CADMUS

Environmental and Social Costs of Natural Gas Pipeline Development in the Delaware River Basin

June 2019

Prepared for:

The New Jersey Conservation Foundation

www.njconservation.org

Acknowledgements

This report was written by the Cadmus Group LLC (Cadmus) and was made possible by generous funding from the William Penn Foundation and the guidance and technical support of the New Jersey Conservation Foundation. The opinions expressed in this report are those of the authors and do not necessarily reflect the views of the William Penn Foundation. Jaime Rooke was the Principal Investigator, and Paul Faeth was the Principal in Charge. Additional authors from Cadmus included Richard Krop, Anna Epstein, Karen Sklenar, Mary Ellen Tuccillo, and Alex Taylor. Lars Hansen of CNA Analysis and Solutions provided extensive data analysis and GIS mapping support. The authors of this report would like to thank Tom Gilbert and Barb Blumenthal of the New Jersey Conservation Foundation, Eve Miari and Alex Bomstein of the Clean Air Council, David Lyon, Elena Krieger, and Eric Friedman for their valuable insight and review. The authors would also like to thank the numerous Pennsylvania residents mentioned throughout the Mariner East 2 case study for sharing their stories. Cover photo courtesy of Ralph Blume.

Suggested citation:
Rooke, J., Faeth, P., Krop, R., Epstein, A., Sklenar, K., Tuccillo, M.E., Taylor, A., and Hanson, L. (2019). Environmental and Social Costs of Natural Gas Pipeline Development in the Delaware River Basin. Prepared by The Cadmus Group LLC for The New Jersey Conservation Foundation.

Table of Contents

Tables

Figures

Overview

The Delaware River Basin (DRB) faces significant disruption and stresses from the development of the natural gas industry in the region. Cumulatively, these stresses result in substantial costs to the environment and communities in the DRB. Such costs should not be overlooked when making decisions about pipeline development in the region. The results of this study suggest that the present value of lifetime environmental and social costs associated with the proposed PennEast and existing Mariner East 2 pipelines in the DRB range from approximately $758 million to $2.4 billion. These estimates represent only the costs that could be quantified and monetized but not the full range of potential costs. In addition, these estimates are conservative based on the assumptions applied to each individual analysis. In other words, these costs are lower bounds. Under other assumptions about uncertain factors, costs could be higher.

The monetized costs include loss of ecosystem services as a result of land cover change in the pipeline right of way (ROW), greenhouse gas (GHG) emissions resulting from the construction and long-term operation of the PennEast pipeline, GHG emissions resulting from the long-term operation of the Mariner East 2 pipelines, lost recreation days resulting from pipeline construction, and the lost investment associated with conservation easements on protected land that will be cleared for the pipeline ROWs.

There are many other important costs that could not be monetized or estimated due to lack of data or uncertainty of the estimates. Examples of these additional costs include: source water quality degradation and associated treatment or procurement of new sources; stream quality and aquatic habitat degradation; loss of property value; and construction disruptions including noise, vibrations, and aesthetics.

Background

Expansion of the network of natural gas pipelines in the eastern U.S. has increased dramatically since 2012 as the development of the Marcellus Shale play, which stretches from New York to Virginia, has risen substantially. This expansion has affected many of the existing land uses and populations (U.S. Energy Information Administration, 2017). During this time, gas production in the region has grown by more than 14 billion cubic feet per day (bcf/d) (U.S. Energy Information Administration, 2017). With this increased development, transport pipelines have also become more common. In New Jersey alone, rapid buildout of pipeline capacity between 2011 and 2018 has added approximately 3 bcf/d, representing approximately a 52 percent increase in pipeline capacity (Blumenthal, 2018). However, recent research suggests that this added capacity is not needed, and the proposed PennEast pipeline may further increase the amount of excess natural gas being piped to the region (Lander, 2016). As of 2016, at least eight large natural gas pipelines, totaling 322 miles, were planned in the DRB (Hanson and Habicht, 2016). Should these pipelines be constructed, they would disrupt 2,977 acres during construction and 1,328 acres permanently during operation, with an estimated 175 stream crossings along the various pipeline routes (Hanson and Habicht, 2016).

The DRB is a critical environmental, social, and economic asset to the region through its support of important ecosystems, recreational activities, agricultural production, and water quality management. Spanning portions of New York, New Jersey, Pennsylvania, and Delaware that include 42 counties and 838 municipalities, the DRB encompasses a large swath of the mid-Atlantic and is home to a plethora of land uses (DRBC, 2017a). With its 216 tributaries, the DRB contains a large volume of freshwater that serves local ecosystems and provides drinking water to more than 15 million people and almost 1,000 community water systems (Delaware River Basin Source Water Collaborative, 2019). The DRB also contains forests, shrubland, agricultural land (both cropland and pasture), and developed land, all of which provide ecosystem services, recreational uses, economic profit, and more.

Scope of Analysis

This study focuses on the PennEast, Mariner East 2, and Mariner East 2X pipelines. The PennEast pipeline is a proposed natural gas pipeline (carrying primarily methane and ethane) that would stretch from northern Pennsylvania into central New Jersey, traversing 120.2 miles. The pipeline project will primarily cut a new right of way (ROW), though several segments are adjacent to existing pipelines or fall along power line rights of way. The bulk of the PennEast route is in the DRB, but the start of the route is in the Susquehanna River Basin, and the very end of the route in Mercer county is just outside the DRB. The Mariner East 2 is a 20-inch diameter pipeline and the Mariner East 2X is a 16-inch diameter pipeline (these pipelines are collectively referred to as Mariner East 2 in this report). The Mariner East 2 pipelines, owned by Sunoco Logistics[1], carry natural gas liquids (e.g., butane, ethane, propane) that are more energy dense and heavier than the methane that accounts for the bulk of natural gas volume. Much of the Mariner East 2 route runs adjacent to the existing Mariner East 1 route, and other pipelines operated by Sunoco and other companies. The pipelines travel from Ohio, through West Virginia, and across Pennsylvania to the export terminal at the Marcus Hook Industrial Complex near Philadelphia. Construction of the Mariner East 2 pipeline began in February 2017 and construction of Mariner East 2X has also begun, and they have faced significant public opposition stemming largely from concerns regarding damage to local water quality and groundwater wells as well as long-term safety risks.

