology. As discussed previously, the Vanport limestone in Armstrong, Butler, and Clarion Counties should be ignored in determining hydrology for study streams.

These regional hydrology computations assume there are no unusual conditions affecting the hydrology of the project stream. For some project streams, the computed flows need to be adjusted for the effects of significant springs or caverns, or for existing water withdrawals or wastewater treatment plant (WWTP) flows. The presence of significant springs can be determined from Flippo (1974). The presence of existing water withdrawals or WWTP flows can be determined from Pa. DEP files.

To use the regional hydrology procedure, locate the project site, using the map shown in Plate 2 and Table 6.8, and determine the appropriate hydrologic region. Then determine the type(s) of geology (or physiography) underlying the watershed upstream from the project site, and determine the drainage area for each type. Next, determine whether adjustments for the effect of springs are necessary from Flippo (1974), or other sources, and the magnitude of the adjustment. Also, determine whether adjustments for WWTP flows are necessary, and the magnitude of the adjustment. Then compute ADF, and median monthly flow time series, using the appropriate gage(s) for the geology/physiography type, add adjustments for WWTP flows and springs, and subtract adjustments for withdrawals. These calculations have to be performed prior to entering the impact analysis program. The data must be entered in units of cfs.

Pending additional studies, different types of geology should be considered when estimating ADF or median monthly flows only if the drainage area underlain by the nondominant geology, or physiography, exceeds 20 percent of the drainage area at the project site. If the nondominant geology is less than 20 per cent of the drainage area, it is expected to have little effect on the median monthly flows and the flow duration curve at the study site. If the nondominant geology exceeds 20 per cent of the drainage area, it may have significant effect on the hydrology at the study site.

6.6.4 <u>Impact analysis using flow and associated habitat duration</u>

6.6.4.1 Analysis procedure

Flow and associated habitat duration impact analysis can be used in developing statewide policies and procedures for managing the impact of withdrawals on fishery resources, and also can be used for site-specific analyses of impacts. The impact analysis procedure, described in this section, addresses the first purpose.

This method combines daily flow duration analyses for a study stream with habitat versus flow relationships to obtain associated habitat duration. The percentage reduction in habitat across a range of flows represents the impact of withdrawals. Flows and withdrawals are expressed as a percentage of ADF, or as unit flows (csm), so that levels of impact and passby flows can be compared across streams within a study region. Impacts and passby flows can be averaged across a region, if appropriate.

The procedure is shown schematically in Figure 6.15. Seasonal flow duration relationships for existing conditions are developed for each study site, using procedures described in section 5.4. One or more levels of withdrawal are selected, and expressed as a percentage of ADF. The

