Watershed Report for Biological Impairment of the Transquaking River Watershed in Dorchester County, Maryland
Biological Stressor Identification Analysis Results and Interpretation

FINAL

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List of Abbreviations

AR	Attributable Risk
BIBI	Benthic Index of Biotic Integrity
BMP	Best Management Practices
BSID	Biological Stressor Identification
COMAR	Code of Maryland Regulations
CWA	Clean Water Act
FIBI	Fish Index of Biologic Integrity
IBI	Index of Biological Integrity
IR	Integrated Report
MBSS	Maryland Biological Stream Survey
MDDNR	Maryland Department of Natural Resources
MDE	Maryland Department of the Environment
MH	Mantel-Haenzel
mg/L	Milligrams per liter
µS/cm	Micro Siemens per centimeter
NH_3	Ammonia
NMP	Nutrient Management Practices
NPDES	National Pollutant Discharge Elimination System
OP	Orthophosphate
SSA	Science Services Administration
TMDL	Total Maximum Daily Load
TN	Total Nitrogen
TP	Total Phosphorus
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey
WQA	Water Quality Analysis
WQLS	Water Quality Limited Segment

Executive Summary

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met.

The Transquaking River watershed (basin code 02130308) is located in Dorchester County, and is included in one Chesapeake Bay listing segment in the Integrated Report (IR): Fishing Bay Mesohaline and the Transquaking River non-tidal. Below is a table identifying the listings associated with this watershed. A 1996 Category 5 listing for nutrients was amended to Category 4a based upon the approval of a TMDL for nutrients in the tidal portion of the watershed by USEPA in 2000.

Table 1. 2010 Integrated Report Listings for the Transquaking River Watershed

Watershed	Basin Code	Non-tidal/Tidal	Designated Use	Year listed	Identified Pollutant	Listing Category
Transquaking River	02130308	Non-tidal	Aquatic Life and Wildlife	2002	Impacts to Biological Communities	5
Fishing Bay Mesohaline	FSBMH	Tidal	Seasonal Migratory fish spawning and nursery Subcategory		TN	3
					TP	3
			Aquatic Life and Wildlife		Impacts to Estuarine Biological Communities	3
			Open Water Fish and Shellfish	1996	TN	3
				1996	TP	3
			Seasonal Shallow Water Submerged Aquatic Vegetation	2008	TSS	3

In 2002, the State began listing biological impairments on the Integrated Report. The current Maryland Department of the Environment (MDE) biological assessment methodology assesses and lists only at the Maryland 8-digit watershed scale, which maintains consistency with how other listings on the Integrated Report are made, TMDLs are developed, and implementation is targeted. The listing methodology assesses the condition of Maryland 8-digit watersheds by measuring the percentage of stream miles that have poor to very poor biological conditions, and calculating whether this is significantly different from a reference condition watershed (i.e., healthy stream, <10% stream miles with poor to very poor biological condition).

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Transquaking River and all tributaries is Use I designation - w*ater contact recreation, and protection of nontidal warmwater aquatic life.* In addition, there are parts of the lower mainstem and tributaries of the Transquaking River that are Use II designation - s*upport of estuarine and marine aquatic life and shellfish harvesting.* (COMAR 2011 a,b,c). The Transquaking River watershed is not attaining its Use I and II designations because of impacts to biological communities. As an indicator of designated use attainment, MDE uses Benthic and Fish Indices of Biotic Integrity (BIBI/FIBI) developed by the Maryland Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS).

The current listings for biological impairments represent degraded biological conditions for which the stressors, or causes, are unknown. The MDE Science Services Administration (SSA) has developed a biological stressor identification (BSID) analysis that uses a case-control, risk-based approach to systematically and objectively determine the predominant cause of reduced biological conditions, thus enabling the Department to most effectively direct corrective management action(s). The risk-based approach, adapted from the field of epidemiology, estimates the strength of association between various stressors, sources of stressors and the biological community, and the likely impact these stressors would have on degraded sites in the watershed.

The BSID analysis uses data available from the statewide MDDNR MBSS. Once the BSID analysis is completed, a number of stressors (pollutants) may be identified as probable or unlikely causes of poor biological conditions within the Maryland 8-digit watershed study. BSID analysis results can be used as guidance to refine biological impairment listings in the Integrated Report by specifying the probable stressors and sources linked to biological degradation.

This Transquaking River watershed report presents a brief discussion of the BSID process on which the watershed analysis is based, and which may be reviewed in more detail in the report entitled *Maryland Biological Stressor Identification Process* (MDE 2009). Data suggest that the biological communities of the Transquaking River watershed are strongly influenced by agricultural land use and its concomitant effects:

altered stream morphology and elevated levels of sediments and nutrients. The development of landscapes creates broad and interrelated forms of degradation (i.e., hydrological, morphological, and water chemistry) that can affect stream ecology and biological composition. Peer-reviewed scientific literature establishes a link between agricultural landscapes and degradation in the aquatic health of non-tidal stream ecosystems.

The results of the BSID analysis, and the probable causes and sources of the biological impairments in the Transquaking River watershed can be summarized as follows:

- The BSID process has determined that biological communities in the Transquaking River watershed are likely degraded due to sediment and in-stream habitat related stressors. Specifically, agricultural runoff has led to increased settling of sediment in the stream substrate throughout the watershed, which is the probable cause of impacts to biological communities. The BSID results confirm the tidal 2008 Category 5 listing for total suspended solids (TSS) as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extend the impairment to the watershed's non-tidal waters. Therefore, the establishment of total suspended solids TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Transquaking River watershed. In addition, the BSID results support the identification of the non-tidal portion of this watershed in Category 5 of the Integrated Report as impaired by TSS to begin addressing the impacts of this stressor on the biological communities in the Transquaking River.

- The BSID process has determined that the biological communities in the Transquaking River watershed are likely degraded due to water chemistry related stressors, specifically (i.e. total phosphorus and orthophosphates). Agricultural land use practices have resulted in the potential elevation of phosphorus inputs throughout the watershed, which are in turn probable causes of impacts to biological communities. The BSID analysis uses a case-control, risk-based approach too systematically and objectively determine the predominant cause(s) and source of degraded biological conditions. Currently, there is no scientific consensus on numeric nutrient criteria for non-tidal streams (ICPRB 2011). Nutrients in excess do not act directly as pollutants in aquatic systems but, rather, manifest their negative effects via changes in chemical and biological metrics. For this reason, numeric thresholds or ranges of nutrient concentrations should not, by themselves, be used to list non-tidal stream segments as impaired by nutrients (Category 5). Maryland has thus taken an alternative, multi-faceted 'causal pathway' approach. Under this approach, a stream segment may be listed as impaired by nutrients only when poor biological conditions are demonstrated (via low Indices of Biotic Integrity or IBIs) in conjunction with (1) high nutrient concentrations, and (2) one or more of the following stressors known to be associated with nutrient over-enrichment and have scientifically defensible regulatory limits: (a) Low dissolved oxygen (DO) concentrations; (b) low or high DO saturation; (c) high pH. Since none of the stressors known to be associated with nutrient over enrichment were identified in the BSID analysis, a Category 5 listing for nutrients is not recommended for Transquaking River. In the absence of a firm causal pathway as described above, concluding that Transquaking River is impaired by nutrients could result in unnecessary planning and pollution control implementation costs.

1.0 Introduction

Section 303(d) of the federal Clean Water Act (CWA) and the U.S. Environmental Protection Agency's (USEPA) implementing regulations direct each state to identify and list waters, known as water quality limited segments (WQLSs), in which current required controls of a specified substance are inadequate to achieve water quality standards. For each WQLS listed on the *Integrated Report of Surface Water Quality in Maryland* (Integrated Report), the State is to either establish a Total Maximum Daily Load (TMDL) of the specified substance that the waterbody can receive without violating water quality standards, or demonstrate via a Water Quality Analysis (WQA) that water quality standards are being met. In 2002, the State began listing biological impairments on the Integrated Report. Maryland Department of the Environment (MDE) has developed a biological assessment methodology to support the determination of proper category placement for 8-digit watershed listings.