The purpose of this study is to identify and understand the environmental and social costs of these pipelines in the DRB. Several studies have attempted to estimate the environmental and social costs of pipeline activities in the region. However, this study differs from other similar research endeavors in a number of ways, one of which is its primary focus on the costs and effects of the PennEast and Mariner East 2 pipelines in the DRB. This report summarizes the results of a literature review on the general effects of, and costs associated with, pipeline development. The report draws from peer reviewed publications and academic, government, and industry reports. This study also includes an in-depth look at the problems caused by the Mariner East 2 pipelines, which are currently under construction. This case study uses publicly available information and personal communication with local residents to explore the breadth of actual damages to communities along the route of the Mariner East 2 pipelines. Additionally, this study examines the claims made by PennEast Pipeline Corporation on the economic

[1] Sunoco is now owned by Energy Transfer Partners.

impact of the pipeline and compares them to the potential job creation of an equal investment in other energy provision options, such as clean energy or energy efficiency.

This report begins with characterization of the environmental and social costs of pipeline development in the region based on a review of existing literature and research (Chapters 1 through 4). It provides an analysis of the range of costs associated with the PennEast and Mariner East 2 pipelines (Chapter 5). The report then offers a case study on the documented effects of Mariner East 2 (Chapter 6) and a jobs analysis of the PennEast pipeline (Chapter 7).

Key Findings and Results

The results of this research and analysis reveal numerous costs to the environment and regional communities. The table below highlights key findings pertaining to the PennEast and Mariner East 2 pipelines and their impacts on the DRB's ecosystems, economies, and populace.

Costs of the PennEast and Mariner East 2 Pipelines – Key Findings
Waterbody Degradation
• The PennEast pipeline will result in 135 stream crossings in the DRB, and the Mariner East 2 pipelines have 72 stream crossings in the DRB. PennEast would cross 80 streams with high value designations, and Mariner East 2 crosses 30 streams with high value designations. These crossings pose concerns for stream health, as well as concerns for the health of trout and long-tailed salamander populations during both construction and operation. • Research indicates that open-cut, isolated, and horizontal directional drilling (HDD) stream crossing methods for pipeline construction have had damaging effects on channel morphology, water quality, and aquatic life and habitats. One study examined 54 HDD installations and concluded that half resulted in inadvertent returns (IRs) of drilling fluid. These IRs occurred most frequently within 200 feet of the HDD entry or exit point. • As of February 2019, there have been approximately 240 inadvertent returns of drilling fluid to land and water along the Mariner East 2 pipeline route, and the PA Department of Environmental Protection had issued 94 notices of permit violations. • Numerous studies indicate that water treatment cost is directly related to turbidity, and additional sediment loading to the Delaware River may create additional costs for surface water treatment systems to manage sedimentation. Pipeline ROWs contribute most to erosion and sedimentation in the natural gas development process, exceeding the erosion and sedimentation effects of well pads and roads. • Overall, approximately 1.2 million individuals consume water from public water systems that could be at risk of contamination or degradation due to the PennEast and Mariner East 2 pipelines. Approximately 1,600 domestic wells could be at risk of contamination, and nearly 500 domestic wells are in close proximity to at least one of the pipelines.

Key Findings (Continued)

Air Quality and Greenhouse Gases

- PennEast estimates that the gas-powered Kidder Compressor Station would emit approximately 90 tons of NO_x, 17 tons of CO, 5 tons of SO_2, 24 tons of PM_{10}, 24 tons of $PM_{2.5}$, and 2 tons of CH_2O each year of continuous operation.
- An independent analysis estimated that the total emissions release related to the development at Marcus Hook to service all Mariner East pipelines will result in approximately 63 tons of NO_x, 163 tons of CO, 40 tons of SO_x, 14 tons of PM, and 13 tons of PM_{10} each year of operation.
- The total cost of greenhouse gas (GHG) emissions for construction and operation of the PennEast pipeline using the average social cost of carbon (SC-CO_2) would be approximately $470 million. If we assume a high impact SC-CO_2, costs could be as high as $1.4 billion over the life of the pipeline. This does not include the cost of any associated downstream emissions, which PennEast estimates to be 21.3 million metric tons of CO_2 equivalents annually.
- The cost of emissions associated with operation of Mariner East 2 at one pump station and operations from operations at the Marcus Hook facility will be approximately $260 million. Using a high impact SC-CO_2, costs could be as high as $800 million for these facilities. These estimates do not include emissions associated with construction or long-term operation of many other pump stations along the pipeline and, therefore, underestimate potential emissions from the Mariner East 2 pipelines.

Ecosystem Services

- The Mariner East 2 and PennEast pipelines will disrupt approximately 2,200 acres of land in the DRB for pipeline construction and long-term operation. We estimate these costs would result in a present value loss of ecosystem services in the DRB of approximately $11 million for Mariner East 2 and $43 million for PennEast.

Recreation and Protected Lands

- Pipeline construction will affect not only the ROW but also the buffer zone, an area spanning 100 meters from either side of the ROW. Acute effects of blasting, noise from heavy machinery, and other construction activities have been shown to be highly disruptive to wildlife in this zone and may significantly reduce or eliminate wildlife-based activities during the construction period. Mariner East 2 and PennEast could cost recreation goers approximately $2.8 million in lost recreation enjoyment as the pipelines are constructed.
- Overall, one quarter of the land the PennEast pipeline is proposed to pass through in the DRB is protected in fee or preserved under conservation easements. Total costs of the acres of preserved land (fee or easement) cleared for the temporary and permanent ROW for PennEast and Mariner East 2 are approximately $4 million.

Key Findings (Continued)

Property Value and Litigation

- Contrary to claims made by pipeline companies, recent studies suggest that transmission pipelines reduce property values in the short term. Pipeline construction has also been demonstrated to have detrimental effects on the quality or value of the property as a result of contaminated wells, alterations to the land, and proximity to the pipelines and operating equipment. Proximity to pipelines may also affect insurance rates or availability.
- The economic value of farmland disturbed by the PennEast and Mariner East 2 pipelines totals approximately $4 million based on average farm real estate values in Pennsylvania and New Jersey.
- Based on the area cleared for the pipeline in the ROW, we estimate that the total value of cleared land in Hunterdon County alone is approximately $1.4 million.
- In response to the safety and environmental concerns about these pipelines, communities, townships, non-profits, and individuals have invested countless hours in efforts they believe necessary to protect their communities, homes, and families. Efforts initiated by these entities include numerous legal actions against Sunoco in an effort to reclaim lost value associated with property, safety, and environmental quality.

