The Impact of Marcellus Gas Development on the Rural Transportation Infrastructure

Prepared for

The Penn State Marcellus Center for Outreach and Research

FINAL REPORT

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16. Abstract

Deterioration was observed to occur in the wearing surfaces, decks, and parapets for all seven of the structures inspected. To date, little to no deck condition change was observed compared to the reviewed inspection reports. However, the oldest bridge in this study was noted to be carrying the highest volume of Gas Play truck traffic and manifested some structural deterioration that was not included in the most recent PennDOT inspection survey. This involved the bridge's superstructure and substructure showing sagging bridge beams. For all other bridges, an increase in traffic as a result of the Gas Play was not shown to significantly change the condition of the superstructure or substructure in the bridges. Bridge 4 received extensive rehabilitation in 2009. After the one-year interval that followed, this study found deterioration to the wearing surface, parapets, and approach slab. All roadways had varying amounts of cracking regardless of Gas Play traffic activity, which generally increased with increased truck traffic. Rutting significantly increased as Gas Play activity increased and was the most common form of deterioration encountered. Secondary and municipal roads have experienced significant deterioration due to the enhanced heavy truck traffic. Full-depth reclamation is being employed as a cost-effective rehabilitation methodology by the gas companies. Reconstruction of dirt and gravel municipal roads has commonly been undertaken without the benefit of good design guidelines. To address this shortcoming, the authors developed and presented a simplified design methodology for the reconstruction of this class of roads. The enhanced heavy truck traffic has a weak correlation to increased severity of traffic accidents. Limited data and lack of a good baseline for comparison limit the strength of associated observations. Focus on the direct impact of drilling (e.g., archaeological survey) on cultural resources, while important, doesn't address important down-the-line impacts. As roads are rebuilt and improved, historic and prehistoric survey is critical but there are not specific resources and staff available for these issues. Local heritage leaders are currently bearing the full weight of the new issues associated with Marcellus development. Creating resources for local and regional leaders is important, so that they can develop long-term planning strategies for cultural resource management and preservation.

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EXECUTIVE SUMMARY

The objective of this study was the development of the current report, which is intended to serve as a pilot study that will allow the development of the methodology to explore the direct impact of the gas extraction activities upon the improved and unimproved roads of the Commonwealth, the impact upon the secondary road bridges, the impact upon other programs that the Commonwealth conducts to aid these communities, the travel safety associated with the demand by the gas companies to produce wells, and the impact on the "quality of life" of the local residents resulting from the degradation of not only the roads but loss of resources and the esthetics of the area.

The study was conducted by four teams and focused on four key aspects:

- Impact on bridges
- Impact on secondary and municipal roads
- Safety
- Cultural impacts

The findings were then integrated into this report. The team's findings are summarized below.

Deterioration was observed to occur in the wearing surfaces, decks, and parapets for all seven of the structures inspected. To date, little to no deck condition change was observed compared to the reviewed inspection reports. However the oldest bridge in this study was noted to be carrying the highest volume of gas play truck traffic and manifested some structural deterioration that was not included in the most recent PennDOT inspection survey. This involved the bridge's superstructure and substructure showing sagging bridge beams. For all other bridges, an increase in traffic as a result of the Gas Play was not shown to significantly change the condition of the superstructure or substructure in the bridges. Bridge Four received extensive rehabilitation in 2009/10. In this 1-year interval, this study found deterioration to the wearing surface, parapets, and approach slab.

All roadways had a varying amount of cracking regardless of Gas Play traffic activity, which generally increased with increased truck traffic. Rutting significantly increased as Gas Play activity increased and was the most common form of deterioration encountered. Secondary and municipal roads have experienced significant deterioration due to the enhanced heavy truck traffic. Most of this class of roads was constructed in the 1930s as a means of assisting farmers to move from simple dirt wagon roads to macadamed roads to reduce mud. The unimproved dirt wagon roads were covered with minimal amounts of aggregate then covered with a top dressing of perhaps as much as 2 inches of penetration asphalt in which the placed aggregate was "shot" with liquid asphalt and then dressed with more aggregate. These roads have served well but were never designed to see the traffic levels of the Gas Play. Full-depth reclamation is being employed as a cost-effective rehabilitation methodology by the gas companies to many of the secondary rural roads. Reconstruction of dirt and gravel municipal roads has commonly been undertaken without the benefit of good design guidelines. To address this shortcoming, the authors developed and presented a simplified design methodology for the reconstruction of this class of roads (see Appendix B).

The enhanced heavy truck traffic has a weak correlation to increased severity of traffic accidents. Limited data and lack of a good baseline for comparison limits the strength of associated observations.

Focus on the direct impact of drilling (e.g., archaeological survey) on cultural resources, while important, doesn't address important down-the-line impacts. As roads are rebuilt and improved, historic and prehistoric survey is critical, but there are not specific resources and staff available for these issues. Local heritage leaders are currently bearing the full weight of the new issues associated with Marcellus development. Creating resources for local and regional leaders is vital, so that they can develop long-term planning strategies for cultural resource management and preservation.

INTRODUCTION

The objective of this study was the development of the current report, which is intended to serve as a pilot study that will allow the development of the methodology to explore the direct impact of the gas extraction activities upon the improved and unimproved roads of the Commonwealth, the impact upon the secondary road bridges, the impact upon other programs that the Commonwealth conducts to aid these communities, the travel safety associated with the demand by the gas companies to produce wells, and the impact on the "quality of life" of the local residents resulting from the degradation of not only the roads but loss of resources and the esthetics of the area.

Within the last few years, the development of Marcellus Shale natural gas drilling has been a greatly debated topic for affected states. Northern and western Pennsylvania have experienced a boom in natural gas drilling operations since 2007. While the processes associated with the drilling operation are well understood, the side effects of this emerging industry are not. The transportation sector in these regions has been greatly affected in terms of infrastructure and traffic. Counties that are experiencing high concentrations of drilling activity are often very rural with underdeveloped highway networks. Roadways that for years were only subjected to passenger cars and light-duty trucks, now routinely experience high volumes of tractor semi-trailers and water tanker trucks.

Transportation infrastructure is one of the fundamental aspects of daily life that impacts all levels of a community. The freedom to move about for daily necessities as well as to conduct business is widely embraced by society as a *quality of life* issue. Infrastructure is accepted to include roads and bridges. Both of these can be classified by size: primary hard surfaced roads are maintained by the Pennsylvania Department of Transportation (PennDOT), secondary hard surfaced roads are maintained by local municipalities, and dirt and gravel roads are also maintained by local municipalities. In total, Pennsylvania has approximately 41,000 miles of paved roads, 17,000 miles of dirt and gravel roads, and approximately 1,300 miles of both paved and dirt and gravel roads in the targeted study area, Bradford County. Bridges likewise are categorized based upon their size, ranging from simple culverts to multispan reinforced concrete structures. Most bridges over 20 ft in length are maintained and inspected by PennDOT, and those smaller in size are maintained and inspected locally. In the state there are some 25,000 bridges and in the study area there are 459, of which 346 are PennDOT's responsibility.

Gas companies have on standby dozens of construction crews who can at a moment's notice arrive at the scene of a distressed roadway and immediately implement repairs thus minimizing inconvenience for the general public; however, the replacement of a failed bridge is a much more significant issue from loss of service, inconvenience to the public, and cost. This component of the study evaluated the potential degradation of local bridges and the roadway leading up to the bridges.

This sudden change in traffic composition may have an adverse effect on transportation safety and mobility. However, little research has been done to conclusively quantify the impacts of this increase in heavy vehicle traffic. In an effort to begin this "cost quantification," this research will use crash data from Adams and Bradford counties in Pennsylvania to determine if there is any correlation between concentrations of drilling activity (wells per municipality) and heavy vehicle-related crashes. Bradford County has had a major increase in Marcellus drilling activity since 2008. Adams County has no Marcellus Shale formation but exhibits an infrastructure similar to Bradford Country and was used as a "control county" in an attempt to compare the effects of the impacts against a measure of baseline performance.

1.0 ROAD AND BRIDGE SURVEY

It was the goal of this study to determine the effect of the Marcellus Gas Play on the local transportation infrastructure in Bradford County, Pa. To accomplish this, a representative sample of bridges, and roadway segments adjacent to those bridges, was selected. Inspection reports provided by PennDOT were reviewed to both assess the condition of the selected bridges over the past several years and to determine if any rehabilitation work had been recently performed. The selected bridges were visually inspected and any significant changes to bridge condition were documented. Roadway inspection included visually examining a 100-ft (30.5-m) segment adjacent to each bridge to assess its condition.

2.0 BRIDGE SELECTION

A variety of factors were considered to obtain a representative sample of bridges. These factors included owner, size, age, condition, average daily traffic (ADT), and proximity to active well sites. Considered bridges were all longer than 20 ft (6.1 m), did not include culverts, and were located in Bradford County. Selected bridges were within reasonable proximity to at least one apparently active well site and, preferably, multiple apparently active sites. Active well sites were identified using Geographic Information Systems (GIS) well location data provided by the GIS Coordinator Bradford County Office of Planning and Grants. Bridge condition information was obtained using sufficiency and condition rating data available from the PennDOT website. Review of this information resulted in selecting seven bridges for inspection.

Of the 459 bridges (not including culverts) in Bradford County listed in PennDOT's sufficiency and condition rating inventory, 308 had a concrete superstructure, 136 had a steel superstructure, and the remaining bridges were of either timber or masonry construction. To reflect the greater number of concrete bridges in the inventory, four concrete and three steel bridges were selected. A majority of the bridges, 346 of the 459, were PennDOT owned. Consequently, five of the seven selected bridges were owned by PennDOT with the remaining two being township owned. Attempts were made to select a wide range of bridge lengths, conditions, ages, and traffic usage levels. The selected bridges' spans ranged from 32 ft to 156 ft (9.7 m to 47.5 m). Three bridges were listed as structurally deficient, with sufficiency ratings ranging from 40.5 to 98.1. Bridge dates of construction ranged from 1933 to 1984, though it was found that some of the selected bridges had undergone rehabilitation as recently as 2009. Finally, reported average daily traffic counts for the seven bridges ranged from as 75 to 7,287 vehicles per day.

Table 1 provides a summary of information for the seven selected bridges, including: owner; length; number of spans; structure type; year built; condition ratings; municipality; and ADT. In the table, bridge ID identifies each bridge's location (the first two digits refer to the county, the next four digits the roadway, the next four the station, and the last four the offset); SUP refers to superstructure rating (0 to 9, with 9 indicating excellent condition and 0 indicating failure); SUB refers to substructure rating (0 to 9); SD stands for structurally deficient, indicating the bridge has deterioration to one or more of its major components; and Suff. Rate is for the sufficiency rating (a 1 to 100 consideration of bridge safety level, serviceability, and how essential it is for public use, with 100 representing entirely sufficient and 0 representing completely deficient).

Appendix A contains a reproduction of the "PennDOT Bridge Inspection Terminology" form, available from the PennDOT website. The form provides additional information on the ratings, sufficiency ratings, and terminology used for the bridge inventory. Contained in the form are the definitions of the standard rating codes (0 through 9) that are used for all PennDOT and township inspection reports.

As stated earlier, well proximity assisted with final bridge down-selection. Figure 1 shows a map of Bradford County with the selected bridges, labeled one through seven, superimposed on existing gas pipelines and active wells as of February 2011. From this figure, it can be seen that each selected bridge appears to have multiple active well sites in close proximity.

Table 1. Bridge Information

Bridge Number	Bridge ID	Feature Carried	Owner Code*	Length		No. of Spans	Structure Type	Year Built	DECK	SUP	SUB	Struc. Def.	Suff. Rate	Municipality	ADT
				Feet	Meters										
1	08001403400602	State Route 14	01	32	9.7	1	Concrete (in place) T-beams	1933	6	4	4	SD	47.0	TROY	7,287
2	08741305110034	Eureka Drive	03	35	10.7	1	Steel, I beams	1963	6	4	6	SD	46.1	TROY	800
3	08402400100478	State Route 4024	01	156	47.5	2	P/S, Box beam (adjacent)	1979	6	3	7	SD	40.5	RIDGEBURY	683
4	08401300501670	State Route 4013	01	44	13.4	1	P/S, Box beam (spread)	1953	9	9	7	--	84.5	WEST BURLINGTON	1,311
5	08022003800000	State Route 220	01	133	40.5	1	Steel, I-welded beams	1974	8	7	7	--	98.1	TOWANDA	2,243
6	08722006080001	Harmony Hill Road	03	48	14.6	1	P/S, Box beam (adjacent)	1984	5	7	5	--	68.5	ROME	75
7	08201400300000	State Route 2014	01	41	12.5	1	Steel, I beams	1954	6	6	5	--	72.9	ASYLUM	120

* 01 –PennDOT, 03 –Town or Township Highway Agency

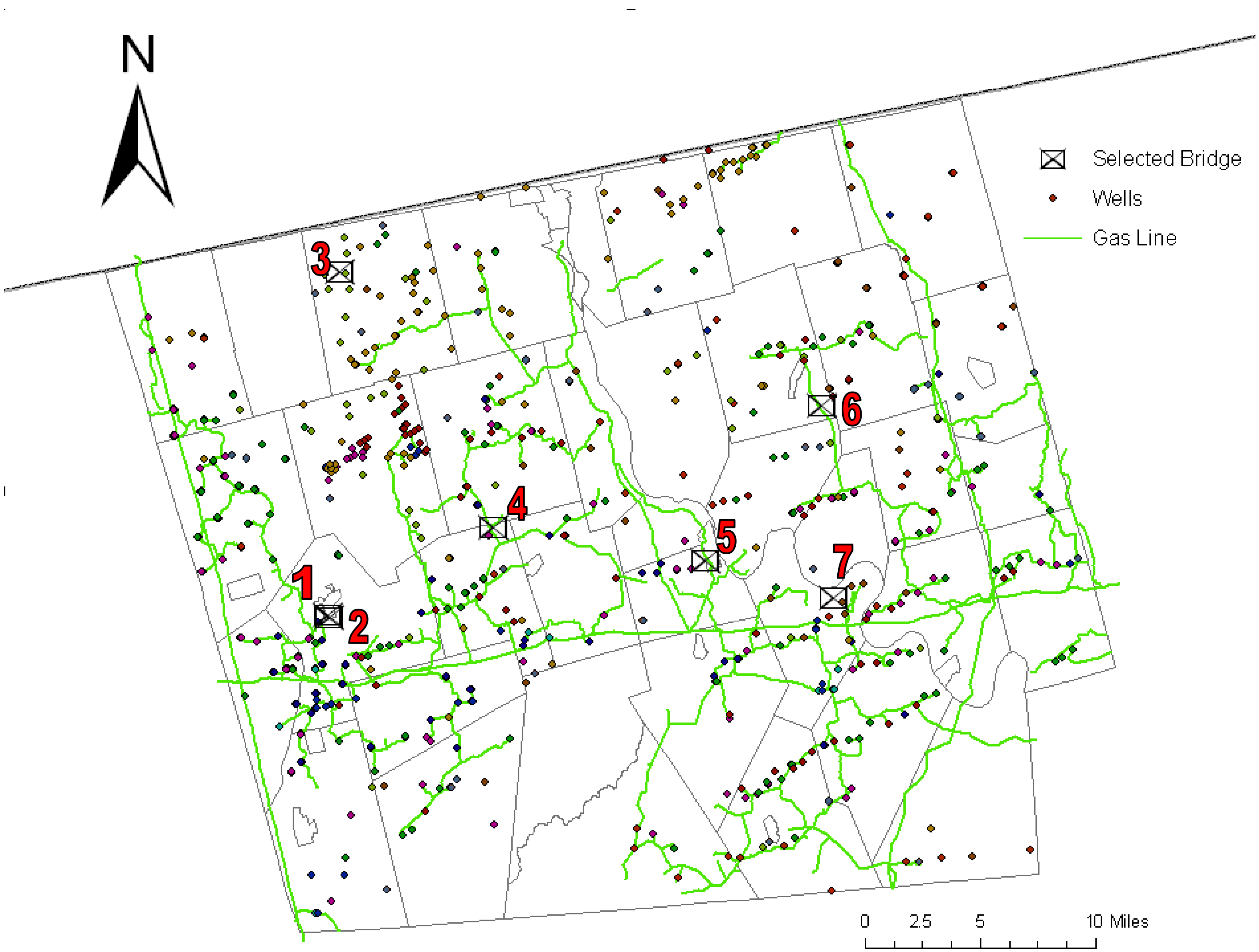


Figure 1. Bradford County Selected Bridges, Gas Pipelines, and Well Locations, February 2011

3.0 BRIDGE INSPECTION

The seven selected bridges were inspected by Penn State personnel in June 2011. The findings of these inspections were compared to notes taken from all available official inspections performed by PennDOT or engineering consultants. This section summarizes information for each critical bridge component as noted from the most recent inspection report, discuss findings of the June 2011 inspection performed by Penn State personnel, and compare and contrast findings from each of the inspections. General trends and a summary are presented at the conclusion of this section. Assessments of roadway condition adjacent to each bridge are presented in the Roadway Inspection section.

3.1 Bridge One, 08-0014-0340-0602

Located in Troy, Pa. along State Route 14, Bridge One is the oldest bridge that was inspected and had the highest ADT. The 32-ft (9.7-m) long single span, as shown in Figure 2, is supported by nine concrete T-beams. During the course of the Penn State inspection a number of Gas Play related trucks crossed the bridge. The reviewed PennDOT inspection report for this bridge was from 2010. The estimated average daily truck traffic, ADTT, was 1,115 as given by this report, with the ADT listed at 7,287. The bridge was listed as structurally deficient and had a sufficiency rating of 47.0.

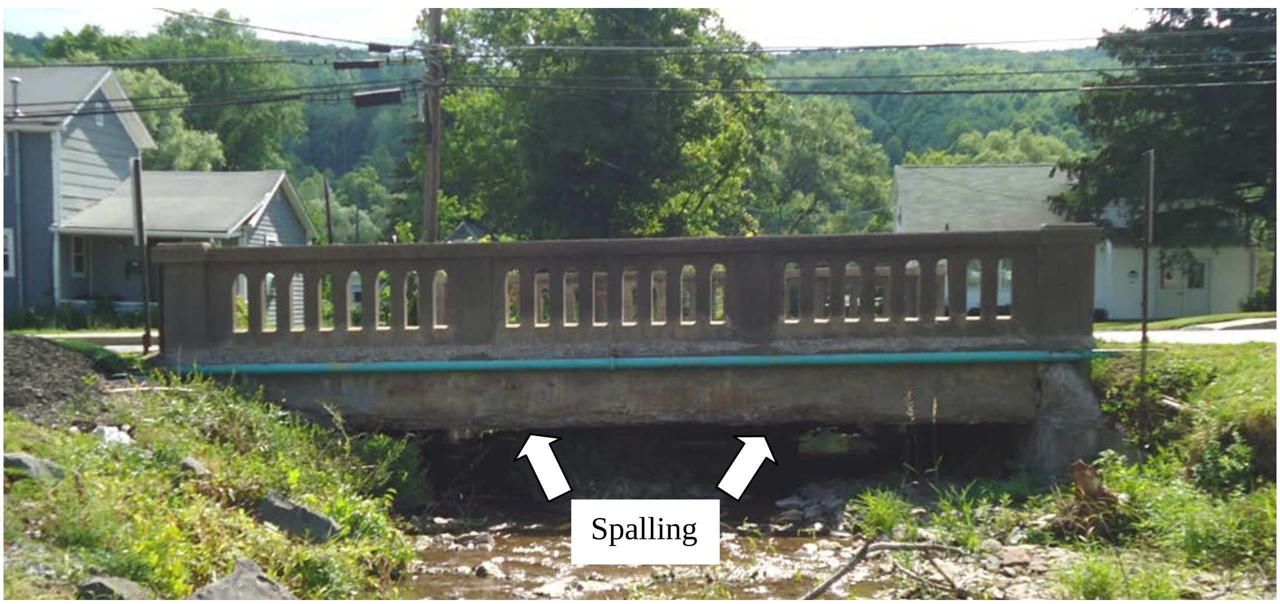
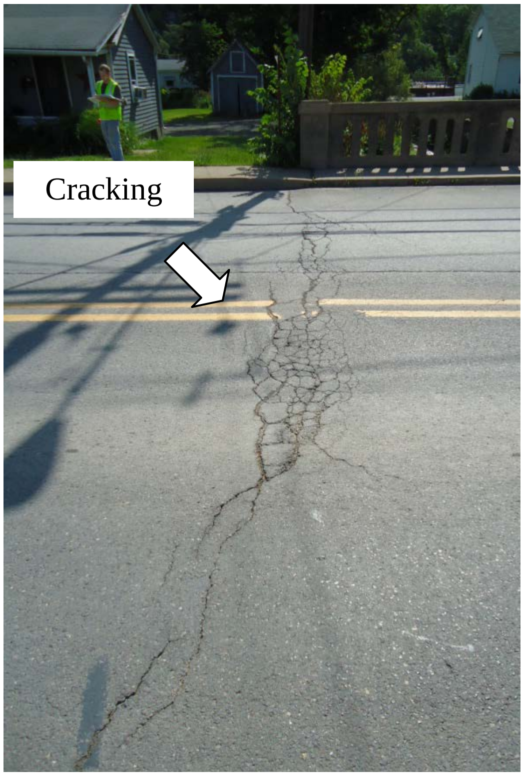


Figure 2. Bridge One Elevation

The PennDOT inspection report indicated that the wearing surface was rated 7, which indicates good condition with some minor problems. In agreement with the PennDOT inspection report, the Penn State visual inspection indicated some minor rutting and isolated longitudinal cracks in the asphalt wearing surface. Multiple cracks up to 1 inch (25.4 mm) wide existed above the northern abutment, which was also noted in the PennDOT inspection report. Figure 3a shows these cracks and Figure 3b shows the crack's propagation into the bridge's sidewalk.



(a) Roadway

(b) Sidewalk

Figure 3. Bridge One Cracking along Northern Abutment

A satisfactory condition rating of 6 was assigned to the deck. Due to the wearing surface covering the deck, only the underside of the deck could be inspected by Penn State personnel. Consistent with previous PennDOT inspection reports, random cracking and efflorescence was observed along with honeycombing, surface scale, and spalling with exposed rebar. A significant amount of spalling was observed along the deck's exterior, which can be seen in Figure 2.