The current MDE biological assessment methodology is a three-step process: (1) a data quality review, (2) a systematic vetting of the dataset, and (3) a watershed assessment that guides the assignment of biological condition to Integrated Report categories. In the data quality review step, available relevant data are reviewed to ensure they meet the biological listing methodology criteria of the Integrated Report (MDE 2010). In the vetting process, an established set of rules is used to guide the removal of sites that are not applicable for listing decisions (e.g., tidal or black water streams). The final principal database contains all biological sites considered valid for use in the listing process. In the watershed assessment step, a watershed is evaluated based on a comparison to a reference condition (i.e., healthy stream, <10% degraded) that accounts for spatial and temporal variability, and establishes a target value for "aquatic life support." During this step of the assessment, a watershed that differs significantly from the reference condition is listed as impaired (Category 5) on the Integrated Report. If a watershed is not determined to differ significantly from the reference condition, the assessment must have an acceptable precision (i.e., margin of error) before the watershed is listed as meeting water quality standards (Category 1 or 2). If the level of precision is not acceptable, the status of the watershed is listed as inconclusive and subsequent monitoring options are considered (Category 3). If a watershed is still considered impaired but has a TMDL that has been completed or submitted to EPA it will be listed as (Category 4a). If a watershed is classified as impaired (Category 5), then a stressor identification analysis is completed to determine if a TMDL is necessary.

The MDE biological stressor identification (BSID) analysis applies a case-control, risk-based approach that uses the principal dataset, with considerations for ancillary data, to identify potential causes of the biological impairment. Identification of stressors responsible for biological impairments was limited to the round two Maryland

Department of Natural Resources Maryland Biological Stream Survey (MDDNR MBSS) dataset (2000–2004) because it provides a broad spectrum of paired data variables (i.e., biological monitoring and stressor information) to best enable a complete stressor analysis. The BSID analysis then links potential causes/stressors with general causal scenarios and concludes with a review for ecological plausibility by State scientists. Once the BSID analysis is completed, one or several stressors (pollutants) may be identified as probable or unlikely causes of the poor biological conditions within the Maryland 8-digit watershed. BSID analysis results can be used together with a variety of water quality analyses to update and/or support the probable causes and sources of biological impairment in the Integrated Report.

The remainder of this report provides a characterization of the Transquaking River watershed, and presents the results and conclusions of a BSID analysis of the watershed.

2.0 Transquaking River Watershed Characterization

2.1 Location

The Transquaking River is located in Dorchester County, Maryland (Figure 1). It originates south of East New Market flowing in a southerly direction and finally drains to the Chesapeake Bay through Fishing Bay roughly seven miles due south of Bestpitch. The Transquaking River watershed has an area of approximately 69,800 acres.

The Transquaking River is tidal throughout its navigable reach, which extends from the highly depositional delta area at its mouth for approximately 20.5 miles upstream to an area known as Higgins Mill Pond. Higgins Mill Pond was previously used as a source of drinking water. A temporary dam was constructed on the upper section of river, but now only a remnant of it remains. Downstream of the Bestpitch area, the river has an oxbow shape. A cut has been made through the bend to decrease the length of the stream for easier navigation. Currently the river flows predominantly through this cut. Depths of the river range from about 4 inches in the headwaters to greater than 11.5 feet at the confluence of Transquaking and Chicamacomico Rivers, and finally to about 6 feet where the Transquaking River meets Fishing Bay.

The watershed is entirely located within the Coastal Plains physiographic region. There are three distinct eco-regions identified in the MDDNR MBSS Index of Biological Integrity (IBI) metrics (Southerland et al. 2005) (see Figure 2).

