Appendix H. Application of the Riparia database analysis to estimate TN, TP and TSS efficiencies

Editor's note: this was originally a handout provided to the panel prior to its May 2019 conference call. Only minor edits (e.g., table/figure numbers) were made when updating it for the panel's report as Appendix H.

This document provides a description of the multiple data sources/lines of evidence available to the Panel to inform efficiency values for the three wetland BMPs (creation, rehabilitation and enhancement). The panel has considered the water quality benefits of natural wetland and restoration wetlands to provide context for assigned efficiency values for the three BMPs. There are four parts to the document as follows:

- Lines of Evidence for Efficiency Values
- Data to support preliminary values for efficiency
- Proposed Method
- Sensitivity to Assumptions

1. Lines of Evidence for Efficiency Values

Error! Reference source not found. attempts to summarize the panel's primary sources and lines of evidence, including a description of how to interpret the efficiency value(s) in the right-hand column. Conceptual models are not included here, as the present concern is only for lines of evidence that deal with numeric efficiencies or related values.

Table H-1 – Summary of and Relationship Between Sources' Efficiency values

Source	What efficiency value(s) emerged	Short summary of method (if completed) or issue (if currently part of panel discussions)	Translation or relation to other sources or line of evidence
WEP 2016	Recommended 42% TN, 40% TP and 31% TSS efficiency values for **wetland restoration**, applied to varying ratios of upland acres based on landscape position and HGMR	The efficiency value was derived from literature values of non-constructed wetlands (included sites whether they were natural, or "restored" in some way). The values likely reflected differences between the input loads and output loads of the sites from the sources cited in the literature.	In relation to the Expert Elicitation survey, the literature-derived efficiency values are similar to the "post-treatment" efficiency values, reflecting the difference between input and output loads for the final site conditions. A net change efficiency was not used in this case.
Expert elicitation survey results	Round Two responses included best guess values for pre- and post-treatment conditions for the BMP categories, which allowed calculation of a "net efficiency" or net change value from pre- to post-treatment conditions	The panel was not comfortable using the survey results as a primary source given the individual panel member's interpretation of the questions (post construction vs net efficiency). There was a lot of uncertainty about the pre-treatment values, and less variability on post-construction efficiency values. The Panel found it agreeable to use the results in combination with other lines of evidence.	The survey essentially asked for the estimated efficiency values of a site under both baseline (pre-treatment) and a BMP-condition (post treatment), allowing calculation of the net change in efficiency – for each BMP category. The net efficiency change reflects the improvement in those efficiencies due to the management action.
Updated/ current lit review	The 2016 literature database was updated with studies reviewed by Panel members. The database allows to separate natural and BMP-wetland sites. Provides a range/quantiles of efficiency values. The updated literature review result in a change in the median, average values compared to the 2016 literature review.	The panel can now distinguish studies for natural and BMP wetland sites. Efficiency values reported in literature, as above, reflect difference between input and output loads post-construction	It remains difficult to distinguish specific interventions or techniques studied in the literature and relate those to the four wetland BMP categories
Riparia data analysis	Data provided for reference, reference standard and created wetlands in the Commonwealth of PA using an HGM field protocol. Values represent "Functional Assessment Model"scores of 0-1 for HGM classified wetlands, not efficiency values.	Use and application of this analysis is currently under panel discussion.	This line of evidence does not provide efficiency values, but it provides information to distinguish amongst wetland types that may relate to efficiency values following development of analytical methods.

Phase 6 Chesapeake Bay Watershed Model	16.75% TN, 32.18% TP and 9.82% TSS efficiency values are in place for the wetland creation, rehabilitation and enhancement BMPs until/unless this panel recommends otherwise. Wetland creation is also a land use change.	The old Phase 5.3.2 "wetland restoration" efficiency values and 1:1 upland acre ratio were approved for the Phase 6 CBWM until another panel recommends otherwise.	The panel expressed unanimous support against this status quo for the wetland creation, rehabilitation and enhancement BMPs. Panel may consider this as supporting evidence but not as a primary source or method.

Based on feedback from a survey and discussion at the March 4th meeting, the Panel reached a general agreement to use the Literature Review as a starting point to quantify the retention efficiencies for the three wetland BMPs and include the restoration wetland BMP for additional context. Additional data sources described in **Error! Reference source not found.** may be used to refine these initial values. For example, panel member, Denice Wardrop provided an analysis of the Riparia and the Pennsylvania Created Wetlands data to estimate and differentiate the relative water quality functions of natural and created wetlands in the Commonwealth of Pennsylvania. A method is proposed using these two data sources to provide preliminary pollutant retention efficiencies for the three wetland BMPs. A description of the two key data sources is provided below.

