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DIVISION OF ENVIRONMENTAL GEOSCIENCES
AAPG

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REGULAR FEATURES

ON THE COVER

Images are of stream reaches in optimal condition from various landscape positions located in South Central Pennsylvania. **Background:** Near Pristine Headwater Complex. **Upper Left:** Optimal forested Mainstem Reach. **Lower Right:** Optimal forested Headwater Reach. *See related article beginning on page 53. Photos courtesy of Dave Goerman.*

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ENVIRONMENTAL GEOSCIENCES

President's Column

April 28, 2013

Division of Environmental Geosciences

Welcome to the June issue of *Environmental Geosciences*. This issue includes an article on the resistivity-based mapping techniques used in Nigeria. It is great to see articles from our international members in the journal. The authors discuss the methods used to map fractures in the near-surface Mamu Formation to aid in the identification of drill sites for better-yielding water wells.

The second article looks at the application of resource assessment protocols for wetland and stream mitigation in the Marcellus shale in Pennsylvania. The article outlines methods to assess impacts of oil and gas activities on the environment. The protocol was developed by the Pennsylvania Department of Environmental Protection and builds on previous work by the U.S. Army Corps of Engineers and the Virginia Department of Environmental Quality. This work should be of great interest to our readers working in shale resource plays.

Also included in this issue are abstracts for DEG oral and poster presentations given at the ACE in Pittsburgh in May 2013. As always, if you have an article that the readers of *Environmental Geosciences* would enjoy, or know someone who does, send them along to our editorial staff. Thank you.

Sincerely,

Tom J. Temples, President
Division of Environmental Geosciences

Wetland and stream mitigation: Application of a resource condition assessment protocol in the Pennsylvania Marcellus Shale

Dave Goerman, Russ Krauss, Dheepa Jayakumar, and Mark Bernstein

ABSTRACT

With the exploration and the production of the Marcellus Shale come inevitable unavoidable environmental impacts to the surface of the Earth and associated waters of the United States including wetlands and streams. Environmental impact assessment includes measurement of impacts to aquatic resources, much of which is associated with the production and transportation of Marcellus Shale gas to market. The Commonwealth of Pennsylvania has prepared a rapid resource condition assessment protocol that will be applied to determine the existing quality of Pennsylvania streams to assess impacts to those streams and to quantify appropriate compensatory mitigation for impacts to these water resources.

This protocol, advanced by the Bureau of Waterways Engineering and Wetlands of the Pennsylvania Department of Environmental Protection, builds on prior work of the U.S. Army Corps of Engineers Norfolk District and the Unified Stream Methodology of the Virginia Department of Environmental Quality to provide a consistent and rapid condition assessment for projects to obtain water obstruction and encroachment permits, for water quality certifications, as well as general permits that affect waterways, floodways, and/or floodplains.

INTRODUCTION

The extensive development of the Marcellus Shale throughout Pennsylvania has caused a large increase of construction-related impacts to land, waters, wetlands, and streams. Regulatory agencies have longer permitting backlogs associated with the increased workload