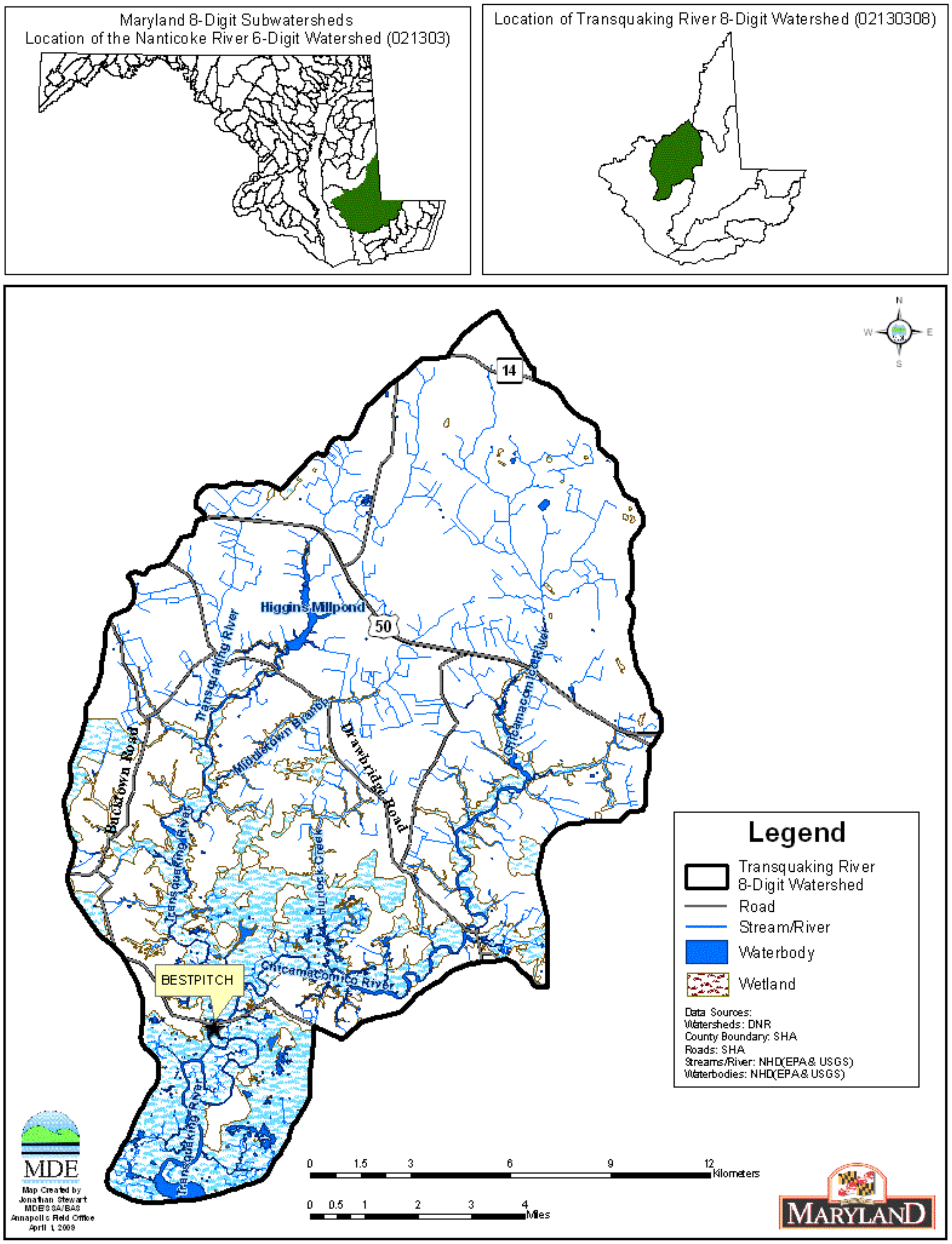

Figure 1. Location Map of the Transquaking River Watershed

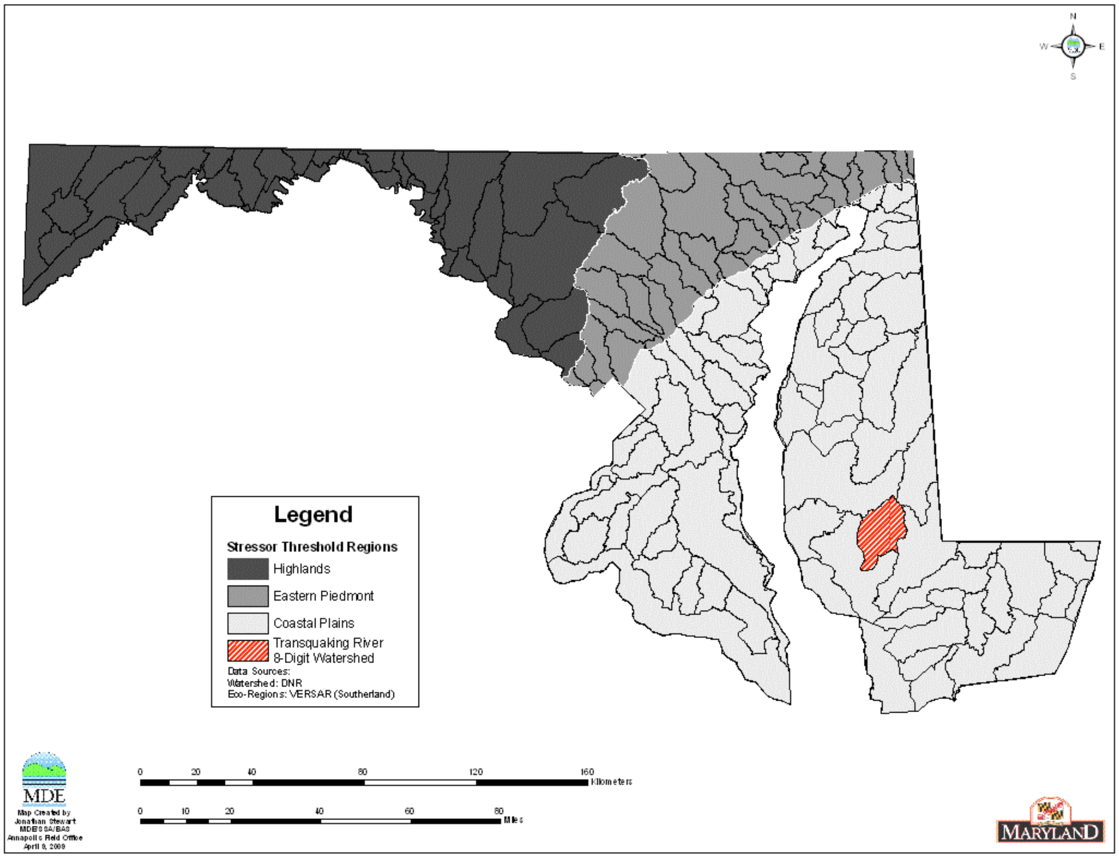

Figure 2. Eco-Region Location Map of the Transquaking River Watershed

2.2 Land Use

Land uses in the Transquaking River watershed consist primarily of forest and agriculture. According to the Chesapeake Bay Program's Phase 5.2 Model the land use distribution in the watershed is approximately 56% forest/herbaceous, 40% agricultural, and 4% urban (USEPA 2010a) (see Figure 3 and Figure 4).

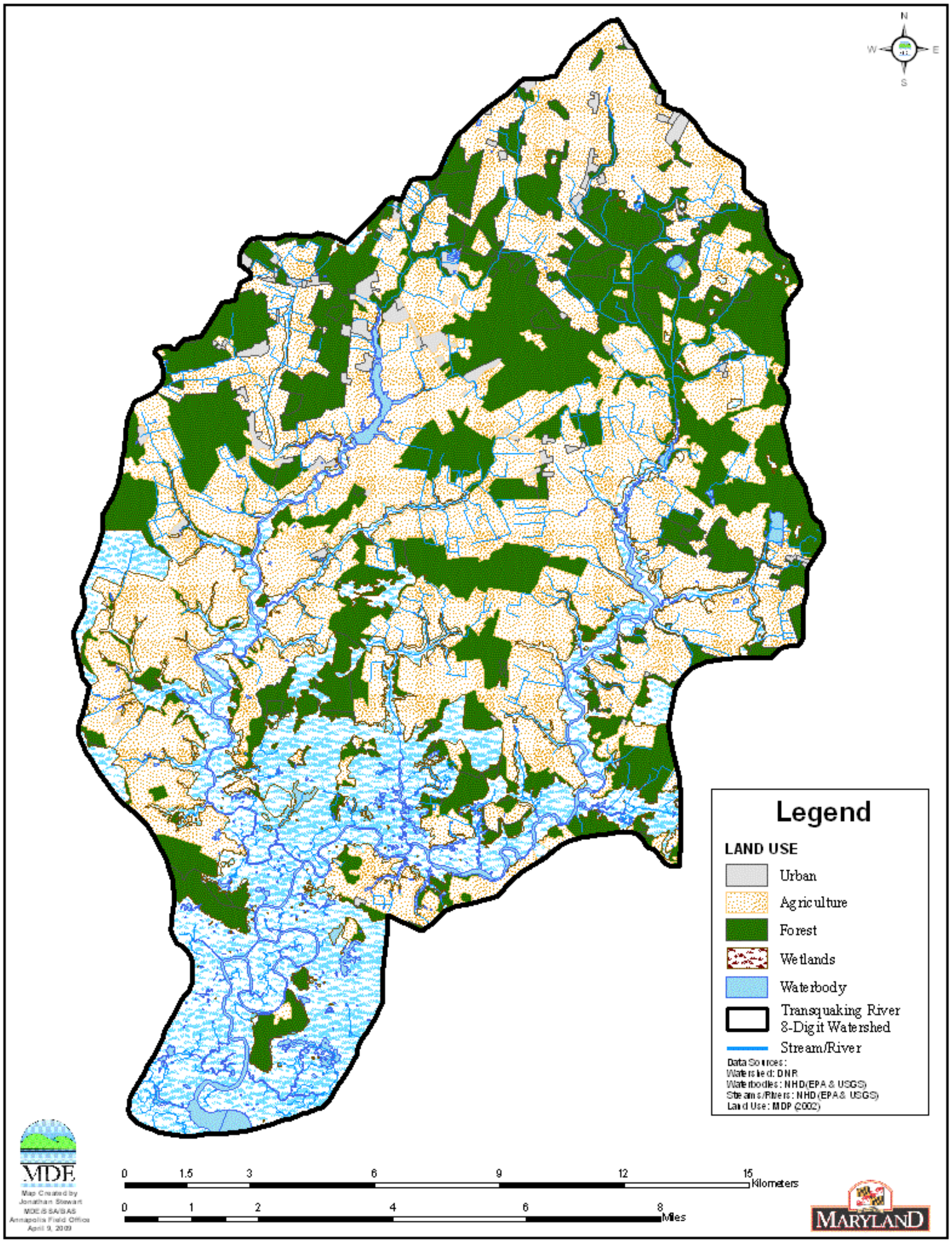

Figure 3. Land Use Map of the Transquaking River Watershed

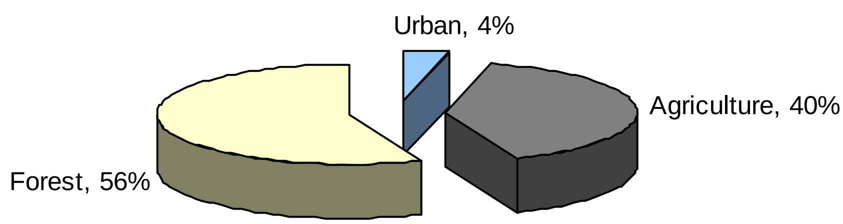

Figure 4. Proportions of Land Use in the Transquaking River Watershed

2.3 Soils/hydrology

The Transquaking River watershed lies within the Coastal Plain physiographic region, which is a wedge-shaped mass of primarily unconsolidated sediments of the Lower Cretaceous, Upper Cretaceous and Pleistocene Ages covered by sandy soils. The Coastal Plain region is characterized by lower relief, and is drained by slowly meandering streams with shallow channels and gentle slopes (MGS 2007).

Soils typically found in the Transquaking River watershed are the Sassafras, Fallsington, Westbrook, and Othello series. The Sassafras series consist of very deep, well drained soils on sandy marine and old alluvial sediments. The Fallsington series consist of very deep poorly drained on coastal plain flatlands. Saturated hydraulic conductivity is high in the subsoil and high to very high in the substratum. The Westbrook series consist of very deep, very poorly drained soils formed in organic deposits over loamy mineral material. They are in tidal marshes subject to inundation by salt water twice daily. Saturated hydraulic conductivity is moderately high to very high in the organic layers and low to high in the underlying mineral sediments. The Othello series consist of very deep, poorly drained soils, with saturated hydraulic conductivity being moderately high (USDA 1977).