Wildlife

- Six federally-listed and 25 state-listed species face habitat disruption as a result of the PennEast pipeline's construction and operation activities.
- The proposed PennEast pipeline route passes through Baldpate Mountain, an important bird area (IBA) that supports numerous migrating and breeding bird species, including 28 species ranked by the American Bird Conservancy as birds of conservation concern. In total, the PennEast pipeline would cross or come within 100 feet of six IBAs, and the Mariner East 2 pipelines cross or come within 100 feet of four IBAs in the DRB.
- When pipelines are constructed with a 100-foot right of way, each mile directly disturbs 12 acres and creates an additional 72 acres of new forest edge, leading to fragmentation and decreases in biodiversity.

Adding the costs identified above, the results of this study suggest that the environmental and social costs associated with the PennEast and Mariner East 2 pipelines are approximately $758 million to $2.4 billion.

GHG emissions are the highest source of monetary costs for both pipelines, amounting to at least $730 million. The high-end estimate for costs associated with GHG emissions is $2.2 billion. Monetary costs of other effects we estimated are also substantial, ranging from approximately $28 million to $170 million. These cost estimates include:

- Loss of ecosystem services in the temporary and permanent ROWs in the DRB.
- Lost recreation days in the DRB during construction.
- Lost investment in conservation easements and fee-protected property disturbed by the pipelines in the DRB.

There are many additional costs that could not be monetized or estimated due to lack of data or uncertainty in the estimates. For this reason, and because we used conservative assumptions in each individual analysis, we believe that our monetary estimates represent lower bound estimates of the total cost of environmental and social damages caused by the pipelines. Under other assumptions and including uncertain factors, costs could be significantly higher. Specific limitations and assumptions that likely result in a lower bound estimate include:

- With the exception of the GHG analysis, this analysis was limited to the effects in the DRB. Approximately 12 percent of the PennEast pipeline and 82 percent of the Mariner East 2 pipelines are located outside of the DRB (in terms of miles).
- Due to a lack of data, the analysis does not include GHG emissions associated with the construction of the Mariner East 2 pipelines or emissions from most long-term operations. Our estimates evaluate operation of one pump station and the Marcus Hook facility.
- The GHG emissions analysis uses a social cost of carbon (SC-CO_2) that is significantly below the cost estimated by recent scientific literature.
- While the health effects of pollutants associated with the pipelines are well understood, the effect of the pipelines themselves and their operating equipment on human health is not known at this time. It was not possible to estimate monetary loss associated with diminished ambient air quality and degraded water and their ultimate health effects.
- There are not enough data to understand the effect of the pipelines on nearby property values. Reductions in property value associated with pipeline risks, drinking well contamination, and sinkholes were not included in the cost estimates.
- This analysis does not include the effects of increased sediment load in streams of the DRB. There are not enough site-specific data to estimate the ultimate effect on turbidity and the consequences for water treatment systems. Furthermore, sediment loading is known to stress freshwater habitats. These costs were not included in the monetary analysis.
- Construction of the Mariner East 2 pipelines and the resulting damage to private wells is well documented, but costs associated with past and potential future contamination of private wells and public water supplies were not included in the monetary estimate.
- Due to data limitations, the estimate does not include costs associated with other disruptions to communities along the pipeline routes including noise, vibrations, and aesthetics.

The PennEast and Mariner East 2 pipelines are just two of several existing and planned pipelines in the region, and they will add to the environmental degradation, habitat fragmentation, and pollution already observed throughout the DRB as the result of pipeline construction and operation.

1. Potential Effects on Ecosystem Services Along the Pipeline Route

Key Findings

- The Mariner East 2 and PennEast pipelines will disrupt approximately 2,200 acres of land in the DRB, the majority of which is forest, agricultural land, or low vegetation, such as grassland or scrub land.
- Over 1,000 acres of forested land will be cleared for PennEast and Mariner East 2 pipeline construction and operation.
- Research indicates that when pipelines are constructed with a 100-foot right of way, each mile directly disturbs 12 acres and creates an additional 72 acres of new forest edge, leading to habitat fragmentation.
- The DRB supports critical water habitats, including 400 miles of designated National Wild and Scenic River, and supplies drinking water to five percent of the nation's population.

The Pipeline Routes

The Mariner East 2 and proposed PennEast pipeline routes cross many types of land cover. Some of that land was previously undeveloped, including forests, grasslands, and other land cover types (shrubland, wetlands, and other water), while other land has been developed, either for built infrastructure (residential, commercial, etc.) or agriculture (PennEast Pipeline Company, LLC, 2015a). According to the GIS analysis conducted for this study, the Mariner East 2 pipelines and PennEast pipeline will affect approximately 2,200 acres of land in the DRB, the majority of which is forest, agricultural land, or low vegetation, such as grassland or scrub land. Table 1 presents a detailed breakdown of land crossed by each pipeline, and Figure 1 provides a map of the pipeline routes. This chapter summarizes the potential effects of pipeline development on these land types.

Table 1. Land Use Types Crossed by Pipelines in the Delaware River Basin

Land Use Type	Acres Affected by Pipelines		
	Permanent Area	Temporary Area	Total
PennEast Pipeline			
Forested	337	463	800
Shrub-Scrub	13	21	34
Wetlands	8	12	19
Agricultural	156	319	476
Grassland	85	132	217
Developed, Barren, Other	42	131	173
Water	1	2	3
Subtotal	*642*	*1,079*	*1,721*
Mariner East 2 pipelines			
Forested	111	93	204
Shrub-Scrub	5	4	9
Wetlands	1	0	1
Agricultural	35	36	71
Grassland	24	23	47
Developed, Barren, Other	61	62	123
Water	0	0	0
Subtotal	*237*	*217*	*454*
Total Acres	**878**	**1,296**	**2,175**

What Are Ecosystem Services?