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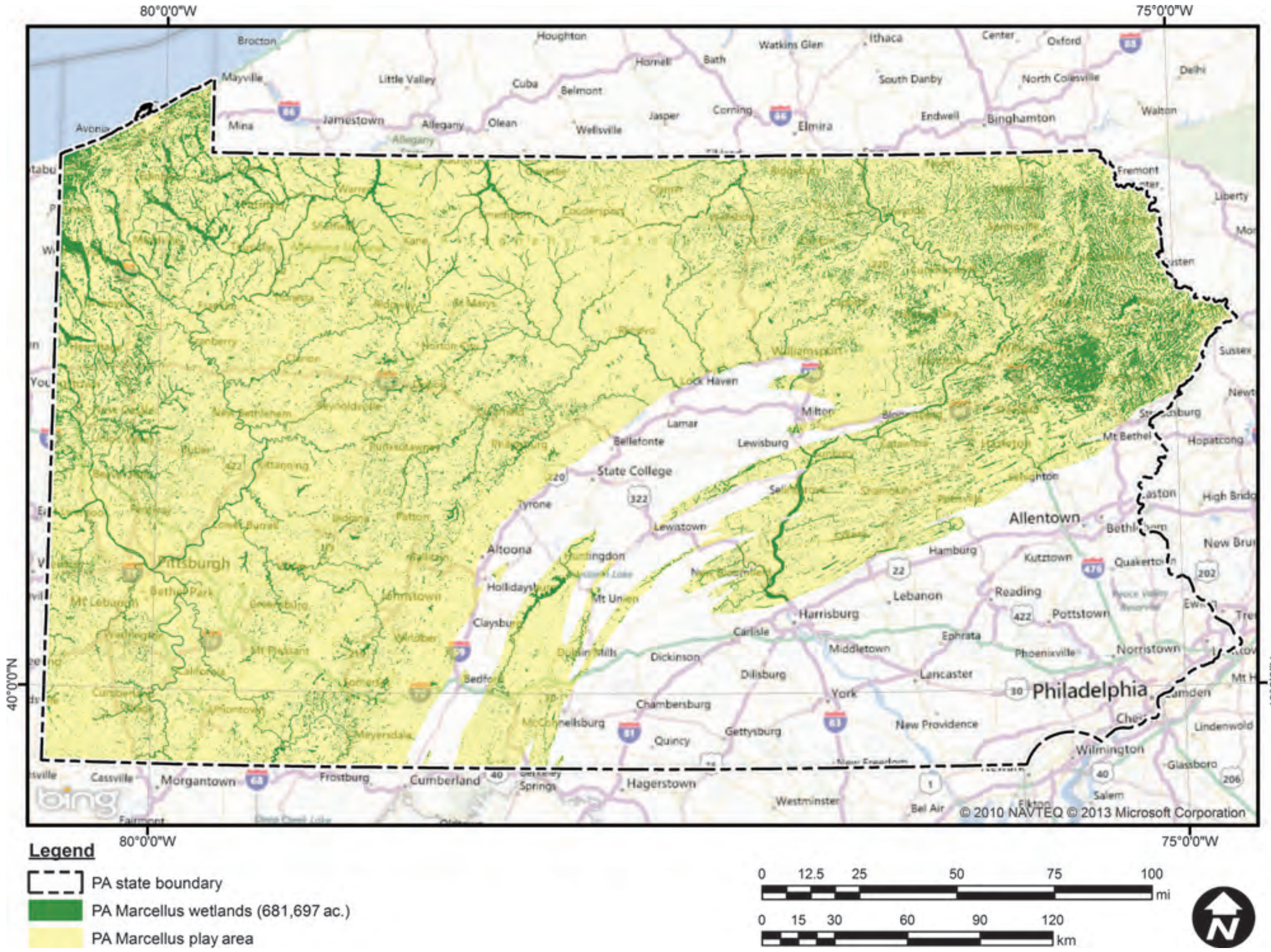

Figure 1. Marcellus Wetlands.

and project complexity. A mechanism for quantifying anthropogenic impacts to wetlands and streams, and a corresponding approach for measuring required compensatory mitigation, has recently been introduced in the Commonwealth of Pennsylvania, which could simultaneously improve permit timing and increase the replacement of impacted resources such as wetlands and streams.

Unavoidable, project-related impacts to wetlands and streams have increased in the early stages of the Marcellus Shale play life cycle because, at the outset, few or no connections from the wellhead were observed to intrastate and interstate pipeline systems. The aerial extent of Marcellus Shale play spans some 60,882,397 ac (24,638,253 ha) (U.S. Energy Information Agency, 2012). More than 16,000,000 ac (6475 ha) have been leased for oil and gas development, and thousands of miles of flowlines, gathering systems, and pipelines are in process or will be constructed (Unconventional Gas Database, 2012). Both the scale and magnitude of potential impacts from surface operations necessitate a more programmatic approach to the assessment of impacts and offsets for streams and wetlands.

If a pipeline runs through wetlands or crosses streams or rivers, permits are needed from the Pennsylvania Department of Environmental Protection (DEP). The Marcellus play area within Pennsylvania encompasses some 21,223,383 ac (8,588,806 ha), and 681,697 wetland acres (275,873 ha) exist within the Commonwealth as measured using the National Wetland Inventory database (U.S. Department of the Interior, 2012). Estimates of waterways, rivers, and streams within the entire play area exceed 197,153 mi (317,285 km); an estimated 70,180 mi (112,565 km) of streams exist within Pennsylvania (National Hydrographic Dataset, 2012). One pipeline development company has estimated that a pipeline must cross a stream every 2000 ft (610 m), meaning that waterways are difficult to avoid and obtaining a permit for a water crossing is commonly required (Figures 1, 2).