2. Data to Support Preliminary Efficiency Values

Literature Review (Updated database)

The results of the literature from 2016 Wetlands Expert Panel (WEP16) was used to assign TN, TP and TSS retention efficiencies to the wetland restoration BMP. Table 9 in the WEP16 report summarizes the results. The current WEP completed a literature review to update the previous panel's work and resulted in the addition of eight additional studies to the database. These eight studies were reviewed by the Center to ensure they were relevant and did not duplicate any previous entries. These studies were used to update Table 9 in the WEP16 report and is presented in **Error! Reference source not found.** below.

Table H-2. Summary of literature review to update WEP16 Table 9. (n= number of studies)

Wetland Type	Vegetation Type	TN % Reduction	TP % Reduction	TSS % Reduction
Headwater/Depressional	All	31.0% (10)	18.8% (16)	28.3% (6)
Floodplain	All	43.8% (22)	26.2% (15)	37.1% (11)
All except constructed	Forest, mixed, and unknown	45.1% (21)	44.4% (45)	37.3% (11)
All except constructed	Emergent	38.8% (22)	18.6% (16)	29.7% (8)
All	All	37.7% (57)	37.6% (88)	43.6% (24)
Chesapeake Bay only	All	26.0% (12)	23.9% (14)	24.4% (8)

All except constructed	All	40.7% (40)	37.6% (61)	34.1% (19)

The data from the literature were further analyzed to separate retention efficiencies for natural and wetland BMPs; constructed wetlands were not included. Appendix A provides the results with a summary in Table H-3.

Table H-3. Average Retention Efficiencies (%) for Natural and Wetland BMPs from the Literature Review, (n= number of studies)

Wetland Type	TN (%)	TP (%)	TSS (%)
Natural wetlands	45 (15)	42 (17)	n/a
Wetland BMPs	39 (21)	42 (46)	43 (12) | 36 (10)[1]

[1] The average TSS percent reduction from all studies in the literature review database is 36%. The analysis was repeated using this value to adjust the TSS retention efficiency values.

Riparia and Created Wetlands Data

The Riparia Reference Wetland Database (herein referred to as PA Reference or Riparia) (Brooks et al., 2016) consists of 222 natural wetland sites that were originally established during the period of 1993-2003; many have been re-sampled on a 10-year interval since then. The uses of the dataset, background on its formation, and definitions of terms can be found in Brooks et al. (2016). The Pennsylvania Created Wetlands Dataset (herein referred to as Created) is the result of a research project by Naomi Gebo, and the majority of the sites (72) in the database are detailed in Gebo and Brooks (2012); this study compared created wetland sites to the natural wetlands contained in the aforementioned database (additional sites were subsequently added to the database).These datasets contain values across three sampling protocols, termed Level 1, 2, and 3. Level 1 is a Landscape Assessment, which characterizes land cover parameters surrounding the site and can give a rough approximation of expected condition of the site based on these parameters. Level 2 is termed a Rapid Assessment, and supplements the Level 1 assessment with a short field visit that obtains data on the presence of various stressors of the site (e.g., evidence of eutrophication, sedimentation, invasive plants) and buffer characteristics. Level 3 involves a detailed field assessment that obtains information required to estimate various condition indicators (e.g., Floristic Quality Assessment Index, Plant-based Index of Biotic Integrity) and a suite of Hydrogeomorphic (HGM) Functional Assessments. The datasets are presented in Table H-4; the data was obtained under various US EPA grant programs, and is considered to be publicly-available.

Table H-4. Datasets Used in the Analysis.