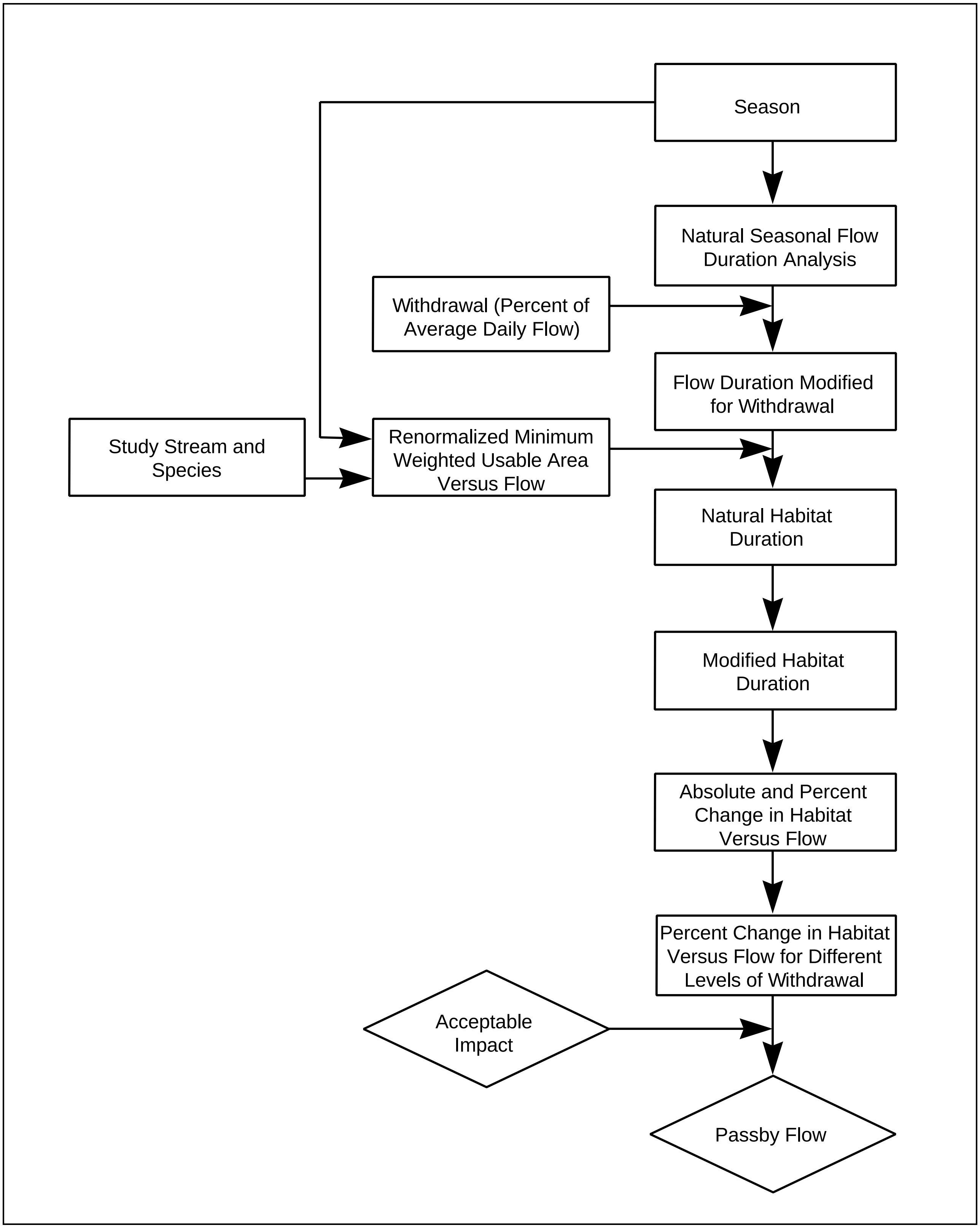

Figure 6.15. Flow and Associated Habitat Duration Impact Analysis Procedures

existing conditions associated habitat durations are developed for each stream from the existing conditions flow duration by determining habitat from the RMWUA versus flow relationship at several flows.

The impacted seasonal flow durations are computed by subtracting selected withdrawal(s) from the existing conditions flow durations. The associated habitat duration is developed from the habitat available at the impacted flow at selected probabilities for each level of withdrawal, as illustrated schematically in Figure 6.16. For each withdrawal, the change in habitat is determined for each selected probability, and expressed as a percentage. Finally, the percentage change in habitat is plotted versus flow for each level of withdrawal. The passby flow for a given withdrawal equals the lowest level of flow for which habitat reduction is equal to a specified level.

The habitat change graphs can be used to evaluate the effect of alternative passby flows and withdrawals by plotting passby flows required versus specified levels of impact for each level of withdrawal**.** The required passby flow for any level of withdrawal and any level of impact can be determined from the respective graphs for each study stream. The values of the passby flows for any specified level of impact can be tabulated for different streams within a stream class to facilitate decisions regarding acceptable level of impact and appropriate passby flows. The effects of establishing different levels of regulatory passby flow for a given level of withdrawal on the fishery can be developed from these graphs. Then the impact on the water supply utility can be estimated, and used to evaluate tradeoffs between effects of different levels of withdrawal and passby flow on both instream and withdrawal uses.

If this procedure was used, the variability of impacts and passby flows for the study sites within each class could be used to statistically verify the assumptions of the stream classification scheme. The validity of the assumption that all the reproducing trout streams in a study region respond similarly to flows and withdrawals could be verified.

The determination of the relationships among flows, withdrawals, and impact can be performed graphically or in a tabular form. The analysis has been programmed into an Excel spreadsheet format.

6.6.4.2 Flow and associated habitat duration impact analysis results

Impact analysis has been performed for brook trout, brown trout, and both species combined. Separate analyses were performed for each season, based on the life stages present. The seasons were determined as discussed in section 6.6.2, except that the analyses made thus far, assumed that the fall season included only the months of October and November. The analyses can be easily modified to include the remaining months in the fall season. Flow duration curves were developed using daily flow data for each season. In these analyses, withdrawal levels of 5, 10, and 15 percent of ADF were used, but any level of withdrawal can be used.

