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RE: **Hydrologic and Environmental Rationale to Bury Gas Pipelines using Horizontal Directional Drilling Technology at Stream and River Crossings**

Ms. van Rossum,

Introduction

At issue is whether replacement of Transcontinental Gas Pipeline Company, LLC (Transco) 30-inch diameter gas pipelines beneath East Branch Brandywine and Ludwig's Run creeks with 42-inch diameter pipes should be conducted via open trench burial methods or utilizing horizontal directional drilling (HDD) technology. Transco addresses HDD as one of the Design and Construction alternatives, determining that this is not the best alternative for this project. HydroQuest does not agree with the Transco conclusion, and recommends that HDD is the best technological option for crossing the East Brandywine and Ludwig's Run, as well as the unnamed tributaries that are part of this proposed project.

Key issues and factors that should be weighed in the decision regarding the appropriate method of stream crossing are presented below, along with recommendations. While the ultimate HydroQuest recommendation to replace gas pipelines using HDD technology is in this letter cast in terms of the Brandywine Creek area, the recommendation applies equally throughout all of the Delaware River watershed and beyond.

Environmental, Safety and Monetary Risks

There are numerous environmental, safety, and monetary risks associated with open trench burial of gas pipelines (wet, dry, slurry). Open trench burial involves the excavation of sediments for pipeline installation perpendicular to or across streams and their sometimes wide floodplains, along with removal of vegetation and well-established ecosystems. HDD involves the placement of pipelines far below stream corridors without disrupting and fragmenting healthy, viable, ecosystems. It removes the potential for pipeline exposure and rupture in a safe manner without denuding and modifying streambeds, banks and the adjacent riparian buffer zone. **Where pipeline crossings have already occurred, such as in the Brandywine Creek area, HDD based pipeline replacement will not require again disturbing the creek and its buffer zone.**

There are serious environmental problems associated with pipeline crossings of streams. The most significant risks associated with open trench pipeline burial include unnecessary disruption and fragmentation of riparian ecosystems, potential for explosions, potential introduction of invasive species, potential pipe exposure due to insufficient sediment depth above bedrock for pipe burial placement below potential scour depth (in some cases), the added potential for pipe exposure and rupture associated with lateral channel migration during flood events, additional stream and ecosystem disturbance during remedial activities, and downstream water quality degradation. Financial benefits of HDD pipeline crossings include the elimination of upfront costs of conducting hydrologic/engineering studies needed to assess maximum potential scour depth on all stream reaches targeted for pipeline crossings (see, for example, Doeing et al., 1997) and avoiding significant future expense involved in remediating storm exposed and ruptured pipelines.

Another significant environmental risk associated with both wet and dry trench methods of gas pipeline crossings of rivers and streams is the potential of releasing hydrocarbons or other contaminants directly into surface water and fragile downstream ecosystems. Gas, as it is extracted from a well, may be mixed with hydraulic fracturing fluids. Hydrocarbon-laced condensate or natural gas liquids (NGLs) associated with natural gas (e.g., benzene) may degrade downstream drinking water supplies as well as underlying aquifers recharged by stream water if pipe rupture occurs. The Brandywine Creek Transco pipeline area is located less than 0.5 miles upstream of a drinking water supply intake. Pipe rupture here might well result in a public health hazard. In the absence of pipe rupture circumstances, massive stream disturbances associated with pipeline installations may result in high total suspended solids (TSS) concentrations for extended periods of time. This may adversely impact and degrade downstream ecosystems, fisheries and water supplies.

Beyond this, open trench pipeline installations may unnaturally alter both stream bank and streambed (i.e., channel) stability, thereby increasing the likelihood of scouring within backfilled pipeline trenches. This is because open trenches themselves, when backfilled, may not be compacted to stable pre-trench sediment permeability conditions. Flooding rivers can scour river bottoms and expose pipelines to powerful water currents and damaging debris. More recently, unusually heavy rains possibly associated with climate change, threaten to increase overall stream degradation and channel migration – thereby exposing shallowly buried pipelines.