Database	Classification System	Level 1 Landscape Assessment	Level 2 Stressor Checklist and Buffer Characterization	Level 3 Intensive Condition and HGM Functional Assessment	Comments
PA Reference Sites (n=222)	HGM	Available	Available	Available	Includes Reference Standard sites in each category of ecoregion/HGM class
PA Created Wetlands (n=120)	HGM	Available	Available	Available	Sampled in 2007/2008; sites ranged in age from 3 to 17 years since construction

Classification System

Both the PA Reference and Created Sites utilize the Hydrogeomorphic System classification. Brinson's (1993) HGM classification system looked to properties of geomorphic setting, water source, and hydrodynamics to derive a set of classes of wetlands associated with their ecological functions. Not all wetlands provide the same functions or to the same level (e.g., wetlands in a floodplain setting provide storage of flood waters, while slope wetlands, which by Brinson's definition do not have contours that create a basin, do not). As stated above, HGM classification describes an approach to classifying wetlands that aids in distinguishing the functions that each type can perform and in the identification of the potential effects of anthropogenic disturbance. For purposes of this exercise, we concentrate on three major HGM classes: Riverine (wetlands located along 4th order or greater streams/rivers), Headwater (wetlands occurring in the riparian areas on up to 3rd order streams), and Isolated Depressions. Fringing wetlands (those wetlands located on lakes and ponds) are excluded from the analysis.

Reference, Reference Standard, and Created

The PA Reference Sites are composed of natural wetlands that cover the full range of condition and level of anthropogenic disturbance. A subset of sites is designated as Reference Standard; Reference Standard refers to conditions at the least, or minimally, impacted sites, thereby providing the potential to develop a quantitative description of the best available chemical, physical, and biological conditions in the wetland resource given the current state of the landscape. This conceptual framework and family of definitions is adaptable to any wetland type in any geographic setting; for example, a Reference Standard can be developed for Riverine wetlands in the Piedmont ecoregion. The PA Reference Sites

were decomposed into two groups for analysis: Reference Standard (i.e., least impacted) and Reference (all remaining sites).

Water Quality Functions

For this analysis, we are concentrating on the HGM water quality functions F5, F6, F7. The results of the complete analysis are provided in Appendix B. As an expanded example, the model for F5, Removal of Inorganic Nitrogen, is shown below:

Removal of Inorganic Nitrogen
$(V_{REDOX} + V_{BIOMASS} + V_{ORGMAT})/3$

Where:
V_{REDOX}: Redoximorphic status of upper soil profile based on mottle and matrix chromas
$V_{BIOMASS}$: Cover of trees, shrubs, and herbs
V_{ORGMAT}: % organic content in the top 5 cm of soil determined by combustion
All variables are data collected in the field.

The remaining models are as follows.

Solute Adsorption Capacity (F6)
$[(V_{FLOODPL} * 0.67) + (V_{ALTFLOODPL} * 0.33)] *$
$[(V_{REDOX}+V_{ROUGH}+V_{MACROTOPO})/3 + V_{ORGMAT}+$
$V_{SOILTEX})/2]/2$

Retention of Inorganic Particulates (F7)
$[(V_{FLOODPL} * 0.67) + (V_{ALTFLOODPL} * 0.33)] * [(V_{ROUGH} +$
$V_{MACROTOPO} + V_{GRAD})]/3$

The following figures provide a summary of how the HGM scores compare in different wetland settings (i.e., floodplain, headwaters and isolated depression).