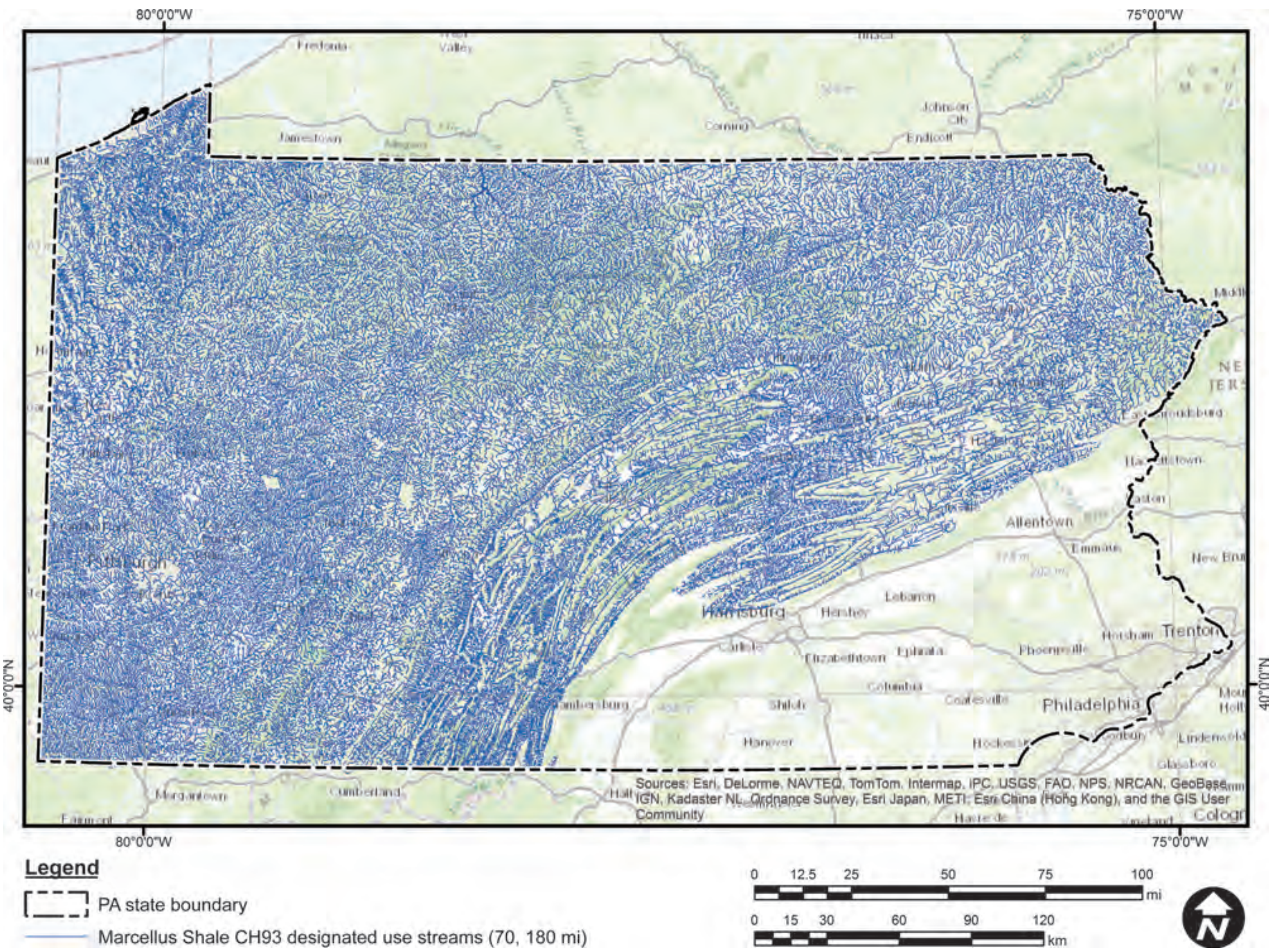

Figure 2. Marcellus Streams.

BACKGROUND

The Clean Water Act of 1972 Section 404 and the Rivers and Harbors Act of 1899 Section 10 direct the U.S. Army Corps of Engineers (USACE) to administer a regulatory program for permitting the discharge of dredged or fill materials in waters of the United States including navigable waterways, rivers, streams, their tributaries, and associated wetlands. Impacts from discharge of dredged or fill materials on wetland and stream functions must be assessed and quantified as part of the permit application process.

Assessment methods used to quantify the functions and values of aquatic resources including wetlands and streams have evolved for the past 50 yr and, most recently, were adapted to consider regional and local conditions. The result is the widely used Hydrogeomorphic Model (Clairain, 2002). Likewise, resource condition assessment methods for streams, riparian zones, and floodplains have been adapted to include local geomorphology. Additionally, each regulatory agency categorizes water resources in their own manner, necessitating a knowledge base of assessment approaches and methods to stay in compliance with play-specific rules and regulations (U.S. Army Corps of Engineers and Galveston District, 2011).

Permit applicants, developers such as oil and gas producers, pipeline and process plant companies, as well as governmental entities, commercial firms, and even residential applicants, use three-step mitigation sequencing to guide their efforts:

Step 1: avoid impacts to regulated and/or other important resources;
Step 2: minimize impacts to those resources that cannot be avoided; and
Step 3: mitigate impacts to those resources that cannot be further minimized.

At Step 3, the permit applicant calculates the amount of compensatory mitigation required to offset the unavoidable impacts of the project (Krauss, 2009).

On June 9, 2008, the USACE and the Environmental Protection Agency made effective the joint Final Rule governing Compensatory Mitigation for Losses of Aquatic Resources. The Final Rule requires that mitigation be identified by the developer before the permit is authorized and provides a foundation for addressing wetland and stream impacts by pointing to mitigation banks as the preferred mitigation solution in any given watershed (Compensatory Mitigation for Losses of Aquatic Resources, Final Rule, 2008).