3.0 Transquaking River Watershed Water Quality Characterization

3.1 Integrated Report Impairment Listings

The Transquaking River watershed (basin code 02130308) is located in Dorchester County, and is included in one Chesapeake Bay listing segment in the Integrated Report (IR): Fishing Bay Mesohaline and the Transquaking River non-tidal. See Table 1, which identifies the listings associated with this watershed. A 1996 Category 5 listing for nutrients was amended to Category 4a based upon the approval of a TMDL by USEPA in 2000.

3.2 Impacts to Biological Communities

The Maryland Surface Water Use Designation in the Code of Maryland Regulations (COMAR) for Transquaking River and all tributaries is Use I designation - *water contact recreation, and protection of nontidal warmwater aquatic life.* In addition, there are parts of the lower mainstem and tributaries of the Transquaking River that are Use II designation - *support of estuarine and marine aquatic life and shellfish harvesting* (COMAR 2011 a,b,c). A water quality standard is the combination of a designated use for a particular body of water and the water quality criteria designed to protect that use. Designated uses include support of aquatic life; primary or secondary contact recreation, drinking water supply, and trout waters. Water quality criteria consist of narrative statements and numeric values designed to protect the designated uses. The criteria developed to protect the designated use may differ and are dependent on the specific designated use(s) of a waterbody.

The Transquaking River watershed is listed under Category 5 of the 2010 Integrated Report for impacts to biological communities. Approximately 67% of stream miles in the Transquaking River watershed are estimated as having benthic and/or fish indices of biological integrity in the poor to very poor category. The biological impairment listing is based on the combined results of MDDNR MBSS round one (1995-1997) and round two (2000-2004) data, which include six stations. Four of the six have benthic and/or fish index of biotic integrity (BIBI, FIBI) scores significantly lower than 3.0 (i.e., poor to very poor). The principal dataset, i.e. MBSS round two contains five MBSS sites; with three having BIBI and/or FIBI scores lower than 3.0. Figure 5 illustrates principal dataset site locations for the Transquaking River watershed.

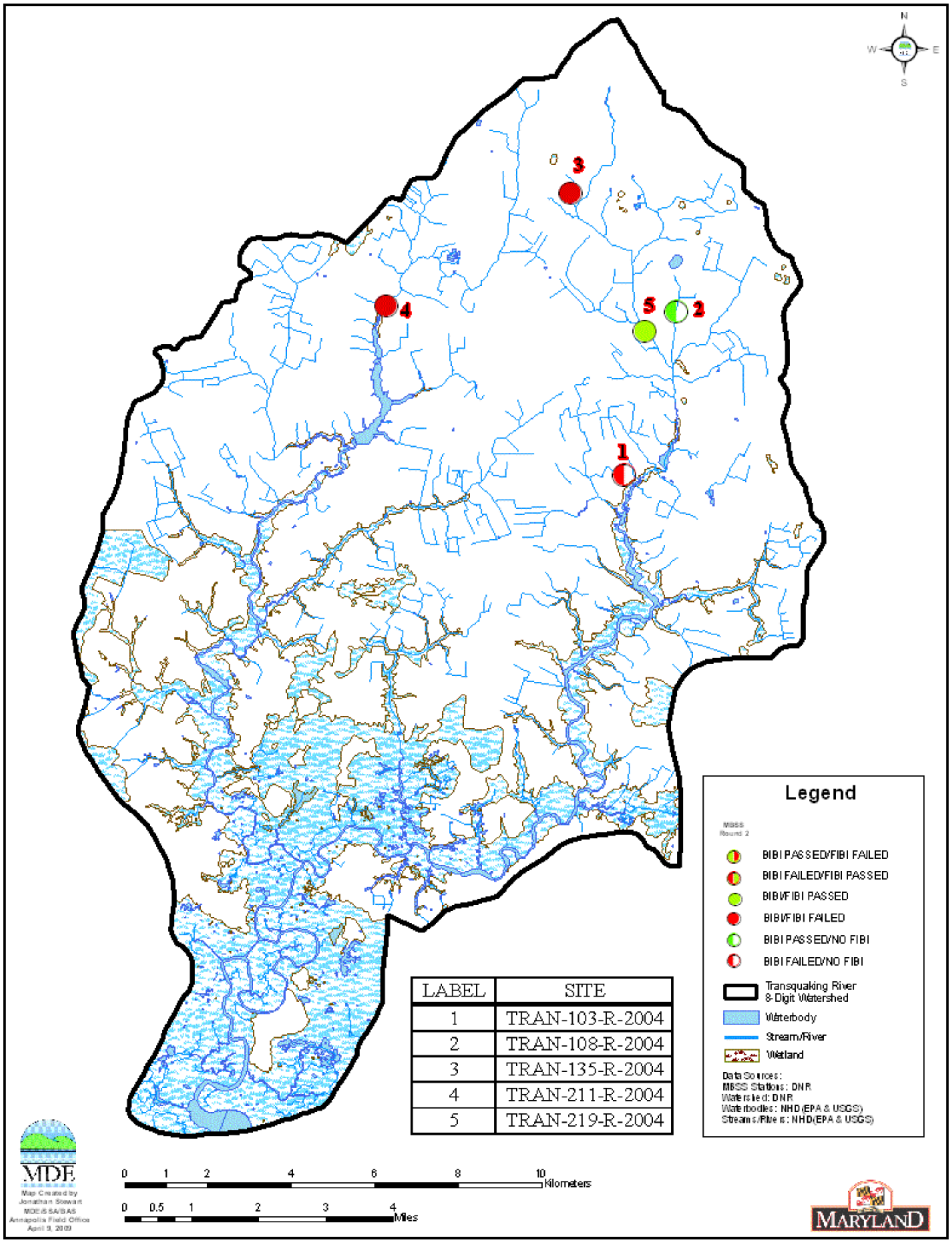

Figure 5. Principal Dataset Sites for the Transquaking River Watershed

4.0 Stressor Identification Results

The BSID process uses results from the BSID data analysis to evaluate each biologically impaired watershed and determine potential stressors and sources. Interpretation of the BSID data analysis results is based upon components of Hill's Postulates (Hill 1965), which propose a set of standards that could be used to judge when an association might be causal. The components applied are: 1) the strength of association which is assessed using the odds ratio; 2) the specificity of the association for a specific stressor (risk among controls); 3) the presence of a biological gradient; 4) ecological plausibility which is illustrated through final causal models; and 5) experimental evidence gathered through literature reviews to help support the causal linkage.

The BSID data analysis tests for the strength of association between stressors and degraded biological conditions by determining if there is an increased risk associated with the stressor being present. More specifically, the assessment compares the likelihood that a stressor is present, given that there is a degraded biological condition, by using the ratio of the incidence within the case group as compared to the incidence in the control group (odds ratio). The case group is defined as the sites within the assessment unit with BIBI/FIBI scores lower than 3.0 (i.e., poor to very poor). The controls are sites with similar physiographic characteristics (Highland, Eastern Piedmont, and Coastal region), and stream order for habitat parameters (two groups – 1^{st} and 2^{nd}-4^{th} order), that have fair to good biological conditions.

The common odds ratio confidence interval was calculated to determine if the odds ratio was significantly greater than one. The confidence interval was estimated using the Mantel-Haenzel (MH) (1959) approach and is based on the exact method due to the small sample size for cases. A common odds ratio significantly greater than one indicates that there is a statistically significant higher likelihood that the stressor is present when there are poor to very poor biological conditions (cases) than when there are fair to good biological conditions (controls). This result suggests a statistically significant positive association between the stressor and poor to very poor biological conditions and is used to identify potential stressors.

Once potential stressors are identified (i.e., odds ratio significantly greater than one), the risk attributable to each stressor is quantified for all sites with poor to very poor biological conditions within the watershed (i.e., cases). The attributable risk (AR) defined herein is the portion of the cases with poor to very poor biological conditions that are associated with the stressor. The AR is calculated as the difference between the proportion of case sites with the stressor present and the proportion of control sites with the stressor present.