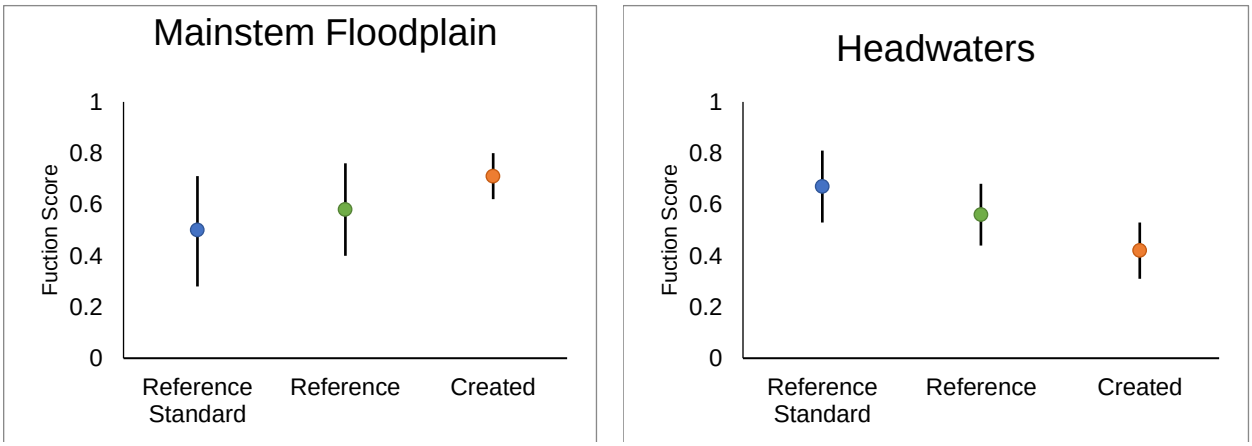


Figure H-1. HGM Scores (Mean with SD Ranges) for Score F5: Inorganic Nitrogen

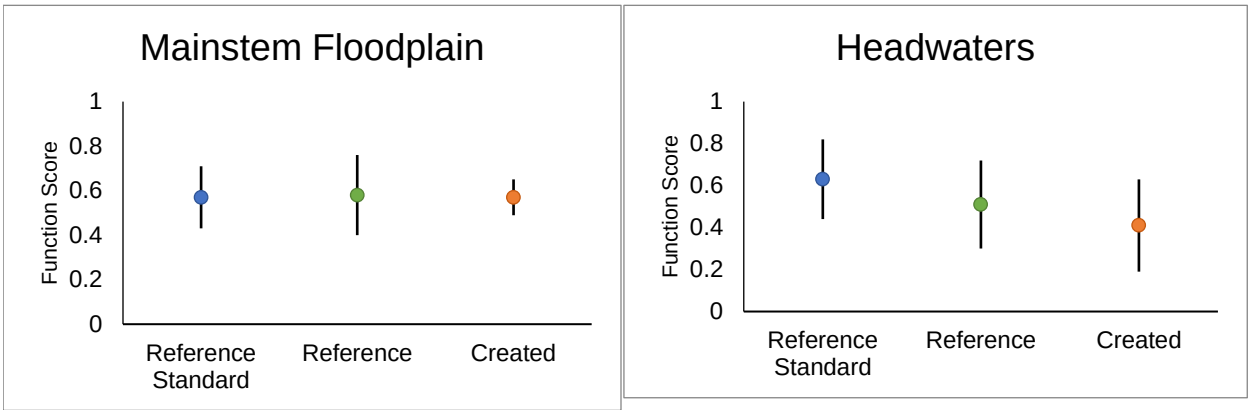


Figure H-2. HGM Scores (Mean with SD Ranges) for Score F6: Solute Absorption

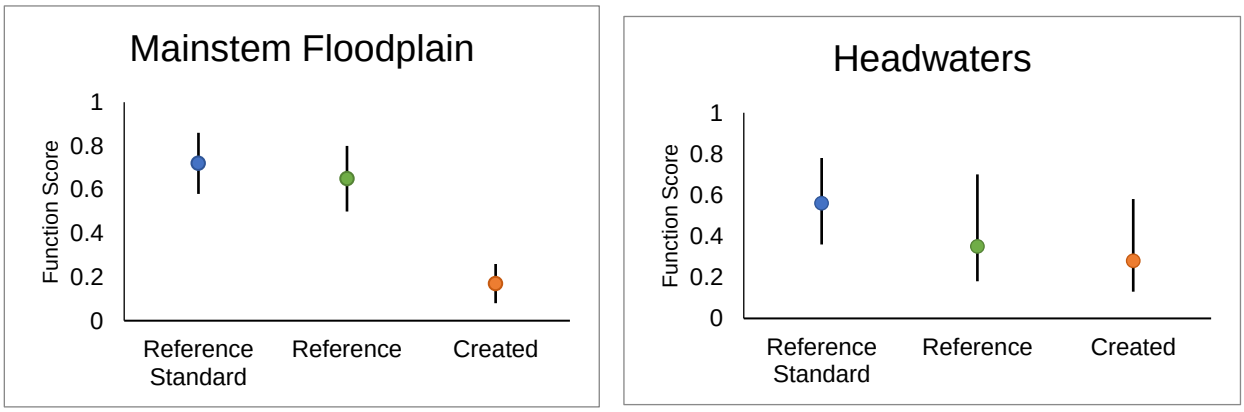


Figure H-3. HGM Scores (Mean with SD Ranges) for Score F7: Retention of Inorganic Particulates

3. Proposed Method

The following outlines a method for using the HGM Scores (using the Headwaters setting as the example) combined with the wetlands literature review database to estimate removal efficiencies. The method uses the scores to represent a percentile among the Wetland Database efficiencies.

To facilitate this analysis, a set of assumptions and a definition of net efficiency was applied.