The Penn State inspection indicated that the superstructure was in very poor condition. The PennDOT inspection reports rated it a 4, indicating advanced section loss and deterioration. Penn State inspection of the concrete T-beams confirmed the poor superstructure condition. Concrete spalling and deterioration was quite prevalent. Exposed and corroded rebar was observed in several beams. Figure 4a and 4b shows an example of this deterioration in the second beam and seventh beam, respectively, as numbered from west to east. These findings were similar to those in the reviewed inspection report. The Penn State inspection indicted that some beams, particularly on the east side of the bridge, had noticeable sag that was not listed in the reviewed inspection reports. Repairs were attempted on beams six and seven in the form of patching, seen in Figure 4b.

(a) Beam One Exposed and Corroded Rebar (b) Beam Seven and North Abutment Deterioration

Figure 4. Bridge One Concrete T-beams and Abutment

The substructure also received a 4 in the reviewed PennDOT inspection report. Both abutments had a number of horizontal cracks, scaling, efflorescence, and areas of unsound concrete, and findings from the Penn State inspection were in general agreement with the reviewed PennDOT inspection report. Heavy corrosion and deterioration existed at the bearings of beams one, six, and seven, and these findings also agreed with the inspection reports. The extent of the abutment deterioration is shown in Figure 4b, which shows a section of the north abutment under beam seven.

Bridge One is relatively old, and age and location likely contribute to its poor condition. The Penn State inspection indicted that several beams were deteriorated and sagging. Additionally, the north abutment had large amounts of spalled and unsound concrete and the wearing surface and sidewalk were also observed to be deteriorated. Deterioration to several components of the bridge coupled with an apparent increase in the amount of truck traffic traversing the bridge during the Penn State inspection, with many trucks appearing to be involved in the Gas Play, should increase the extreme load cycles that the bridge sees and, subsequently, the importance of improving its condition via rehabilitation or replacement.

3.2 Bridge Two, 08-7413-0511-0034

Bridge Two, shown in Figure 5, is a Troy Township owned, 35-ft (10.7-m) long, steel girder, open grid deck, single-span bridge. It is located in Troy, Pa., along Eureka Drive directly off of State Route 14. The bridge was built in 1963 and was rehabilitated in 2001. Its sufficiency rating was listed at 46.1, deeming it structurally deficient. The ADT was given at 800 with no information provided on the ADTT. During the Penn State inspection, trucks were observed passing over the structure, though they were not likely related to the Gas Play. The trucks observed were all departing from a large industrial facility located close to the bridge. 2009 was the year of the latest reviewed township inspection report.

Figure 5. Bridge Two Elevation

The steel grid deck, partially shown in Figure 6a and 6b, was rated a 6 in the reviewed township inspection reports, meaning it was of satisfactory condition with some minor deterioration. Heavy to moderate corrosion and several bent grid deck bars were observed. Minor corrosion and scraping was evident along the railing with corroded and bent grid deck bars prevalent along the sidewalk. These observations were in agreement with the reviewed township inspection reports. Not listed in the township inspection reports but observed during the Penn State inspection was damage to the asphalt at the approach slab to bridge transition along both the west and east ends of the bridge, shown in Figure 6a and 6b, respectively. Up to ¼ inch (6.35 mm) of settlement was measured adjacent to the east abutment.

(a) West Transition Pavement Damage

(b) East Transition Pavement Damage

Figure 6. Bridge Two Transitions

The bridge superstructure, made up of 11 steel beams, received a rating of 4 in the reviewed township inspection reports, indicating poor condition. Six of the 11 beams, as noted in the reviewed township inspection reports, were newer and likely replaced during the 2001 rehabilitation. Those beams were observed during the Penn State inspection to be mostly in satisfactory condition with minor corrosion and some section loss. The remaining four beams had considerable corrosion. Figure 7a shows Beam 10 (labeled from south to north) with considerable corrosion. Beam Three had several areas of section loss in the bottom flange and the web near the west abutment. Beam Six, shown in Figure 7b, was observed during the Penn State inspection to be severely corroded and was considered not to carry load, as noted by the reviewed inspection reports. Cross-frames showed moderate surface corrosion. Bearings plates had heavy corrosion and minor section loss, with several anchor bolts having considerable section loss. These findings were all consistent with the reviewed township inspection reports.

(a) Beam Ten Corrosion

(b) Beam Six Corrosion and Section Loss

Figure 7. Bridge Two Steel I-Beams

The substructure received a satisfactory rating of 6 in the reviewed township inspection reports. The findings of the Penn State inspection were similar to those reported in the reviewed reports. Both abutments had spalled concrete, up to 1 inch (25.4 mm) deep in some areas, in addition to vertical cracks with efflorescence.

The superstructure and substructure showed little if any change during the Penn State inspection compared to the reviewed township inspection reports. Their condition was more likely a result of age rather than traffic, considering most of the damage to the structure was due to corrosion. Some additional deterioration not explicitly mentioned in inspection reports was observed in the asphalt at the bridge ends, as shown in Figure 6. However, given the location of the bridge, the damage is assumed not likely to be from Gas Play traffic.

3.3 Bridge Three, 08-4024-0010-0478

Bridge Three is a 156-ft (47.5-m) long, two-span, prestressed concrete, adjacent box beam bridge. It is located in Ridgebury, Pa., along State Route 4024, adjacent to the Berwick Turnpike. An elevation view of the bridge is shown in Figure 8. The bridge's sufficiency rating was the lowest of all the selected bridges, at 40.5, and it was identified as being structurally deficient. The ADT was listed at 683, with 7 percent being truck traffic. A storage site for drilling equipment was located a few hundred feet from the bridge, indicating this bridge likely supported intermittent truck traffic related to the Gas Play. The most recent PennDOT inspection report was from 2010.

Figure 8. Bridge Three Elevation

The bridge's wearing surface and approach roadway were resurfaced with a bituminous overlay in 2009. The wearing surface received a rating of 8 in the PennDOT inspection reports that followed the resurfacing. A $^{1}/_{8}$-inch (3.17-mm) transverse crack, not noted in the inspection report, was observed during the Penn State inspection directly over the pier, as shown in Figure 9a. Otherwise, the wearing surface inspection was in agreement with the reviewed PennDOT inspection reports. The bridge's non-composite deck received a rating of 6 in the PennDOT inspection reports, though neither the top nor the underside was visible during the Penn State inspection.

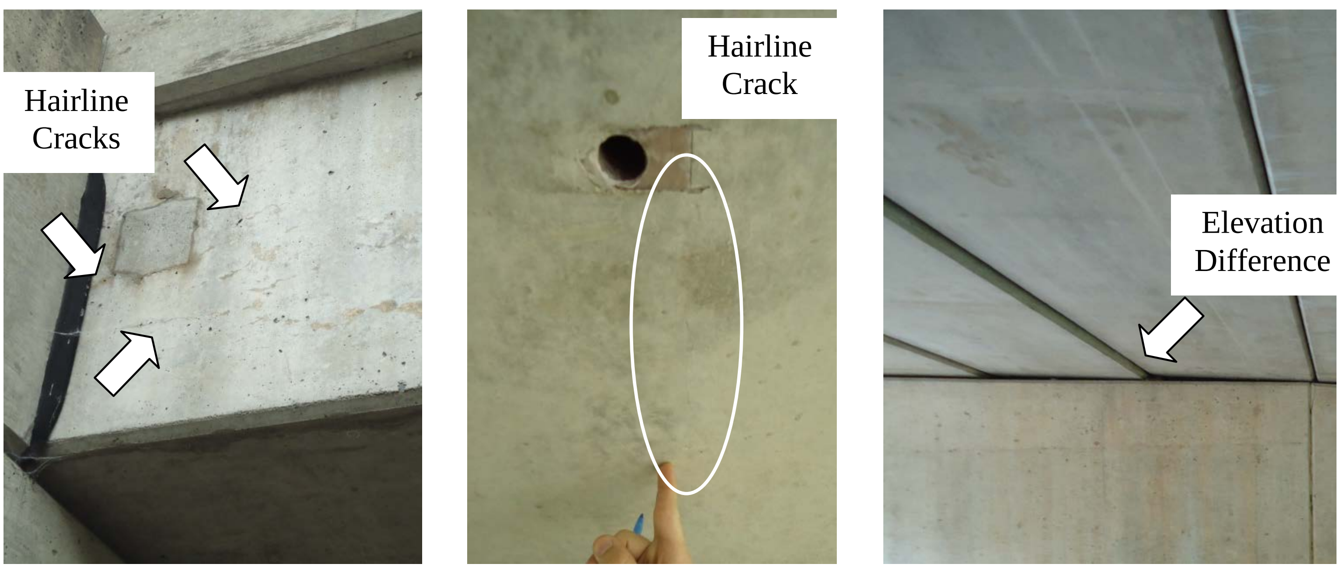
(a) 1/8" (3.2 mm) Crack at Pier   (b) Hairline Vertical Crac Parapet   (c) North Parapet Spalling

Figure 9. Bridge Three Wearing Surface and Parapet

The parapets received a rating of 6 in the reviewed PennDOT inspection reports, meaning they were adequate. Areas of vehicle-related scrapes, honeycombing, and vertical hairline cracking were noted in the PennDOT reports. These items were observed during the Penn State inspection in a few isolated areas. Not included in the PennDOT inspection reports were observed areas of spalling of the parapet at the deck intersection. Instances of parapet vertical hairline cracking and spalling are shown in Figure 9b and 9c, respectively.

A rating of 3 was assigned to the superstructure in the reviewed PennDOT inspection reports, indicating that serious section loss, deterioration, spalling, or scour seriously affected the primary structure. The PennDOT inspection reports noted varying amounts of sag from beam to beam, in addition to multiple beams having height differences at their stem and a slight twist. Multiple longitudinal, diagonal, and vertical cracks as well as efflorescence between beams and staining at drain holes were noted in the reviewed PennDOT reports. The fascia beams were noted to have several cracks.

The Penn State inspection indicated instances of cracking and staining, as documented in the reviewed PennDOT inspection reports. Most cracking was hairline and located along the fascia. These cracks often formed around grout used to cover tendon tensioning ducts. An example of this is shown in Figure 10a, which displays a patch along the north fascia at the west abutment. The beam undersides generally had few hairline cracks observed during the Penn State inspection. Figure 10b shows one such crack extending from a drain hole in an intermediate beam. Efflorescence between beams was observed, as noted by PennDOT inspection reports. The elevation difference at the stem of the beams listed in the PennDOT inspection reports was observed, shown in Figure 10c, though the twist mentioned in the reports was not evident during the Penn State inspection.



(a) North Fascia Beam at East Abutment

(b) Crack at Drain Hole of Intermediate Beam

(c) Beam Elevation Difference at East Abutment Stem

Figure 10. Bridge Three Beam Condition

The substructure of Bridge Three was assigned a 7 in the reviewed PennDOT inspection reports, indicating good condition. Listed in the reviewed PennDOT inspection reports were hairline vertical and map cracks in both abutments. Efflorescence was also noted on both abutments. The Penn State inspection yielded the same observations, noting the abutments were generally in good condition.

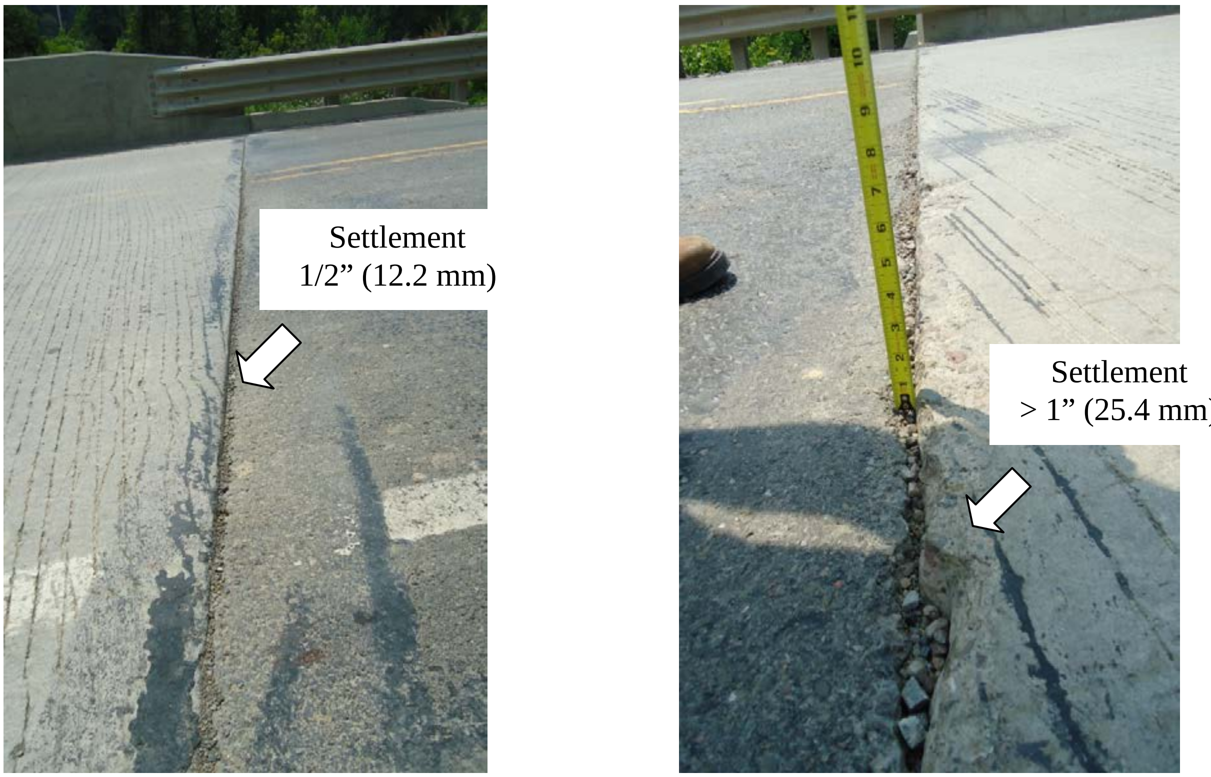
Bridge Three had the worst sufficiency rating of all selected bridges. The reviewed PennDOT inspection reports gave ratings of satisfactory or better to nearly all bridge components except the superstructure, which was given a very poor condition rating. The Penn State inspection of the superstructure did locate multiple cracks, efflorescence, and staining, though all items were judged to be minor. No serious loss of section, deterioration, or spalling was observed as the reviewed PennDOT inspection reports and ratings would indicate. The only observed deterioration, in addition to the instances noted in the inspection reports, was the cracking of the wearing surface above the pier. Given that a Gas Play equipment storage site was observed close to one end of the structure during the Penn State inspection, it likely the bridge supported a moderate amount of truck traffic related to the Gas Play.

3.4 Bridge Four, 08-4013-0050-1670

Bridge Four is a 44 ft (13.4 m) long, prestressed, spread, single-span, concrete, box beam bridge. The original structure, built in 1953, was rehabilitated in 2009, when the deck, wearing surface, parapets, superstructure and abutments caps were replaced. Reflective of the recent rehabilitation, the bridge had a sufficiency rating of 84.5, indicating it was in good condition. The bridge is located on State Route 4013 in West Burlington, Pa. A number of trucks that appeared to be involved with the Gas Play were observed crossing the bridge during the Penn State inspection, although the ADT of 1,113 provided on the reviewed PennDOT inspection reports had a 4 percent truck composition. Additionally, a pipeline assumed to be associated with the Gas Play was being installed close to the bridge, as shown in Figure 31. Figure 11 provides an elevation of Bridge Four looking west with a truck containing aggregate, likely related to the Gas Play, shown traversing the bridge. 2010 was the year of the latest reviewed PennDOT inspection report.

Figure 11. Bridge Four Elevation

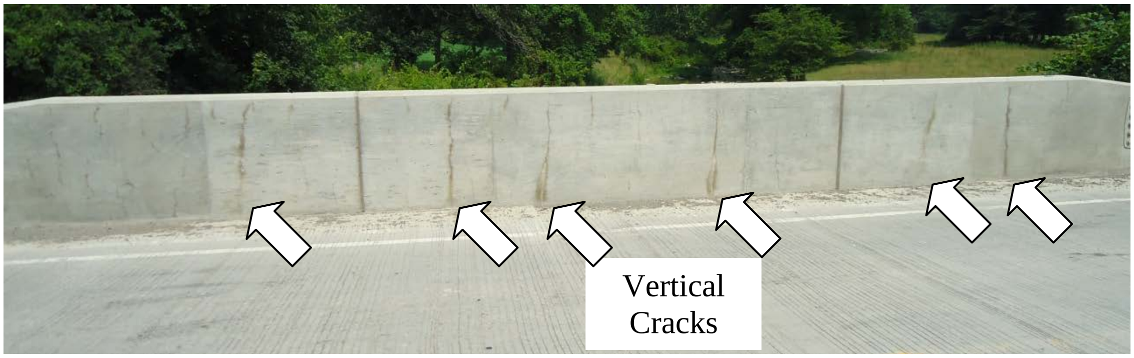
The bridge's wearing surface and deck received ratings of 8 and 9, respectively, in the reviewed PennDOT inspection reports. The only deficiencies noted in the reports were isolated longitudinal cracks and isolated surface edge spalls along the deck. These problems were also observed during the Penn State inspection. Not mentioned in the reports were areas of rutting and wear of the wearing surface noticed during Penn State inspection. Additionally, approach slab settlement was observed at both abutments. The north end had some areas of settlement up to ½ inch (12.7 mm) and the south had instances of settlement greater than 1 inch (25.4 mm). Figure 12a and 12b display settlement adjacent to the north and south abutments, respectively.



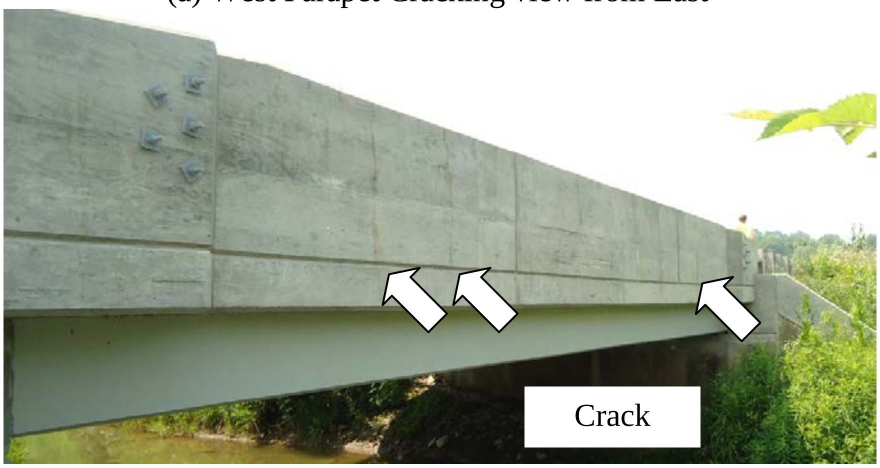
(a) Settlement at North Abutment (b) Settlement at South Abutment

Figure 12. Bridge Four Transitions

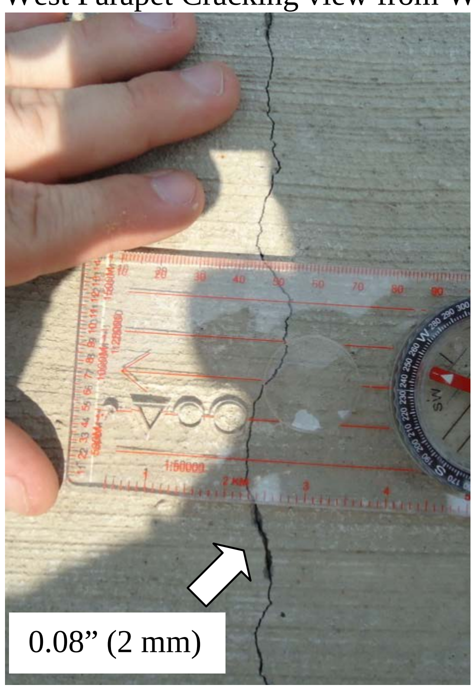
The concrete parapets were, as discussed, replaced during the 2009 rehabilitation and received a rating of 8, with only isolated hairline cracks and limited efflorescence listed as deficiencies in the PennDOT inspection reports. The Penn State inspection indicated several full-height, through-thickness vertical cracks at multiple locations in both parapets. Map cracking was also evident. The width of the cracks typically ranged from hairline to slightly greater than 1/16 inch (1.6 mm). Some cracks are visible in Figure 11 and, in general, they indicated that moisture was intruding into the parapet at their locations, as water staining was visible in nearly all cracks. Figure 13a shows the cracking in the east parapet. Figure 13b shows crack penetration through the thickness of the parapet. Finally, Figure 13c shows the width of the typical cracks that were observed. The maximum width in this photo is 0.08 inch (2 mm).



(a) West Parapet Cracking view from East



(b) West Parapet Cracking view from West



(c) Typical Parapet Cracking Width, 0.08” (2 mm) maximum

Figure 13. Bridge Four East Parapet

The superstructure received the highest rating of 9 in the reviewed PennDOT inspection report. The findings of the Penn State inspection were in agreement with this rating. The beams were in excellent condition with no cracking observed. The substructure was rated 7, indicating good condition. Approximately 10 inches (254 mm) at the top of each abutment was replaced during the 2009 rehabilitation. Both old and new portions of each abutment were observed during the Penn State inspection to contain a small number of hairline vertical cracks. This was in agreement with the reviewed PennDOT inspection reports as well.

The Penn State inspection of Bridge Four, which was shown to be in close proximity to Gas Play activity due to pipeline installation in close proximity and the large number of trucks observed crossing the bridge, showed deficiencies that, given the recent (2009) and extensive rehabilitation that occurred (wearing surface, deck, superstructure and portion of substructure replaced), are a concern. It was noted during the Penn State inspection that measurable settlement between the approach slab and bridge abutments existed along with deck wear and rutting, as shown in Figure 12. In addition, multiple full-thickness cracks were clearly evident in both parapets. Neither of these items was noted in the 2010 PennDOT inspection report that was reviewed prior to the Penn State inspection. The accelerated levels of deterioration of the deck surface and parapets are a concern given the short time duration since the rehabilitation. It could be surmised that one contributor to the accelerated deterioration level is the increased load demand, both in magnitude and number of cycles, that has occurred as a result of Gas Play related trucks traversing the structure.