Once the AR is calculated for each possible stressor, the AR for groups of stressors is calculated. Similar to the AR calculation for each stressor, the AR calculation for a group of stressors is also summed over the case sites using the individual site characteristics (i.e., stressors present at that site). The only difference is that the absolute risk for the controls at each site is estimated based on the stressor present at the site that has the lowest absolute risk among the controls.

After determining the AR for each stressor and the AR for groups of stressors, the AR for all potential stressors is calculated. This value represents the proportion of cases, sites in the watershed with poor to very poor biological conditions, which would be improved if the potential stressors were eliminated (Van Sickle and Paulsen 2008). The purpose of this metric is to determine if stressors have been identified for an acceptable proportion of cases (MDE 2009).

The parameters used in the BSID analysis are segregated into five groups: land use sources, and stressors representing sediment, in-stream habitat, riparian habitat, and water chemistry conditions. Through the BSID data analysis of the Transquaking River watershed, MDE identified sources, sediment, in-stream habitat, and water chemistry stressors as having significant association with poor to very poor fish and/or benthic biological conditions. Parameters identified as representing possible sources are listed in Table 2 and include various agricultural land use types. Table 3 shows the summary of combined AR values for the source groups in the Transquaking River watershed. As shown in Table 4 through Table 6, numerous parameters from the sediment, in-stream habitat, and water chemistry groups were identified as possible biological stressors. Table 7 shows the summary of combined AR values for the stressor groups in the Transquaking River watershed.

Table 2. Stressor Source Identification Analysis Results for the Transquaking River Watershed

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Urban	high impervious surface in watershed	5	3	214	0%	5%	No	----
	high % of high intensity urban in watershed	5	3	214	0%	9%	No	----
	high % of low intensity urban in watershed	5	3	214	0%	4%	No	----
	high % of transportation in watershed	5	3	214	0%	7%	No	----
	high % of high intensity urban in 60m buffer	5	3	212	0%	7%	No	----
	high % of low intensity urban in 60m buffer	5	3	212	0%	5%	No	----
	high % of transportation in 60m buffer	5	3	212	0%	9%	No	----

Table 2. Stressor Source Identification Analysis Results for the Transquaking River Watershed (Cont.)

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Agriculture	high % of agriculture in watershed	5	3	214	67%	18%	Yes	48%
	high % of cropland in watershed	5	3	214	67%	27%	No	----
	high % of pasture/hay in watershed	5	3	214	33%	6%	No	----
	high % of agriculture in 60m buffer	5	3	212	67%	8%	Yes	59%
	high % of cropland in 60m buffer	5	3	212	67%	18%	Yes	49%
	high % of pasture/hay in 60m buffer	5	3	212	100%	8%	Yes	92%
Sources Barren	high % of barren land in watershed	5	3	214	33%	23%	No	----
	high % of barren land in 60m buffer	5	3	212	0%	6%	No	----
Sources Anthropogenic	low % forest in watershed	5	3	214	67%	5%	Yes	62%
	low % of forest in 60m buffer	5	3	212	67%	5%	Yes	62%

Table 2. Stressor Source Identification Analysis Results for the Transquaking River (Cont.)

Parameter Group	Source	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with source present	% of control sites with source present	Possible stressor (Odds of stressor in cases significantly higher than odds of sources in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Source
Sources Acidity	atmospheric deposition present	5	3	208	0%	40%	No	----
	AMD acid source present	5	3	208	0%	0%	No	----
	organic acid source present	5	3	208	0%	6%	No	----
	agricultural acid source present	5	3	208	0%	7%	No	----

Table 3. Summary of Combined Attributable Risk Values of the Source Group in the Transquaking River Watershed

<table>
<tr><th>Source Group</th><th colspan="2">Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)</th></tr>
<tr><td>Urban</td><td>----</td><td rowspan="5">94%</td></tr>
<tr><td>Agriculture</td><td>92%</td></tr>
<tr><td>Barren Land</td><td>----</td></tr>
<tr><td>Anthropogenic</td><td>62%</td></tr>
<tr><td>Acidity</td><td>----</td></tr>
</table>

Sources Identified by BSID Analysis

All the sources identified by the BSID analysis (Table 2) are the result of agricultural development within the Transquaking River watershed. A significant amount of the watershed is comprised of agricultural land uses (40%). BSID results also identified cropland and pasture/hay land uses within the sixty meter riparian buffer zone as having significant association with degraded biological conditions.

The high percentages of cropland and pasture/hay within the 60 meter buffer zone is indicative of agricultural crops that are cultivated all the way to the stream banks, as well as agricultural practices that allow cattle to have direct access to ditches and streams. Although nutrient and best management practices (NMPs and BMPs) are in place to control nutrient and sediment runoff in the watershed, the BSID analyses revealed that agricultural practices continue to create conditions in the watershed that are impacting biological resources. Sediments in runoff from cultivated land and livestock trampling are considered to be particularly influential in stream impairment (Waters 1995).

Based on literature review, Allan (2004) reported declines in water quality, habitat, and biological assemblages as the extent of agricultural land increases within catchments; also streams draining agricultural lands support fewer species of sensitive benthic and fish taxa than streams draining forested catchments. Agricultural land use degrades streams by increasing nonpoint source loads of pollutants, impacting riparian buffer zones, and stream channel habitats.

Agricultural land use is an important source of pollution when rainfall carries sediment, fertilizers, manure, and pesticides into streams; which are potential sources for the elevated levels of nutrients. Streams in highly agricultural landscapes tend to have poor habitat quality, reflected in declines in habitat indexes and bank stability, as well as greater deposition of sediments on and within the streambed (Roth, Allan, and Erickson 1996; Wang et al. 1997).

The BSID source analysis (Table 2) identifies various types of agricultural land uses as potential sources of stressors that may cause negative biological impacts. The combined AR for the source group is approximately 94% suggesting that agricultural development potentially impacts almost all of the degraded stream miles in the Transquaking River watershed (Table 3).

All the stressors identified in the BSID analysis for the Transquaking River watershed can be linked to the typical ecological results of agricultural development. The remainder of this section will discuss identified stressors and their link to degraded biological conditions in the watershed.

Table 4. Sediment Biological Stressor Identification Analysis Results for the Transquaking River Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Sediment	extensive bar formation present	5	3	112	0%	22%	No	----
	moderate bar formation present	5	3	112	33%	54%	No	----
	bar formation present	5	3	112	67%	80%	No	----
	channel alteration marginal to poor	5	3	109	33%	61%	No	----
	channel alteration poor	5	3	109	0%	24%	No	----
	high embeddedness	5	3	112	0%	0%	No	----
	epifaunal substrate marginal to poor	5	3	112	67%	40%	No	----
	epifaunal substrate poor	5	3	112	67%	8%	Yes	59%
	moderate to severe erosion present	5	3	112	0%	45%	No	----
	severe erosion present	5	3	112	0%	13%	No	----
	poor bank stability index	5	3	112	0%	23%	No	----
	silt clay present	5	3	112	100%	99%	No	----

Table 5. Habitat Biological Stressor Identification Analysis Results for the Transquaking River Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
In-Stream Habitat	channelization present	5	3	114	33%	13%	No	----
	in-stream habitat structure marginal to poor	5	3	112	100%	35%	Yes	67%
	in-stream habitat structure poor	5	3	112	67%	4%	Yes	63%
	pool/glide/eddy quality marginal to poor	5	3	112	67%	38%	No	----
	pool/glide/eddy quality poor	5	3	112	33%	3%	Yes	31%
	riffle/run quality marginal to poor	5	3	112	67%	43%	No	----
	riffle/run quality poor	5	3	112	67%	19%	No	----
	velocity/depth diversity marginal to poor	5	3	112	67%	53%	No	----
	velocity/depth diversity poor	5	3	112	67%	11%	Yes	57%
	concrete/gabion present	5	3	117	0%	2%	No	----
	beaver pond present	5	3	110	0%	7%	No	----
Riparian Habitat	no riparian buffer	5	3	114	33%	12%	No	----
	low shading	5	3	112	33%	9%	No	----