1. The scores for the Reference wetlands in the Riparia database are representative of post-construction BMP wetland conditions for restoration and rehabilitation. Both wetland BMPs have similar outcomes according to the Chesapeake Bay definitions, where a restoration and rehabilitated wetland should result in the return or repair of wetland functions similar to a historic or natural wetland, respectively. As such, **Error! Reference source not found.** presents the following wetland conditions assigned for the purposes of method development.

Table H-5. Wetland condition assigned to wetlands in the Riparia database.

Wetland type	Description	Condition
Reference Standard	Existing wetlands in forested settings	Natural, undisturbed wetland
Reference	Existing wetlands in agricultural or urban settings	Approximate water quality functions of a restored or rehabilitated wetland
Created	Created wetlands	Created wetlands

2. The mean scores (0-1) represented by each wetland type are used to scale efficiency values between wetland types.
3. The results using the Headwater Wetlands category are used in the analysis, as these wetlands are predominant in Pennsylvania, where the Riparia data originate from.
4. A net efficiency definition is used, where it is assumed that a restoration and created wetland have a pre-treatment of "0" as there is no wetland present. For the Pre-BMP Condition for Rehabilitation, we assume that the score is equivalent to the 10th percentile for Reference Wetlands. This was based on best professional judgement given the distribution of the Riparia data and a first estimation.

Error! Reference source not found. provides a summary of the data used for the Headwater Wetlands from analysis provided by Denice Wardrop.

Table H-6. Mean Scores from the HGM Functional Assessment Models for Headwater Wetlands for Each Wetland Type

Wetland Type	Wetland BMP State Represented	Scores (Headwater Wetlands)		
		F5. Inorganic Nitrogen	F6. Solute Adsorption	F7. Inorganic Particulates
Reference	Post-BMP for Rehabilitation and Restoration	0.56	0.51	0.50
Created	Created	0.42	0.41	0.38
10th percentile for Reference Wetlands[1]	Pre-BMP Condition for Rehabilitation	0.41	0.24	0.24
1: This value is estimated assuming a normal distribution, and the mean and standard deviation provided for each score.				

Scaling Factor Method

In this approach, the scores from the HGM Functional Assessment Models (the HGM scores) are used to represent the ratio of performance for each wetland condition. Using this approach, the efficiency for any condition is calculated using the following equation:

$$E = E_{base} \times F$$

Where:

- E = Efficiency for a particular wetland state and pollutant
- E_{base} = "Base" efficiency represented as the mean value for wetland BMPs (from Table 2)
- F = Factor used to scale the efficiency (derived from HGM Scores)

As a first step, we derive individual F values for each HGM score, assuming that:

1) The Scaling Factor for Reference Values is 1.0, since the efficiency for this condition is equivalent to the mean efficiency from the wetlands database. That is, the efficiency value from the literature review database from Table H-2 is multiplied by 1.
2) Other scaling factors are calculated by determining the ratios of the score for a particular condition relative to the reference value.

As an example calculation, the Efficiency Ratio for F5 for Created wetlands is calculated as:

$F_{F5\text{-}Created}$ = (F5 HGM Score for Created) /(F5 HGM Score for Reference)

= 0.42 /0.56

= 0.75

The resulting scaling Factors (Table H-7) begin to indicate the relative condition for each wetland state. Although the factors for each score are relatively similar across each wetland type, there are some distinctions. For example, the F5 scaling factor for the Pre-BMP Condition for Rehabilitation (0.72) is much higher than the ratio for other factors (0.47-0.48).

Table H-7. Scaling Factors (F) for HGM Scores

Wetland Type	Wetland BMP State Represented	Scores		
		F5. Inorganic Nitrogen	F6. Solute Adsorption	F7. Inorganic Particulates
Reference	*Post-BMP for Rehabilitation and Restoration*	*1.00*	*1.00*	*1.00*
Created	*Created*	*0.75*	*0.80*	*0.76*
10th percentile for Reference Wetlands	*Pre-BMP Condition for Rehabilitation*	*0.72*	*0.47*	*0.48*

The scaling factors (F) in Table H-7 can then be used to estimate a composite or average factor for each chemical parameter. Since each score represents a different wetland function, we represent the performance for each chemical parameter using a different set of scores, as follows:

- TN is the average of F5 (Inorganic Nitrogen Retention) and F7 (Inorganic Particulate Retention)
- TP is the average of F6 (Solute Adsorption) and F7 (Inorganic Particulate Retention)
- TSS is F7 (Inorganic Particulate Retention)

The resulting average ratios are presented in Table H-8. As indicated in the table, we generally see similar scaling factors across different parameters, except for an elevated scaling factor (0.60) for TN for the Pre-BMP condition for Rehabilitation, compared with 0.48 for TP and TSS for the same condition.