An example impact calculation is shown in Table 6.11**.** The impacted RMWUA could not be determined for certain high probability flows, because the impacted flow (existing conditions flow minus withdrawal) is less than any historical flow. An example habitat change versus flow relationship is shown in Figure 6.17. Certain values from the graph are summarized in Table 6.12. The specified levels of reduction were selected arbitrarily for illustration only.

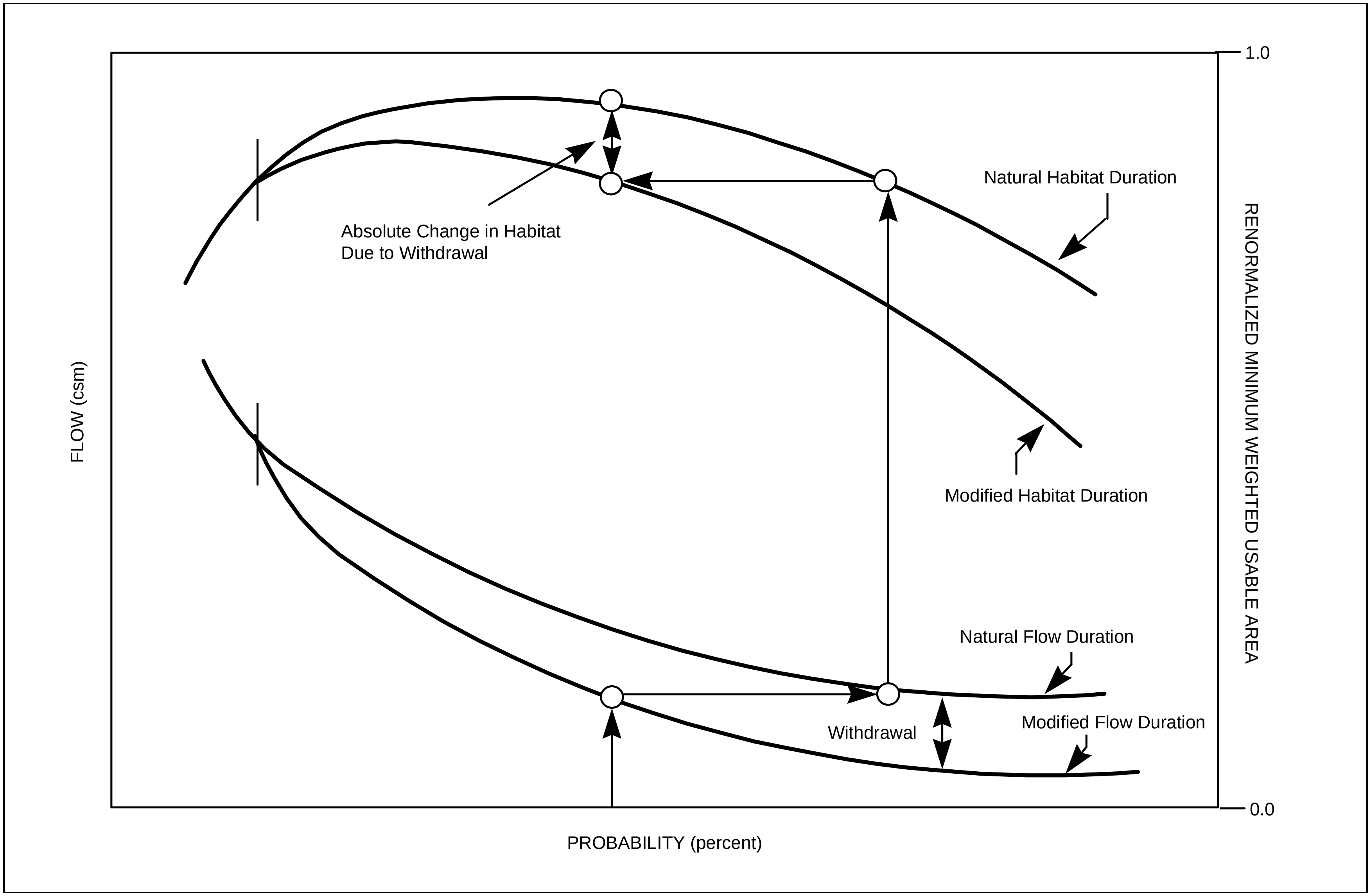

Figure 6.16. Schematic of Computation of Impact of Withdrawal on Habitat

Table 6.11. Sample Computation of Impact, Bear Run, Union County, Brook Trout, Summer Season

