7.0 SUMMARY, CONCLUSIONS, AND RECOMMENDATIONS

7.1 Summary

7.1.1 Study purpose and methods

Existing procedures for determining mandated conservation releases from major water supply reservoirs, or mandated passby flows at smaller dams and intake structures, have certain deficiencies, as explained in section 1.0. To correct these deficiencies, Pa. DEP, SRBC, PFBC, COE, MDE, and GSBRD developed a procedure for determining instream flow protection levels that: (1) is based on fishery resource protection; (2) is clearly applicable to Pennsylvania streams; (3) does not require expensive site-specific studies; and (4) can be easily applied during the administrative review of applications for surface water allocations. The procedure is based on fishery habitat. Instream flow needs are derived from hydrologic data and the data developed in the study.

The basic approach to the problem is to conduct instream flow needs assessment studies at selected representative sites, and then regionalize the results of the site-specific assessments to develop the procedure. Because of existing critical conflicts between instream and withdrawal uses on small trout streams in the Ridge and Valley, and unglaciated parts of the Appalachian Plateaus, physiographic provinces, the study focuses on those areas. Some streams in the Piedmont Upland physiographic section in Maryland also were studied. All the study streams had naturally reproducing trout populations, with drainage areas less than 100 square miles. Therefore, the procedure applies only to those streams at this time.

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

7.1.2 Evaluation species and habitat suitability criteria

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

For these species, depth and velocity suitability criteria were selected from the literature for use in the PHABSIM components of the IFIM methodology. A substrate/cover classification scheme and corresponding suitability criteria were developed for use in the study, based on professional judgement.

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

7.1.3 Study regions and study stream selection

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

Study regions were based on physiographic provinces and sections (Pa. DER, 1989). In the Ridge and Valley physiographic province, streams were classified into study regions based on limestone (including dolomite) or freestone (e.g., sandstone, shale, conglomerate) geology, rather than physiographic sections. In the Appalachian Plateaus physiographic province, streams were classified into glaciated and unglaciated study regions, based on the location of the glacial boundary (Pa. DEP, 1989). Streams in the unglaciated physiographic sections were combined into one study region called the Unglaciated Plateau. Trout streams in the Piedmont Province were classified based on physiographic section and limestone/freestone geology. Because of time and cost constraints, only the Ridge and Valley Limestone, Ridge and Valley Freestone, Unglaciated Plateau, and Piedmont Upland (freestone) study regions were included in this study.

Parts of five counties in the southwestern corner of Pennsylvania were deleted from the study, because the streams have very low yield, and there are few reproducing trout streams in the area. For these reasons, there are few water withdrawals from reproducing trout streams in that area. The area deleted is shown in the maps in Plates 1 and 2.

Lists of streams with naturally reproducing trout populations (reproducing trout streams) in each study region in Pennsylvania were developed from existing PFBC and Pa. DEP data. The list of trout streams in Maryland was developed from a report prepared by Steinfelt (1991). The presence of reproducing trout populations on certain study streams selected in Pennsylvania was verified in the field, because the PFBC records were incomplete. Potential study streams were selected from these lists by stratified random sampling. The actual study streams were selected in the field from the list of potential streams, also using stratified random sampling.

Study streams were divided into segments based on stream length, which was used as a surrogate for stream slope. The maximum allowable length of stream segments was set at 5 miles, based on statistical analysis of stream length data. The actual segment length depended on the total length of stream.

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

7.1.4 Field data collection

Once the study streams were chosen, a representative study site was selected near the midpoint of each segment. All study sites had good access, reproducing trout populations, good water quality, and no significant human influences. Then the relative amount of each different mesohabitat type (riffle, run, pool) was estimated for each study site. A representative occurrence of each mesohabitat type was selected, and a transect was located near the midpoint of the respective mesohabitat type.

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

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

7.1.5 Hydrology and habitat modeling

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

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

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

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

A pilot study was conducted to determine whether binary HSC should be used instead of univariate HSC, as recommended by Bovee and others (1994). WUA versus flow relationships for each type of criteria were computed and plotted. The WUA curves based on univariate criteria appeared more realistic and consistent with expected relationships for the study streams, which support good trout populations. The marginal habitat, which is not considered in the binary criteria, may be very important to trout populations. For that reason, univariate criteria were used to develop the WUA relationships used in the impact analysis.

7.1.6 Wetted perimeter analysis

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

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

7.1.7 Impact assessment methods and results

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

To obtain WUA versus flow relationships for each study site, each species, and each season, the life stage with the least habitat at any simulation flow was assumed to be the most critical life stage to be protected at that flow. A procedure was developed and implemented to compute these relationships, which are called the RMWUA.

To determine a conservation flow that would protect the habitat available, two alternative definitions of habitat loss were considered, no-loss of habitat, and no-net-loss of median monthly habitat. For this study, no-loss of habitat was defined as no reduction in RMWUA at any flow. No-net-loss of habitat was defined as no reduction of RMWUA at the median monthly flow. The no-loss criterion unnecessarily limits withdrawals under a wide range of conditions, considering that natural flow and available habitat fluctuate within months, and years, and among years. The no-net-loss criterion was found to significantly limit withdrawals during the summer season. Therefore, more detailed procedures were developed to assess the impact of water withdrawals on the habitat available.

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

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

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

A computer program has been developed in Microsoft Excel 7.0 format to estimate the impact of withdrawals for any site within a study region. There are two separate, but related, programs included in the package. The first, designated the detailed analysis program, provides a complete analysis of any combination of withdrawal and passby flow, and can analyze a number of different combinations of species and trout management procedures. This program also estimates the percent of time the withdrawal is not available for a given combination of withdrawal and passby flow. The second computer program, called the "preliminary analysis program," is designed to provide general estimates of impacts caused by withdrawals.

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

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

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

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

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

A partial list of limestone streams has been provided. Additional streams not included in the list should be classified as limestone or freestone, based on particular characteristics.

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

For all three study regions, the impact curves for brown trout and combined brown and brook trout are similar, so that either impact curve can be used. The brown trout curves are included in this report, because they are slightly more conservative. There are significant differences between impacts on brook trout, and combined brook and brown trout, as well as significant differences between impacts on brook and brown trout.

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

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

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

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

7.2 Conclusions

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

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

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

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

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

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

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

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

7.3 Recommendations

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

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

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

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

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

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

7.4 Areas for Further Research

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

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

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

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

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

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

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