Broadly, ecosystem services entail the indirect benefits provided by a species or ecosystem to human economic production (Kroeger and Manalo, 2006). These include non-market benefits, such as supportive services (e.g., nutrient-cycling), regulating services (e.g., flood and disease control), and cultural services (e.g., recreation and spiritual purposes) (Kroeger and Manalo, 2006). Although difficult to estimate economically, ecosystem services are nevertheless valuable aspects of the land. The Mariner East 2 and proposed PennEast pipelines would span approximately 160 linear miles through the DRB, altering approximately 2,200 acres of the land in the temporary construction and permanent right-of-way (ROW) required for construction and operation. This land use modification will disrupt or degrade these ecosystem services. Consequently, understanding their value is critical to quantifying the economic costs of the pipelines.

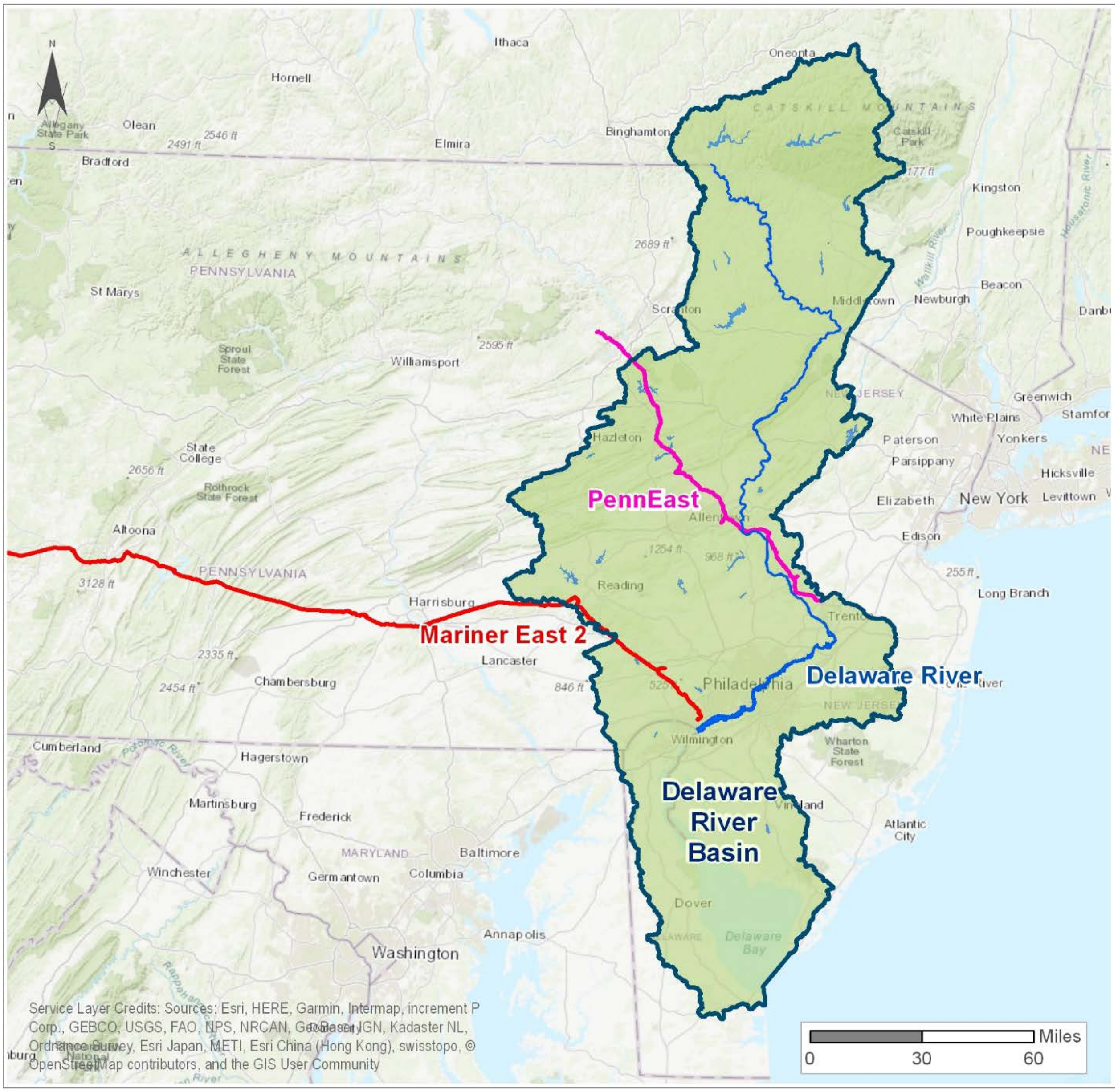


Figure 1. Map of PennEast and Mariner East 2 Pipelines in the Delaware River Basin

Pipeline construction will disturb land and may reduce ecosystem services on those lands. In the permanent ROW, some land use types will be permanently altered, potentially reducing the breadth or quality of ecosystem services provided in the long-term.

Because ecosystem services are not sold and purchased, non-market valuation methods are used to estimate their values. Primary estimates of the economic values associated with ecosystem services specifically in the DRB are rare. However, numerous studies from around the world have estimated the economic values of ecosystem services for land use types similar to those in the DRB. In the sections that follow, we provide a selection of the most relevant valuation estimates to demonstrate the range of values associated with each land use type. Most of these values were collected from the Ecosystem Services Valuation Database, which provides more than 1,300 valuation estimates of ecosystem services (Van der Ploeg et al., 2010). The values presented in this report are the most relevant based on the geographic location of the study, the type of ecosystem, and the type of ecosystem service.

Ecosystem services values vary widely, both across land types and within the same ecosystem service and land type. Several factors contribute to this variation. Ecosystems (i.e., land types) offer different bundles of services, and the strength of each service (and its corresponding value) varies across ecosystems. Other factors that affect an estimated value for an ecosystem service are methodological and include the location of the study and valuation methodology. Similar ecosystems (lakes, rivers, forests, grasslands, etc.) are located in different environments across the globe, and each unique ecosystem may have underlying characteristics that affect its estimated values. Ecosystem services valuations can be difficult or expensive to conduct, so it is a common practice to approximate ecosystem services values using the values estimated for the same ecosystem from another location. This is known as the benefit transfer method, which is used widely to estimate the value of ecosystems. (Examples include Costanza et al. 1997, Delaware Valley Regional Planning Commission 2011, and Kauffman 2013.) There are several other recognized valuation methods for estimating ecosystem services (e.g., travel cost, avoided cost, contingent valuation, hedonic pricing). Each of these methods can result in different estimated ecosystem services values.