Flow Duration and Normalized Minimum Habitat
SEASON Summer (July-Sept)
Species Brook Trout
Stream Bear Run
Annual Mean = 4.120
% of ADF Withdrawal = 5%
% of ADF Withdrawal = 10%
% of ADF Withdrawal = 15%

Natural Flow			RMWUA	Impact of 5% ADF Withdrawal				Impact of 10% ADF Withdrawal				Impact of 15% ADF Withdrawal			
	Flow	Percent		Flow		RMWUA Difference		Flow		RMWUA Difference		Flow		RMWUA Difference	
Probability	(cfs)	Annual Mean		(cfs)	RMWUA	Absolute	Percent	(cfs)	RMWUA	Absolute	Percent	(cfs)	RMWUA	Absolute	Percent
100.00	0.39	9.49	0.270	0.18	No Value			0.00	No Value			0.00	No Value		
97.91	0.44	10.78	0.305	0.24	No Value			0.03	No Value			0.00	No Value		
95.99	0.53	12.94	0.362	0.33	No Value			0.12	No Value			0.00	No Value		
94.40	0.58	14.02	0.391	0.37	No Value			0.17	No Value			0.00	No Value		
89.88	0.67	16.17	0.431	0.46	0.315	-0.116	-26.90	0.25	No Value			0.05	No Value		
83.78	0.76	18.33	0.454	0.55	0.373	-0.081	-17.90	0.34	No Value			0.14	No Value		
70.65	0.89	21.56	0.473	0.68	0.435	-0.037	-7.86	0.48	0.326	-0.147	-31.07	0.27	No Value		
53.60	1.02	24.80	0.500	0.82	0.463	-0.037	-7.42	0.61	0.412	-0.088	-17.52	0.40	0.278	-0.222	-44.32
43.06	1.15	28.03	0.529	0.95	0.485	-0.044	-8.28	0.74	0.451	-0.078	-14.78	0.54	0.365	-0.164	-31.04
33.70	1.33	32.35	0.547	1.13	0.523	-0.024	-4.31	0.92	0.479	-0.067	-12.33	0.71	0.444	-0.103	-18.84
27.84	1.55	37.74	0.590	1.35	0.550	-0.040	-6.84	1.14	0.527	-0.063	-10.74	0.94	0.483	-0.107	-18.21
22.07	1.78	43.13	0.631	1.57	0.593	-0.038	-5.97	1.36	0.553	-0.078	-12.37	1.16	0.530	-0.101	-16.02
17.81	2.04	49.60	0.657	1.84	0.637	-0.020	-3.01	1.63	0.605	-0.051	-7.82	1.43	0.565	-0.092	-13.97
14.72	2.31	56.07	0.686	2.10	0.663	-0.024	-3.43	1.90	0.643	-0.043	-6.31	1.69	0.617	-0.069	-10.03
11.62	2.67	64.69	0.731	2.46	0.706	-0.025	-3.43	2.25	0.679	-0.052	-7.11	2.05	0.657	-0.073	-10.06
8.61	3.07	74.40	0.753	2.86	0.743	-0.010	-1.39	2.65	0.730	-0.023	-3.08	2.45	0.704	-0.049	-6.52