Table H-8. Efficiency Scaling Factors for Each Chemical Parameter

Wetland BMP State Represented	Parameter		
	TN	TP	TSS
Post-BMP for Rehabilitation and Restoration	*1.00*	*1.00*	*1.00*
Created	*0.78*	*0.78*	*0.76*
Pre-BMP Condition for Rehabilitation	*0.60*	*0.48*	*0.48*

Next, these ratios can be translated into efficiencies, using the mean values from the wetland literature database to represent the mean efficiencies for the Post-Restoration/Rehabilitation condition. Each other efficiency can then be determined using the multipliers in Table H-8.

For example:

- The Mean TN for non-natural wetlands from the wetland literature review database is 39%.
- The ratio to convert to a Created wetland efficiency is 0.78

Calculate the TN removal for created wetlands as: 0.78*39% = 30.42% (use 30%)

For Rehabilitation, we assume that the rehabilitation efficiency is the difference between the Post-BMP and Pre-BMP condition. For example, the TN efficiency would be calculated by the following:

- The Mean TN for non-natural wetlands from the wetland literature review database is 39%.
- The ratio for a Pre-BMP Condition is 0.60

Calculate the TN removal for rehabilitation as: 39%*(1-0.60) = 15.6% (use 16%)

The Resulting efficiencies are presented in Table H-9.

Table H-9. Estimated Wetlands Efficiencies Using Scaling Factors

	Wetland BMP Efficiency	Parameter		
		TN	**TP**	**TSS**
Restoration[1] **Mean from our literature review database**	*Pre-Restoration*	0%	0%	0%
	Post-Restoration	39%	42%	43%
	Lift	39%	42%	43%
Creation	*Pre-Creation*	0%	0%	0%
	Post-Creation Riparia Scaling of restored efficiency (ratio of Created to Reference)	30%	33%	35%
	Lift:	30%	33%	35%
Rehabilitation	*Pre-Rehabilitation Riparia Scaling (ratio of 10th percentile Reference to Mean of Reference)*	23%	20%	20%
	Post-Rehabilitation	39%	42%	43%
	Lift	16%	22%	23%

1: Note that these efficiencies are derived from the updated literature review database and are not the same as those used in the Watershed Model.

4. Sensitivity to Assumptions

Some of the assumptions made for this analysis may alter the estimated efficiency (i.e., the lift). Two that panel members expressed concern about include:

1) The representation of Rehabilitation (i.e., using the 10th percentile of reference for pre-BMP and the Mean of reference for post-BMP).
2) Using Headwaters wetlands to represent the overall wetland condition.

Assumption 1: Representing Rehabilitation

To address panel member concerns regarding how to estimate the Pre-BMP and Post-BMP efficiencies for Rehabilitation, we evaluated the potential impacts of alternative assumptions. We evaluated the effect of using different percentiles of the reference wetlands for the pre- and post-treatment condition. We used the 25th percentile and 75th percentile values for the pre- and post- condition, respectively, with resulting HGM scores presented in Table H-10. Using the same process as described in Section 3, the resulting removal percentages for each condition would vary based on the underlying assumptions (Table H-11).