A handful of studies have estimated the value of ecosystem services in and around the DRB using the benefit transfer method. A 2010 study estimated the total annual value of New Jersey's ecosystem services to be approximately $12 billion to $19 billion, which is equivalent to a present value of approximately $370 billion over 100 years at a 3 percent discount rate (in 2004 dollars) (Liu et al., 2010). A more recent study by the University of Delaware Water Resources Center estimated ecosystem services in the DRB at approximately $21 billion per year, which is equivalent to a present value of approximately $683 billion over 100 years (all in 2010 dollars, Kauffman, 2016). The sections that follow summarize the ecosystem services for land types along the pipeline route and provide a list of values from studies with estimated values for these ecosystem services and land types. In *Chapter 5. Analysis of Costs Associated with the PennEast and Mariner East 2 Pipelines*, we select what we believe to be the most appropriate values from these sections and apply them in our own benefit transfer analysis.

Forests

Forested regions provide a vast array of ecosystem services for local environments and populations. The Mariner East 2 and proposed PennEast pipeline routes traverse more forested acreage than any other land cover type. This poses a risk of damage in the short term during construction as well as possible long-term damage due to pipeline operation and maintenance. Most of the 7,800 square miles of forest in the DRB fall into three primary forest types: deciduous, evergreen, and mixed (Hanson and Habicht, 2016). According to our analysis, the proposed route of the PennEast pipeline in the DRB will disturb approximately 340 acres of this forested land for the permanent right of way (ROW) and approximately

460 acres for the construction ROW. This land cover disturbance may affect numerous ecosystems services currently provided by the forested region.

Large swaths of uninterrupted forest offer habitats for a multitude of species and help to preserve local biodiversity. While broad in its implications, maintenance of biodiversity can help ensure genetic diversity within species, provide natural pest and disease control, and maintain pollination (Krieger, 2001). When pipelines are constructed with a 100-foot ROW, each mile directly disturbs 12 acres and creates an additional 72 acres of new forest edge (Johnson, et al., 2011). While this edge may benefit species that thrive on the borders of forests and open spaces, fragmentation diminishes habitat quality and may harm species that rely on undisturbed “core” forest to thrive (Johnson, et al., 2011). This separation into smaller parcels of land reduces biodiversity; studies have shown the smaller areas support fewer types of species as well as lower populations of individuals within those species (Eggert, 2016). Fragmentation affects not only the ecosystems directly tangent to the ROW but also the buffer zone. Fragmentation is particularly harmful in forests, where the buffer zone spans 300 feet from each border (Eggert, 2016). Many species require interior forest habitats, with significant buffer from the forest edge. Interior forests provide increased shade and humidity as well as canopy protection (Johnson, et al., 2011). Some examples of Pennsylvania species that rely on interior forest include blue warblers, salamanders, and woodland flowers. When the ROW is constructed, it fragments the forest and inhibits movement of these interior forest species (Johnson, et al., 2011).

Forested areas also support healthy water and wetlands. When precipitation falls on forested land, a portion of that water is absorbed into the soil and root systems, reducing flooding and preventing erosion of topsoil and sedimentation (Krieger, 2001). This water is filtered by the soil, removing nutrients, pollutants, and bacteria and reducing turbidity and total organic carbon (TOCs), thus contributing to better water quality (Warziniak, et al., 2016). When forests are cleared however, the soil cannot absorb water as easily, and instances of flooding, elevated peak flows, and landslides may increase (Schwartz and Kocian, 2015).

Forested lands can also improve air quality by capturing and removing airborne particulate matter and producing oxygen. These functions contribute to an overall higher quality of ambient air, benefiting human health (Krieger, 2001). Forests also absorb carbon dioxide from the atmosphere and serve as carbon sinks, capturing and storing carbon in new growth. For example, deciduous forests in New England captured approximately 1.4 to 2.8 metric tons of carbon per hectare per year between 1991 and 1995 (Goulden, et al., 1996). This is a particularly valuable ecosystem service as increasing amounts of carbon dioxide are released into the atmosphere, driving climate change.

The trees that comprise forests provide consumptive benefit in the form of lumber (Schwartz and Kocian, 2015). People can also benefit from use of forested areas for activities such as hiking, biking, camping, and hunting. Having available forests as a recreational destination can improve both physical and mental health (Schwartz and Kocian, 2015), and proximity to protected land and its plethora of recreational activities can also elevate nearby property values (Zeph and Mowery, Unknown).

Table 2 presents a range of values for ecosystem services values for forests. As previously discussed, these estimates vary according to the type of service, location, and study. High and low estimates for each ecosystem service type can be used to develop aggregate high and low estimates for forest ecosystem services values. The total ecosystem services value at the end of the table uses a global aggregate average of ecosystem services for temperate and boreal forests.

Table 2. Ecosystem Services Values for Temperate and Boreal Forests

Ecosystem Service	Value (2017 USD/acre/year)	Source
Air quality	$460	Ministerie van Landbouw, Natuur en Voedselkwaliteit (2006)
Biological Control	$7.8	Anielski, M. and S.J. Wilson (2005)
Biological Control	$2.6	Brenner-Guillermo, J. (2007)
Climate	$1.1 to $1,100	Anielski, M. and S.J. Wilson (2005)
Climate	$70	Brenner-Guillermo, J. (2007)
Erosion	$64	Brenner-Guillermo, J. (2007)
Biodiversity	$0.02	Anielski, M. and S.J. Wilson (2005)
Biodiversity	$1,200	Brenner-Guillermo, J. (2007)
Biodiversity	$2,500	Loomis, J. and E. Ekstrand (1998)
Biodiversity	$11	Phillips, S., et al., (2008)
Biodiversity	$44	Walsh, R.G., et al., (1984)
Biodiversity	$10	Brenner-Guillermo, J. (2007)
Pollination	$210	Brenner-Guillermo, J. (2007)
Recreation	$160	Brenner-Guillermo, J. (2007)
Recreation	$1.3 to $4.7	De la Cruz, A. and J. Benedicto (2009)
Recreation	$5.5	Phillips, S., et al., (2008)
Soil fertility	$6.3	Brenner-Guillermo, J. (2007)
Waste	$57	Brenner-Guillermo, J. (2007)
Waste	$9.0	De la Cruz, A. and J. Benedicto (2009)
Waste	$26	Perrot-Maître, D. and P. Davis (2001)
Water	$0.03	Anielski, M. and S.J. Wilson (2005)
Water	$210	Brenner-Guillermo, J. (2007)
Water	$49	De la Cruz, A. and J. Benedicto (2009)
Total Ecosystem Services	$200	Costanza, R., et al., (1997)