Most if not all of these risks can be avoided by using HDD technology to place pipelines far below elevations of maximum channel scour and lateral channel migration, preferably within bedrock where possible. Concern has been raised regarding the use of the clay mineral bentonite to thicken drilling mud during HDD operations. Review of industry

Material Safety Data Sheet (MSDS) ecotoxicologic data specific to bentonite (CETCO, 2012; CAS# 1302-78-9) reveals that the Lethal Concentration (LC50) in water that would kill 50 percent of freshwater fish would require 16,000 mg/l continuously for 96 hours (rainbow trout LC50: 19,000 mg/l, 96 hours), an extremely high and unlikely concentration should leakage or spillage occur. Bentonite has a low solubility in water and does not bio-accumulate. The risks relative to using bentonite during HDD operations appear to be low.

HDD is now sufficiently advanced to the point where it is commonly used to cross beneath streams during gas pipeline installations. The HDD procedure readily removes most potential short and long-term environmental impacts associated with open trench pipeline installations. Thus, it is not necessary to disrupt the physical integrity of stream corridors, their ecosystems and intact fisheries. It should be incumbent upon pipeline companies to adhere to commonly used HDD practices now widely employed in order to minimize their environmental footprint and harm.

Examples of Channel Bed Scouring and Gas Pipeline Failures

Buried pipelines may be exposed by streambed lowering resulting from channel degradation, channel scour, or a combination of the two (Fogg and Hadley, 2007). Scour hole development in streams and rivers adjacent to buried pipelines may expose and damage pipelines, thereby posing a significant threat to the downstream environment. Scour hole development proximal to pipelines is well-documented in both stream and seabed settings. To illustrate this point, a number of pipe exposure and failure instances are documented here. For example, deep scour holes were found adjacent to a 42-inch gas pipeline crossing in a shallow Eems seabed crossing between the Netherlands and Germany (Spiekhout and Russ, 2002). Because of a decrease in the depth of sediment cover, rocks had been dumped on the pipeline several times in the past. The evaluation showed that the pipeline was now situated in what could be regarded as an underwater groyne (i.e., a wall of rocks extending from a riverbank outward into a river to control erosion). Scour hole development occurred due to turbulent flow. In some places the cover was inadequate or completely absent. The responsible authorities had indicated that rock dumping was not to be used again in future.

In 1993, the flooding Gila River in Arizona ruptured a 36-inch pipeline, sending natural-gas bubbling to the surface (Randazzo, 2010). In addition, and also associated with 1993 flooding in Arizona from heavy water releases from San Carlos Lake, several El Paso Natural Gas pipelines, which crossed the Gila River near Coolidge, Winkleman, and Kelvin were "scoured" and uncovered by the force of the water and failed (Wikipedia).

Doeing et al. (1997) further document six gas pipelines in the Gila River Basin that were either exposed on bridges or failed due to stream erosion stemming from January 1993 floods in Arizona. The failures were critical because these were major transmission lines that supplied natural gas to residential and industrial users in whole communities and groups of communities. Stream-based pipe *"(f)ailures were caused not only by vertical* *scour of the streambed but also by bank erosion, lateral channel migration, avulsions, bridge scour, and secondary flows outside the main channel. ... Several of the pipelines in the study failed as a result of a meander migration or avulsion of the stream into previously less active or nonexistent channels*." Based on field observations and hydraulic modeling for the 100-year design flood, researchers documented maximum vertical scour to 26.6 feet (8.1 meters) and lateral scour to 6,274 feet (2,050 meters) at some failed pipeline crossings. The results of their analyses provide solid justification to use HDD technology to avoid the costly and environmentally damaging consequences associated with shallow pipe burial as is being proposed by Transco and other pipeline companies in the region.

Clean up associated with pipeline breaks can be extremely expensive. As such, the extra costs of HDD pipeline installation versus open trench pipe burial may be offset both monetarily and in terms of avoiding adverse environmental impacts. For example, Federal officials investigating a July 2011 pipeline break that spilled 1,500 barrels of oil into a Montana river said that few companies take river erosion and other risks into account when evaluating pipeline safety. ExxonMobile expects that cleanup costs associated with fouling an estimated 70 miles of shoreline of the Yellowstone River may cost about $135 million (Billings Gazette, 2012). The Department of Environmental Quality in Montana is also concerned with thousands of pipelines that cross small or intermittent streams.