Developers who purchase compensatory mitigation credits from an approved mitigation bank offset environmental impacts to wetlands or streams. A mitigation credit is used to offset these environmental losses in the form of wetland credits or stream credits. Mitigation banks are sites where resources such as wetlands, streams, or riparian areas are restored, established, enhanced, or preserved. The volume of mitigation credits approved and released by regulatory agencies for use is based on physical, biological, and chemical factors including total acreage or linear feet of habitat restored, restoration type and quality, and overall environmental benefits. When mitigation bank credits are used for compensatory mitigation, liability for required mitigation transfers from the developer to the mitigation bank sponsor.

PROPOSED APPROACH OF PENNSYLVANIA

On July 1, 2011, the USACE issued the Pennsylvania Special Programmatic General Permit-4 (PASPGP-4). The DEP and county conservation districts can authorize the use of the PASPGP for minor activities (crossings) in wetlands, streams, rivers, and other waters without additional USACE review. The PASPGP-4 contains key changes that impact linear projects ranging from natural gas pipelines to water and sewer pipelines to electrical transmission, cable television, and telephone lines. Permit applicants must supply the locations for the start and end points, along with each proposed crossing, as well as the total cumulative impacts needed to complete the entire project. These are used to determine the activity category of the impact. For example, if the cumulative impact project is greater than 1 ac of jurisdictional waters or 250 linear ft of streams, then the entire project will be a Category III activity and will be reviewed by the USACE and DEP.

The PASPGP-4 includes clarification on the calculation of the linear footage of stream impact, now to be measured from the top of the bank to the top of the opposite bank and from the upstream to downstream limits of work. The linear footage of stream impact will be the greater of these two measurements. As such, linear project rights of way will typically be the basis of the calculations used to determine the linear footage of stream impacts for midstream pipeline projects. The Department of Environmental Protection permits for water crossings considered PASPGP-4 PA Chapter 105 applications a general permit or joint permit.

During 2011 and 2012, DEP worked to a standardized process for determining aquatic resource compensation requirements and simultaneously establish a standardized process for determining the potential value of proposed aquatic resource compensation projects including mitigation banks. The protocol is intended for use in determining functional compensation requirements for projects affecting waters of the United States, which require authorization from the DEP and USACE regulatory programs.

The Pennsylvania Function-Based Aquatic Resource Compensation Protocol is applied to authorized activities permitted via Title 25 PA Code Chapters 105 and 106 and ensures compliance with the Final Rule (Pennsylvania Code, 2012). This protocol would replace the current ratio-based approach of calculating required offsets relative to unavoidable project impacts.

The protocol includes the Pennsylvania Riverine Condition Level 2 Rapid Assessment method, developed to determine the effect of a proposed project on the basic functions that comprise the riparian ecotone and to ensure that adequate compensation is provided to offset those effects. The primary modification made to the popular Unified Stream Methodology reflects the approach of DEP to establish the condition of a riverine resource using a riparian ecotone. Riparian ecotones are a three-dimensional space of interaction that includes terrestrial and aquatic ecosystems, which extend down into the groundwater, up above the vegetative canopy, out across the floodplain, up the near slopes that drain water, laterally into the terrestrial ecosystem, and along the watercourse at a variable width. The riparian ecotone includes the 100-yr floodplain and 100 ft (31 m) landward along the valley, where obvious slumps

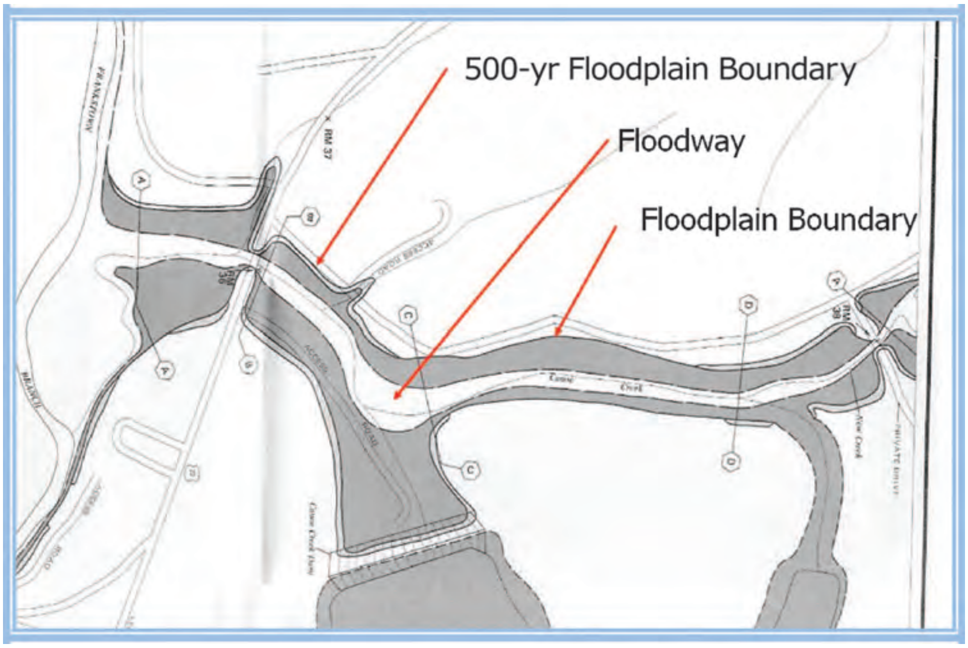

Figure 3. Schematic of stream assessment reach.

or landslides are added with a 45-ft (14-m) band around their edge (Verry et al, 2004).