Table 6. Water Chemistry Biological Stressor Identification Analysis Results for the Transquaking River Watershed

Parameter Group	Stressor	Total number of sampling sites in watershed with stressor and biological data	Cases (number of sites in watershed with poor to very poor Fish or Benthic IBI)	Controls (Average number of reference sites with fair to good Fish and Benthic IBI)	% of case sites with stressor present	% of control sites with stressor present	Possible stressor (Odds of stressor in cases significantly higher than odds of stressor in controls using p<0.1)	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Stressor
Water Chemistry	high total nitrogen	5	3	208	33%	25%	No	----
	high total dissolved nitrogen	0	0	0	0%	0%	No	----
	ammonia acute with salmonid present	5	3	208	100%	39%	Yes	61%
	ammonia acute with salmonid absent	5	3	208	67%	26%	No	----
	ammonia chronic with salmonid present	5	3	208	100%	67%	No	----
	ammonia chronic with salmonid absent	5	3	208	100%	57%	No	----
	low lab pH	5	3	208	0%	38%	No	----
	high lab pH	5	3	208	0%	0%	No	----
	low field pH	5	3	207	0%	39%	No	----
	high field pH	5	3	207	0%	0%	No	----
	high total phosphorus	5	3	208	67%	3%	Yes	63%
	high orthophosphate	5	3	208	100%	13%	Yes	88%
	dissolved oxygen < 5mg/l	5	3	206	33%	14%	No	----
	dissolved oxygen < 6mg/l	5	3	206	33%	22%	No	----
	low dissolved oxygen saturation	5	3	184	33%	18%	No	----
	high dissolved oxygen saturation	5	3	184	0%	0%	No	----
	acid neutralizing capacity below chronic level	5	3	208	0%	9%	No	----
	acid neutralizing capacity below episodic level	5	3	208	0%	48%	No	----
	high chlorides	5	3	208	0%	6%	No	----
	high conductivity µS/cm	5	3	208	33%	5%	No	----
	high sulfates	5	3	208	0%	4%	No	----

Table 7. Summary of Combined Attributable Risk Values of the Stressor Group in the Transquaking River Watershed

Stressor Group	Percent of stream miles in watershed with poor to very poor Fish or Benthic IBI impacted by Parameter Group(s) (Attributable Risk)	
Sediment	59%	94%
In-Stream Habitat	92%	
Riparian Habitat	----	
Water Chemistry	94%	

Stressors Identified by BSID Analysis

All eight stressor parameters identified by the BSID analysis (Tables 2, 3, and 4), as being significantly associated with biological degradation in the Transquaking River watershed are emblematic of agriculturally developed landscapes.

Sediment Conditions

BSID analysis results for Transquaking River watershed identified one sediment parameter that had statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community). The parameter is *epifaunal substrate (poor)* (Table 4).

Epifaunal substrate (poor) was identified as significantly associated with degraded biological conditions in the Transquaking River, and found to impact approximately 59% of the stream miles with poor to very poor biological conditions. Epifaunal substrate is a visual observation of the abundance, variety, and stability of substrates that offer the potential for full colonization by benthic macroinvertebrates. The varied habitat types such as cobble, woody debris, aquatic vegetation, undercut banks, and other commonly productive surfaces provide valuable habitat for benthic macroinvertebrates. Epifaunal substrate is confounded by natural variability (i.e., streams will naturally have more or less available productive substrate). Greater availability of productive substrate increases the potential for full colonization; conversely, less availability of productive substrate decreases or inhibits colonization by benthic macroinvertebrates. Epifaunal substrate conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, where stable substrate is lacking, or particles are over 75% surrounded by fine sediment and/or flocculent material; and 2) marginal to poor, where large boulders and/or bedrock are prevalent and cobble, woody debris, or other preferred surfaces are uncommon.

The BSID analysis applied a threshold of 100% for embeddedness in the Coastal Plains since the eco-region is naturally embedded. Consequently, embeddedness was not identified as significantly associated with degraded biological conditions in the Transquaking River watershed in this analysis. The data review did, however, identify all of the MDDNR MBSS round two sites used in this analysis as 100% embedded. Embeddedness describes the percentage of fine sediment surrounding gravel, cobble, and boulder particles in the streambed.

Agricultural development especially in the riparian buffer zones typically results in increased sediment deposition throughout the streambed primarily through settling of sediment in the stream substrate, as demonstrated by the lack of adequate epifaunal substrate. This effect is compounded by the low topographic relief throughout the watershed that does not allow for sediment transport to downstream reaches. Sediment deposited on the streambed can suffocate benthic organisms, especially in the embryonic and larval stages (NRCS 1997). The sediment deposition in the watershed has led to a loss of suitable habitat to support the full colonization of a healthy fish and benthic macroinvertebrate community.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the sediment stressor group is approximately 59% suggesting these stressors impact a considerable proportion of the degraded stream miles in Transquaking River watershed (See Table 7).

In-stream Habitat Conditions

BSID analysis results for the Transquaking River watershed identified four habitat parameters that have a statistically significant association with poor to very poor stream biological condition*: in-stream habitat structure (marginal to poor & poor), pool/glide/eddy quality (poor),* and *velocity/depth/diversity (poor)* (Table 5).

In-stream habitat structure was identified as significantly associated with degraded biological conditions in the Transquaking River watershed, and found to impact approximately 67% (*marginal to poor* rating) and 63% (*poor* rating) of the stream miles with poor to very poor biological conditions. In-stream habitat is a visual rating based on the perceived value of habitat within the stream channel to the fish community. Multiple habitat types, varied particle sizes, and uneven stream bottoms provide valuable habitat for fish. In-stream habitat is confounded by natural variability (i.e., some streams will naturally have more or less in-stream habitat). High in-stream habitat scores are evidence of the lack of sediment deposition. Low in-stream habitat values can be caused by high flows that collapse undercut banks and by sediment inputs that fill pools and other fish habitats. In-stream habitat conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels: 1) poor, which is defined as less than 10% stable habitat where lack of habitat is obvious; and 2) marginal to poor, where there is a 10-30% mix of stable habitat but habitat availability is less than desirable.

Pool/glide/eddy quality (poor) was identified as significantly associated with degraded biological conditions in the Tranquaking River watershed, and found to impact approximately 31% of the stream miles with poor to very poor biological conditions. Pool/glide/eddy quality is a visual observation and quantitative measurement of the variety and spatial complexity of slow or still water habitat and cover within a stream segment referred to as pool/glide/eddy. Stream morphology complexity directly increases the diversity and abundance of fish species found within the stream segment. The increase in heterogeneous habitat such as a variety in depths of pools, slow moving water, and complex covers likely provide valuable habitat for fish species; conversely, a lack of heterogeneity within the pool/glide/eddy habitat decreases valuable habitat for fish species. Pool/glide/eddy quality conditions are described categorically as optimal, sub-optimal, marginal, or poor. Conditions indicating biological degradation are set at two levels 1) poor, defined as minimal heterogeneous habitat with a max depth of <0.2 meters or being absent completely; and 2) marginal, defined as <10% heterogeneous habitat with shallow areas (<0.2 meters) prevalent and slow moving water areas with little cover.

Velocity/depth diversity (poor) was identified as significantly associated with degraded biological conditions in the Transquaking River watershed, and found to impact approximately 57% of the stream miles with poor to very poor biological conditions. Velocity/depth diversity is a visual observation and quantitative measurement based on the variety of velocity/depth regimes present at a site (i.e., slow-shallow, slow-deep, fast-shallow, and fast-deep). Like riffle/run quality, the increase in the number of different velocity/depth regimes likely increases the abundance and diversity of fish species within the stream segment. The decrease in the number of different velocity/depth regimes likely decreases the abundance and diversity of fish species within the stream segment. The poor velocity/depth/diversity category could identify the absence of available habitat to sustain a diverse aquatic community. This measure may reflect natural conditions (e.g., bedrock), anthropogenic conditions (e.g., widened channels, dams, channel dredging, etc.), or excessive erosional conditions (e.g., bar formation, entrenchment, etc.). Poor velocity/depth diversity conditions are defined as the stream segment being dominated by one velocity/depth regime. Velocity is one of the critical variables that controls the presence and number of species (Gore 1978). Many invertebrates depend on certain velocity ranges for either feeding or breathing (Brookes 1988).