Note: Values have been adjusted from original studies to 2017 dollars per acre per year and rounded to two significant figures.

Agriculture

Agricultural lands provide numerous ecosystem services to nearby residents and the environment in addition to food production. (Food productivity is evaluated in *Chapter 2. Potential Effects on Industries*.) Most notably, agricultural lands provide regulating services for wildlife, hydrology, and climate (Swinton et al., 2007). For example, agricultural lands help to keep pollinators, pests, and natural pathogens in a healthy balance. Managing wildlife and biological pests is critical for maintaining food supplies (Pimentel et al., 1997). Agriculture also improves soil retention and formation and, if proper tillage methods are practiced, reduces runoff and allows for greater infiltration of water into the soil. In turn, infiltration of runoff makes more water available for plant growth and increases groundwater recharge. Well-managed agricultural lands can also increase soil fertility and help to prevent natural hazards such as floods and landslides by trapping water in the soil (Swinton et al., 2007). In this way, the benefits of agricultural land extend beyond food production and include benefits to habitats and watersheds.

Table 3 provides a list of ecosystem services for agricultural land and their values. Because the productive value of agricultural land is accounted for in a later section of this analysis (*2. Potential Effects on Industries*), the ecosystem services below do not include food production.

Table 3. Ecosystem Services Values for Cultivated Land

Ecosystem Service	Value (2017 USD/acre/year)	Source
Biological Control	$16	Brenner-Guillermo, J. (2007)
Erosion	$28 to $75	Pimentel, D., et al., (1995)
Gene pool	$1,100	Brenner-Guillermo, J. (2007)
Pollination	$10	Brenner-Guillermo, J. (2007)
Recreation	$19	Brenner-Guillermo, J. (2007)
Soil fertility	$120	Pimentel, D., et al., (1995)
Waste	$140	Perrot-Maître, D. and P. Davis (2001)
Total Ecosystem Services	$61	Costanza, R., et al., (1997)

Note: Values have been adjusted from original studies to 2017 dollars per acre per year and rounded to two significant figures.

Surface Water

Rivers, streams, and lakes all provide ecosystem services in the DRB. In fact, the hydrologic features of the DRB are one of its key defining characteristics, and the ecosystem services provided by surface waters of the DRB are critical to the health and function of the region. Rivers, streams, and lakes are critical habitats for many animals native to the DRB. Surface waters provide breeding, nesting, and feeding grounds for waterfowl, fish, shellfish, reptiles, and amphibians. These include commercial and game species as well as non-game, threatened, and endangered species. These surface water habitats and the species that use them are integral to ecosystem health in the DRB (Delaware River Basin Commission, 2013). By supporting the food chains of which these animals are a part, open water habitats help to preserve biodiversity (Industrial Economics, 2011). Healthy surface waters also provide natural water filtration and can serve as sources of drinking water (Evans and Kiesecker, 2014). Although the DRB only accounts for 0.4 percent of land area in the continental U.S., it supplies drinking water to 5 percent of the nation's population (Kauffman, 2011). Open water also has cultural significance as a source of recreational activities such as boating, fishing, and swimming, in addition to adding aesthetic value to landscapes (Keeler et al., 2012). Rivers, streams, and lakes are a significant aspect of the region's natural heritage.

Wetlands, which are often found near open water, provide important ecosystem services. In addition to their role as habitat for wildlife, wetlands act as natural water filters. They mitigate a number of pollutants, including nutrients (i.e., nitrogen and phosphorous) entering the water via runoff from application of fertilizers for agriculture. By mitigating nutrient inputs, wetlands can increase water clarity, thus improving the quality of downstream surface waters (Keeler et al., 2012). Wetlands also help to mitigate flooding and control the transport of sediment. They absorb overflow from flooded rivers and streams and can thus reduce property damages from flooding events (Industrial Economics, 2011). Furthermore, around 30 percent of all organic carbon is stored in wetlands. They naturally sequester carbon from the atmosphere, aiding in climate stability (Industrial Economics, 2011). Table 4 provides a list of wetland ecosystem services and their corresponding values from the literature.

Table 4. Ecosystem Services Values for Wetlands

Ecosystem Service	Value (2017 USD/acre/year)	Source
Climate	$160	Brenner-Guillermo, J. (2007)
Cultural service [general]	$5.20 - $1,200	Brenner-Guillermo, J. (2007)
Extreme events	$110 - $4,700	Brenner-Guillermo, J. (2007)
Gene pool	$150	Brenner-Guillermo, J. (2007)
Gene pool	$8.10	Donaghy et al. (2007)
Soil fertility	$110	Gren et al. (1995)
Waste	$1,100	Brenner-Guillermo, J. (2007)
Waste	$27	Gren et al. (1995)
Waste	$5,000	Meyerhoff and Dehnhardt (2004)
Waste	$180	Gren and Soderqvist (1994)
Waste	$220	Lant and Roberts (1990)
Water	$2,000 – $2,500	Brenner-Guillermo, J. (2007)
Water flows	$3,900	Brenner-Guillermo, J. (2007)

Note: Values have been adjusted from original studies to 2017 dollars per acre per year and rounded to two significant figures.