Fifteen years prior to the above mentioned Yellowstone River spill, a damaging flood event in Texas ruptured eight pipelines and spilled more than 35,000 barrels of oil and oil products into the San Jacinto River (Billings Gazette, 2011). While gas pipelines are not conducting oil, natural gas commonly includes condensates that include hydrocarbons and other pollutants which, if released into the environment, pose an environmental risk (e.g., to potential bog turtle habitat and travel corridors, fisheries, water supplies). Fogg and Hadley (2007) of the Bureau of Land Management recognized and addressed this critical issue:

> *"In 2002, the U.S. Fish and Wildlife Service raised concerns about the potential for flash floods in ephemeral stream channels to rupture natural-gas pipelines and carry toxic condensates to the Green River, which would have deleterious effects on numerous special-status fish species (Figure 1)."*

Photo from Fogg and Hadley (2007) of an exposed pipeline crossing the Green River, Utah. Natural gas pipeline breaks during flooding can release condensate toxic to sensitive fish species. Ludwig's Run and the East Branch of Brandywine Creek are a stocked trout fishery.

Fogg and Hadley (2007) evaluated hydraulic considerations for pipeline crossings stream channels. Their Figure 10, shown below, depicts lateral migration of a stream channel during high water that excavated a section of pipeline under the floodplain that was several feet shallower than at the original stream crossing. Ludwig's Run has had similar lateral migration of the channel.

Photo from Fogg and Hadley (2007) of an exposed pipeline crossing an unnamed western US river. Here, lateral migration of a stream channel during high water excavated a section of pipeline under a floodplain that was several feet shallower than at the original stream crossing.

Talke and Swart (2006) and De La Motte (2004) discuss gas pipelines and how man-made changes and actions have altered channel morphology and changed channel stability in an estuary setting. Soil erosion and channel migration in a low gradient mud flat area reduced the soil cover over a pipeline, resulting in scour hole formation and making the pipeline vulnerable to rupture.

Existing regulations regarding pipe burial depth are wholly insufficient. Federal regulations require that pipelines crossing rivers be buried at least four feet underneath most riverbeds (Billings Gazette, 2011). Kirkbride (2009) states that the East Brandywine Creek pipeline is buried just under a meter below grade. While bridge piers are more readily exposed to stream scouring than pipelines, it is telling that bridge failure analyses have determined that channel scour occurs to depths of up to three times that of maximum river floodwater depth (e.g., scour to 30 feet with a 10 foot floodwater depth). Many hydrologic and geomorphic factors contribute to the assessment of maximum scour depth potential under the wetted invert or base of a stream channel during a 500-year flood event. HDD technology presents the best safety mechanism for insuring preservation of channel integrity, water quality and health of downstream fisheries.

River Crossing Technology & Risks

Pisano et al. (2001) detail state-of-the-art river crossing technology as of 2001 using an annular casing system pressurized with nitrogen, and routine leak detection monitoring. This system could be considered in Pennsylvania river and stream crossings. Aronson et al. (2007) review international industry best practices for Russia/CIS for effective management of pipeline crossings, especially where high quality salmonid fisheries may be involved. A review of their work points out that stream pipeline crossing pose a number of potential environmental risks including an increase in total suspended solids loads with increased sediment transport, alteration of river hydraulics, impact to fisheries, stream stabilization, damage to ecological integrity, and soil erodibility.

HDD, discussed below, presents one of the newest and most effective means of installing gas pipelines below streambeds while minimizing land disturbance and adverse environmental impacts. HDD may be conducted such that land disturbance at pipeline burial locations can be set back from streams beyond floodplains, thereby avoiding infringement into riparian areas inclusive of streambeds and banks. In this manner, areas next to streams can be preserved intact versus being adversely impacted by trenching machinery and open cut trenches extending across streams.