3.5 Bridge Five, 08-0220-0380-0000

Bridge Five, located in Towanda, Pa., along State Route 220, is a seven steel beam, single-span bridge having a133-ft (40.5-m) span. The bridge was built in 1974 and was rehabilitated in 2009. The reviewed PennDOT inspection reports assigned it an excellent sufficiency rating of 98.1 in 2010. Traffic observed during the Penn State inspection consisted of a number of trucks, some of which were likely related to the Gas Play. The ADT was 2,241 and the ADTT 76 in the reviewed PennDOT inspection reports. Figure 14 shows the western elevation of Bridge Five.

Figure 14. Bridge Five Elevation

The deck and wearing surface were both given ratings of 8 in the reviewed PennDOT inspection reports, meaning they were in very good condition. A concrete overlay was placed in 2009. The Penn State inspection revealed several hairline longitudinal and transverse cracks in wearing surface areas mentioned in the reviewed PennDOT inspection reports. In general, the deck and wearing surface were observed during the Penn State inspection to be in good condition and in agreement with the PennDOT inspection reports. Exceptions noted during the Penn State inspection consisted of some minor rutting in the travel lanes and up to ¾ inch (19.1 mm) of settlement in the approach slab at the south abutment, shown in Figure 15. The parapet also had minor vertical cracks and scrapes, findings that were in agreement with the PennDOT inspection report.

Figure 15. Bridge Five Settlement at South Abutment

The PennDOT inspection reports rated the superstructure a 7, meaning good condition. The beams and cross-frames were generally in good condition with some areas of light to moderate surface corrosion and peeled paint. The observed condition during the Penn State inspection was generally similar to that listed in the reviewed PennDOT inspection reports.

The substructure also received a rating of 7 in the reviewed PennDOT inspection reports, indicating good condition. The top 2 ft (0.6 m) of each abutment was replaced during the 2009 rehabilitation. The Penn State inspection yielded similar observations as the reviewed PennDOT inspection reports. Random hairline vertical and longitudinal cracks were seen in both abutments as well as some staining in the north abutment. The only additional instance of deterioration identified during the Penn State inspection but not listed in the reviewed PennDOT inspection reports was cracking of the west fascia girder's seat in the south abutment, as shown in Figure 16.

Figure 16. Bridge Five Cracking of the West Fascia Girder Seat at the South Abutment

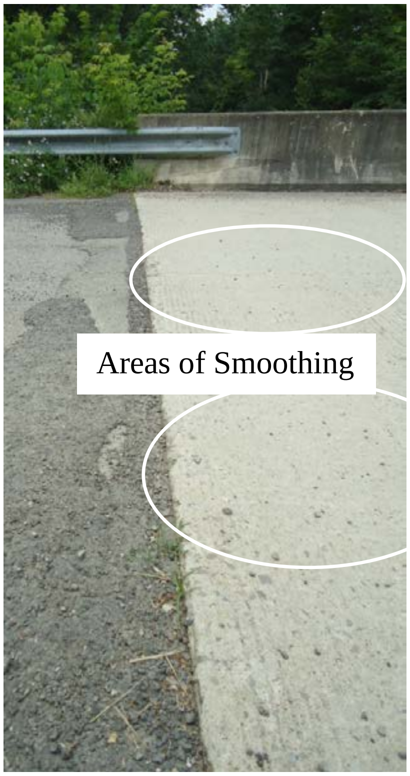
Bridge Five, with a recent rehabilitation, showed some signs of deterioration during the Penn State inspection that differed from the reviewed PennDOT inspection reports. The wearing surface was observed to have some minor rutting and the bridge's south approach slab indicated some settlement. Cracking in the abutment under the west fascia girder was a previously unreported observation, though the remainder of the bridge was largely in similar condition to what was reported in the reviewed PennDOT inspection reports.

3.6 Bridge Six, 08-7220-0608-0001

Bridge Six is owned by and located in Rome Township, Pa., along Harmony Hill Road. The bridge is a single, 48-ft (14.6-m) span and is supported by seven prestressed, adjacent box beams. The bridge was built in 1984 and was assigned a sufficiency rating of 68.5 in the township inspection report. The ADT was reported to be 75. Very little traffic was observed during the time of the Penn State inspection. It was surmised during the Penn State inspection that minimal Gas Play was traversing the structure.

Figure 17. Bridge Six Elevation

The bridge wearing surface and deck were both given ratings of 5 in the reviewed township report, which indicates that all structural elements are sound but may have some minor section loss. Findings from the reviewed township inspection report were very similar to observations made during the Penn State inspection. The deck was observed during the Penn State inspection to have exposed construction joints and some hairline cracks. The Penn State inspection also indicated that the wearing surface had heavy wear and smoothed surfaces with exposed aggregate, as shown in Figure 18a. A few minor popouts and surface spalls were also present. Settlement of up to ¾ inch (19.1 mm) of the approach slab, displayed in Figure 18b, was observed at the south abutment during the Penn State inspection. No assessment of parapet condition was given in the township inspection report and, during the Penn State inspection, they were observed to have a number of hairline vertical cracks and efflorescence, as shown in Figure 17.



(a) Smoothing of Wearing Surface

(b) Settlement above South Abutment

Figure 18. Bridge Six South Transition

The reviewed township inspection report assigned a rating of 7 to the superstructure, indicating good condition. The fascia box beams had various hairline longitudinal and map cracks with efflorescence along their exterior faces. Beams two and three, numbered west to east, had hairline longitudinal cracks at the north abutment. The condition of the superstructure as observed during the Penn State inspection was generally identical to the description provided in the reviewed township inspection report, with one possible exception. Efflorescence between beam joints was mentioned and listed as minor in the reviewed inspection report. Efflorescence and staining observed during the Penn State inspection (Figure 19) appeared more prevalent and likely had increased since the last inspection. This could possibly be indicative of a failing joint between adjacent beams.

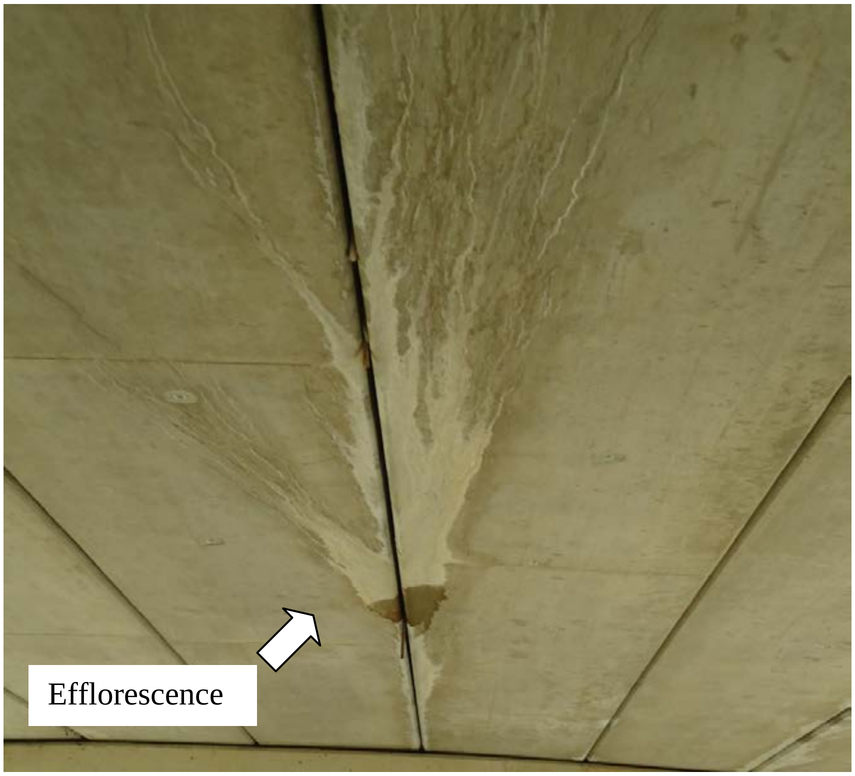


Figure 19. Bridge Six Efflorescence between Beam Three and Four

The substructure received a rating of 5 in the reviewed township inspection report, meaning it was in fair condition and showing minor cracks and signs of deterioration. The observed condition of the abutments during the Penn State inspection was in agreement with the reviewed township inspection report. Both abutments had some scour. Several full-height vertical cracks of varying width were observed along the center of both abutments. The footings for both abutments had moderate to heavy scaling. Spalling existed at the south abutment. Various amounts of efflorescence and honeycombing were observed in both abutments.

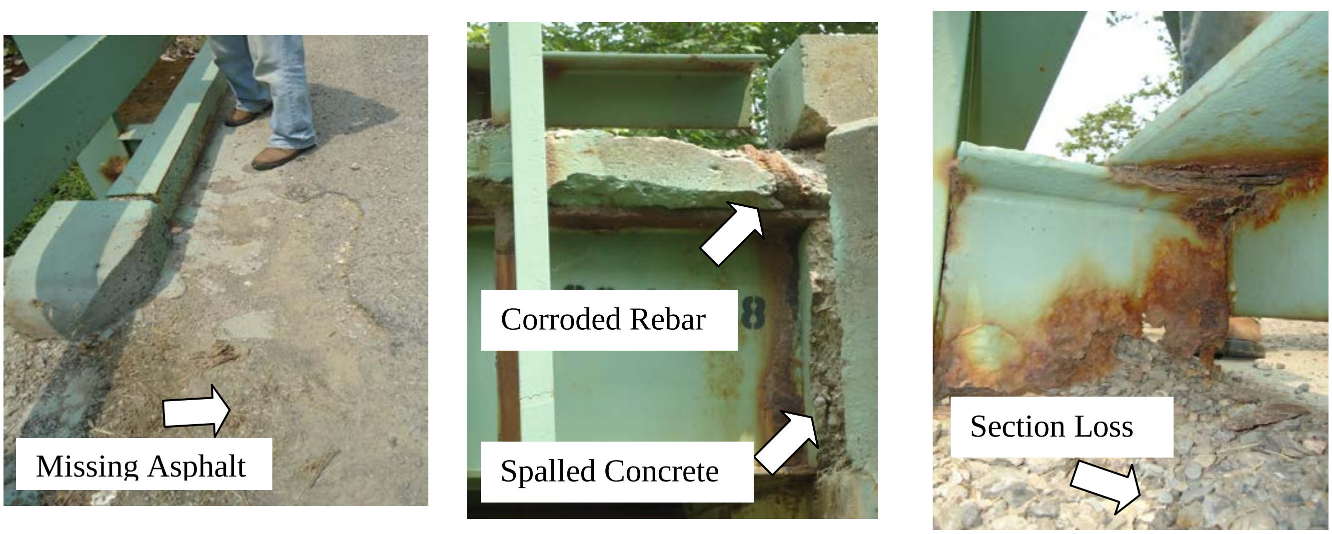
In summary, Bridge Six showed a few signs of deterioration during the Penn State inspection that differed from the reviewed PennDOT inspection reports. The most apparent difference was the increased level of efflorescence and staining observed between adjacent box beams, possibly indicating a failed joint. This deficiency was not necessarily attributed to Gas Play activity, as a relatively low amount of traffic was observed during the Penn State inspection with little being attributed to Gas Play activity.

3.7 Bridge Seven, 08-2014-0030-0000

The seventh bridge, depicted in Figure 20, is located in Asylum, Pa., on State Route 2014. The 41-ft (12.5-m) long steel, multi-beam bridge was rehabilitated in 2006. The structure received a sufficiency rating of 72.9. The latest reviewed PennDOT inspection report, from 2009, listed the ADT at 184, with 9 percent being truck traffic. During the Penn State inspection no heavy trucks that appeared to be affiliated with the Gas Play were observed traversing the bridge. However, Gas Play vehicles were observed in the area.

Figure 20. Bridge Seven Elevation

Satisfactory ratings of 6, meaning some minor deterioration exists, were assigned to both the wearing surface and deck in the reviewed PennDOT inspection reports. The Penn State inspection indicated that the wearing surface had areas of rutting and pumping asphalt. A section of asphalt adjacent to the railing was missing, as shown in Figure 21a. The deck had several areas of edge spalling and delaminated concrete. Rebar at the south edge of the bridge was exposed and corroded, as shown in Figure 21b. The deck underside also had areas of spalling and longitudinal and transverse cracks with efflorescence. The metal railing of the bridge was rated a 4 in the reviewed PennDOT inspection reports, indicating poor condition with advanced section loss. It was observed during the Penn State inspection to have heavy corrosion and areas of complete section loss at connection plates to the deck, as shown in Figure 21c. Field observations during the Penn State inspection were largely in agreement with deficiencies noted in the reviewed PennDOT inspection reports.



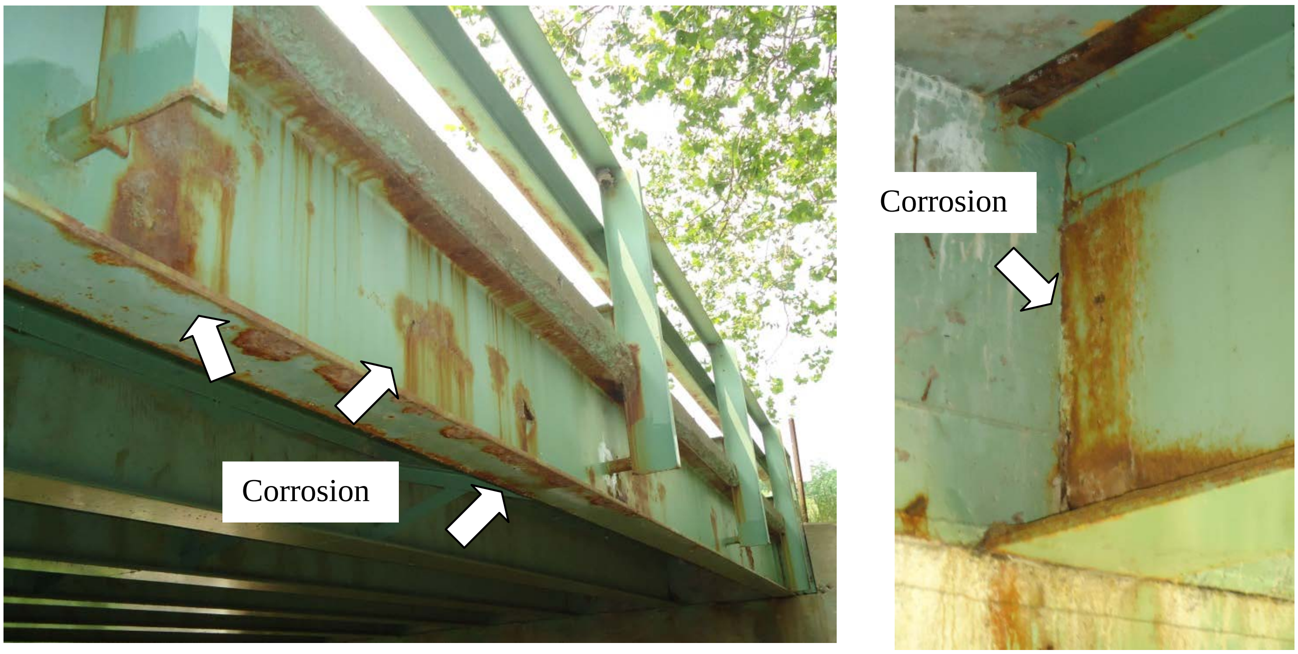
(a) Missing Asphalt Along Railing

(b) Spalled Concrete and Exposed Rebar

(c) Railing Connection Plate Section Loss

Figure 21. Bridge Seven Deck and Wearing Surface

The superstructure was rated a 6 in the reviewed PennDOT inspection reports, which indicated satisfactory condition with some minor deterioration. Corrosion was observed during the Penn State inspection to be prevalent on the beams, especially the fascia beams, and in some locations on the beams near the abutments, as depicted in Figure 22a and 22b, respectively. Compared to the fascia beams, interior beams generally had less corrosion. The condition of the superstructure as observed during Penn State inspection did not appear to significantly change compared to the reviewed PennDOT inspection reports.

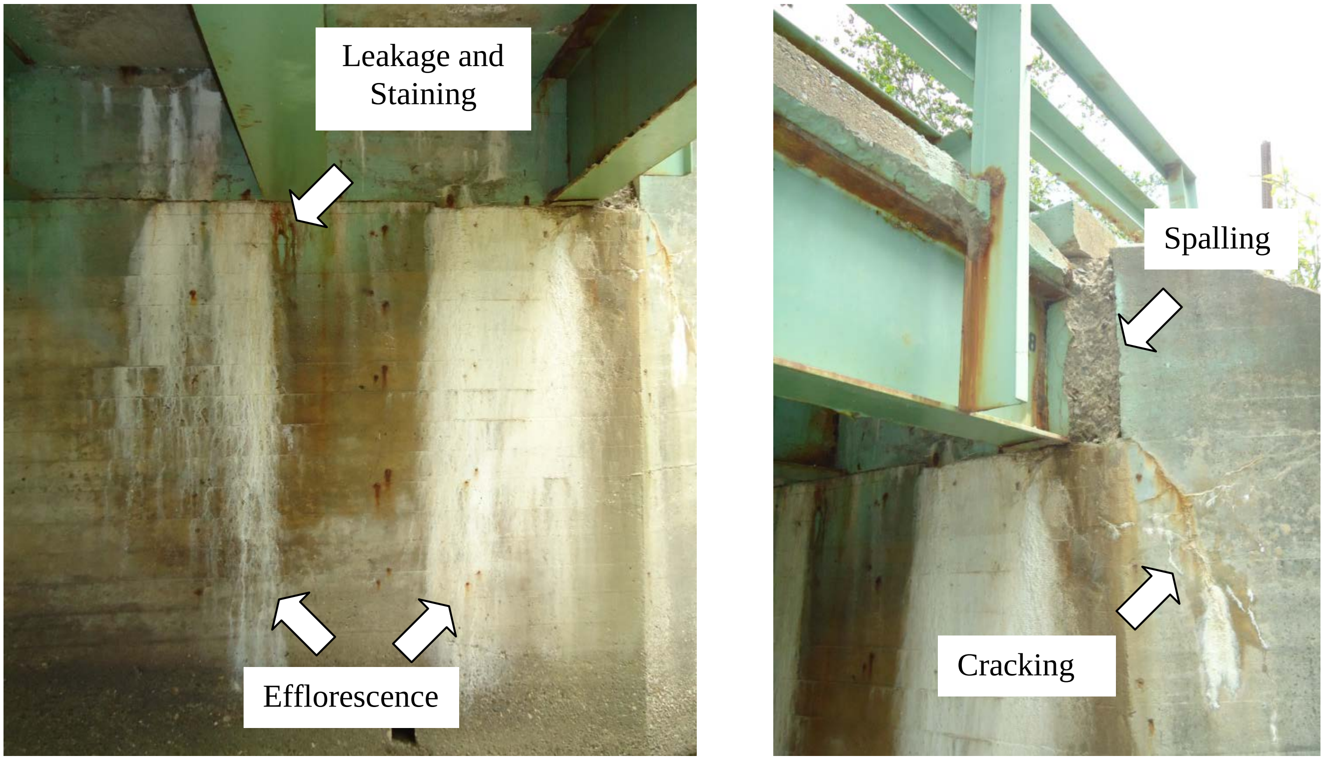


(a) North Fascia Corrosion

(b) Corrosion of Interior Beam at East Abutment

Figure 22. Bridge Seven Girders

The substructure received a rating of 5 in the reviewed PennDOT inspection reports, indicating fair condition with some section loss. Observations made during the Penn State inspection were similar to the PennDOT inspection reports. Large areas of leakage, efflorescence, and corrosion staining from the beams were present on both abutments. Multiple hairline and map cracks were observed in addition to surface spalling. Figure 23a details an example of the observed leakage and efflorescence and Figure 23b shows an example of cracking and spalling in the east abutment. Light to moderate scaling of the concrete at the waterline was observed for both abutments during the Penn State inspection.



(a) Leakage, Staining and Efflorescence (b) Cracking and Spalling

Figure 23. Bridge Seven East Abutment

Bridge Seven had very little change in condition observed during the Penn State inspection as compared to items noted in the reviewed PennDOT inspection reports. The asphalt wearing surface had a fair amount of rutting and asphalt deterioration. It is not definitive how much if any additional traffic the bridge supports due to Gas Play activities, but based on observations made during the Penn State inspection it is surmised that limited traffic occurs.

3.8 Bridge Inspection Summary

The seven inspected bridges varied significantly in terms of age, condition, type, size and traffic levels. Despite these differences, general trends were observed. In addition, two structures, Bridge One and Bridge Four, provided interesting insight into possible Gas Play activity influence on bridge condition level and deterioration rate.

General trends found during the Penn State inspections will be grouped and summarized in relation to the major bridge components. Firstly, the wearing surfaces of all bridges show appreciable wear. Rutting, longitudinal and transverse cracks, and approach slab settlement were very common. Deterioration of the wearing surface was seemingly accelerated in bridges having more truck traffic, with that traffic appearing to be related to Gas Play activities. The decks of the selected bridges were typically covered by the wearing surface with only the deck undersides being visible for the non-adjacent box beam bridges. The observations made during the Penn State inspections indicated little to no deck condition change compared to the reviewed inspection reports. Any increase in traffic as a result of the Gas Play was not shown to significantly change the condition of the superstructure or substructure in the bridges when Penn State observations were compared to PennDOT and township inspection reports.

Bridge One, one of the two structures mentioned earlier that could be considered to provide more insight into Gas Play activity influence on bridge condition and deterioration, was of increased interest because of the large volume of Gas Play traffic it supported and its generally low condition ratings. The structure was built in 1933 and was observed during the Penn State inspection to be carrying a large number of trucks affiliated with the Gas Play. The bridge's superstructure and substructure were heavily deteriorated. The PennDOT inspection report rating of the bridge beams was very low. Not previously mentioned in the report, however, were instances of beam sag. This may be an indication of increased deterioration. More importantly, Bridge One serves as an example of how aging and structurally deficient bridges are supporting an increasing number of heavy truck loads affiliated with Gas Play activities.