All the in-stream habitat parameters identified by the BSID analysis are intricately linked with habitat heterogeneity, the presence of these stressors indicates a lower diversity of a stream's microhabitats and substrates, subsequently causing a reduction in the diversity of biological communities. Substrate is an essential component of in-stream habitat to macroinvertebrates for several reasons. First, many organisms are adapted to living on or obtaining food from specific types of substrate, such as cobble or sand. The group of organisms known as scrapers, for instance, cannot easily live in a stream with no large substrate because there is nothing from which to scrape algae and biofilm. Hence substrate diversity is strongly correlated with macroinvertebrate assemblage composition (Cole, Russel, and Mabee 2003). Second, obstructions in the stream such as cobble or boulders slow the movement of coarse particulate organic matter, allowing it to break down and feed numerous insects in its vicinity (Hoover, Richardson, and Yonemitsu 2006).

The presence of a well-developed pool/glide/eddy system is indicative of different types of habitat, and is typically assumed to have a higher biodiversity of organisms (Richards, Host, and Arthur 1993). Often sedimentation and increased flooding can disrupt pool/glide/eddy sequences (Richards et al. 1993). The geomorphological characteristics described above are often strongly influenced by land use characteristics, e.g., agricultural development within the riparian buffer zone allowing for increased sedimentation and flow to alter natural in-stream habitat.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the in-stream habitat stressor group is approximately 92% suggesting this stressor impacts almost all of the degraded stream miles in the Transquaking River (Table 7).

Riparian Habitat Conditions

BSID analysis results for Transquaking River did not identify any riparian habitat parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community) (Table 5).

Water Chemistry Conditions

BSID analysis results for Transquaking River identified three water chemistry parameters that have statistically significant association with a poor to very poor stream biological condition (i.e., removal of stressors would result in improved biological community). These parameters are *ammonia acute with salmonid present*, *high total phosphorus,* and *high orthophosphate* (Table 6).

Ammonia acute with salmonid present is significantly associated with degraded biological conditions in Transquaking River, and found in 61% of the stream miles with poor to very poor biological conditions. Acute ammonia toxicity refers to potential exceedences of species tolerance caused by a one-time, sudden, high exposure of ammonia. Ammonia acute with salmonid present or absent is a USEPA water quality criteria for ammonia concentrations causing acute toxicity in surface waters where salmonid species of fish are present or absent (USEPA 2006). Ammonia (NH_3) is a measure of the amount of NH_3 in the water column. Ammonia is a nitrogen nutrient species; in excessive amounts it has potential toxic effects on aquatic life. National Pollutant Discharge Elimination System (NPDES) permitted discharges, urban runoff, atmospheric deposition, fertilizers, animal waste, failing septic systems, and leaking wastewater infrastructure are potential sources of ammonia to surface waters. There are two minor industrial NPDES permitted dischargers in the Transquaking River watershed. Ammonia loads from any point source is dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

Identification of NH_3 toxicity by the BSID analysis is indicative of degradation to water quality due to nutrient loading in the Transquaking River watershed. Under natural conditions, nitrate and nitrite occur in moderate concentrations and are not generally harmful to most aquatic life, but NH_3 is highly toxic to aquatic organisms. Livestock waste is one of the primary agricultural sources of NH_3 and total nitrogen (TN), and a significant contributor to instream total phosphorus (TP) (USEPA 2000; USEPA 2009). Pasture/hay land use within the sixty meter riparian buffer zone was identified as an significant source in the watershed (AR 92%). Typically pasture/hay land use is associated with areas containing livestock. In surface water, manure’s oxygen demand and NH_3 content can result in fish kills and reduced biodiversity (USEPA 2009).

There are five MBSS stations in the Transquaking River watershed and minimal sampling for ammonia was conducted (one time sample) at each station. Acute ammonia toxicity refers to potential exceedences of species tolerance caused by a one-time, sudden, high exposure of ammonia. However, chronic ammonia toxicity refers to potential exceedences of species tolerance caused by repeated exposure over a long period of time. To make an accurate determination of acute and chronic ammonia toxicity, MDE reviewed additional data to determine if there is ammonia toxicity impairment in these waters. During the years of 1998, 2004, 2005, and 2010, MDE collected six hundred and seventy-nine water quality samples from the Transquaking River watershed. Samples were collect at fifteen stations through out the watershed , with most stations being sampled monthly for approximately a year. Of these samples, only three samples (<0.44%) had ammonia values above the USEPA water quality criteria for chronic toxicity, and there was only one (<0.15%) exceedances to the ammonia acute toxicity criteria (USEPA 2006). Due to these results from the MDE water quality data analysis, it was determined that ammonia toxicity is not a widespread problem in the Transquaking River watershed.

High total phosphorus levels were identified as significantly associated with degraded biological conditions and found in approximately 63% of the degraded stream miles within the Transquaking River watershed. TP is a measure of the amount of TP in the water column. Phosphorus occurs naturally in rocks and other mineral deposits, and is usually found in the form of phosphates in natural waters. The majority of phosphate mined in the United States is used for fertilizers, with a minor component used for animal feed supplements and other products. Anthropogenic sources of phosphorus are fertilizers, chemicals, animal waste and municipal sewage. TP input to surface waters typically increases in watersheds where urban and agricultural land uses are predominant.

High orthophosphate concentrations were identified as significantly associated with degraded biological conditions in the Transquaking River watershed, and found to impact approximately 88% of the stream miles with poor to very poor biological conditions. The orthophosphate (OP) parameter is the measure of the amount of OP in the water column. OP is the most readily available form of phosphorus for uptake by aquatic organisms. Phosphorus forms the basis of a very large number of compounds, the most important class of which is the phosphates. For every form of life, phosphates play an essential role in all energy-transfer processes such as metabolism and photosynthesis. Excessive phosphorus concentrations in surface water can accelerate eutrophication, resulting in increased growth of undesirable algae and aquatic weeds. Eutrophication can potentially result in low dissolved oxygen and high pH levels, which can exceed tolerance levels of many biological organisms. OP loads to surface waters typically increases in watersheds where urban and agricultural developments are predominant.

Water chemistry is another major determinant of the integrity of surface waters that is strongly influenced by land-use. Agricultural land uses comprise forty percent of the Transquaking River watershed. Agricultural land uses within the watershed as well as within the sixty-meter riparian zone were found to be significantly associated with poor to very poor biological conditions in the watershed. These types of land uses often result in increased nutrients loads to surface waters. The three major nutrients in fertilizers and manure are nitrogen, phosphorus, and potassium. In Wisconsin streams, Wang, Robertson, and Garrison (2007) found that many macroinvertebrate and fish measures were significantly correlated with phosphorus and nitrogen concentrations, implying that nutrients have direct and/or indirect links with those biological assemblages.

Point source discharges are also a potential source of nutrients to surface waters. There are two industrial discharges in the Transquaking River watershed. According to the nutrient TMDL developed by MDE in 2000, one of the point sources, Darling International Inc., was considered to be contributing a major load to the watershed. Darling International Inc. is a rendering facility and contributes 354,050 lb/yr of nitrogen and 1,825 lb/yr phosphorous to the basin. Nutrient loads from any wastewater treatment facility are dependent on discharge volume, level of treatment process, and sophistication of the processes and equipment.

The combined AR is used to measure the extent of stressor impact of degraded stream miles with poor to very poor biological conditions. The combined AR for the water chemistry stressor group is approximately 94% suggesting this stressor impacts almost all of the degraded stream miles in the Transquaking River watershed (Table 7).

Discussion

Numerous studies have documented declines in water quality, habitat, and biological assemblages as the extent of agricultural land increases within catchments (Roth, Allan, and Erickson 1996 & Wang et al. 1997). Researchers commonly report that streams draining agricultural lands support fewer species of sensitive insect and fish taxa than streams draining forested catchments (Wang et al. 1997). Agricultural land uses comprise 40% percent of the Transquaking River watershed consisting of row crops and pasture/hay fields that are commonly cultivated all the way to the stream banks, resulting in disturbed buffer zones. Cattle in the watershed have direct access to ditches and streams. Despite the nutrient management practices (NMPs) and best management practices (BMPs) applied in the watershed, agricultural practices continue to impact the water quality.