Physical Limits of Horizontal Directional Drilling

Hair (2011) assesses the current state of the art in horizontal directional drilling for pipeline installation. Key factors that potentially limit the feasibility of HDD installation are subsurface conditions, pipe diameter, and drilled length. With a few exceptions, most subsurface geologic materials may be successfully penetrated for HDD installations. "*Experience in the mining industry with raise bores indicates that reaming tools in diameters exceeding anything contemplated for a pipeline (in excess of 10 feet) can be rotated with long strings of drill pipe*." (Hair, 2011). The ream hole must be twelve inches larger than the outside diameter of the pipeline to be pulled through the hole. Hair (2011) addresses the industry's current maximum demonstrated pipe diameter and the routine nature of HDD application:

> "*Demonstrated Maximum Pipe Diameter*
>
> *The feasibility of HDD for installation of very large diameter welded steel pipelines is demonstrated by experience in 2004 on the Cross Island Pipeline Project for The National Gas Company of Trinidad and Tobago. This 56-inch diameter pipeline project included three HDD crossings in lengths of 2,230 feet (680 meters), 2,517 feet (767 meters), and 2,415 feet (736 meters). Seventy-two inch reaming tools were employed.*
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> ***The explosion of new natural gas transmission pipeline construction over the last three years has made HDD installation of 42-inch diameter pipe common, if not routine.*** (Emphasis added) *This is demonstrated by the fact that,*

in the last three years alone, the author's engineering firm has designed fifty (50) 42-inch HDD crossings with a total length of over twenty miles. The length of eight of these crossings exceeded 4,200 feet (1,300 meters) with the longest exceeding 5,500 feet (1,700 meters)."

Depending on a number of factors including pipe diameter, demonstrated HDD distance, using the drilled intersect technique may make maximum pilot hole lengths of up to 14,000 feet (3,676 meters) achievable (Hair, 2011). Another benefit of HDD is that ice scour damage associated with pipeline landfalls may be avoided (Hair, 2011). Furthermore, rupture of pipelines shallowly buried within stream corridors (i.e., placed in formerly open trenches) will almost certainly require immediate and costly remedial action. In such cases, there will not be sufficient time or resources available to minimize adverse environmental impacts. These impacts are likely to be far-reaching because most pipe ruptures occur during flood events where contaminant dispersal is likely to be great. Unfavorable impacts associated with shallowly buried pipelines argue for using deep HDD methods to avoid degradation of stream corridor ecosystems and habitat fragmentation.

Clearly, with the current state of the art of HDD technology, there is no need to jeopardize stream and river water quality or downstream ecosystems.

HDD Pipeline Endpoints Should be Placed Outside the 500-Year Floodplain

HDD endpoints should be located beyond the 500-year floodplain boundary. Rapid and/or turbulent stream flow has the potential of causing pipeline rupture, as documented in a number of examples provided above. Determination of what flood recurrence interval (e.g., 50-year, 100-year, 500-year) should form the basis of locating HDD endpoints should be based on a statistical assessment of recorded flood events from one or more long-term nearby USGS stream gaging stations. Major flood events are not isolated in nature, instead they tend to occur within broad areas with regional, widespread, storms. As an example of the type of analysis required to assess the flood recurrence intervals associated with major storm systems, HydroQuest hereby provides the results of a statistical assessment conducted for the Schoharie Valley, New York State area. This may be reviewed at: http://hydroquest.com/Schoharie, and is hereby incorporated by reference.

In this example, HydroQuest used long-term peak water year data (102 years) for the Schoharie Creek at Prattsville, inclusive of USGS's peak flow estimate there for the Hurricane Irene storm of 8-28-11. USGS (pers. comm.) estimates the peak flow at Prattsville was between 100,000 cubic feet per second (cfs) and 120,000 cfs. A value of 110,000 cfs was used by HydroQuest to conduct a statistical analysis of the flood return interval associated with floodwaters of Hurricane Irene. The HydroQuest Log-Normal Distribution plot and related statistical data supporting a 500-year flood return are presented at: http://hydroquest.com/Schoharie/. It is important to recognize that a 500-

year flood is a statistically-based number that may, in fact, occur back-to-back in consecutive years. Clearly, regional flooding to 500-year flood return stream stage levels provides a solid basis for placing HDD endpoints outside 500-year floodplains.