The DRB supports critical water habitats in its streams, rivers, and lakes, including 400 miles of designated National Wild and Scenic River; less than one percent of U.S. river miles have received such designation (National Park Service, 2012). The mainstem of the Delaware River is one of the largest stretches of river unimpeded by a dam east of the Mississippi River, and it provides significant habitat and ecosystem benefits to its native inhabitants, including productive cold-water fisheries that are important to native trout populations (National Park Service, 2012; Woidt Engineering and Consulting, 2017). However, freshwater ecosystem services values were difficult to identify compared to other ecosystems crossed by the pipelines. Notably, we were unable to identify a value for the habitat or biodiversity protection offered by freshwater ecosystems in comparable locations. Therefore, the ecosystem services values for freshwater ecosystems provided in Table 5 may underestimate the true value of water in the DRB.

Table 5. Ecosystem Services Values for Freshwater

Ecosystem Service	Value (2017 USD/acre/year)	Source
Various	$1.1	Loomis, J., et al., (2000)
Water	$530	Brenner-Guillermo, J. (2007)
Recreation	$460	Brenner-Guillermo, J. (2007)
Recreation	$150	Postel, S. and S. Carpenter (1997)
Waste	$11	Gibbons, D.C. (1986)

Note: Values have been adjusted from original studies to 2017 dollars per acre per year and rounded to two significant figures.

Grassland and Shrubland

Shrubland and open ecosystems such as fields and grasslands are crucial components of the regional ecosystem. Grasslands and shrublands are nesting and feeding habitats for a diverse array of species. In Pennsylvania and New Jersey, these include several species of endangered birds, mammals, and reptiles (Pennsylvania Game Commission, 2018; New Jersey Division of Fish & Wildlife, 2018). Grassy biomes also play an important role in nutrient cycling in soils and natural filtration of groundwater. Furthermore, grasslands and shrublands have been shown to sequester as much carbon underground as forests do (Veldman et al., 2015). Finally, open lands are important community resources for outdoor recreation, including hiking, biking, and picnicking, and they increase the aesthetic amenity value of local landscapes (Delaware Valley Regional Planning Commission, 2011). The proposed PennEast pipeline route would disturb approximately 52 acres (permanent) and 64 acres (temporary) of easements that preserve open space.

Table 6 lists a range of ecosystem services values for grasslands. According to these studies, erosion and water purification have the highest potential value of the ecosystem services provided by grasslands.

Table 6. Ecosystem Services Values for Grasslands

Ecosystem Service	Value (2017 USD/acre/year)	Source
Biological Control	$16	Brenner-Guillermo, J. (2007)
Climate	$3.7	Brenner-Guillermo, J. (2007)
Climate	$0.03 to $0.78	Sala, O.E. and J.M. Paruelo (1997)
Erosion	$18	Barrow, C.J. (1991)
Erosion	$19	Brenner-Guillermo, J. (2007)
Erosion	$28	Ministerie van Landbouw, Natuur en Voedselkwaliteit (2006)
Erosion	$70	Sala, O.E. and J.M. Paruelo (1997)
Pollination	$17	Brenner-Guillermo, J. (2007)
Soil fertility	$3.7	Brenner-Guillermo, J. (2007)
Waste (water purification)	$57	Brenner-Guillermo, J. (2007)
Waste (water purification)	$7.2 to $79	Ministerie van Landbouw, Natuur en Voedselkwaliteit (2006)
Water flows	$2.6	Brenner-Guillermo, J. (2007)

Note: Values have been adjusted from original studies to 2017 dollars per acre per year and rounded to two significant figures.

Table 7 provides a list of ecosystem services for woodland and scrub or shrub ecosystems. The source data set for these values did not distinguish between woodlands and scrub or shrub ecosystems. Without a more comprehensive set of data, we are using the ecosystem services values for woodlands and scrub or shrub ecosystems as representative of the scrub or shrubland in our GIS land cover analysis. Once again, water purification is the ecosystem service with the highest potential value, but the range is high, with a low estimate of $0.12 per acre per year. Climate regulation is another potentially high-value ecosystem service provided by scrub or shrublands.

Table 7. Ecosystem Services for Woodland and Scrub/Shrub

Ecosystem Service	Value (2017 USD/acre/year)	Source
Air quality	$46	Ministerie van Landbouw, Natuur en Voedselkwaliteit (2006)
Climate	$220	Ministerie van Landbouw, Natuur en Voedselkwaliteit (2006)
Erosion	$28	Ministerie van Landbouw, Natuur en Voedselkwaliteit (2006)
Waste (water purification)	$0.12 to $400	Ministerie van Landbouw, Natuur en Voedselkwaliteit (2006)
Medical	$1.5	Rausser and Small (2000)
Medical	$0.00	Rausser and Small (2000)

Note: Values have been adjusted from original studies to 2017 dollars per acre per year and rounded to two significant figures.

2. Potential Effects on Industries

Key Findings

- The economic value of farmland disturbed by the PennEast and Mariner East 2 pipelines totals approximately $4 million based on average farm real estate values in Pennsylvania and New Jersey.
- The proposed PennEast pipeline route passes through Baldpate Mountain, an important bird area that supports numerous migrating and breeding bird species, including 28 species ranked by the American Bird Conservancy as birds of conservation concern. In total, the PennEast pipeline would cross or come within 100 feet of six IBAs and the Mariner East 2 pipelines cross or come within 100 feet of four IBAs in the DRB.
- Some of the region's most popular outdoor recreational areas would be crossed by the PennEast pipeline. Acute effects of blasting, noise from heavy machinery, and other construction activities have been shown to be highly disruptive to wildlife in this zone and may significantly reduce or eliminate wildlife-based activities during the construction period. Mariner East 2 and PennEast could cost recreation goers approximately $2.8 million in lost recreation enjoyment as the pipelines are constructed.
- Recent studies suggest that transmission pipelines reduce property values in the short term. Pipeline construction has also been demonstrated to have detrimental effects on the quality or value of the property as a result of contaminated wells, alterations to the land, and proximity to the pipelines and operating equipment. Proximity to pipelines may also affect insurance rates or availability.