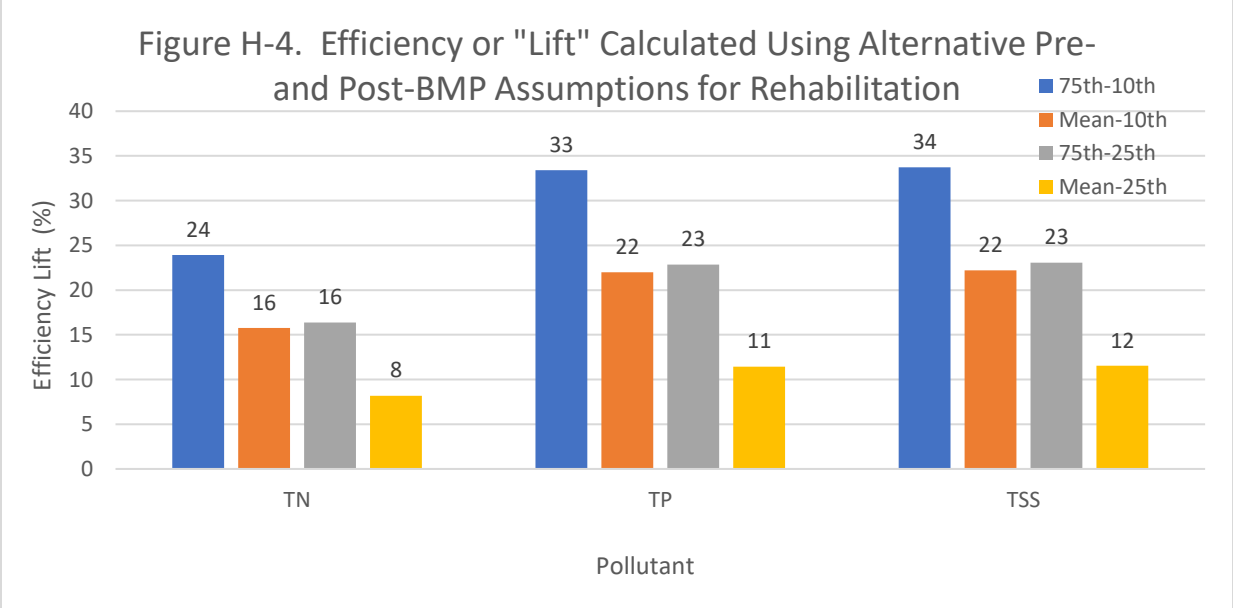
Table H-10. Riparia Scores Using Alternative Assumptions for Rehabilitation

Wetland Type[1]	**Wetland BMP State Potentially Represented**	**Scores (Headwater Wetlands)**		
		F5. Inorganic Nitrogen	**F6. Solute Adsorption**	**F7. Inorganic Particulates**
Reference	Post-BMP for Rehabilitation	0.56	0.51	0.50
75th Percentile		0.64	0.65	0.63
10th percentile	Pre-BMP Condition for Rehabilitation	0.41	0.24	0.24
25th Percentile		0.48	0.37	0.37
1: Percentiles estimated assuming a normal distribution, and the mean and standard deviation provided for each score.				

Table H-11. Resulting Percent Pollutant Removal for Rehabilitation Using Alternative Assumptions for the Pre- and Post-Wetland Condition (this does not express the "net improvement" or "lift")

Wetland Type[1]	Wetland BMP State Potentially Represented	Removal Efficiency		
		TN	TP	TSS
Reference	Post-BMP for Rehabilitation and Restoration	39%	42%	43%
75th Percentile		47%	53%	55%
10th percentile	Pre-BMP Condition for Rehabilitation	23%	20%	20%
25th Percentile		31%	33%	35%
1: Percentiles estimated assuming a normal distribution, and the mean and standard deviation provided for each score.				

The resulting lift will vary depending on how these assumptions are combined. As illustrated in Figure H-4, the lift is quite different when the extreme assumptions (in either condition) are made. For example, by assuming that Rehabilitation increases performance from a very degraded (10th percentile) wetland to a highly functioning (75th percentile), it would result in a 24% lift for TN, compared with the 16% estimated using our "baseline" assumption of an increase from the 10th percentile to the Reference Mean. However, when we compare the two more moderate assumptions (i.e., increasing from the 10th percentile to the mean, or increasing from the 25th percentile to the 75th percentile), there is almost no difference, in that the calculated lift is within 1% regardless of the method used.



Assumption 2: Use of Headwaters Data

The Riparia dataset includes both Headwaters and Floodplain wetlands. In developing our efficiency methods, we chose to use Headwaters wetlands to reflect the conditions of wetlands at various states. Since this dataset is from Pennsylvania, where the great majority of wetlands were in the headwaters, it was determined that these values may be a more representative depiction of performance. However, this assumption did result in different efficiency values than we would have calculated using headwater calculations. For wetland creation, the estimated efficiency ranges from 30% and 33% depending on the pollutant using headwater wetlands, but the efficiency ranges from about 11% for TSS up to 43% for TN using floodplain data (Figure H-5). The results between the two datasets are more similar for wetland rehabilitation. Using the headwaters data, the efficiency is 16% for TN, and 22% for TP and TSS. When using the floodplain data, the TN efficiency is still 16%, but the TP and TSS efficiencies are 15% and 13%, respectively (Figure H-6).