Bridge Four possibly provides the best example of how Gas Play activities can influence bridge condition and deterioration rates, as it was extensively rehabilitated in 2009 and the reviewed 2010 PennDOT inspection report largely indicated good condition. These items, coupled with the location of the bridge relative to known Gas Play work (pipeline installation adjacent to the bridge) and a large amount of observed Gas Play affiliated truck traffic, made the bridge ideal for study. The Penn State inspection indicated deterioration to certain areas of the wearing surface, parapets, and approach slab. More specifically, they included accelerated wearing surface rutting, approach slab settlement that measured to be a maximum of 1 inch (25.4 mm), and, most alarmingly, a large number of full penetration vertical cracks in the parapets that were holding moisture. These findings were surprising to the investigators, given the recent rehabilitation, and were indicative of deterioration that would exceed the norm. While the superstructure and substructure were largely unaffected, the excessive parapet and wearing surface deterioration could be considered to be a precursor to possible future accelerated deterioration to other areas of the bridge.

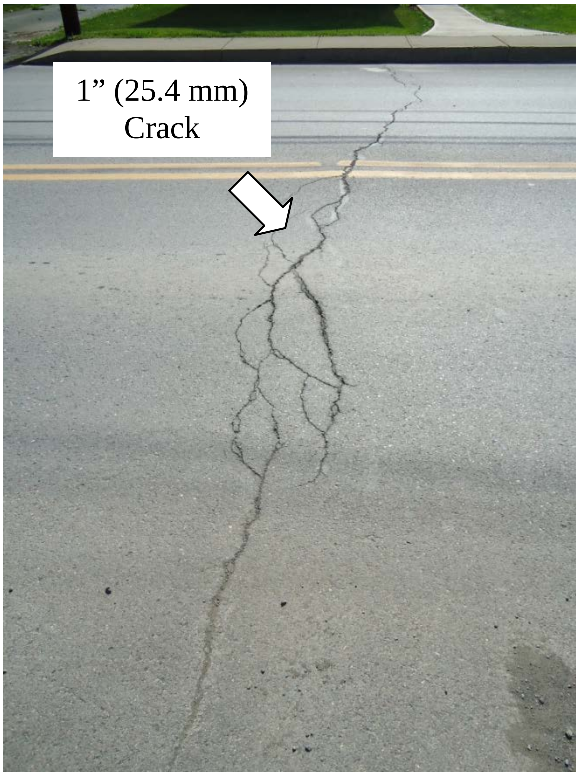
4.0 ROADWAY INSPECTION

Portions of the roadways adjacent to the bridges were examined by Penn State personnel in conjunction with the bridge inspections. An arbitrarily selected distance of 100 ft (30.5 m) at either end of the bridge was examined. Each reviewed PennDOT bridge inspection report typically provided information and a general rating of the bridge approaches. This information was used in similar fashion to bridge inspection information obtained from the reviewed reports to provide a baseline condition level for comparative purposes. This section will provide the rating of each bridge approach as listed in the reviewed PennDOT and township inspection reports along with figures and descriptions of the roadway condition adjacent to each bridge, as observed during the Penn State inspections. Traffic and location information for each corresponding bridge approach is contained in the Bridge Inspection section.

4.1 Approach Roadway - Bridge One, 08-0014-0340-0602

The approach roadway for Bridge One was rated a 7 in the reviewed PennDOT inspection report, indicating good condition. Longitudinal cracks were noted in the shoulder of the south approach and minor rutting was noted in both approaches.

The inspection performed by Penn State personnel indicated that the south approach roadway had several cracks. Figure 24a shows a full-width, 1-inch (25.4-mm) wide transverse crack. The southbound lane also had considerable pavement deterioration and cracking emitting from a storm drain, as shown in Figure 24b. Large longitudinal cracks were observed in both lanes and shoulders, as shown in Figure 24b.

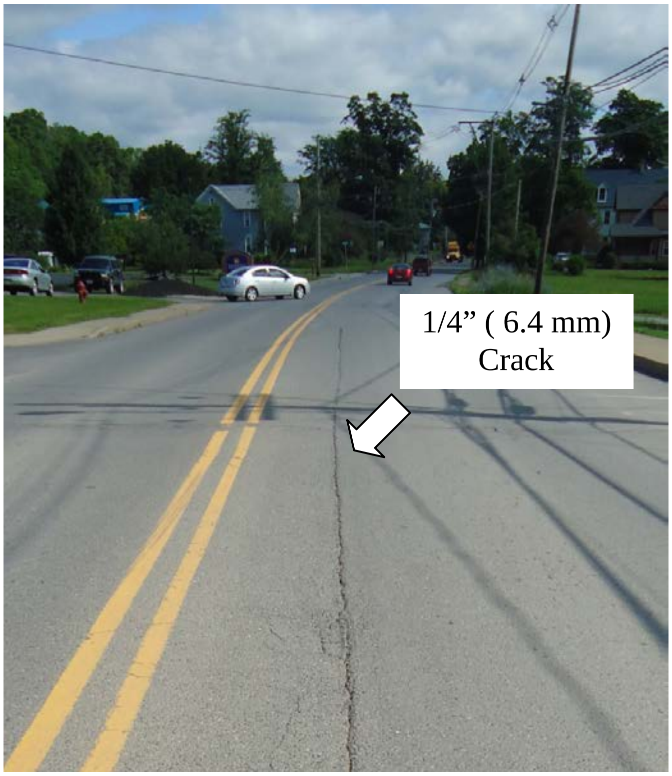


(a) 1" (25.4 mm) Wide Transverse Crack

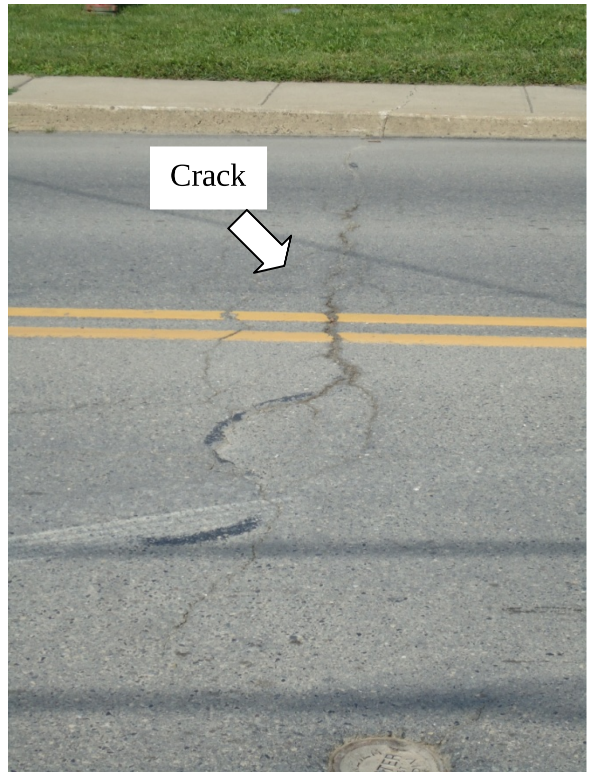
(b) Pavement Deterioration and Longitudinal Cracks

Figure 24. Bridge One South Approach Roadway

The north approach also had a large number of cracks. Several longitudinal cracks, ranging from 1/8 inch to ¼ inch (3.2 to 6.4 mm) wide were observed. The largest longitudinal crack extended away from the examined region in the northbound lane and continued across the bridge wearing surface. Multiple transverse cracks, up to 1 inch (25.4 mm) wide, were also observed during the Penn State inspection. Typical longitudinal transverse cracks are presented in Figure 25a and 25b, respectively.



(a) Northbound Lane 1/4” (6.4 mm) Wide Longitudinal Crack



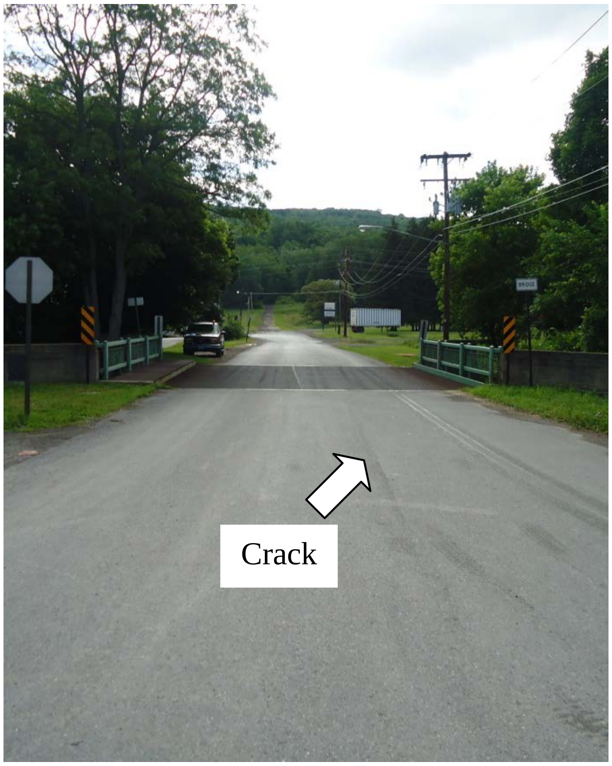
(b) Typical Transverse Crack

Figure 25. Bridge One North Approach Roadway

4.2 Approach Roadway Bridge Two, 08-7413-0511-0034

The reviewed township inspection reports for Bridge Two rated the approaches a 7, indicating good condition. Noted deficiencies included longitudinal edge cracks in both approaches and longitudinal cracking in the travel lanes.

The west approach was inspected by Penn State personnel to the intersection with Pennsylvania State Route 14, a distance that was less than 100 ft (30.5 m). A single longitudinal crack existed in the eastbound lane, shown in Figure 26a. Significant pavement damage and cracking was observed along the edge of the westbound lane, as shown in Figure 26b.



(a) Eastbound Lane Longitudinal Crack

(b) Westbound Lane Edge Pavement Damage and Cracking

Figure 26. Bridge Two West Approach Roadway

The east approach was observed by Penn State personnel to be similar in condition to the west approach. The eastbound lane contained multiple longitudinal cracks with some extending to the bridge. Figure 27a shows longitudinal cracks in the eastbound lane. The westbound lane contained a large area of map cracking and pavement deterioration at the shoulder. Figure 27b displays the westbound lane's most significant area of damage. Longitudinal cracks were also present in the westbound lane and typically were offset 2 ft (0.6 m) from the edge of the pavement.

(a) Eastbound Lane Longitudinal Cracks

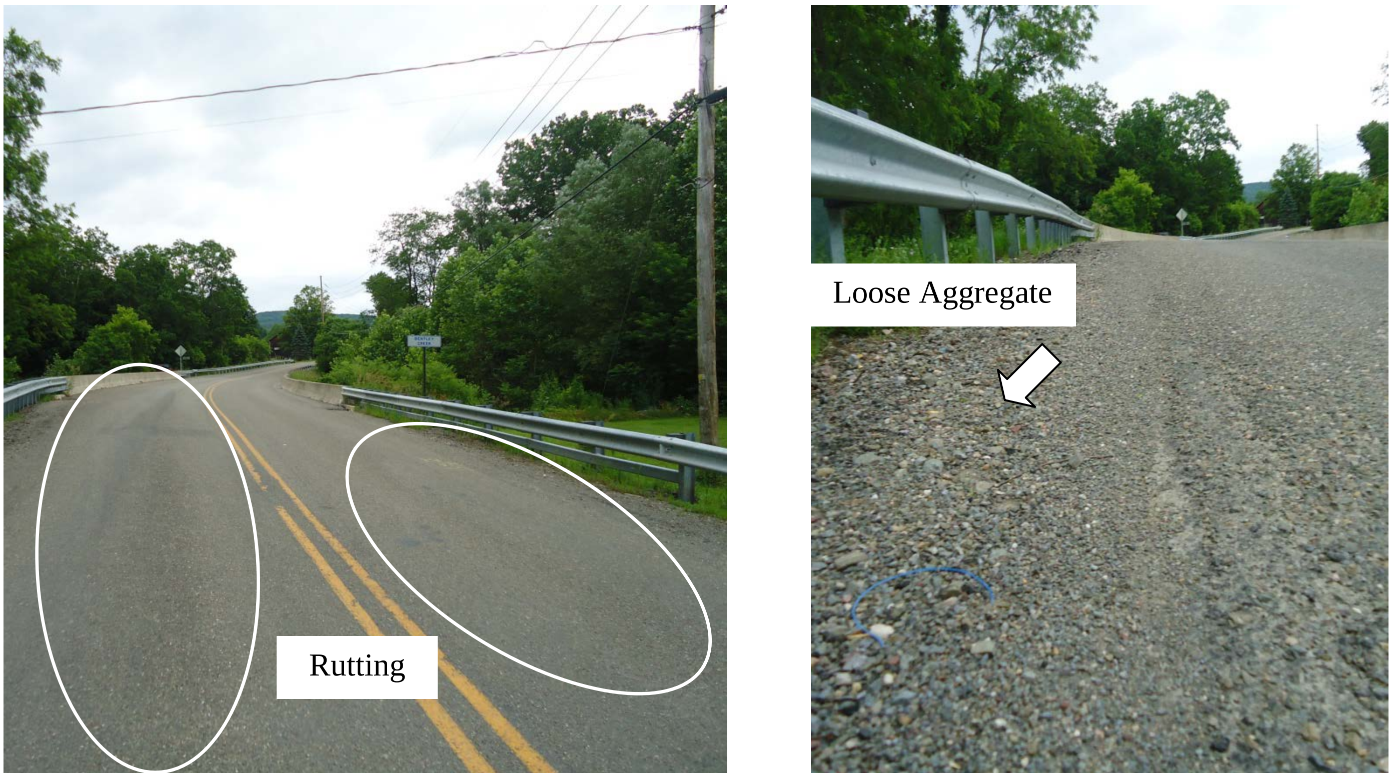
(b) Westbound Lane Edge Pavement Damage and Cracking

Figure 27. Bridge Two East Approach Roadway

4.3 Approach Roadway Bridge Three, 08-4024-0010-0478

Review of the PennDOT inspection reports for Bridge Four indicated that the approaches had new bituminous overlays placed in 2009. The approaches were rated a 7, indicating good condition, with loose surface treatment aggregate listed as the only deficiency.

The roadway west of Bridge Three was also observed to be generally in good condition during the Penn State inspection. Both lanes had minor rutting. As noted in the inspection report, areas of loose aggregate were observed, typically near the shoulders. Figure 28a shows west approach rutting and 28b north shoulder loose aggregate.

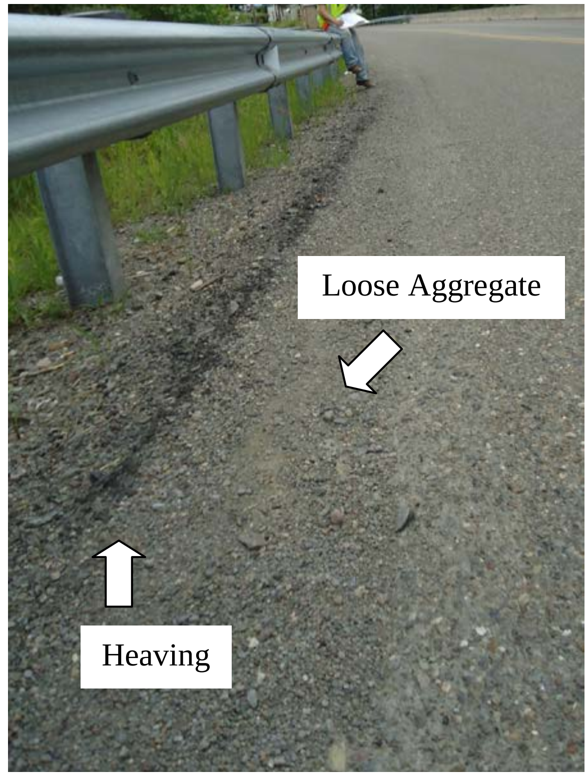


(a) Rutting (b) Shoulder Loose Aggregate

Figure 28. Bridge Three West Approach Roadway

The east approach was observed to be of similar condition during the Penn State inspection. Rutting was slightly more significant than the west approach. Ruts up to 2 inches (50.8 mm) deep and 10 inches (254 mm) were measured in the eastbound lane, as shown in Figure 29a. Loose aggregate and heaving were also prevalent along the shoulders, as shown in Figure 29b.

(a) Eastbound Lane Rutting



(b) Loose Aggregate and Heaving

Figure 29. Bridge Three East Approach

4.4 Approach Roadway Bridge Four, 08-4013-0050-1670

Review of PennDOT inspection reports indicated that the approach roadway of Bridge Four was rated an 8, meaning it was determined to be in very good condition. No specific problems were identified.

The south approach roadway was typically observed to be in good condition during the Penn State inspection. Some minor spalling and wear of the pavement was observed. Minor rutting was present in both lanes. Multiple longitudinal cracks had developed along the road centerline, as depicted in Figure 30. The north approach was very similar to the south approach. Minor rutting and wear of the pavement was evident. Longitudinal cracks similar to those in Figure 30 were observed.

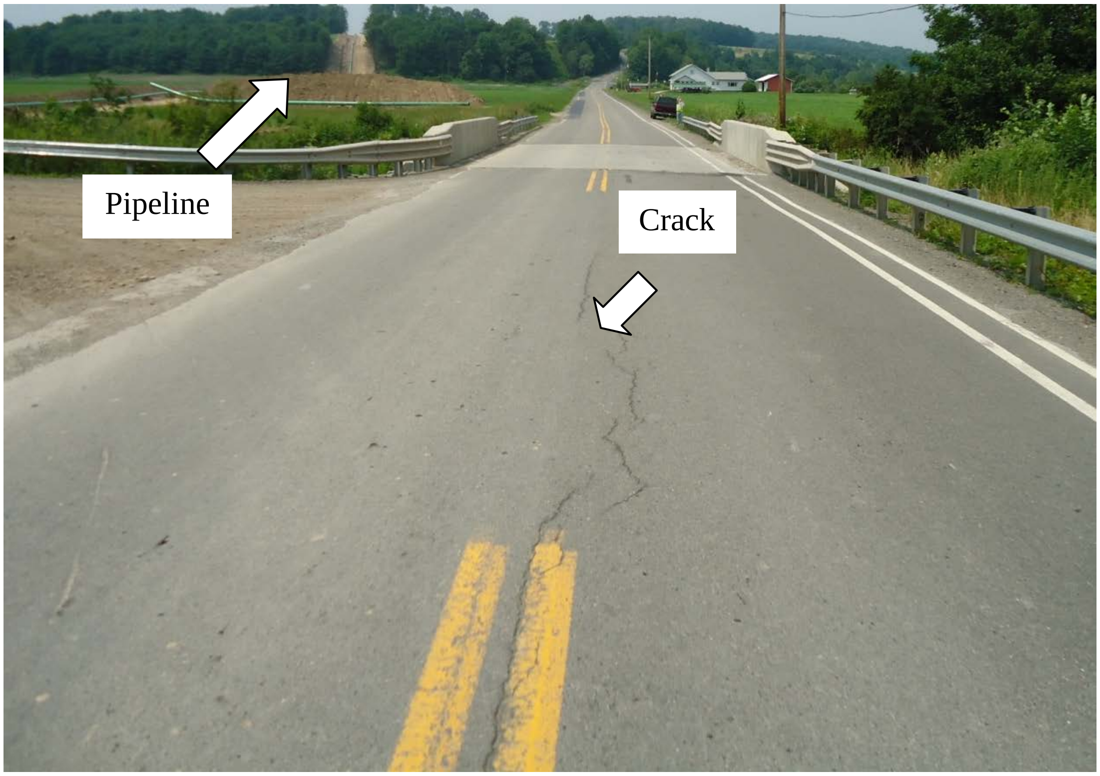


Figure 30. Bridge Four South Approach Longitudinal Cracks at Roadway Centerline

4.5 Approach Roadway Bridge Five, 08-0220-0380-0000

Review of the PennDOT inspection reports indicated that portions of Bridge Five's approach roadway were replaced in 2009. The most recent reviewed bridge inspection report rated the approach roadway an 8, indicating very good condition. Sealed and open longitudinal cracking was noted in areas where the approach was not replaced.

It was observed during the Penn State inspection that the south approach had several transverse cracks, with both open and sealed cracks evident in both lanes. Cracking was more significant along the edge of the roadway, where parts of the pavement had completely deteriorated up to 1 inch (25.4 mm) deep. Figure 31a shows the cracks and pavement deterioration in the south approach. Figure 31b shows an example of the pavement deterioration typically observed at the roadway edge. The new pavement placed in 2009 was observed during the Penn State inspection to typically be in good condition with minor wear. The roadway north of Bridge Five showed similiar deterioration to the south approach. The cracks shown in Figure 31a are representative of those observed in the north approach during the Penn State inspection.

(a) Transverse and Longitudinal Cracking (b) Pavement Deterioration at Roadway Edge

Figure 31. Bridge Five South Approach

4.6 Approach Roadway Bridge Six, 08-7220-0608-0001

Review of township inspection reports indicated that the approaches were assigned a rating of 5, meaning fair condition. Deficiencies that were discussed for the south approach included full-width transverse cracks and heavy deterioration. Map cracks and isolated transverse cracks were noted for the north approach.

The south approach consisted of approximately 25 ft (7.6 m) of asphalt pavement transitioning to gravel for the remainder of the road. The Penn State inspections indicated that the gravel portion showed some minor rutting. The transition between gravel and asphalt, shown in Figure 32, was heavily deteriorated, with transverse cracks up to 2 inches (50.8 mm) wide. Longitudinal cracks along the road centerline and other location were observed. Some map cracking was present along the southbound lane edge.