Agricultural land use is an important source of pollution when rainfall carries fertilizers, manure, and pesticides into streams. High concentrations of phosphorus and ammonia in agricultural streams are often correlated with nutrient inputs from fertilizers and manure used for crops and from livestock wastes (USGS, 1999). The BSID analysis identified cropland (AR 49%), and pasture/hay (AR 92%) in the riparian buffer zone as having significant association with poor to very poor biological conditions in the watershed. Forested riparian zones were found to retain 86% of the nitrogen reaching these areas in runoff, while nearby cropland retained only 8% in a coastal plains basin (Peterjohn and Correll 1984). The agricultural land uses in the Transquaking River watershed are potential sources for the elevated levels of TP, OP, and NH_3.

Agricultural land use in watersheds and riparian buffer zones often results in alterations of stream geomorphic structure. Such disturbances lead to increased fine sediment input to the stream along with direct changes in channel structure. Embeddedness and siltation often eliminate natural riffle-pool complexes and loss of stable diverse substrates. Loss of quality in-stream habitats, riffle/pool/glides, and velocity/depth diversities are serious habitat related problems in the Transquaking River. As the variety and abundance of substrates decreases, habitat structure becomes monotonous, diversity decreases, and potential for recovery following disturbances decreases. As the physical habitat changes, increased stress is placed on aquatic organisms. These stresses, depending on the tolerance of the species and individuals, may limit growth, abundance, reproduction and survival (Lynch, Corbett, and Hoopes 1977).

The combined AR for all the stressors is approximately 94%, suggesting that sediment, in-stream habitat, and water chemistry stressors identified in the BSID analysis would account for almost all of the degraded stream miles the Transquaking River watershed (Table7).

The BSID analysis evaluates numerous key stressors using the most comprehensive data sets available that meet the requirements outlined in the methodology report. It is important to recognize that stressors could act independently or act as part of a complex causal scenario (e.g., eutrophication, urbanization, habitat modification). Also, uncertainties in the analysis could arise from the absence of unknown key stressors and other limitations of the principal data set. The results are based on the best available data at the time of evaluation.

Final Causal Model for the Transquaking River Watershed

Causal model development provides a visual linkage between biological condition, habitat, chemical, and source parameters available for stressor analysis. Models were developed to represent the ecologically plausible processes when considering the following five factors affecting biological integrity: biological interaction, flow regime, energy source, water chemistry, and physical habitat (Karr 1991; USEPA 2010b). The five factors guide the selections of available parameters applied in the BSID analyses and are used to reveal patterns of complex causal scenarios. Figure 6 illustrates the final causal model for the Transquaking River watershed, with pathways to show the watershed's probable stressors as indicated by the BSID analysis.

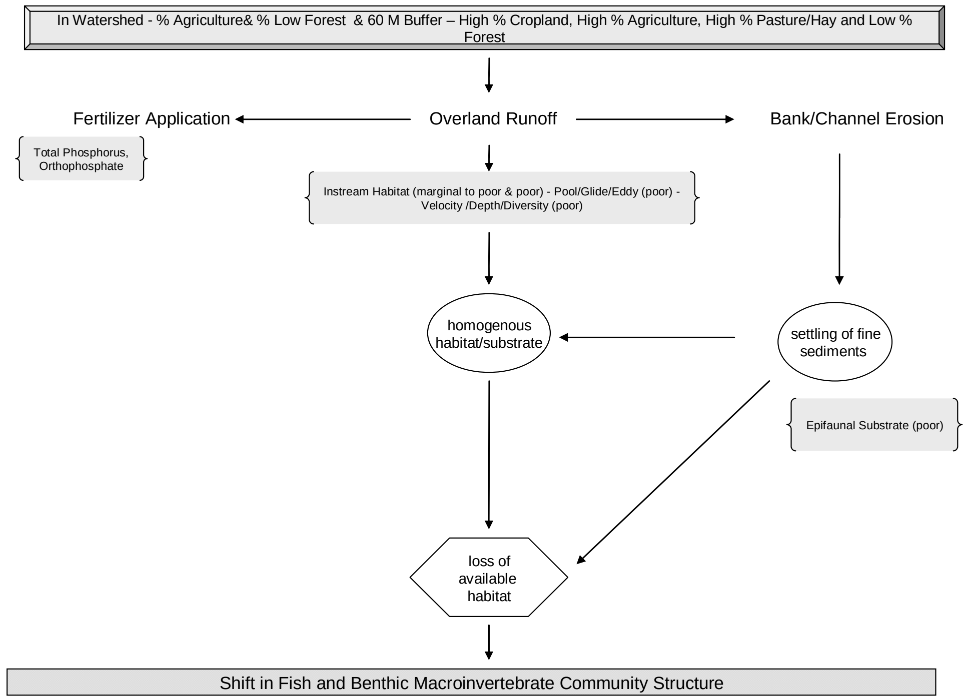

Figure 6. Final Causal Model for the Transquaking River Watershed

5.0 Conclusions

Data suggest that the Transquaking River watershed's biological communities are strongly influenced by agricultural land use resulting in increased nutrient pollutant and sediment loading. There is an abundance of scientific research that directly and indirectly links degradation of the aquatic health of streams to agricultural landscapes, particularly those landscapes with agricultural land uses with in the riparian buffer zone, which often results in even larger contaminant loads from runoff. Based upon the results of the BSID analysis, the probable causes and sources of the biological impairments of the Transquaking River watershed are summarized as follows:

- The BSID process has determined that biological communities in the Transquaking River watershed are likely degraded due to sediment and in-stream habitat related stressors. Specifically, agricultural runoff has led to increased settling of sediment in the stream substrate throughout the watershed, which is the probable cause of impacts to biological communities. The BSID results confirm the tidal 2008 Category 5 listing for total suspended solids (TSS) as an appropriate management action in the watershed, and links this pollutant to biological conditions in these waters and extend the impairment to the watershed's non-tidal waters. Therefore, the establishment of total suspended solids TMDL in 2010 through the Chesapeake Bay TMDL was an appropriate management action to begin addressing this stressor to the biological communities in the Transquaking River watershed. In addition, the BSID results support the identification of the non-tidal portion of this watershed in Category 5 of the Integrated Report as impaired by TSS to begin addressing the impacts of this stressor on the biological communities in the Transquaking River.

- The BSID process has determined that the biological communities in the Transquaking River watershed are likely degraded due to water chemistry related stressors, specifically (i.e. total phosphorus and orthophosphates). Agricultural land use practices have resulted in the potential elevation of phosphorus inputs throughout the watershed, which are in turn probable causes of impacts to biological communities. The BSID analysis uses a case-control, risk-based approach too systematically and objectively determine the predominant cause(s) and source of degraded biological conditions. Currently, there is no scientific consensus on numeric nutrient criteria for non-tidal streams (ICPRB 2011). Nutrients in excess do not act directly as pollutants in aquatic systems but, rather, manifest their negative effects via changes in chemical and biological metrics. For this reason, numeric thresholds or ranges of nutrient concentrations should not, by themselves, be used to list non-tidal stream segments as impaired by nutrients (Category 5). Maryland has thus taken an alternative, multi-faceted 'causal pathway' approach. Under this approach, a stream segment may be listed as impaired by nutrients only when poor biological conditions are demonstrated (via low Indices of Biotic Integrity or IBIs) in conjunction with (1) high nutrient concentrations, and (2) one or more of the following stressors known to be associated with nutrient over-enrichment and have scientifically defensible regulatory limits: (a) Low dissolved oxygen (DO) concentrations; (b) low or high DO saturation; (c) high pH. Since none of the stressors known to be associated with nutrient over enrichment were identified in the BSID analysis, a Category 5 listing for nutrients is not recommended for Transquaking River. In the absence of a firm causal pathway as described above, concluding that Transquaking River is impaired by nutrients could result in unnecessary planning and pollution control implementation costs.

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