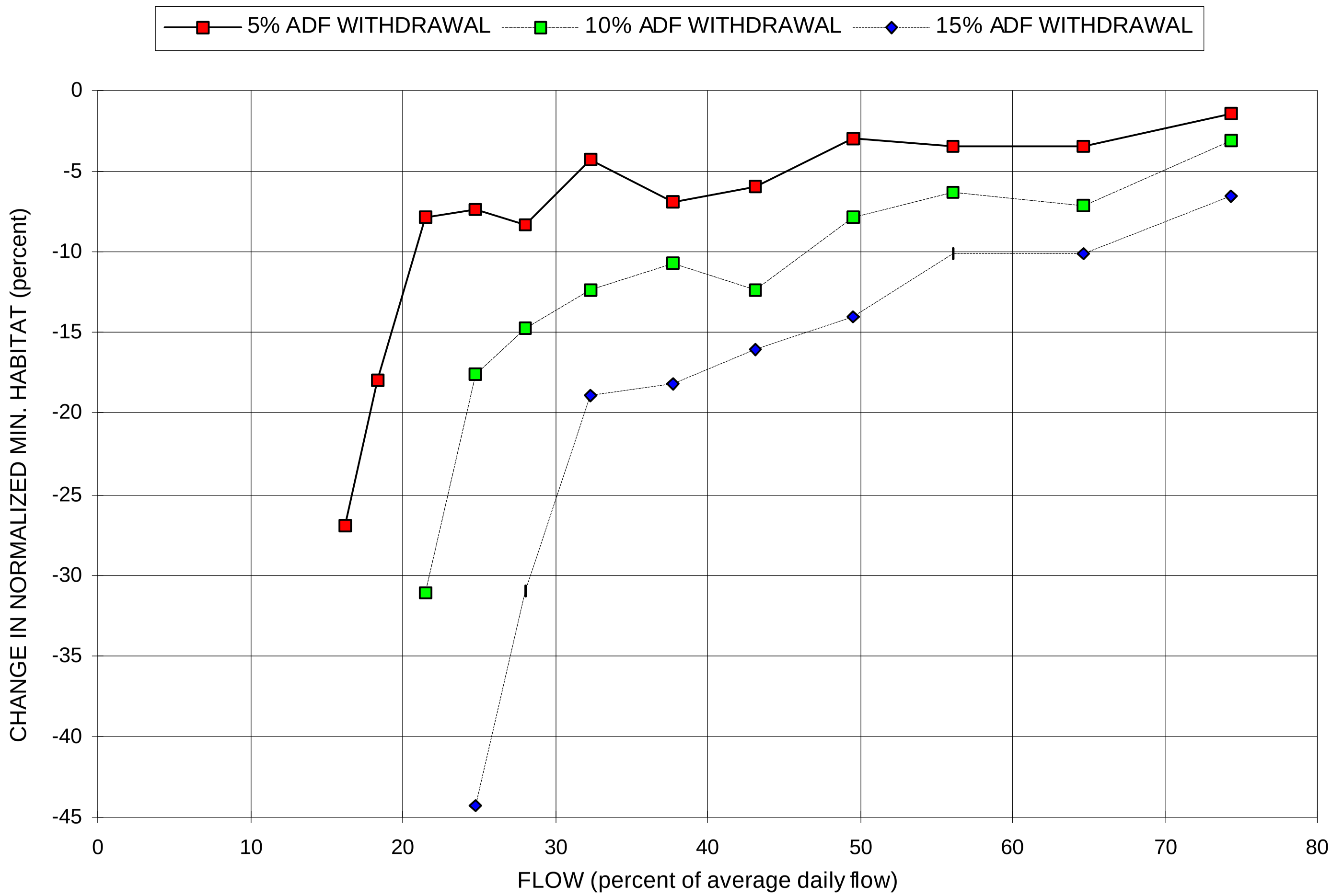

Figure 6.17. Habitat Change and Flow Relationship for Selected Withdrawals for Bear Run, Union County, Brook Trout, Summer Season

Table 6.12. Selected Points from Habitat Reduction Plot, Bear Run, Union County, Brook Trout, Summer Season

	Percentage Habitat Reduction for Selected Withdrawals		
	5	**10**	**15**
	percent ADF		
Flow at maximum impact (percent ADF)	17	22	25
Maximum impact (percent)	27	31	45
Flow at 15 percent impact	19	28	46
Flow at 25 percent impact	16	23	30

As expected, the percentage reduction decreases with increasing flow for a given level of withdrawal. The maximum percentage reduction in habitat is considerably larger than the percentage reduction in flow. The passby flows depend on the withdrawal and the level of impact, as expected. An increase in the level of reduction from 15 to 25 percent ADF decreases the passby flow by 3 to 16 percent ADF, depending on the level of withdrawal.

An example graph showing the relationship of passby flows versus level of impact for different levels of withdrawal is shown in Figure 6.18. This example shows that, for a 10 percent level of impact and a 5 percent ADF withdrawal, a passby flow equal to 20 percent of ADF is required. It also shows that, for a 5 percent ADF level of withdrawal, the passby flow requirement changes very little as the impact increases from 10 percent to 20 percent. The corresponding change in passby flow is larger for greater withdrawals. Other conclusions can be drawn from these graphs, if desired.