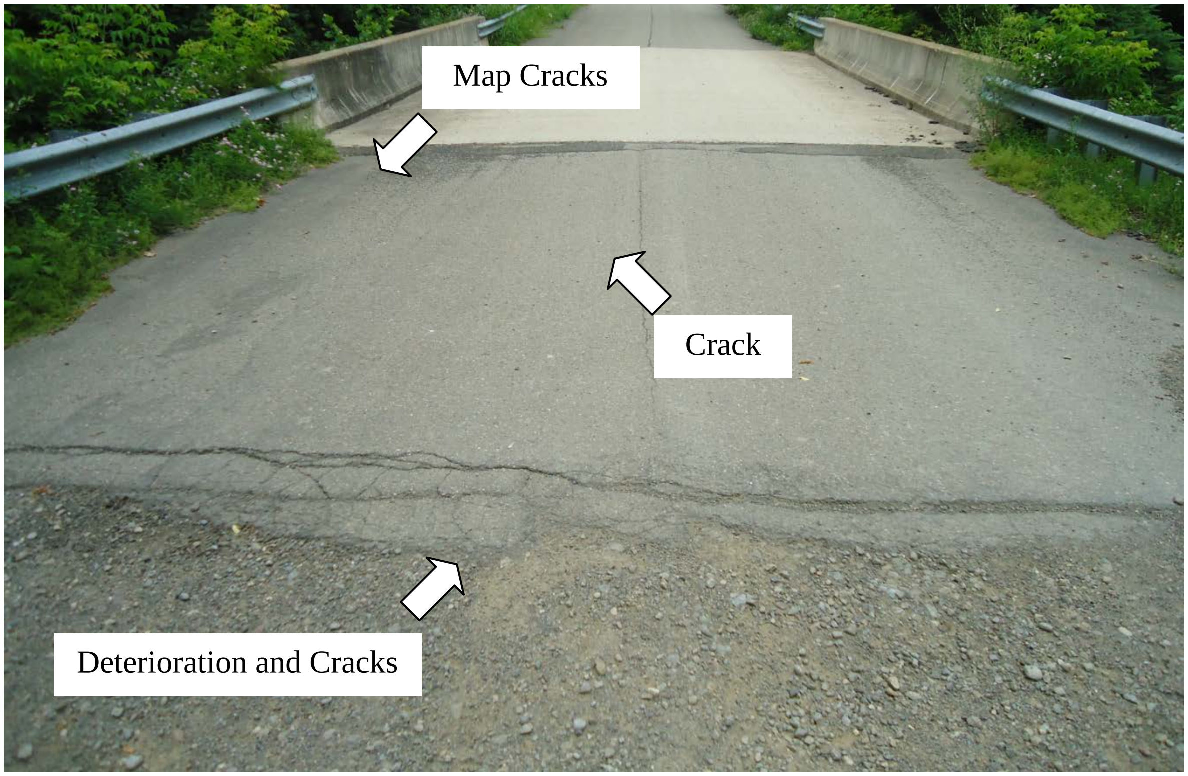
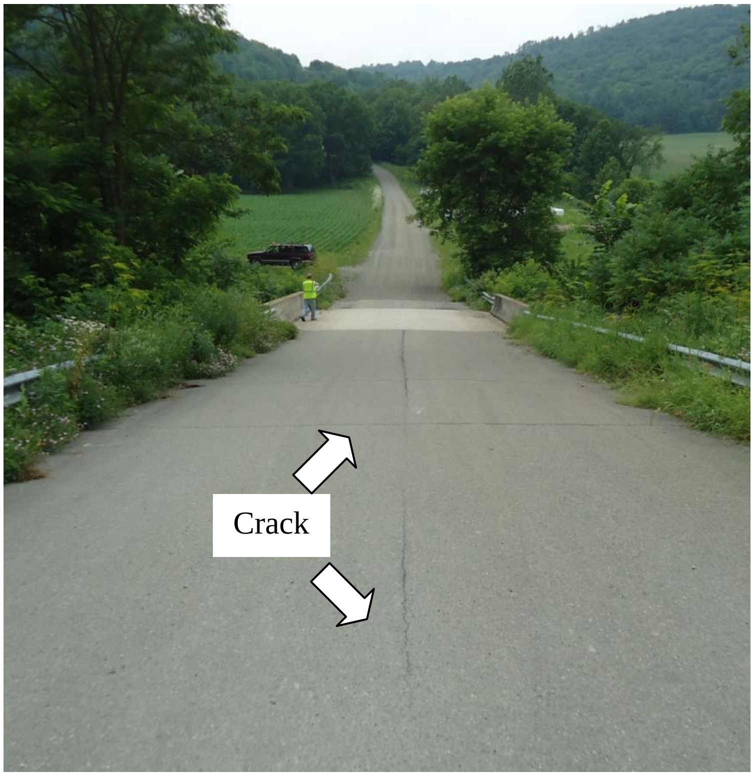
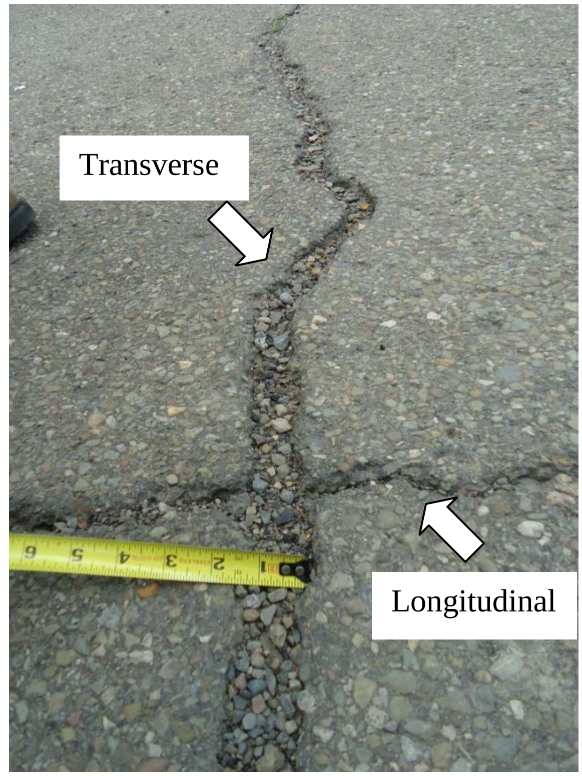


Figure 32. Bridge Six South Approach

The north approach, which intersected Pennsylvania State Route 467, was an asphalt pavement. The pavement had a 1½-inch (38.1-mm) wide longitudinal crack along the centerline that extended along nearly the entire 100 ft (30.5 m) of the Penn State inspected segment. Three full-width transverse cracks were also observed. The cracks, shown in Figure 33a, were typically 1½ inches (38.1 mm) wide, and are shown in Figure 33b.



(a) Longitudinal and Transverse Cracks



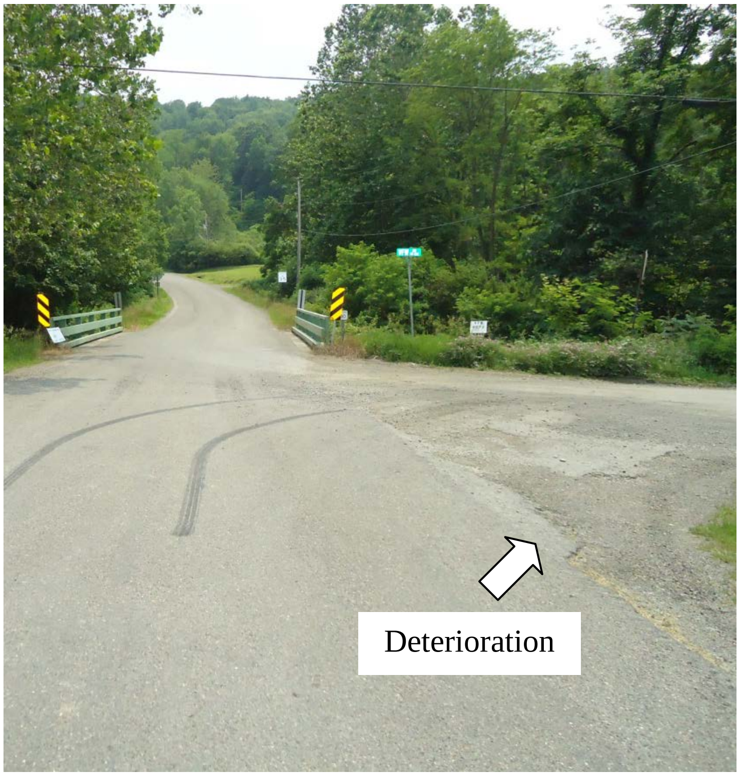
(b) Typical Crack Width

Figure 33. Bridge Six North Approach

4.7 Approach Roadway Bridge Seven, 08-2014-0030-0000

Inspection reports reviewed from PennDOT rated the approaches satisfactory (a rating of 6). Noted problems were bleeding asphalt, minor rutting, isolated cracks, and uneven areas.

The roadway west of Bridge Seven had few isolated cracks observed during the Penn State inspection. The road showed considerable deterioration at the intersection with VFW Road, visible in Figure 34a. Rutting was also prevalent in both lanes. The rutting depths typically ranged from ½ inch to ¾ inch (12.7 to 19.1 mm). Figure 34b displays a typical rut. Other than the ruts, the pavement was observed to be in good condition.



(a) Deterioration at VFW Road Intersection

(b) Typical Rutting Depth

Figure 34. Bridge Seven West Approach

The east approach showed a similar amount and depth of rutting to the west approach. Several longitudinal cracks were observed along the shoulder of the westbound lane, shown in Figure 35a. The eastbound lane of the east approach had severe pavement deterioration and complete loss of asphalt near the transition of the bridge, as depicted in Figure 35b.

(a) Shoulder Longitudinal Cracking

(b) Pavement Deterioration at Bridge Transition

Figure 35. Bridge Seven East Approach

4.8 Roadway Inspection Summary

Though some information was available on roadway approach conditions from the reviewed PennDOT and township bridge inspection reports, the exact length of roadway considered for each report is unknown. Therefore, conclusions from the roadway inspections will largely consider conditions observed during the Penn State inspections in conjunction with the roadway's traffic type and whether the roadways had recently placed overlays or replacements, as indicated in reviewed reports.

Three inspected sections had recent overlays, allowing for assessment of damage accrued in a relatively short time span. The entire roadway of Bridge Three had a bituminous overlay placed in 2009. Gas Play activity was observed in the area and likely translated into some increased traffic levels and loads. Cracking of the pavement was not observed in the Penn State inspection; however, rutting was evident in both approaches and was up to 2 inches (50.8 mm) deep in some areas. The majority of Bridge Four's roadway that was inspected by Penn State personnel was also replaced in 2009 and Gas Play activity was evident in the area. Rutting and wear were prevalent in both approaches in addition to longitudinal cracking along the centerline of the roadway. Finally, a portion of Bridge Five's roadway was replaced in 2009. This roadway was observed during the Penn State inspection to carry a mix of Gas Play affiliated vehicles and other vehicles, though the total number of Gas Play vehicles observed was less than Bridge Four. The new roadway showed minor signs of wear. The older portion of roadway had several cracks and deteriorating pavement.

The roadway traversing Bridge One, with no recent overlay, had possibly the most Gas Play activity of all the inspected locations. The roadway had several longitudinal and transverse cracks. Other areas of the roadway had heavy deterioration. Bridge Seven was located on a less trafficked road. The roadway likely supported a small amount of Gas Play traffic and had rutting and some areas of deterioration.

The two inspected municipal roads, adjacent to Bridge Two and Bridge Six, were in poor condition. These locations likely saw little to no Gas Play affiliated traffic. The deterioration of these roads was typically in the form of cracking.

In general, the older roadways inspected by Penn State personnel were judged to be in fair to poor condition. Older roadways with high Gas Play affiliated traffic activity were found to be in poor condition, such as Bridge One's roadway, and the older portion of Bridge Four's roadway. Recently replaced roadways typically had less damage; however, more damage was observed at locations that appeared to have a concurrent increase in Gas Play truck traffic during the Penn State inspections. Rutting appeared to be the most common deficiency in roads that appeared to carry more Gas Play affiliated traffic.

Additional observations were made during the Penn State inspections beyond the scope of the study. It was observed that several roadways traveled during the course of the Penn State inspection were undergoing construction and roadway repair, with most of the work occurring along the roadway shoulders. Of the roadways traveled undergoing construction, some amount of Gas Play traffic was observed to be present on all of them. Though these observations are strictly anecdotal, they still serve as an indicator to the correlation of Gas Play traffic and the roadway conditions in Bradford County.

5.0 CONCLUSIONS

Seven bridges in Bradford County, Pa. and adjacent roadway segments were inspected to ascertain if any connections existed between Gas Play activities, bridge and roadway condition, and bridge and roadway deterioration rates. Bridge inspection reports provided by PennDOT were reviewed to establish condition of the selected bridges and approaches over the past several years and to determine if rehabilitation work had been recently performed. The selected bridges and approaches were then visually inspected and any significant changes to condition documented.

Using the information from the Penn State bridge inspections and reviewed inspection reports provided by PennDOT, it was concluded that:

- Deterioration was observed to occur in the wearing surface, deck, and parapets for all 7 inspected structures.
- Settlement, rutting, and parapet cracking were the most common observed occurrences of deterioration.
- The condition of the superstructure and substructure remained unchanged from reviewed PennDOT or township inspection reports for most of the bridges regardless of traffic levels, types, and association with Gas Play activities.
- Two structures, Bridge One and Four, had findings that appeared to indicate that Gas Play truck traffic affected either the current bridge condition or the importance placed on repairing or rehabilitating the structure.
    - Bridge One, noted as being structurally deficient, is the structure for which an accelerated rehabilitation or replacement program should be instituted given its current condition and the level of Gas Play affiliated truck traffic it is experiencing.
    - Bridge Four, a structure that recently had extensive rehabilitation, is the structure that has clearly evident accelerated deterioration in the deck and parapets that appears to be the result of Gas Play affiliated truck traffic.

Table 2 provides a summary of notes taken from the reviewed PennDOT inspection reports and corresponding observations from the Penn State inspections. Evidence of Gas Play activity was considered to exist if trucks related to drilling were observed crossing the bridge during the Penn State inspections or if other

Gas Play vehicles or sites that would likely use the bridge were observed in the immediate area. Refer to the Bridge Inspection section for more detail on the Penn State inspections.

Table 2. Bridge Inspection Summary

Bridge No.	Inspection Report Condition Ratings				Built (Rehabilitation)	ADT	ADTT	Evidence of Gas Play	Condition Change/ Additional Observations from Penn State Inspections
	WS*	Deck	Super	Sub					
1	7	6	4	4	1933	7,287	1,115	Yes	• Multiple sagging beams
2	-	6	4	6	1963 (2001)	800	-	No	• Asphalt deterioration at E & W transitions • ¼” (6.4 mm) Approach slab settlement at E abutment
3	8	6	3	7	1979 (2009)	683	50	Yes	• Crack in pavement over pier • Superstructure appears to be in better condition than listed in PennDOT inspection report
4	8	9	9	7	1953 (2009)	1,113	39	Yes	• Settlement at both abutments • Pavement rutting and wear • Multiple full penetration, full height parapet cracks
5	8	8	7	7	1974 (2009)	2,241	76	Yes	• Minor pavement rutting • ¾” (19.1 mm) approach slab settlement at S abutment • Cracking of abutment seat below W fascia
6	5	5	7	5	1984	75	-	No	• Increased efflorescence between girders
7	6	6	6	5	1954 (2006)	184	16	Yes	None

*WS refers to Wearing Surface

Damage to the roadways from Gas Play traffic was also observed. From the information collected during the Penn State inspections, the following was concluded:

- All roadways had a varying amount of cracking regardless of Gas Play traffic activity.
- Rutting significantly increased as Gas Play activity increased.
- Roadway deterioration generally increased with increased truck traffic.

Table 3 provides a summary of the inspected roadways' condition and traffic information.

Table 3. Roadway Inspection Summary

Bridge No.	Inspection Report Approach Condition Rating	ADT	ADTT	Evidence of Gas Play	Observed Deficiencies
1	7	7,287	1,115	Yes	South Approach • Multiple full width transverse cracks • Multiple longitudinal cracks • Cracking and deterioration at storm drain North Approach • Multiple full width transverse cracks • Multiple longitudinal cracks
2	7	800	-	No	West Approach • Map cracks and pothole at edge of westbound lane • Single longitudinal crack near centerline East Approach • Map cracks at edge of westbound lane • Multiple longitudinal cracks
3	7	683	50	Yes	West Approach • Minor rutting • Loose aggregate along shoulder East Approach • Minor to moderate rutting • Loose aggregate and heaving along shoulder
4	8	1,113	39	Yes	South & North Approach • Multiple longitudinal cracks at centerline • Minor rutting, spalling, and wear
5	8	2,241	76	Yes	South & North Approach • Multiple open and sealed transverse and longitudinal cracks • Minor rutting • Areas of heavy cracking and complete deterioration along roadway edge
6	5	75	-	No	South Approach • Minor rutting in gravel roadway • Heavy deterioration and transverse cracking at gravel to pavement transition • Longitudinal crack at centerline • Map cracking at southbound lane edge North Approach • Multiple full width transverse cracks • Longitudinal crack at centerline
7	6	184	16	Yes	West Approach • Isolated cracking • Moderate rutting • Damage at VFW Rd. intersection East Approach • Multiple longitudinal cracks at westbound lane shoulder • Heavy deterioration of eastbound lane near bridge

6.0 SECONDARY AND MUNICIPAL ROADS

The network of secondary and municipal unpaved roads serves as a vital component of Pennsylvania's overall infrastructure picture. These roads service the four major industries of the Commonwealth: agriculture, lumbering, mining, and tourism. Many families have moved to rural homes along unpaved roads as a quality-of-life choice. The unpaved roads in Bradford County are either so-called "pancake" roads or dirt wagon roads that have no improved base or sub-base, that have received 2 to 4 inches of asphalt; or are Pinchot Roads, named after Governor Gifford Pinchot, who vowed in the 1930s to "lift the farmers out of the mud." Pinchot roads stabilized the base course of the road by working 3-inch sized gravel into the dirt roadway sometimes to a depth exceeding 16 inches and then upon that applying a 2- to 4-inch asphalt surface. It is clear that 80 years ago when these roads were constructed, there was no concept of the magnitude of traffic to which they would be exposed decades later. Several factors become important when considering municipal roads, including: (a) what traffic loads are anticipated for the gas activities and (b) what design criteria and methodology should be applied to repair them.

The answers to both of these questions are not straightforward. There is only one study that has been identified that quantifies the number and type of vehicles that are involved in the construction and drilling of a gas well. This was a doctorial thesis from Texas by Mason [1981]. The study was poised well in that all traffic onto and off of the drill site was able to be captured so a reasonable degree of confidence can be placed in the traffic numbers. In a recent Webinar presented by Deputy Secretary of Highway Administration R. Scott Christie (2012), from PennDOT, he presented data for the Pennsylvania Gas Play, but a careful examination of the presentation suggests that the numbers for heavy vehicles do not add up, therefore the Texas study of Mason is still the reference of choice. What has to be assumed in the use of these numbers is that the nature of the drilling was compatible with what is occurring in Bradford County. We know that the rigging is similar, large three-section gas rigs; we don't know if the depths are comparable, but we do know that the numbers in Bradford must be amended to include the contribution of trucking of 7 million gallons of frac water to the site and the removal of about 1.8 million gallons of flow back waters and the contribution of some 3,500 tons of frac sand. Because of the much longer laterals that are being used in Bradford County, they accumulate 800 tons per well of drill cutting, which will incrementally add to the overall traffic load.

Traffic based on the Texas study on the drilling pad accumulated by the different activities that were taking place; these included: access road installation and pad construction [<8days], rigging installation [~5 days], drilling and fracing [~10 to 20 days], derigging [2 days], well completion [~5 days] for a total of approximately 40 days. Personal communication with several of the drilling companies [Range Resources and Chesapeake Energy] in Bradford County confirmed that the average length of time between initiation of a well and putting it into production is more like 25 days, but still follows the same necessary activities. Based upon the Texas study there were an accumulated 7,760 vehicles of various sizes accessing the site during the 40-day period. In addition, another 2,588 vehicles were recorded during the first month of production of the well. During the first 70 days of the well's existence, 10,383 vehicles were observed, which represented 22,923 single-axle repetitions. These numbers must be extended by an additional 1,540 trucks carrying water and an additional 161 trucks carrying frac sand, which will push the single-axle repetitions well in excess of 23,000 for a 25-day period. Although these are the best statistics that are currently available and they may not accurately represent what is taking place in Pennsylvania, logically they represent an extremely large number of heavy vehicular traffic on these rural cartways that were never intended to accommodate the traffic. The accompanying set of side-by-side before-and-after pictures, Figure 36a,b, graphically illustrate the impact of this traffic on a dirt and gravel road. Figuree 36b is considered by the industry a "well" maintained road surface for access to a drill pad.

Figure 36a,b. Side by Side Comparison of a Well-Implemented Gravel Road [a] before the Heavy Gas Truck Traffic and [b] after Exposure to the Heavy Traffic

These rural municipal roads were maintained at 12 to 14 ft (3.6 to 4.2 m) wide within a right of way of about 30 ft (9 m). This width is insufficient for two semi-trailers to safely pass and has been gradually widened by the passing vehicles to a width now approaching 20 to 24 ft (6 to 7.2 m), as seen in Figure 36b. Pennsylvania is unusual among all of the states with gas plays ongoing, in that the gas companies have assumed the responsibility for management and maintenance of the road systems that they are using. In all other states, the responsibility of reconstructing the roadway system has fallen to the state's DOT. In Pennsylvania, the gas companies have retained all of the major engineering and construction companies within the Commonwealth to serve in this capacity. Direct contact with several of Central Pennsylvania's major contractors had revealed that the engineering practices that they were employing for the rural road repairs was not based on fundamental engineering principles but on historical experience, which results in a wide variety of reconstruction practices. Appendix B is a protocol based upon a proven and accepted design approach following the flexible pavement protocol from AASHTO [1993]. This methodology was arrived at after an extensive literature review, which revealed that there are no specific design methodologies in practice that will address the magnitude of the truck traffic that can be anticipated on the municipal roads of the Gas Play. From the geographic distribution of municipal roads and the current location of gas wells, figures 37 and 38, it is clear that these roads have the possibility of seeing 100,000 heavy vehicles as multiple wells access common roads.