This rapid condition assessment approach was developed to use the components of the riparian ecotone concept while balancing the cost of information gathering requirements. Ease of data capture, rapid calculation, and comprehensive application by practitioners, commonly biologists, ecologists, geologists, and hydrologists, were key design elements of the assessment approach.

ASSESSING STREAMS AND RIPARIAN AREAS

Permit applicants will propose projects that have unavoidable impacts to streams of varying type and quality. Therefore, it is important to assess the quality of the stream reach being impacted and to ensure that adequate compensation is required to offset any unavoidable impacts. Those assessing impacts must establish the upper and lower boundaries of the Stream Assessment Reach (SAR) to represent the overall condition of the area where the structures or activities may occur. Factors to consider in determining these boundaries include:

- the upstream influence of backwater projected as part of the hydrologic and hydraulic analysis and application of the same distance downstream;
- 20 times the channel width at bankfull stage upstream and downstream; and
- 250 ft (76 m) upstream and downstream of the proposed location of the structure or activity, whichever is greater.

Once the upper and lower limits of SAR are established, the assessor establishes the boundaries of the riparian vegetation and the riparian zone of influence (ZOI). Riparian vegetation boundaries can be established by:

- hydrologic modeling analysis to determine 100-yr storm-event elevations;
- 100-yr Federal Emergency Management Agency (FEMA) floodplain mapping;
- in FEMA unmapped areas, estimating the flood prone area width by determining the elevation that corresponds to twice the maximum depth of the bankfull channel as taken from the established bankfull stage; or
- 100 ft (31 m) from the stream bank (only used in FEMA unmapped areas) when hydrologic modeling analysis and stream cross section data are not available for determining the flood-prone area.

Figure 3 shows an example of FEMA floodplain mapping. When mapped floodplains are available, they may be used to establish boundaries for the riparian vegetation and the ZOI. Once the riparian vegetation boundaries are established, the ZOI boundaries are determined by extending the riparian vegetation boundaries 100 ft (31 m) landward on each side along the length of the riparian vegetation area.

1. Channel Condition: Assess the cross section of the stream and prevailing condition (erosion, aggradation)

	Conditional Category					
	Optimal	Suboptimal	Marginal	Poor	Severe	
Channel Condition	Very little incision or active erosion; 80%-100% stable banks. Vegetative surface protection or natural rock, prominent (80%-100%). AND/OR Stable point bars/bankfull benches are present. Access to their original floodplain or fully developed wide bankfull benches. Mid-channel bars, and transverse bars few. Transient sediment deposition covers less than 10% of bottom.	Slightly incised, few areas of active erosion or unprotected banks. Most banks are stable (60%-80%). Vegetative protection or natural rock prominent (60%-80%) AND/OR Depositional features contribute to stability. The bankfull and low flow channels are well defined. Stream likely has access to bankfull benches, or newly developed floodplains along parts of the reach. Transient sediment covers 10-40% of the stream bottom.	Commonly incised, but less than severe or poor. banks more stable than severe or poor due to lower bank slopes. Erosion may be present on 40%-60% of both banks. Vegetative protection on 40%-60% of banks. Streambanks may bevertical or undercut. AND/OR 40%-60% of stream is covered by sediment. Sediment may be temporary/transient, contribute instability. Deposition that contribute to stability, may be forming/present. AND/OR V-shape channels have vegetative protection on > 40% of	Overwidened/incised. Vertically/laterally unstable. Likely to widen further. Most of both banks are near vertical. Erosion present on 60%-80% of banks. Vegetative protection present on 20%-40% of banks, and is insufficient to prevent erosion. AND/OR 60%-80% of the stream is covered by sediment. Sediment is temporary/transient in nature, and contributing to instability. AND/OR V-shape channels have vegetative protection is present on > 40% of the banks and stable sediment deposition is absent.	Deeply incised (or excavated), vertical/lateral instability. Severe incision, flow contained within the banks. Streambed below average rooting depth, most banks vertical/undercut. Vegetative protection present on less than 20% of banks, is not preventing erosion. Obvious bank sloughing present. Erosion/raw banks on 80%-100%. AND/OR Aggrading channel. Greater than 80% of stream bed is covered by deposition, contributing to instability. Multiple thread channels and/or subterranean flow.	CI
Score	20 19 18 17	16 15 14 13	12 11 10 9	8 7 6 5	4 3 2 1	0.00
NOTES>>						

Figure 4. Channel condition index.