Additional support for using 500-year floodplain levels as HDD endpoints comes from the work of Fogg and Hadley (2007) who state that pipelines that cross stream channels on the surface should be located above all possible flood flows that may occur at crossing the site. They also state that at a minimum, pipelines must be located above the 100-year flood elevation and preferably above the 500-year flood elevation. By analogy, buried pipes should be located sufficiently deep so as to not be adversely impacted by scouring under 500-year floodwater depths.

HydroQuest Flood Return Interval Analysis of Brandywine Creek

Preliminary assessment of data from USGS gage 01480700 East Branch Brandywine Creek near Downingtown, PA located 0.83 miles upstream from the pipeline crossing, documents a stream stage of 12.06 feet and discharge of 8,070 cubic feet per second on June 22, 1972 associated with Hurricane Agnes. The watershed area upstream of this gaging station encompasses 60.6 mi^2. If one assumes a roughly similar channel cross-sectional area and floodplain width at the Brandywine pipeline crossing it is possible to assess whether this 12 foot creek depth is likely to be a maximum depth expected to be associated with a storm with a 500-year flood return interval.

HydroQuest evaluated this question by conducting a statistical analysis to determine the likely flood return interval of the 1972 twelve-foot stream depth recorded at the USGS Brandywine gaging station. Forty-six years of annual peak flow data was statistically analyzed (Figure 1). To some unknown degree some of the flow was affected by regulation or diversion. To be valid, each of the four tests conducted had to pass a Chi-Square Test. Type 1 Gumbel distribution and Normal distribution tests failed the Chi-Square Test. Both the Log-Pearson Type III distribution (Figure 2) and Log-Normal Distribution (Figure 3) tests passed, providing a statistically based flood return interval for the 1972 flood of about 50 years. Thus, the 1972 flooding and associated depth of Brandywine Creek is far less than what will certainly occur during 100-year and 500-year flood events. An idea of the relative magnitude of flow difference may be obtained by examining the statistically determined stream flow (discharge (Q) in cubic feet per second: cfs) for different flood return intervals (Tr in years):

Tr (years)	Log-Normal Distribution Q (cfs)	Log-Pearson Type II Distribution Q (cfs)
1.01	643	646
2	2,415	2,412
5	3,895	3,894
10	5,002	5,006
25	6,531	6,546
50	7,758*	7,787
100	9,058	9,105
200	10,437	10,507
500	12,392	12,502
1000	13,979	14,125

*: June 22, 1972 peak stream flow of record was 8,070 cfs with a stage of 12.06 feet.

While comparative measurements of creek cross-sectional area are required both at the USGS gaging station and at the Brandywine pipe crossing to determine flood depths, it is probably reasonable to assume that the 500-year flood has an associated maximum stream depth of at least 15 feet, perhaps more depending on the cross-sectional area at the pipeline crossing. Field work should be conducted to refine this number, inclusive of Rosgen flood depth field characterization methods. Creek depth is one of a number of important factors that influences potential scour depth. Doeing et al. (1997) conducted scour evaluations using a combination of field data and numerical sediment transport models HEC-6 and HEC-2 for 100-year design floods. Based on model assumptions, sediment composition and thickness, channel width, stream discharge, stream velocity, channel curvature, channel morphology, presence of armor layers, field evidence of dunes and anti-dunes, and numerous other factors, they found that potential scour depth varied to depths in excess of 100-year stream flood depths (i.e., Gila River at Duncan). Thus, potential scour depths may equal or exceed maximum 100-year flood water depths. Since 500-year flood return intervals not only will occur but have in recent time (i.e., see Schoharie Creek flood return interval analysis above), it is reasonable to assume that the potential Brandywine scour depth associated with the 50-year return interval flood of 1972 (possibly to at least 12 feet) is far less than the 500-year return interval flood.