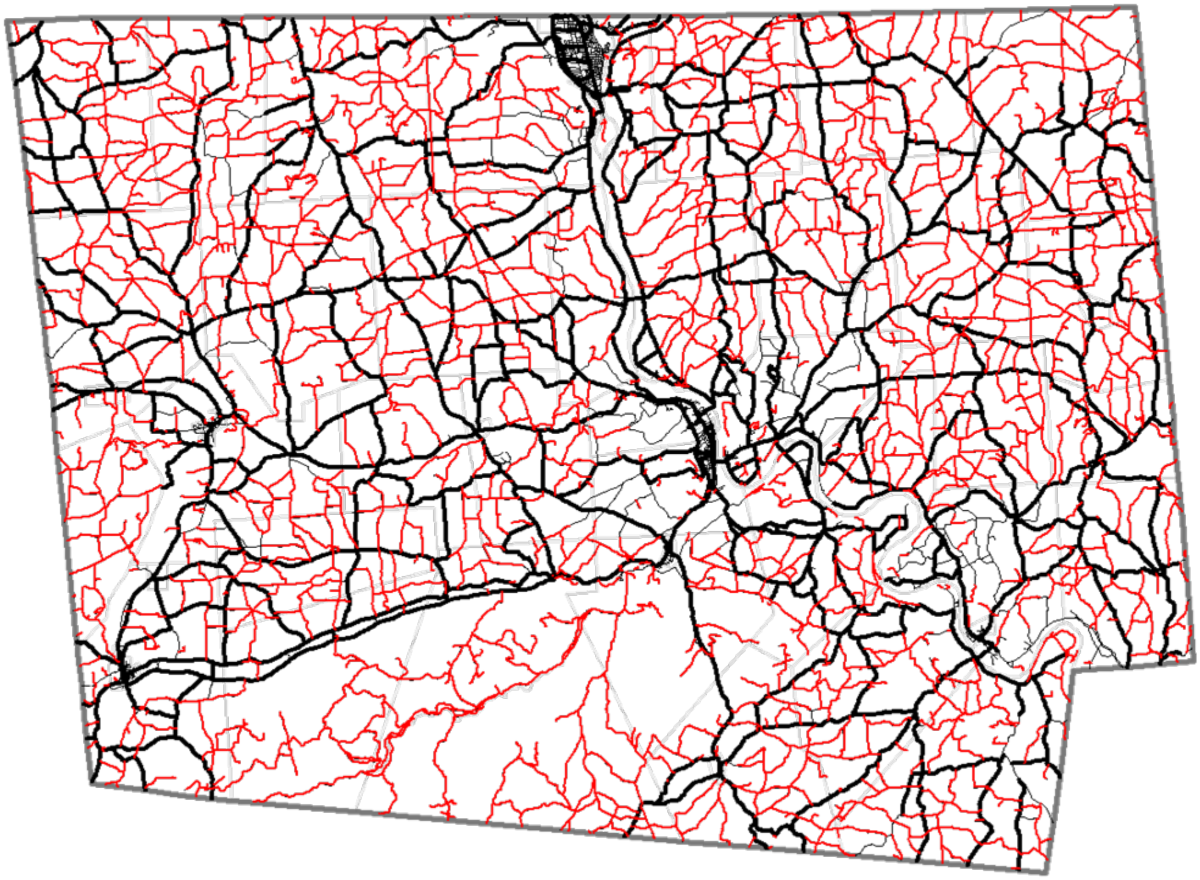


Figure 37. Base Map of Bradford County with Municipal [Dirt and Gravel] Roads in Red and Primary and Secondary PennDOT Roads in Black. A Total of 2,750 Miles of Roads are Represented.

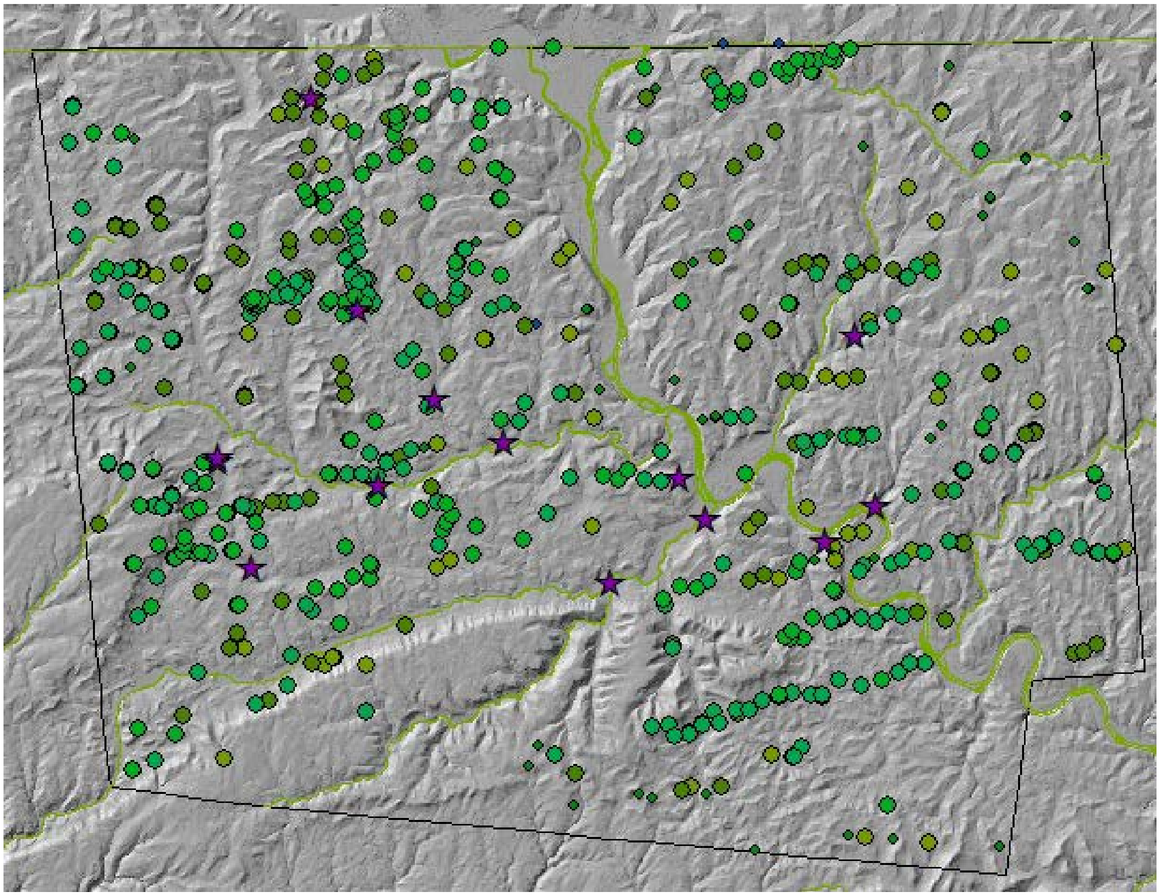


Figure 38. Distribution of Recorded Gas Wells in Bradford County. Different Colors Represent Time Frames of Installation. Purple Stars Represent the Location of Bridges Examined as Part of This Study [After Bradford County GIS coordinator, Office of Planning and Grants].

The road usage will be further exacerbated with the continued expansion of activities over the next few years. The gas companies have signed land lease agreements in preparation for the drilling campaign. The lease agreements were originally completed at very low leasing rates on a dollar per acre rate and with a 5-year implementation clause. The gas companies are now rushing to consummate these leases. The rationale behind this rush is the demonstrated value of the mineral resource in Bradford County will mean that they will not be able to release the same land at the low initial rate offering a significant economic driver for them to complete as much as they can under the current leasing agreements. What these activities mean is that in a few years, the gas companies will reassess the productivity of the already completed wells and will come back to those pad sites that warrant further production activities and instead of placing one or two wells per pad will complete and implement up to ten to twelve additional wells per pad site. The consequence of this development strategy is that the roadways will be severely impacted now and will most likely be impacted once again in the coming years, and most likely to a greater extent than currently if improvements are not made to the roads to accommodate the enhanced traffic.

On PennDOT primary and secondary paved roadways, the gas companies are sharing the responsibilities for repair. Rehabilitation designs are presented to PennDOT for review, and PennDOT is providing the acceptance for the designs. For these roadways, the only practical methodology for rehabilitation is through full-depth reclamation because of limitations associated with the current road elevations due to overhead utilities and bridges. To this end, it has been reported by the Marcellus Gas Consortium [Herrera, 2012] that the industry has invested $411 million dollars into these classes of roads during the 2010 construction season; Chesapeake in Bradford County alone reported investing $110 million.

The ultimate question, then, is: how much of the total roadway system in Bradford County will be impacted and how much will it cost? The answers are that the primary and secondary roadways are the main arteries to bring goods and services into the region; all have seen substantial increases in heavy truck traffic, and it can be anticipated that all of those will see significant degradation and need for rehabilitation. Of the 1,512 miles of unpaved roads in Bradford County, it was not possible within the scope of this study to get an accurate assessment of the percentage impacted, but from Figures 38 and 39 it is clear that as of the time of this study, about 60 to 70 percent are currently being impacted and will be in need of rehabilitation.

Developing an estimate for the total costs is also not straightforward, since most of the exact rehabilitation figures are company proprietary. Generalized numbers can be assessed from current practices outside of the gas patch and assumed to apply there. We estimate approximately $43/yard for Full Depth Reclamation topped with a sufficient thickness of asphalt to carry the enhanced traffic load. PennDOT District 3-0 has responsibility for 1,232 miles of paved roads in Bradford County. These numbers come to $0.75 billion in potential costs. If we assume that 70 percent of the 1,512 miles of unpaved roads will be reconstructed with the addition of 3 ft of crushed stone at $6/cubic yard, these figures come to an additional $87 billion dollars. Clearly these estimated numbers are extremely unreliable because of the lack of hard data for the estimates; however, it does point out that the critical investment in transportation infrastructure in Bradford County alone is enormous, and the continued cooperation of the gas companies with roadway rehabilitation will be critical to the county and Commonwealth. The Transportation Funding Advisory Commission [PennDOT, 2011] has recommended $300 million for “local” bridge and road projects. The Natural Gas Extraction fee being considered in the legislature would result in an estimated $675 million in the next 5 years and would be dedicated to assist counties and local municipalities with infrastructure repairs.

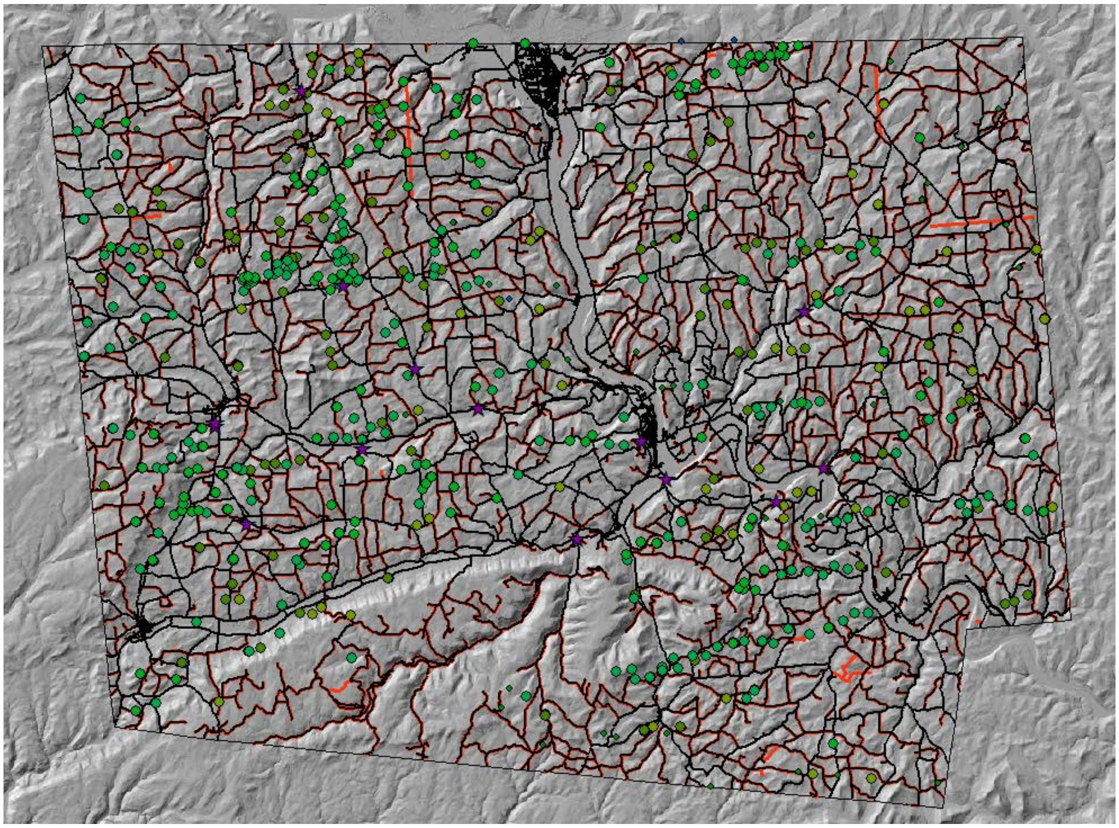


Figure 39. Co-location of All 2,750 Miles of Roads and Gas Wells in Bradford County. Purple Stars are the Locations of the Bridges from this Study.

7.0 EVALUATION OF HEAVY TRUCK TRAFFIC'S CONTRIBUTION TO SAFETY

7.1 Data Sources

To perform the analyses presented below, several sources of data were used, including roadway inventory, crash, and well drilling locations. The Pennsylvania Department of Transportation provided the roadway inventory and crash data, while the Pennsylvania Department of Environmental Protection (PA DEP) provided the well drilling site data. Each data source is described in more detail below.

Roadway Inventory Data

Electronic roadway inventory data, from PennDOT's Roadway Management System, were provided for the years 2007-2009 (inclusive). These data consist of county, route, segment, cross-section, and traffic volume data for approximately 40,000 miles of state-owned roadways in the Commonwealth. Bradford County has approximately 927 miles of roadway; over 80 percent of this mileage is classified as local or collector roads. In terms of average annual daily traffic, volumes for Bradford County range from 34 to over 17,000 vehicles per day. When considering all segments, the average is about 1,300 vehicles per day. Most of the highway mileage exhibits a two-lane cross section, with a small proportion of three-lane cross sections that contain a truck climbing lane. In addition to the roadway inventory data, a separate set of heavy vehicle traffic data was provided by PennDOT for the same years. These data included information concerning heavy vehicle volume data for individual roadway segments. The data provided did not include heavy vehicle data for each analysis year because heavy vehicle counts are not performed annually by PennDOT. Therefore, information had to be interpolated or extrapolated from years where counts were performed to fill in the years where traffic volume counts were not available.

Crash Data

Electronic crash data were obtained from PennDOT for the years 2007 through 2009. These data contained information about the location and time of the crash, vehicle involvement, crash characteristics, severity outcomes, and other event-based information. The crash data and roadway inventory data were appended using information about the country, route, and segment location.

Well Drill Location Data

The well drill location data were provided by the PA DEP. These data indicate all information regarding permitting and drill operations. Information regarding well locations includes global position coordinates, coordinate data, well depths, county, municipality, and whether the well uses horizontal drilling; the data are compiled annually. These data can be accessed on the World Wide Web (PA DEP, http://www.portal.state.pa.us/portal/server.pt/community/oil_and_gas_reports/20297). As shown in Figure 40, these data were then used to generate GIS maps to show the progression of drill site concentrations on an annual basis. It should be noted that no well drilling activity was present in Bradford County during 2007, but there were 52 well sites in 2008 and more than 400 in 2009.

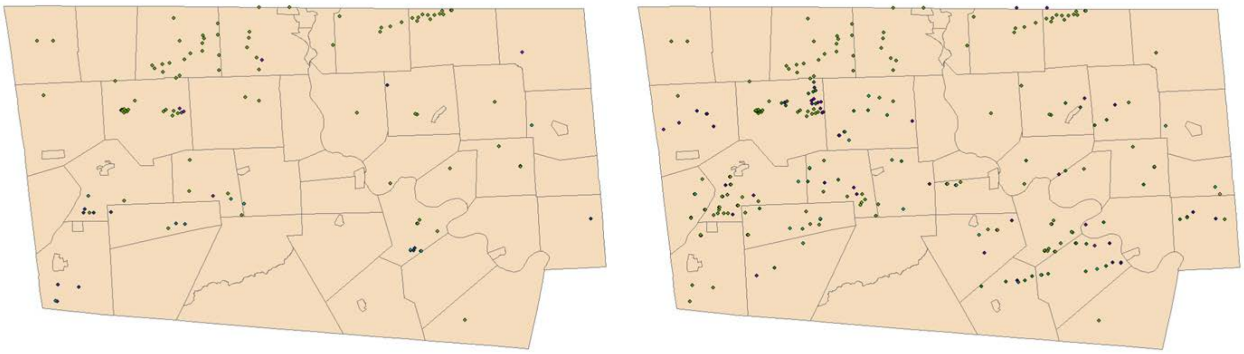


Figure 40. Bradford County Well Sites 2008 (left) and 2009 (right)

7.2 Control County

In order to assess the traffic impacts of natural gas drilling, it was important to find another county (similar to Bradford County) that exhibits no Marcellus shale formation. Considering that the shale mostly covers the northern and western parts of Pennsylvania, the south and east provided the most likely regions of the Commonwealth to identify a “control county.” Finding a comparable county in this region is difficult because of the urban populations in Philadelphia, Reading, Lancaster, and the Lehigh Valley; Bradford County is primarily rural with very little urban population. Two counties were identified as possibilities--Adams County and Franklin County. Both counties have no Marcellus natural gas drilling and are relatively rural, having only small urban areas (Gettysburg in Adams County and Chambersburg in Franklin County). Considering that the focus is on roadway crashes, the roadway inventory for Adams and Franklin counties were compared to Bradford County to identify an appropriate control county.   Figures 41 and 42 show the highway mileage composition of each county.

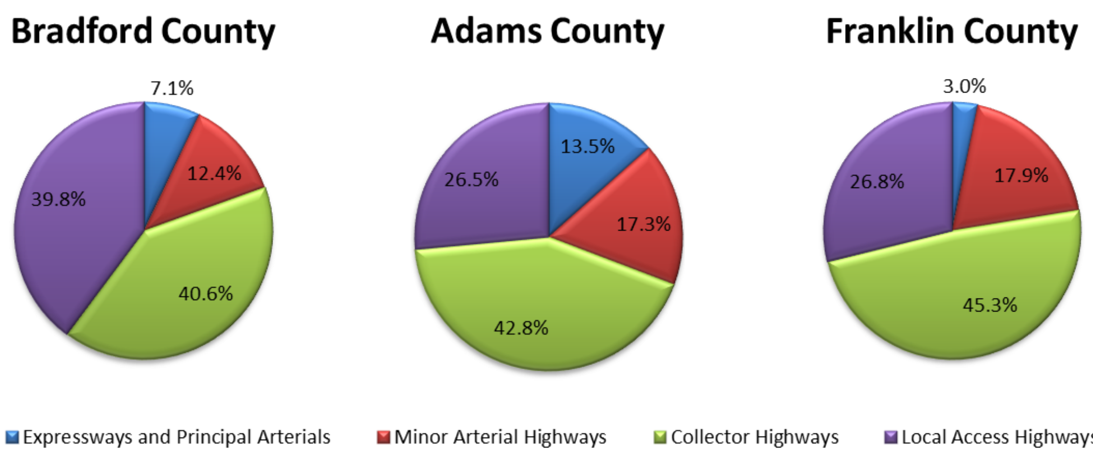


Figure 41. Rural Highway Composition by Functional Class

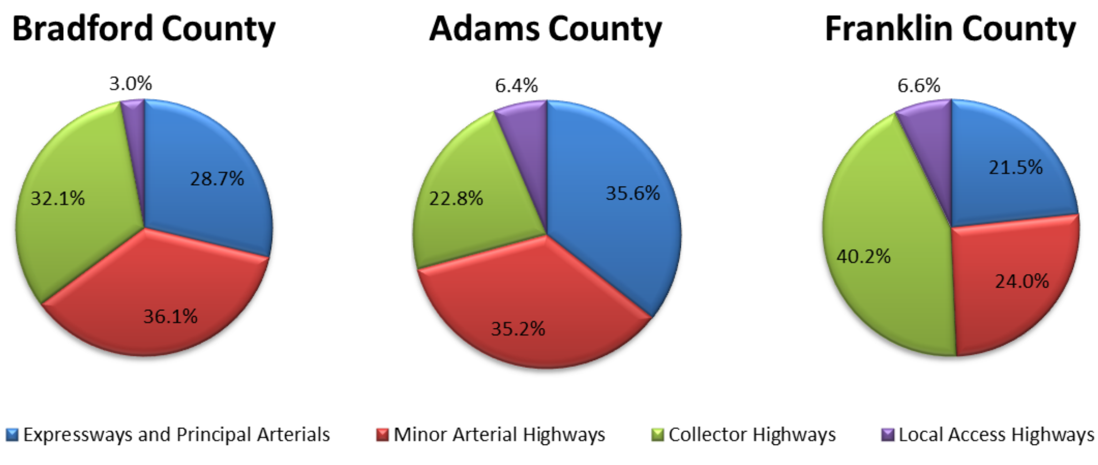


Figure 42. Small Urban Highway Composition by Functional Class

Of the two potential control counties, Adams County appears to more closely resemble Bradford County in terms of highway functional class composition.

7.3 Crash Frequency Analysis

As a first step to assess traffic safety in Bradford County and the potential control counties, crash frequencies were compiled for each county from 2000 through 2009. Each year, crash frequencies were found for total crashes, fatal and major injury crashes, heavy vehicle-related crashes, and heavy vehicle-related fatal and major injury crashes. In general, Franklin County exhibits a greater frequency of crashes, followed by Adams County, and Bradford having the least. This is most likely due to significant differences in average annual daily traffic (AADT) between the counties. These frequencies are shown between 2000 and 2009 in Figure 43.

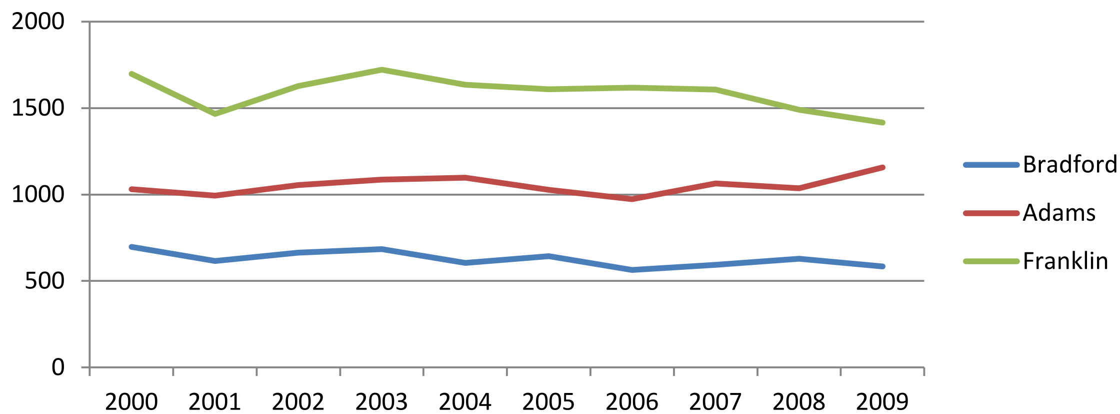


Figure 43. Total Crash Frequencies, 2000-2009

When considering total crash frequencies, there is little to demonstrate any negative safety effects from Marcellus drilling in Bradford County; the county appears to exhibit a relative decrease in crashes since 2000, similar to Franklin County. Total crash frequencies in Adams County appear to be relatively constant since 2000, although a slight increase in crashes appears to occur in 2009. There is also little to suggest that, when considering total fatal and major injury crashes (Figure 44) and total heavy vehicle-related crashes (Figure 45), that an increase in well drilling activity in 2008 and 2009 increases crash severity or heavy vehicle crash frequencies.