CONDITION INDICES

The individual indices used to establish the overall Riparian Ecotone Condition Index (RECI) are:

- Channel/floodplain condition index
- Riparian vegetation condition index
- Riparian zone of influence condition index
- Instream habitat condition index
- Channel alteration condition index

Each index, and its components and calculations are described below.

Channel/Floodplain Condition Index

Under most circumstances, stream channels respond to disturbances or changes in flow regime in a sequential predictable manner (Rosgen, 1996). The way a stream responds to changes is by degrading to a lower elevation and eventually restabilizing at that lower elevation

2. RIPARIAN VEGETATION: Assess the floodplain along the entire SAR (Visual estimates of areal covergae from aerial photographs with field verified acceptable)

	Conditional Category							NOTES>>
	Optimal	Suboptimal		Marginal		Poor		
Riparian Vegetation (Floodplain)	Tree stratum (dbh > 3 in.) present, with > 60% tree canopy cover. Wetlands and stream channels located within the riparian areas.	**High Suboptimal:** Riparian areas with tree stratum (dbh > 3 in.) present, with 30% to 60% tree canopy cover and containing both herbaceous and shrub layers or a nonmaintained understory.	**Low Suboptimal:** Riparian areas with tree stratum (dbh > 3 in.) present, with 30% to 60% tree canopy cover and a maintained understory. Recent cutover (dense vegetation).	**High Marginal:** Nonmaintained, dense herbaceous vegetation with either a shrub layer or a tree layer (dbh > 3 in.) present, with <30% tree canopy cover.	**Low Marginal:** Nonmaintained, dense herbaceous vegetation, riparian areas lacking shrub and tree stratum, hay production, ponds, open water. If present, tree stratum (dbh >3 in.) present, with <30% tree canopy cover with maintained understory.	**High Poor:** Lawns, mowed, and maintained areas, nurseries; no-till cropland; actively grazed pasture, sparsely vegetated non-maintained area, recently seeded and stabilized, or other comparable condition.	**Low Poor:** Impervious surfaces, mine spoil lands, denuded surfaces, row crops, active feed lots, trails, or other comparable conditions.	
		High	Low	High	Low	High	Low	
Scores	20 19 18 17 16	15 14	13 12 11	10 9	8 7 6	5 4	3 2 1	

1. Identify condition category areas along the floodplain using the descriptors above.
2. Estimate the % area within each condition category. Calculators are provided for you below.
3. Enter the % riparian area and score for each category in the blocks below.

Ensure the sums of % riparian blocks equal 100

Right Side	% Riparian Area>							0%			
	Score >										
									CI = Sum (Rt and Lt sub-Indeces)/2		
Left Side	% Riparian Area>							0%	Rt Sub-Index>	0.00	CI
	Score >								Lt Sub-Index>	0.00	0.00

Figure 5. Riparian vegetation condition index. SAR = stream assessment reach.

(Figure 4). By analyzing the stream channel cross section at different points along the stream, the differing stages of the stream-channel evolutionary process can be directly correlated with the current state of stream stability. The condition of a channel can be determined by visually assessing certain geomorphological indicators related to the channel geometry, stability, and active floodplain connection.

Channel Geometry

Visually assess the channel profile to determine the degree of incision and/or widening. Channel incision is a common response of alluvial channels that have excess amounts of flow energy or stream power relative to the sediment load. This change in flow regime results in the stream eroding the stream bed, causing steep, easily eroded banks. If the cohesiveness of the bank material is very low, such as loose sand, the channel will erode the banks and have a wide cross section compared to its depth. This instability presents itself as an overwidened channel.

Channel Stability

Assess visual indicators of stability or instability. In a stable stream, the pattern of erosion and deposition occurs in an orderly and predictable manner. Indicators of an unstable stream channel include depositional features such as mid-channel bars, transverse bars, and transient sediments, as well as erosion features such as erosion scars, denuded banks, and threaded channels.

Active Floodplain Connection

Active floodplain is the land between the active channel at the bankfull elevation and the terraces that are flooded by stream water on a periodic basis. Natural channels at or immediately below surrounding floodplain elevations will be connected to the active floodplain. Channels that are deeply incised or channelized will be below the elevation of the floodplain and will no longer be able to likely flood the floodplain during normal high-water events.

The Channel Condition Index is calculated as:

$$\text{Channel CI} = \frac{\text{Condition Score}}{20} \quad (1)$$

Riparian Vegetation Condition Index

This condition index is a qualitative evaluation of the cover types that make up the riparian vegetation within the 100-yr floodplain limits. This index is determined by evaluating what cover types occupy what percentage of the total riparian vegetation area for each side of 100-yr floodplain within the SAR. The left side and right side are determined by facing downstream. Aerial photography combined with a visual observation of the riparian area is used to determine this condition index (Figure 5).

The ideal and/or optimal riparian vegetation would be homogenous with a mature hardwood and/or conifer forest occupying 100% of the assessment area. Any tributary stream channels or wetlands located within the riparian vegetation area are scored as optimal. If the riparian vegetation area is heterogeneous (e.g., 33% forested, 33% cropland, and 34% pavement), it is possible that the riparian vegetation area could contain multiple condition categories. In that case, each condition category present within the riparian vegetation area is scored and weighted by the percent it occupies within the riparian vegetation area. An estimate of the percent area that each cover type occupies may be made from visual estimates made on the ground or by measuring each different area to obtain its dimensions.