The flow and habitat duration impact analysis has not been completed, because of time and cost constraints. The plots of percentage reduction in habitat have been prepared for the study sites in Pennsylvania, but not for the Maryland study sites. However, analysis of the plots is incomplete.

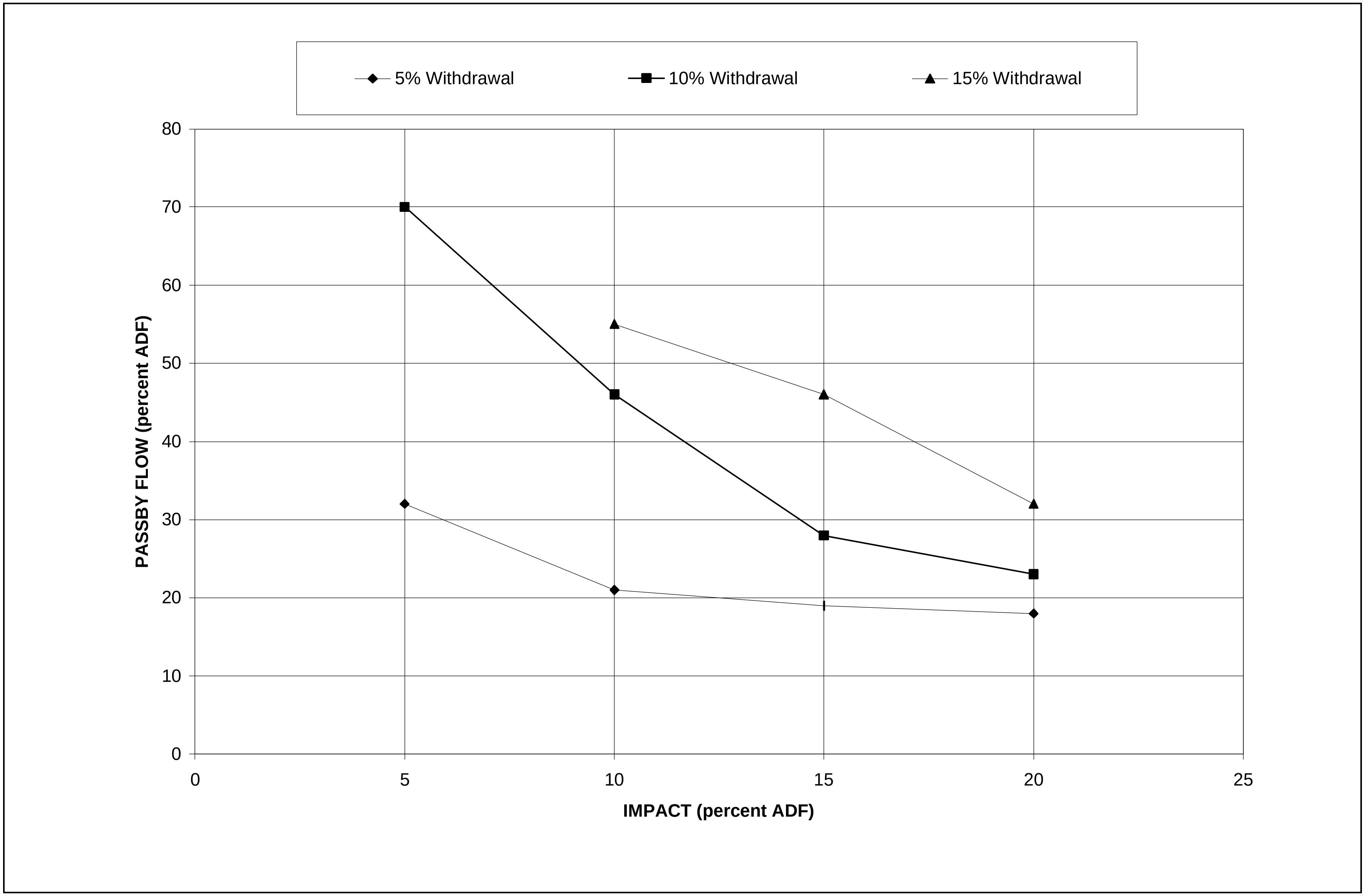

Figure 6.18. Example Passby Flow Versus Impact for Different Levels of Withdrawal, Bear Run, Brook Trout, Summer Season