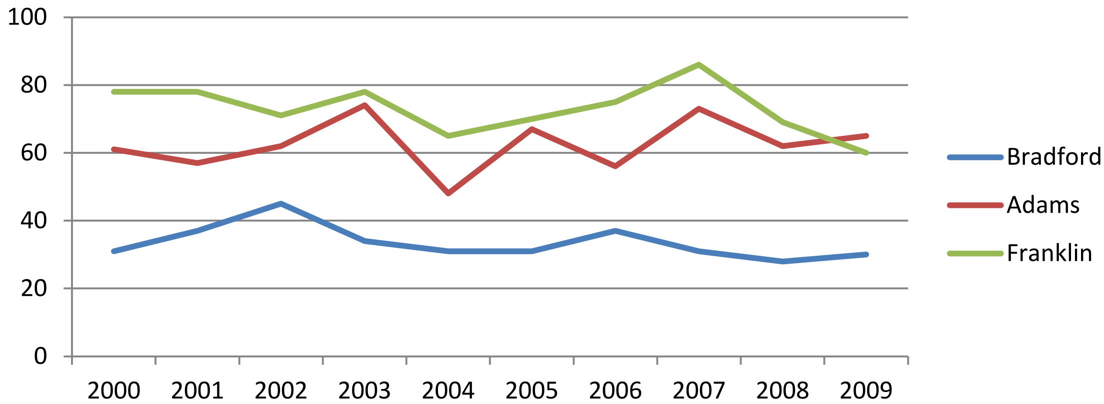


Figure 44. Total Fatal and Major Injury Crash Frequencies, 2000-2009

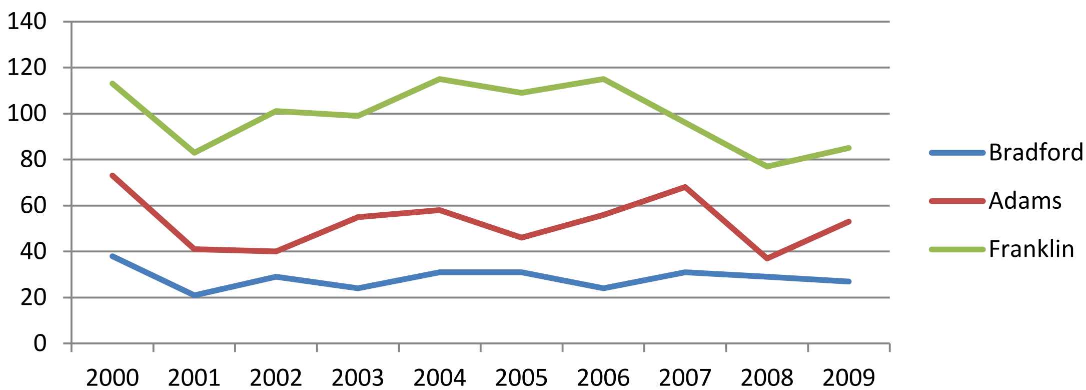


Figure 45. Total Heavy Vehicle Related Crashes, 2000-2009

When considering heavy vehicle-related fatal and major injury crashes, however, there is a noticeable increase in Bradford County between 2007 and 2009, while Adams and Franklin counties exhibited a decrease high-severity heavy vehicle crashes (Figure 46).

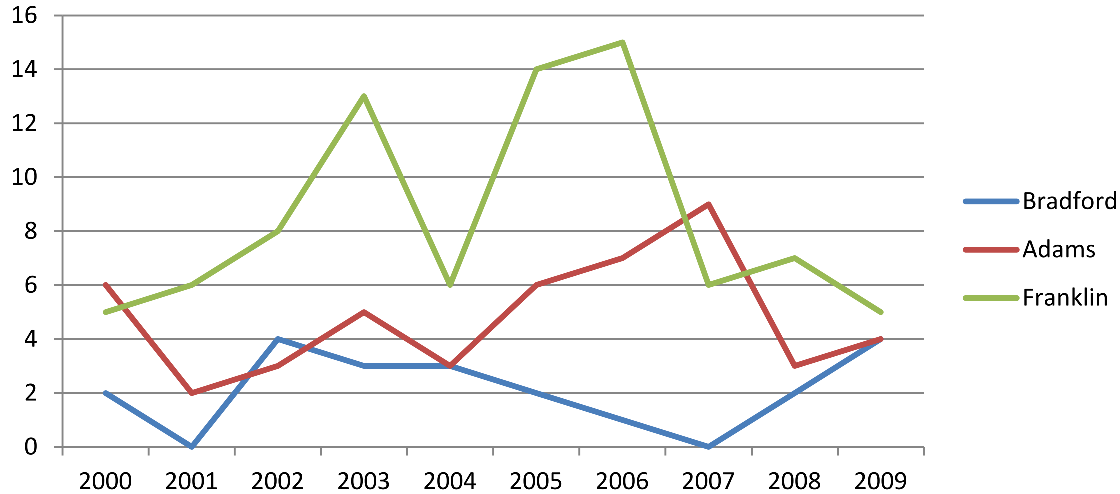


Figure 46. Total Heavy Vehicle Related Fatal and Major Injury Crashes, 2000-2009

7.4 Spatial Analysis

Bradford County has a total of 52 municipalities (15 boroughs and 37 townships). Future analysis to determine any adverse effects to highway safety should use count data analysis methods (e.g., negative binomial regression) and categorical data analysis methods (e.g., logistic regression) to find possible statistical associations between the number of well sites and various roadway features in a municipality. Count regression methods will be used to evaluate crash frequency, while categorical data analysis methods will be used to assess crash severity.

As a first step, it was important to quantify the number of well sites within each municipality for each year of analysis. Drilling operations in Bradford County began in 2008; therefore, only two years (2008 and 2009) were available for the analysis. Figure 47 shows the number of well sites within each municipality for 2008 and 2009. Only townships with drilling activity during 2008 or 2009 are shown in Figure 47. It is clear that while drilling began in 2008, the drilling activity increased significantly in 2009. Only one township, Asylum Township, experienced a decrease in new well sites from 2008 to 2009. Figure 48 shows the heavy vehicle-related crash frequency by township for 2007, 2008, and 2009. A preliminary assessment suggests little association between well site activity and heavy vehicle-related crashes. Additional crash data from 2010 would most likely increase the potential to determine any kind of association.

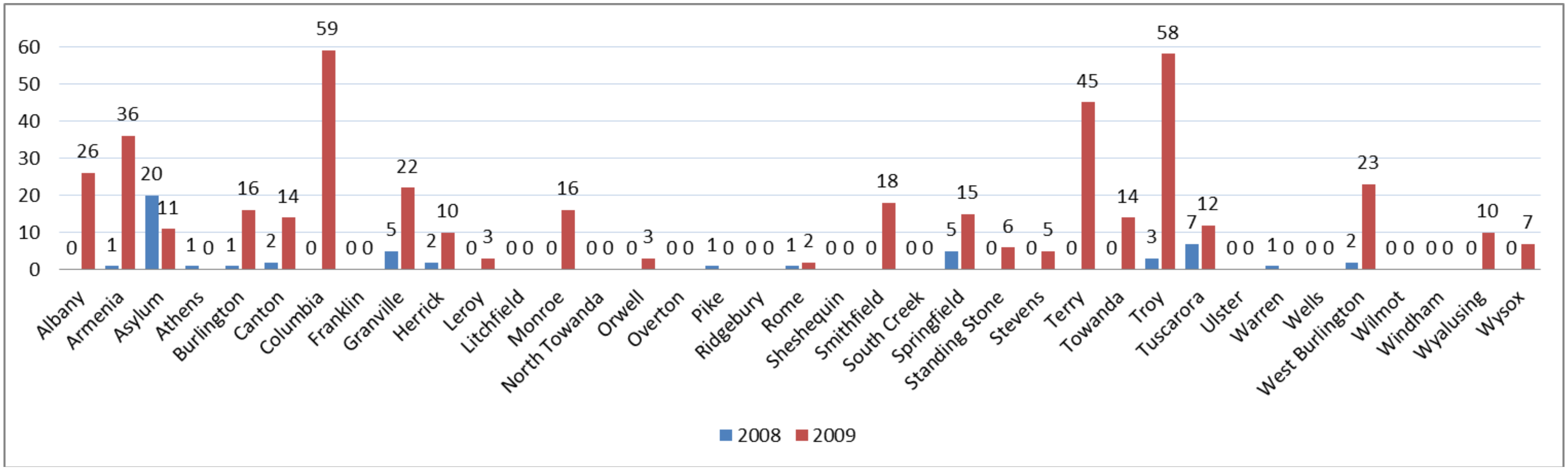


Figure 47. Number of Wells per Township (2008-2009)

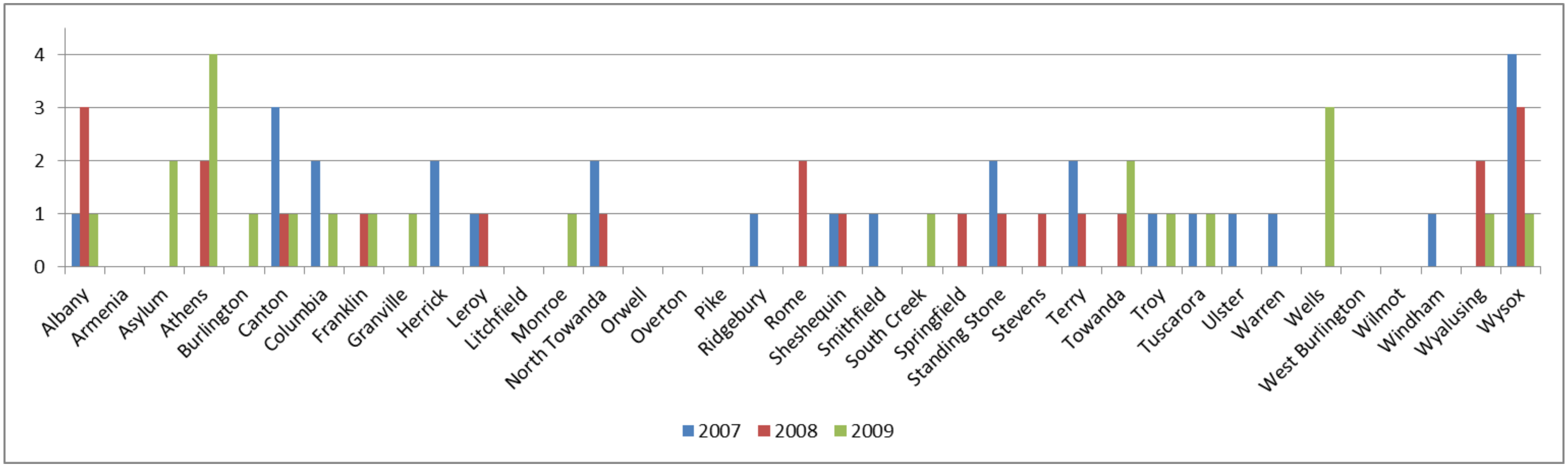


Figure 48. Number of Heavy Vehicle-related Crashes per Township (2007-2009)

7.5 Conclusions

An increase in motor vehicle traffic, particularly in heavy truck traffic, may increase crash occurrence or severity in Marcellus shale gas drilling regions. To preliminarily assess this issue, electronic roadway inventory, crash, and well drilling data were compiled from a variety of state agencies. The descriptive crash statistics presented in this report suggest that there may be an association between increased well-drilling activity and severe (fatal and major injury) crashes involving heavy vehicles; these results are based on data from Bradford County. An additional year of roadway, crash, and well drilling data would be beneficial to include in future analysis of safety performance. Future research will include estimation of statistical models to evaluate the association between safety performance, well drilling activity, and roadway features.

8.0 CULTURAL RESOURCES AND MARCELLUS SHALE TRANSPORTATION

8.1 Methodology

Beginning July 1, 2010, a cultural resource survey to identify potential intersections between transportation development and activity and state listed/undocumented cultural resources in Bradford County, Pa., was initiated. This portion of the project relied heavily on collaborations with local and regional heritage leaders. This survey activity involved personnel who participated in a number of regionally sponsored workshops in order to identify some of the critical issues facing cultural resources and communities. The processed started with a transportation summit held in September, 2010. Members of the Endless Mountains Heritage Region (EMHR) were present for the summit and provided key information and contacts for further study. One representative of the Pennsylvania Historical Museum Commission (PHMC) was also present. This contact resulted in an invitation to participate in several regional planning conferences that brought together landowners, heritage leaders, state representatives, and the PHMC. Five regional meetings were attended during the course of the year. The primary purposes of the meetings were to identify observed intersections between cultural resources and Marcellus transportation activity and to target specific sites/landscapes for field observations. In addition, five site/regional visits throughout Bradford County were made, and beginning in April 2011 work started on a geospatial tool informed by the regional meetings and site visits.

8.2 Summary of Results

The increased traffic and associated rehabilitation of the rural road infrastructure has significantly impacted cultural resources. Many of these impacts are measurable, such as traffic in downtown historic districts or damage/disturbance to documented or undocumented historic and prehistoric sites. Some of the impacts are proving difficult to quantify and relate more to the aesthetic qualities and secondary impacts on cultural resources and landscapes. For example, the increased transportation has had a negative impact on local river outfitters, as measured by decreased boat rentals and guided river tours, while an informal survey of those participating in river recreation also suggests a decreased quality of experience, primarily related to water extraction. Because of the complexity of the issues, a geospatial tool was designed to provide leaders with basic overlay analysis about the location of permits and wells as they relate to cultural resources, and a planning tool would best equip local leaders to address some of the issues they have been experiencing (see Figure 49 for a conceptual diagram of the tool).

The tool will help leaders identify important sub-basins (those with substantial quantity of cultural resources or potential for significant resources), while overlaying the permit and drilling activity to provide leaders with a documented list of high-priority sub-basins (where important sub-basins will be potentially impacted by new or existing drilling activity). Figure 50 illustrates some of the analysis included in the tool, such as viewsheds, while Figure 51 illustrates first results of the geospatial tool, presently under review. Importantly, Over this time interval, the discussion of these issues with the PHMC and the Pennsylvania Board of Historic Preservation has expanded considerably to include participation in two important statewide conferences addressing these issues (Pennsylvania Heritage and Byways) as well as working with private cultural resource firms who are already experiencing an increase in historic and archaeological review (section 106). Some of these private firms are working closely with gas companies and in some cases have already performed reviews of sites. While the analysis is ongoing, some preliminary analysis demonstrates that:

1. Focus on the direct impact of drilling (e.g., archaeological survey) on cultural resources, while important, doesn't address important down-the-line impacts. As roads are rebuilt and improved, historic and prehistoric survey is critical.
2. There will be an increased demand for section 106 and related archaeological and historic reviews in the next two decades as the infrastructure for Marcellus development expands beyond initial testing and drilling.
3. Local heritage leaders are currently bearing the full weight of the new issues associated with Marcellus development. PHMC staff is supplementing their efforts, but ***there are not specific resources and staff available for these new issues.***
4. Aesthetic and scenic impacts of the transportation changes are substantial, but presently not addressed in planning and permitting outside of DCNR.
5. Creating resources for local and regional leaders is critical, so that they can develop long-term planning strategies for cultural resource management and preservation.

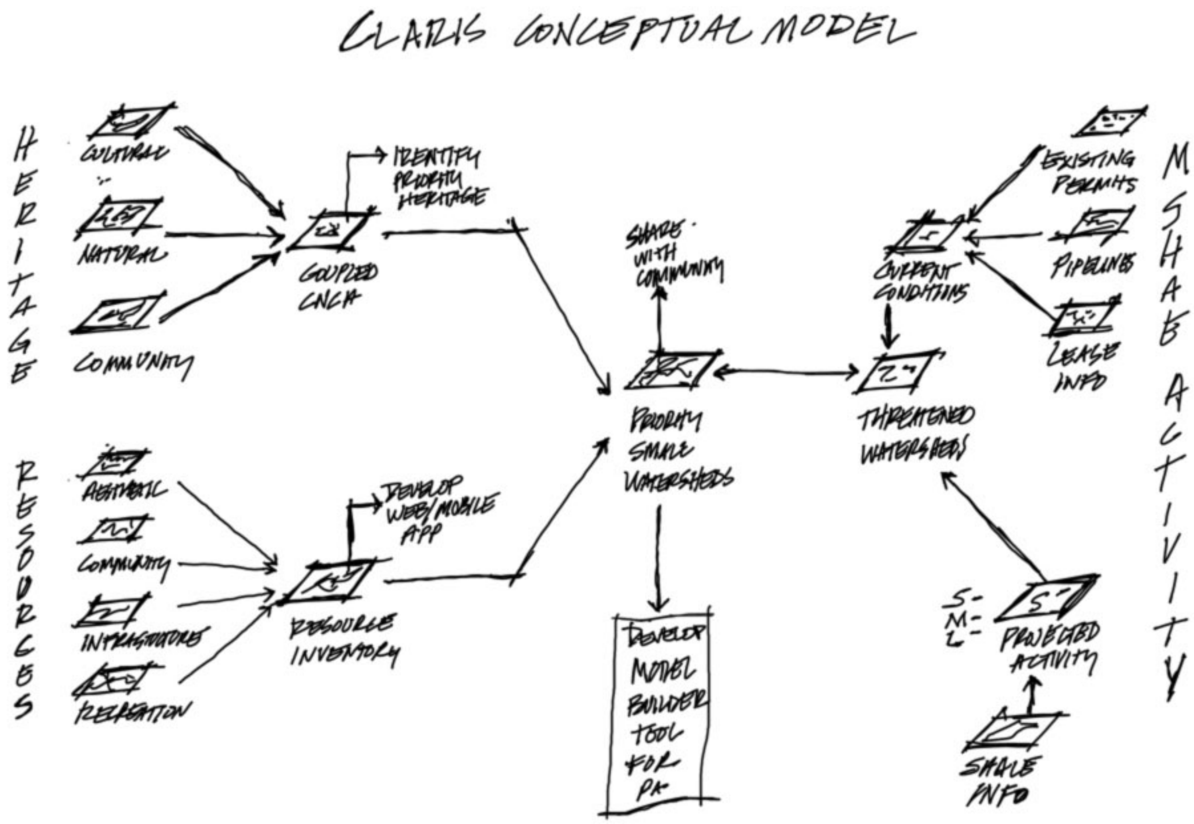


Figure 49. Conceptual Model for Geospatial Tool.

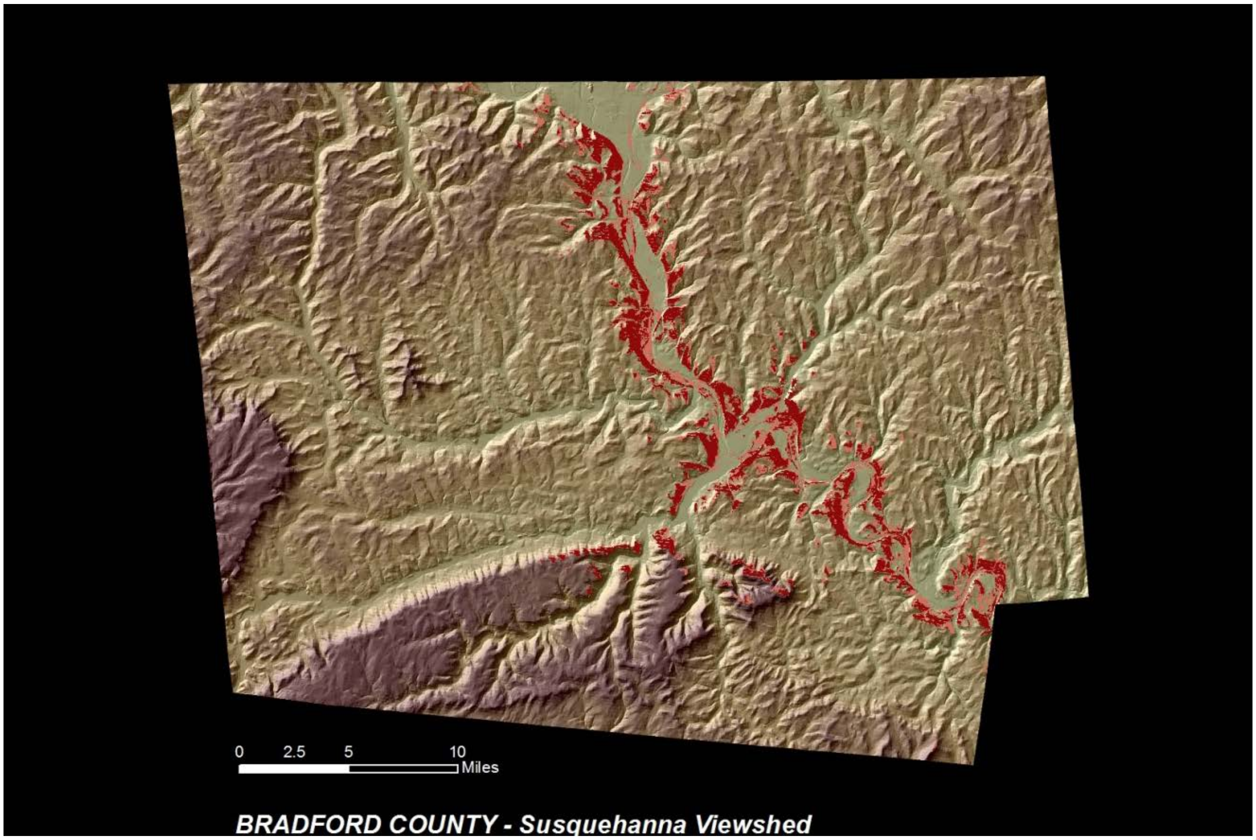


Figure 50. Susquehanna Viewshed Analysis as Part of the Geospatial Tool. Areas in Red Illustrate Highly Visible Landscapes when Traveling by Boat along the Susquehanna.