The following formulas are used in establishing the right and left sides of the riparian vegetation:

$$\frac{\text{Left Side Sub} - \text{Index} = \text{SUM}(\%\text{Areas} \times \text{Scores})}{20} \quad (2)$$

$$\frac{\text{Right Side Sub} - \text{Index} = \text{SUM}(\%\text{Areas} \times \text{Scores})}{20} \quad (3)$$

$$\frac{\text{Riparian Vegetation CI} = (\text{Left Side CI} + \text{Right Side CI})}{2} \quad (4)$$

Riparian Zone of Influence Condition Index

This index is a qualitative evaluation of the cover types that make up the ZOI. The riparian ZOI is the land extending 100 ft (31 m) into the adjacent uplands from the 100-yr floodplain limits on both sides of the valley floor. The score for this index is determined by evaluating which cover type occupies what percent of the total ZOI area for each side of the floodplain within the SAR. The total ZOI assessment area (on each side of the 100-yr floodplain limits) is calculated by multiplying the length of the SAR by 100 ft (31 m). The left side and right side are determined by facing downstream. The ideal ZOI would have a homogenous land cover composed of a mature hardwood and/or coniferous forest occupying 100% of the assessment area. Any tributary stream channels or wetlands located within the ZOI areas are scored as optimal. If the ZOI is composed of heterogeneous land cover (e.g., 33% forested, 33% cropland, and 34% pavement), it is possible that the ZOI could contain multiple condition categories. In that case, each condition category present within the ZOI is scored and weighted by the percent it occupies within the ZOI.

The following formulas are used if establishing right and left sides of the Riparian ZOI:

$$\frac{\text{Left Side Sub} - \text{Index} = \text{SUM}(\%\text{Areas} \times \text{Scores})}{20} \quad (5)$$

$$\frac{\text{Right Side Sub} - \text{Index} = \text{SUM}(\%\text{Areas} \times \text{Scores})}{20} \quad (6)$$

$$\frac{\text{Riparian ZOI CI} = (\text{Left Side CI} + \text{Right Side CI})}{2} \quad (7)$$

In-Stream Habitat Condition Index

The in-stream habitat assessment considers the habitat suitability for effective colonization or use by fish, amphibians, and/or macroinvertebrates. This parameter does not consider the abundance or types of organisms present, nor the water quality of the stream. Other factors beyond those measured in this methodology (i.e., watershed conditions) also affect the presence and diversity of aquatic organisms. Therefore, evaluation of this parameter seeks to assess the suitability of physical elements within the SAR to support aquatic organisms.

This parameter includes the relative quantity and variety of natural structures in the stream, such as cobble (riffles), large rocks, fallen trees, logs and branches, persistent leaf packs, and undercut banks, available as refugia, feeding, or sites for spawning and nursery functions of aquatic macro fauna. A wide variety and/or abundance of instream habitat features provide macroinvertebrates and fish with a large number of niches, thus increasing species diversity. As variety and abundance of cover decreases, habitat structure becomes homogenous, diversity decreases, and the potential for recovery after disturbance decreases. Riffles and runs are critical for maintaining a variety and abundance of benthic organisms and serve as spawning and feeding refugia for certain fish. The extent and quality of the riffle is an important factor in the support of a healthy biological condition. Riffles and runs offer habitat diversity through a variety of particle sizes. Snags and submerged logs are also productive habitat structures for macroinvertebrate colonization and fish refugia.

Typically, most streams in Pennsylvania are high gradient, with the exception of streams in the coastal plain, low gradient streams flowing through wetlands or wet meadows, and tributary streams flowing through larger floodplains (e.g., tributaries flowing to the Delaware and Susquehanna rivers) throughout the state. Headwater stream channels have intermittent hydrologic regimes and may not have the diversity of habitat features found in higher-order stream channels. Hyporheic flow may comprise all of the flow in intermittent streams during dry times of the year. A high-gradient stream should not be scored lower because of the lack of submerged aquatic vegetation. Likewise, a low-gradient stream should not be scored lower because it does not contain riffles and is sand-dominated substrate.