Potential Brandywine Scour Depth at the Pipeline Crossing

In the absence of detailed field data and modeling, it would be prudent to assume that potential channel scour depth (not field and model analyzed) may at least equal the maximum 500-year flood stage water column at the Brandywine pipeline crossing, as well as at other pipeline crossings. This 500-year flood depth can be reasonably determined through comparative field survey work of channel cross-sectional areas and flow assumptions (i.e., at the nearby USGS gaging station and at the Brandywine pipeline crossings). In the absence of detailed hydraulic evaluation of the Brandywine pipeline crossing within an as yet un-delineated 500-year floodplain (using methods comparable to that of Doeing et al.), it would not be prudent to bury a replacement pipeline at a depth of less than twice the maximum 50-year stream flood stage. Thus, Brandywine pipeline protection from scour may require burial to at least 24 feet, far below the current 3 foot or so pipe burial depth. Pipe rupture protection would best be accomplished by using HDD technology to isolate gas pipelines far below 500-year floodwater scour depth potential while avoiding channel degradation and habitat fragmentation within the riparian zone.

Important Brandywine Creek Scour Risk

Importantly, if the thickness of sediment cover present below the stream invert (i.e., channel bottom) and above bedrock is less than the potential scour depth, then pipe burial in an open sediment-walled trench will knowingly and unnecessarily place the stream environment and downstream water supply at risk from contaminants released from pipe rupture. Review of the Brandywine Creek 42” Mainline “A” Replacement Alternatives Analysis reveals text in a number of places that imply that the depth to bedrock below the stream invert may be quite shallow. Nowhere in the text is this quantified. **If sediment thickness is less than potential scour depth, then all open trench pipe replacement options should be abandoned.**

Even if there is sufficient sediment thickness to allow replacement pipe to be installed below the maximum potential scour depth, open trench excavations have too many undesirable environmental risks, as discussed above. These risks include exposure to toxic materials released into the environment from pipe ruptures. The HDD alternative section of the alternatives analysis seeks, to a large degree, to downplay this option because of somewhat longer times local residents will be inconvenienced. The alternative option section should be rewritten to include discussion of potential repeated times of inconvenience associated with remedial pipeline replacement activities following pipe exposure and rupture.

Recommendations

Open trench crossings of streams and rivers for gas transmission pipelines may disrupt and adversely impact the physical integrity of stream corridors, their ecosystems and intact fisheries, and stream water quality. Field data collection and modeling are necessary to determine potential maximum channel scour depth far in advance of initial pipeline burial or replacement burial. It is highly unlikely that the needed data exists for the Brandywine pipeline crossing, otherwise the existing pipeline would have been buried far deeper than it is. Pipeline replacements at stream crossings provide an opportunity to forever remove the numerous environmental and other risks associated with pipeline exposure and rupture that stem from no or inadequate evaluation of scour potential.

The explosion of new natural gas transmission pipeline construction over the last three years has made Horizontal Directional Drilling installation of large-diameter pipe common, if not routine. HydroQuest recommends that all gas transmission pipelines be placed using HDD technology, locating pipe endpoints beyond the limit of 500-year floodplains. While this recommendation is cast in terms of the East Brandywine Creek area, it applies directly throughout all of the Delaware River watershed and beyond.

Should HDD not be contemplated at all new and replacement pipeline crossings of streams and rivers, no open trench pipe burial should occur without full hydrologic and engineering analysis of all the variables discussed in this letter, as well as those addressed in the evaluation methodology used by Doeing et al. (1997) and the hydraulic evaluations of other researchers. To do so would not be prudent and would knowingly place pipelines, residents and the environment at risk. Furthermore, in light of today's knowledge base relative to mechanisms and variables associated with pipeline exposure and rupture, failure to fully evaluate streambed scour potential before installing or replacing pipelines may needlessly place pipeline companies at legal risk.

HydroQuest also recommends that the Horizontal Directional Drilling alternative provided be substantially redone. Instead of being advanced as an alternative riddled with problems, it should be rewritten as the preferred best option that is stated as being "*technically feasible*" with a detailed discussion of how best to overcome any outstanding issues. We suggest that an RFP be put out to obtain HDD design plans and bids from qualified contractors, including John D. Hair of J. D. Hair & Associates, Inc. (see References below).

In addition, the alternatives analysis needs to be rewritten to consider the open trench harms discussed in this comment and to assess the impacts and costs of laying the pipe in a trench that is a minimum of 24 feet below the surface of the creek bed in order to protect against exposure and/or rupture by scour.

Sincerely yours,

Paul A. Rubin

Paul A. Rubin
HydroQuest

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