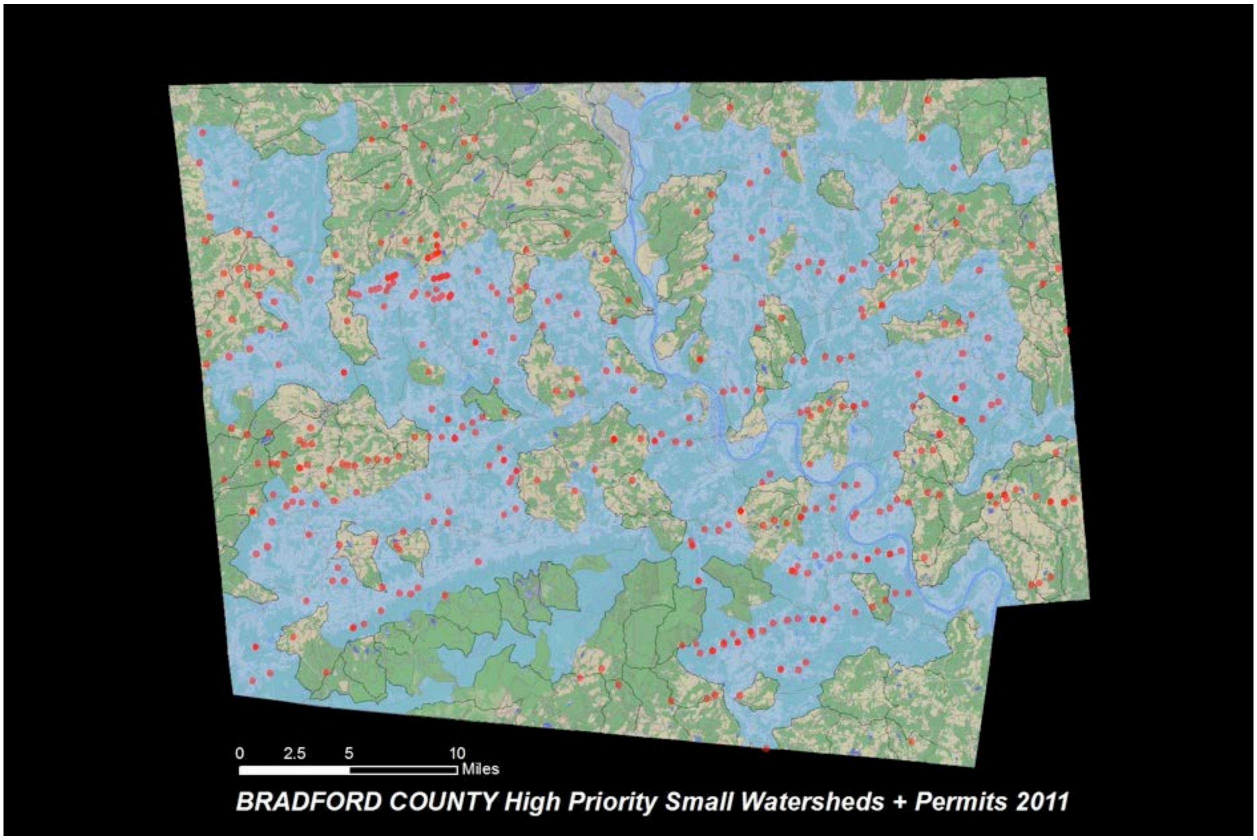


Figure 51. Preliminary Analysis Illustrating the Location of "high priority" Small Basins (i.e., those with a high density of documented historic and archaeological resources, important recreational landscapes, and scenic vistas)

9.0 PROJECT SUMMARY

9.1 Bridge Inspection Summary

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- Rutting, longitudinal and transverse cracks, and approach slab settlement were very common.
- Deterioration of the wearing surface was seemingly accelerated in bridges having more truck traffic, with that traffic appearing to be related to Gas Play activities. The decks of the selected bridges were typically covered by the wearing surface, with only the deck undersides being visible for the non-adjacent box beam bridges. The observations made during the Penn State inspections indicated little to no deck condition change compared to the reviewed inspection reports.
- Any increase in traffic as a result of the Gas Play was not shown to significantly change the condition of the superstructure or substructure in the bridges when Penn State observations were compared to PennDOT and township inspection reports.

- Bridge One, one of the two structures mentioned earlier that could be considered to provide more insight into Gas Play activity influence on bridge condition and deterioration, was of increased interest because of the large volume of Gas Play traffic it supported and its generally low condition ratings. The structure was built in 1933 and was observed during the Penn State inspection to be carrying a large number of trucks affiliated with the Gas Play. The bridge's superstructure and substructure were heavily deteriorated. The PennDOT inspection report rating of the bridge beams was very low. ***Not previously mentioned in the report, however, were instances of beam sag***. This may be an indication of increased deterioration. More importantly, Bridge One serves as an example of how aging and structurally deficient bridges are supporting an increasing number of heavy truck loads affiliated with Gas Play activities.
- Bridge Four possibly provides the best example of how Gas Play activities can influence bridge condition and deterioration rates, as it was extensively rehabilitated in 2009 and the reviewed 2010 PennDOT inspection report largely indicated good condition. These items, coupled with the location of the bridge relative to known Gas Play work (pipeline installation adjacent to the bridge) and a large amount of observed Gas Play affiliated truck traffic made the bridge ideal for study. ***The Penn State inspection indicated deterioration to certain areas of the wearing surface, parapets and approach slab. More specifically, they included accelerated wearing surface rutting, approach slab settlement that measured to be a maximum of 1 inch (25.4 mm), and, most alarmingly, a large number of full-penetration vertical cracks in the parapets that were holding moisture***. These findings were surprising to the investigators, given the recent rehabilitation, and were indicative of deterioration that would exceed the norm. While the superstructure and substructure were largely unaffected, the excessive parapet and wearing surface deterioration could be considered to be a precursor to possible future accelerated deterioration to other areas of the bridge.

9.2 Roadway Approach to Bridges

- Deterioration was observed to occur in the wearing surface, deck, and parapets for all seven inspected structures.
- Settlement, rutting, and parapet cracking were the most common observed occurrences of deterioration.
- The condition of the superstructure and substructure remained unchanged from reviewed PennDOT or township inspection reports for most of the bridges regardless of traffic levels, types, and association with Gas Play activities.
- Two structures, Bridges One and Four, had findings that appeared to indicate that Gas Play truck traffic affected either the current bridge condition or the importance placed on repairing or rehabilitating the structure.
    - Bridge One, noted as being structurally deficient, is the structure for which an accelerated rehabilitation or replacement program should be instituted given its current condition and the level of Gas Play affiliated truck traffic it is experiencing.

- Bridge Four, a structure that recently had extensive rehabilitation, is the structure that has clearly evident accelerated deterioration in the deck and parapets that appears to be the result of Gas Play affiliated truck traffic.

9.3 Secondary and Municipal Roads

- Hard data for truck traffic to and from well pad sites in Pennsylvania do not exist.
- Roadway deterioration is widespread and extensive.
- The major deterioration occurs during the time that the roadway is thawing in spring.
- Full-depth reclamation is a viable approach to rehabilitating the roadways.
- Continued cooperation of the gas companies will be necessary to maintain the existing infrastructure because of the large costs associated with the necessary rehabilitation.

9.4 Evaluation of Heavy Truck Traffic's Contribution to Safety

- Data analyses suggest that there may be an association between increased well-drilling activity and severe (fatal and major injury) crashes involved heavy vehicles.

9.5 Cultural Resources and Marcellus Shale Transportation

- Focus on the direct impact of drilling (e.g., archaeological survey) on cultural resources, while important, doesn't address important down-the-line impacts. As roads are rebuilt and improved, conducting historic and prehistoric surveys will be critical.
- There will be an increased demand for section 106 and related archaeological and historic reviews in the next two decades as the infrastructure for Marcellus development expands beyond initial testing and drilling.
- Local heritage leaders are currently bearing the full weight of the new issues associated with Marcellus development. PHMC staff is supplementing their efforts, but ***there are not specific resources and staff available for these new issues.***
- Aesthetic and scenic impacts of the transportation changes are substantial, but presently not addressed in planning and permitting outside of DCNR.
- Creating resources for local and regional leaders is critical, so that they can develop long-term planning strategies for cultural resource management and preservation.

APPENDIX A

Table A-1. PennDOT Bridge Inspection Terminology and Sufficiency Ratings

COLUMN ID and NAME	**DEFINITION**
a. BRKEY	Unique identifier assigned to the bridge structure.
b. County	Name of county where bridge is located.
c. Bridge ID	Identification number assigned to bridge location.
d. Location / Structure Name	Geographic location of bridge, or the official or commonly used name for bridge.
e. Feature Carried	Roadway that continues (or is carried) over bridge. Roadway is identified by either the assigned street name or number, and possibly the direction of traffic using the bridge (for example, EB means eastbound). Abbreviation indicates whether the roadway is a federal highway (I for interstate), state-owned roadway (SR for state route), or local roadway owned by township/municipality.
f. Feature Intersected	Roadway, waterway or railroad (or combination of these) that exists underneath the bridge.
g. Owner Code Codes:	Two-digit code identifying governmental agency or railroad that owns bridge and is responsible for inspecting and maintaining the physical structure. 01 PennDOT 02 County Highway Agency 03 Town or Township Highway Agency 04 City, Municipal Highway Agency, Borough 11 State Park, Forest or Reservation Agency 12 Local Park, Forest or Reservation Agency 21 Other State Agencies 25 Other Local Agencies 26 Private (other than railroad) 27 Railroad 31 State Toll Authority 32 Local Toll Authority 60 Other Federal Agencies (not listed below) 62 Bureau of Indian Affairs 64 U.S. Forest Service 66 National Park Service 68 Bureau of Land Management 69 Bureau of Reclamation 70 Military Reservation Corps of Engineers 80 Unknown
h. Length (feet)	Length of the bridge measured in feet.
i. Deck Area	The bridge deck area in square feet as determined by multiplying the maximum structure span length by the out-to-out width of the bridge deck.
j. # Spans	Total number of sections (or spans) to the bridge from edge of roadway to support (pier), and from support to support.
k. Structure Type	Material and construction type of bridge’s superstructure.
l. Year Built	Year the bridge was built.

<table>
<tr><th>COLUMN ID and NAME</th><th>DEFINITION</th></tr>
<tr><td>m. Post Status</td><td>Operational status of bridge:

Open – bridge is open to traveling public.

Closed – bridge is closed to vehicular traffic (barriers and signs put in place). Pedestrian traffic may/may not be allowed.

Posted – bridge is open but signs have been placed stating a weight limit that can travel across the bridge.

Temp – bridge has temporary supports and/or restrictions in place.

U/CON- bridge is closed due to construction.</td></tr>
<tr><td>n Weight Limit – Single (Tons)</td><td>If bridge is posted, signs are placed to indicate the maximum weight (in tons) of a single vehicle (for example, a concrete mixer truck) that can travel on the bridge. “1 TRK” means that the bridge is limited to one truck traveling on it a time without a weight limit.</td></tr>
<tr><td>o. Weight Limit – Comb (Tons)

(Combination)</td><td>If bridge is posted, signs are placed to indicate the maximum weight (in tons) of a combination vehicle (for example, tractor trailer) that can travel on the bridge. “1 TRK” means that the bridge is limited to one truck traveling on it a time without a weight limit.</td></tr>
<tr><td>p. Weight Limit Other (Tons)</td><td>When a bridge is posted and limited to one truck at a time, signs are placed to indicate the maximum weight (in tons) of that truck.</td></tr>
<tr><td>q. Condition Rating – Deck</td><td>Single-digit number that describes the physical condition of the deck (top surface of bridge that carries traffic) compared to its original as-built condition. Number is assigned by state-certified bridge inspectors during each inspection of the bridge, which occurs at least every two years. Number range is nine to zero.

See the description for Condition Rating – Superstructure for a general definition of each number.</td></tr>
<tr><td>r. Condition Rating - Super

Superstructure is the underlying or supporting part of a bridge, for example steel members under the deck.</td><td>Single-digit number that describes the physical condition of the superstructure compared to its original as-built condition. Number is assigned by state-certified bridge inspectors during each inspection of the bridge, which occurs at least every two years.

Number range is nine to zero. A rating of 4 or below indicates poor conditions that result in a structural deficient classification.

N = Not applicable
9 = Excellent
8 = Very good
7 = Good, some minor problems noted
6 = Satisfactory, structural elements showing minor deterioration
5 = Fair, primary structural elements are sound but showing minor cracks and signs of deterioration
4 = Poor, deterioration of primary structural elements has advanced
3 = Serious, deterioration has seriously affected the primary structural components
2 = Critical, deterioration of primary structural components has advanced and bridge will be closely monitored, or closed, until corrective action can be taken.
1 = Imminent failure, major deterioration in critical structural components. Bridge is</td></tr>
</table>

COLUMN ID and NAME	DEFINITION
	closed but corrective action may put the bridge back into light service. 0 = Failed, bridge is out of service and beyond corrective action.
s. Condition Rating – Sub *Substructure* is the part of the bridge that supports the super-structure such as piers and abutments.	Single-digit number that describes the physical condition of the **substructure** compared to its original as-built condition. Number is assigned by state-certified bridge inspectors during each inspection of the bridge, which occurs at least every two years. See the description for Condition Rating – Superstructure for an explanation of each number.
t. Condition Rating – Culv *Culvert* is a curved or rectangular structure below the roadway surface used primarily for water flow.	Single-digit number that describes the physical condition of the **culvert** compared to its original as-built condition. Number is assigned by state-certified bridge inspectors during each inspection of the bridge, which occurs at least every two years. See the description for Condition Rating – Superstructure for an explanation of each number.
u. Struct Def (Structurally Deficient)	Indication of bridge's overall status in terms of structural soundness and ability to service traveling public. "SD" indicates that the bridge has deterioration to one or more of its major components.
v. Func Obsol (Functionally Obsolete)	Indication of bridge's overall status in terms of structural soundness and ability to service traveling public. "FO" indicates that the bridge has older features (for example, road widths and weight limits) compared to more recently built bridges.
w. Suff Rate (Sufficiency Rating)	A calculated rating indicating the bridge's sufficiency (or capability). Factors included in the calculation are: • the structure's adequacy and safety (accounting for 55% and based on inspection data), • the structure's serviceability and functional obsolescence (accounting for 30% and based on ability of bridge to meet current traffic conditions), and • how essential the bridge is for public use (accounting for 15%). Ratings range from 100 (entirely sufficient) to 0 (entirely insufficient or deficient). The Sufficiency Rating is considered by the federal government when a state requests federal bridge dollars to improve the condition of the bridge. Bridges with low sufficiency ratings are eligible for more funds. Sufficiency Rating — Funding Eligibility 80 – 100 — Not available 50 – 79 — Eligible for costs to rehabilitate or refurbish bridge 0 – 49 — Eligible for costs to replace bridge
x. MPO – Metropolitan Planning Organization	Organization of several municipalities that serve areas with greater than 50,000 people for the purpose of planning in a more comprehensive manner; PA has 15 MPOs.

COLUMN ID and NAME	**DEFINITION**
y. Muni Code – Municipal Code	Code corresponding to the local municipality that owns the bridge.
z. ADT – Average Daily Traffic	This is the average number of vehicles that cross the bridge each day.

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APPENDIX B

Design Methodology of Unpaved Roads to Handle Heavy Truck Traffic

Background

Degradation of the transportation infrastructure as a result of the extraction activities of natural gas in the Marcellus Shale Gas Play is an inevitable consequence. The enhanced traffic that accompanies these activities is far beyond the design limits that the majority of rural Pennsylvania roads were ever expected to witness. Three classifications of roads are involved: (a) major PennDOT highway (e.g, Rt. 6); (b) secondary PennDOT roads with four-digit SR designation; and (c) municipal dirt and gravel roads. Of these, the first two classifications are receiving direct oversight by PennDOT where proven standards for roadway design exist [AASHTO, 1993]. Gas companies are shouldering their responsibilities to reconstruct these roads and are doing so in cooperation with PennDOT. It is the third classification of roads, the dirt and gravel roads, where the major concerns and issues are focused because the responsibilities are borne by local municipalities with limited financial and engineering support.

Although the gas companies are assuming the responsibilities for remediating the damage done to most dirt and gravel roadways, no one accepted standard exists that can be specifically used for these reconstruction activities at traffic levels that are projected to travel on these roads. AASHTO [1993], U.S. Forest Service [1983], Asphalt Insitute [1986], South Dakota LTAP [2000], and Army and Air Force [1995] as well as the software model by Huang [2004] can be used to offer some guidance, but no one source provides the answer. AASHTO [1993] addresses design methodology for “flexible” roadways, which is an asphalt driving course and differentiated from a cement driving course designated as a “rigid” roadway. This model, with a flexible roadway encompassing a driving course, base course, and sub-base course can be modified to work on gravel roads by eliminating the asphalt component of the model and by including the performance of geotextiles.

How to Judge if a Gravel Road Design is Adequate

A design for a gravel road can be evaluated in this approach from the ***Structure Number*** that is calculated to correspond to an anticipated traffic count of heavy vehicles. See Table B-1.

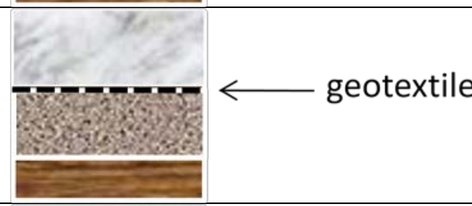
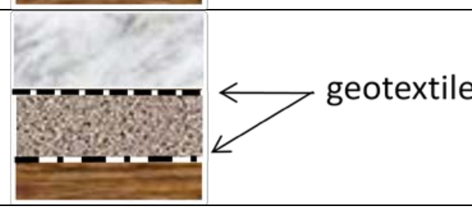
Table B-1. Structure Numbers Corresponding to Anticipated Traffic Counts of Heavy Vehicles

100,000 Heavy Trucks	400,000 Heavy Trucks
≤3.4	≤4.25

If the design that is presented to you meets these criteria, the AASHTO design methodology indicates that the roadway should support the designated traffic load. The calculation as presented does not address longevity; if the 100,000 vehicle count is met in 3 months or 3 years is irrelevant, only the 100,000 vehicles is important.

The road design can take on four different configurations, as shown in Table B-2.

Table B-2. Four Different Road Design Configurations.

Road Design	**Schematic View**
No geotextile	
1 layer geotextile between sub-grade and driving surface	
1 layer geotextile between driving course and sub-base	
2 layers of geotextile between driving course and sub-base and between sub-base and sub-grade	

Since there is no one unique design, different thicknesses, D, in the following equations, are selected to meet the Structure Number calculated to address the traffic count. The use of geotextiles will result in a reduction in the overall thickness of the roadway and can contribute to potentially significant cost savings on aggregate, as detailed in the accompanying example.

The following range of variables in the model calculation will provide insight to ensure that the selections of variables in the calculations are reasonable:

Table B-3. Range of Variables in the Model Calculation

a_x	Ranges from 0.11 to 0.14 for good quality aggregate
M_x	Ranges from 0.4 to 1.4 depending on the quality of drainage
LCR	Ranges from 1.42 to 1.75 and is a function of the geotextile quality, the interaction of the geotextile with the soil/aggregate that it is in contact beneath the geotextile
M_r	Average modulus of PA sub-grade soils with freeze/thaw cycling = 7500 psi
ΔPSI	2.5 inch rut depth

Model Calculation

Applying the flexible roadway design and effectively eliminating the asphalt driving course allows for the calculation of the remaining gravel components in the design. The methodology is based upon selecting an appropriate structure number that is a complex relation that reflects the traffic load, calculation reliability, condition at failure, and the roadway soils. The relationship is:

$$SN = a_1D_1 + a_2D_2m_2 \quad \text{(B-1)}$$

where:

SN = structure number [2 – 9]
a_1 and a_2 = layer coefficients [typical aggregate base course values 0.11-0.14]
m_2 = drainage conditions [0.1 o 1.0]
D_1 and D_2 = thickness in inches of base course and sub-base course, respectively.

Once the SN is calculated for the anticipated traffic load and the properties of the aggregate are established, the thicknesses of the two components to the design can be iteratively calculated.

As an example calculation, let's assume the following conditions:

- A single layer of aggregate
- 300,000 18K ESALs
- A well draining graded aggregate
- Layer coefficient , a_1, = 0.14
- Drainage is very good, m_1 = 1.0
- Reliability 90%; standard deviation 0.3
- Resilience modulus of roadway soil 1500psi.

When these assumptions are factored into the design formula, an SN of 4.62 results. Substituting into Equation B-1 and solving for D_1

$$D_1 = SN/a_1 = 4.62/0{,}14 = 33 \text{ inches}$$

Since there is no one unique solution to these equations, design optimization based on available materials and economic constrains can be practiced. In the design practice, AASHTO cautions that if the reliability factors are utilized, designers are alerted to use "average materials values" rather than relying upon a conservative approach and using "minimum materials values."

Geosynthetic materials have been widely used in flexible roadway designs because, if properly integrated, these materials distribute the wheel load over a broader area, hence the force per unit area is decreased and the demand on the load carrying capacity of the base course and sub-base course can be diminished. Equation B-1 is modified with an additional term that reflects the load-carrying capabilities of the geosynthetic materials in the form:

$$SN = a_1D_1LCR + a_2D_2m_2LCR \quad \text{(B-2)}$$

where the terms are the same as Equation B-1 and LCR represents the Layer Coefficient Ratio. The LCR is effectively the force multiplier resulting from the geosynthetic materials integrated into the design and are a function of the sub-grade soil strength and the strength design of the geosynthetic material itself.

Repeating the design calculation above with the additional assumptions:

- Two-layer design approach with geogrid at approximately mid-section
- LCR = 1.75
- PennDOT geotextile class 4, type B beneath sub-base separating roadway soils and aggregate
- Base course = PennDOT 2A; sub-base PennDOT #67

Substituting into Equation B-2 results in:

$$4.66 = [9''][0.14][1.75] + [10''][0.14][1.75]$$

With the integrated use of geosynthetic materials into the roadway design, the thicknesses of the constructed roadway can be reduced by 42 percent, from 33 inches to 19 inches, at a cost savings in excess of 37 percent.

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