Channel Alteration Condition Index

This condition index considers direct physical alteration to the stream channel from anthropogenic sources. The SAR may or may not have been altered throughout its entire length. Examples of channel alterations evaluated in this condition index that may disrupt the natural conditions of the stream include, but are not limited to, the following:

- Straightening of channel or other channelization
- Stream crossings (bridges and culverts)
- Riprap along stream bank or in stream bed
- Concrete, gabions, or concrete blocks along stream bank
- Manmade embankments on stream banks, including spoil piles
- Constrictions to stream channel or immediate flood-prone area

This condition index evaluates the physical channel alteration, separate from any impact the alteration is having on the assessment reach. Any impact to the assessment reach resulting from the alteration (i.e., scouring, head cuts, vertical banks, etc.) is accounted for in the channel/floodplain condition index. Any revegetation or natural restabilization of the channel is also accounted for in that condition index. For example, consider two assessment reaches, each with similar bridges: the first reach shows no adverse effects to the stream channel or banks, whereas the second shows significant scouring. The alteration is the bridge, not the effects of the bridge; therefore, it is the length of the bridge relative to the length of the assessment reach that is evaluated. The scour effect of the bridge would be considered under the channel/floodplain condition and in the scoring of that condition index. The presence of a structure does not necessarily result in a reduced score. For instance, a bridge that completely spans the floodplain would not be considered an alteration. Also, the assessor is cautioned not to make assumptions about past alterations. Incision can commonly be mistaken for past channelization.

Riparian Ecotone Condition Index

The RECI is a numerical value placed on the SAR using the scores determined from each individual condition index during the stream assessment. Each individual condition index score should result in a value from 0.05 to 1.0. The RECI score should also result in a score from 0.05 to 1.0. If values greater than 1.0 result, then it is likely that the individual scores are being used and not the calculated indexes. The individual condition indexes are equally weighted, and the RECI is calculated by summing the individual condition indexes and then dividing by 5. The following equation is used to determine the RECI:

$$\frac{\text{RECI} = (\text{Sum of Condition Index Scores})}{5} \tag{8}$$

COMPENSATORY MITIGATION CREDIT DETERMINATION

The indices and scores determined by the application of the Pennsylvania Riverine Condition Level 2 Rapid Assessment method are applied to the Compensation Requirement Equation to determine the number of credits required to offset the measured impact. The RECI parameter is one of the four parameters used in this equation with the other three being the area of impact, the project effect factor—a score of the relative impact on biogeochemical, habitat, and hydrologic groups—and the resource value—a Pennsylvania Chapter 93 designation noting the category of the stream being affected using designations made in state statutes. The resulting credits required as a compensation requirement are calculated as:

$$\begin{aligned}\text{Credits Required} = {} & \text{Area of Impact} \\ & \times \text{Project Effect Factor} \\ & \times \text{Resource Value Factor} \times \text{RECI}\end{aligned} \tag{9}$$

For the assessor/practitioner, therefore, the riverine compensation requirement is a matter of answering four questions:

1. What is the area of impact? This is measured as the area of stream and/or floodplain impacted. For pre-impact permits, this is commonly the area of the stream open cut for pass through. If stream crossings via horizontal directional drilling are used to minimize impacts, the area of impact may be located at the entry and exit points of the bore. For after-the-fact permits, include any horizontal directional drilling frac-out impacts and unplanned temporary workspaces as impact areas.
2. What is the nature of the impact? This is a relative rating from none to severe.
3. What is the Chapter 93 Stream Designation? The designations by Pennsylvania via Title 25 PA Code Chapter 93 are exceptional value, high quality, trout stocked fishery, cold water fishery, migratory fishery and warm water fishery.
4. What is the RECI? The condition index score that results from the assessment of chemical, physical and biological attributes that contribute to maintaining downstream water quality designations and uses.

The developer would then seek to source the resulting number of compensatory mitigation credits from an approved mitigation bank to satisfy the mitigation requirement of the permit application. The permitting authority is assured that the mitigation offset debited from the mitigation bank are ecologically sound in the actual wetland and/or stream restoration has occurred, thus maintaining the no net loss of wetland and stream policy, established in the United States in 1977 (Executive Order 11990, 1977).

CONCLUSIONS AND RECOMMENDATIONS

In terms of impacts and offsets to the waters of the United States, the authors are aware of dozens of assessment methods applied by regulatory agencies to permit projects in each unconventional play (Krauss, 2013). These projects include drilling pad sites, access roads, flowlines, gathering systems, trunks, laterals and pipelines to transport captured hydrocarbons from wellhead to market and between interstate markets. Pennsylvania, mostly as a response to impacts from Marcellus Shale gas drilling and associated field infrastructure development, has applied a riparian ecotone approach to create a new rapid assessment method that ensures the long-term viability of riverine aquatic resources and quantifies both unavoidable impacts and required compensatory offset mitigation. This approach is a framework for resource planning and is a quantitative approach that builds on mitigation sequencing. The Level 2 riverine assessment method provides a standardized measurement and replacement mechanism for resource impacts. The compensation protocol readily assesses ecosystem services in terms of their biogeochemical, hydrologic, habitat, and resource support functions. This method will be applied to diverse water resources across Pennsylvania, used as a tool for permittees to plan, avoid and minimize impacts, and used by agencies as part of a streamlined regulatory review process. The new approach recognizes the aquatic resource functions and values impacted from permittee projects, provides a standard method of quantifying ecologically appropriate compensatory mitigation, and ultimately enables all practitioners to do their jobs easier, faster, and in an environmentally responsible manner.

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