Agriculture

The pipeline routes cut through a sizeable amount of agricultural land, disrupting farmland during construction and possibly damaging farms during operation. Construction is the activity that will likely have the largest immediate impact on agricultural production because it will render that part of the ROW unusable during construction. Additionally, the time of year during which construction occurs may affect the land use beyond just the time it takes to build the pipeline; depending on the crop and season, some areas may not be suitable for growing crops until the next growing cycle. Once farmers do regain use of their land following construction, they may find it difficult to restore to its previous productive capacity because the soil will have been compacted by heavy machinery (Hamza and Anderson, 2005). According to our analysis, PennEast and Mariner East 2 will collectively disrupt approximately 390 acres of cultivated land and 150 acres of pasture or grassland that is currently in agricultural use in the DRB. Approximately 135 acres of cultivated land and 58 acres of pasture or grassland will be in the permanent ROW.

In Pennsylvania, the average value of farm real estate is $5,600 per acre, with approximately $6,000 per acre for cropland and $2,800 per acre for pasture (USDA, 2017a). In New Jersey, those land values are higher; the average value of farm real estate is $12,800 per acre, cropland is $13,000 per acre, and pasture is $12,500 per acre (USDA, 2017a). Using GIS data from this analysis, this equates to approximately $4 million of property value disturbed by the pipelines. Although these values do not directly translate into costs associated with the pipelines, they demonstrate the economic value of farmland that would be disturbed by the pipelines. During field studies for the PennEast pipeline route, active cropland observed along the ROW grew corn, soybeans, and hay. In 2017, Pennsylvania's corn was valued at $3.80 per bushel, soybeans were valued at $9.34 per bushel, and hay was valued between $160 and $177 per ton (USDA, 2017b). In 2017, the economic productivity per acre of corn was $612; soybeans, $444; and hay $496 in Pennsylvania (USDA, 2017c). Figures estimating the net revenue after costs were not available.

While construction poses the most visible and immediate disturbance to agricultural lands, the pipeline may also have long-term effects on agricultural productivity. According to the PennEast Environmental Impact Statement (EIS), the company will take steps to mitigate any long-term damage to the agricultural productivity of the pipeline ROW. However, mitigation efforts do not completely eliminate all damaging effects of pipelines, and there may be long-term effects on productivity. For example, changes in soil quality may reduce the long-term productivity of the crops. There is evidence that pipeline ROWs have increased heavy metal contamination in the soil, including chromium, cadmium, copper, nickel, lead, and zinc (Shi, et al., 2014).[2] Studies have also shown that erosion can reduce agricultural production and subsequent economic output (Panagos, et al., 2018). Topsoil typically has a higher soil water capacity, the loss of which contributes to increased water stress in crops (National Soil Erosion-Soil Productivity Research Planning Committee, 1981). Additionally, it contains a higher concentration of plant nutrients than subsoil, and its depletion necessitates additional fertilization (National Soil Erosion-Soil Productivity Research Planning Committee, 1981). The PennEast EIS indicates that topsoil will be replaced on agricultural land after construction is complete, but the effects of disturbing topsoil are unknown.

Few domestic studies have been conducted on the health of crops grown directly above the pipeline during ongoing operations, and there is no conclusive evidence on whether the pipelines do or do not have an effect on crop productivity. However, a handful of studies have identified potential effects. For example, once soil has been compacted by heavy machinery, it is difficult to restore agricultural land to its previous productive capacity (Hamza and Anderson, 2005). One study in central New York found that crops appeared to grow at higher rates when directly over the pipeline. The authors theorized that this

[2] It is worth noting that this study was conducted in China. The risk of heavy metal contamination may be affected by pipeline construction practices, which may be different in the U.S. and China.

may result from soil temperatures being affected by gas running through the pipeline, increased soil water content from moisture collecting along the pipeline, or promotion of plant growth by cathodic action (Fisher, et al., 2000). While these effects can spur increased plant growth directly above the pipelines, the faster growth rate may not be universally beneficial, such as when it causes faster maturation in wheat plants (Fisher, et al., 2000).

News articles have offered anecdotal, unproven accounts of negative effects of pipelines on plant growth. One Lancaster County, PA farmer claimed that crop yields in areas in a permanent ROW containing two pipelines are noticeably lower than in other areas of his farm (Crable, 2014). Limited to anecdotal evidence, it is not possible to determine whether the operation of a pipeline reduces productive output of crops grown on the ROW. There is no conclusive evidence demonstrating that agricultural productivity is unharmed. The PennEast Pipeline Company, LLC has indicated it plans to measure crop yields prior to and after pipeline installation until yields have returned to normal, which they estimate will occur within three years. The company indicated it would compensate farmers for losses in yield (PennEast Pipeline Company, LLC, 2015a).

Logging

Pipeline construction could have detrimental effects on the region's logging industry, which is a significant source of economic productivity. As the nation's largest producer of hardwood lumber, Pennsylvania depends on logging for employment and tax revenue, particularly in rural communities (Jacobson, 2004). Production in Pennsylvania alone is valued at over $10 billion a year (Lord, 2013). Industry output is high because the region's forests contain valuable species such as red oak, maple, black cherry, yellow-poplar, and white oak (Forest Service, 2017). According to our analysis, the proposed PennEast pipeline route will cut through approximately 800 acres of forest (of which 337 are permanent), and the Mariner East 2 pipelines will disturb 204 acres of forest (of which 111 acres are permanent). However, we do not know the extent to which this land is used for logging. For any areas that are used for logging, the permanent acres will remain clear-cut for the permanent right-of-way, and aboveground facilities and logging will not be possible after construction of the pipeline.

After construction has ended and the temporary right-of-way is revegetated, the forest that regrows will not be the same as the forest that was cleared. It takes decades for trees to reach the maturity at which they could be harvested again, and unless hardwoods are replanted, species that voluntarily grow will likely be less valuable soft woods. Clear-cutting also provides a potential foothold for fast-growing invasive plant species to take root and suppress the growth of native species (Eggert, 2016). Furthermore, the permanent ROW is a long-term disturbance to forested lands. As previously discussed, cutting through wooded areas fragments forests into smaller tracts, thus reducing the area of "core" interior forest. This creates micro-climates along the right-of-way that act as a barrier to some plant species, effectively breaking the forest up into smaller sections. Fragmented forests are less equipped to respond to changes in temperature and rainfall caused by climate change and are less suitable for more highly valued species (Forest Service, 2017). Over time, fragmentation leads to a reduced quality of forest products, which could directly affect the market for Pennsylvania and New Jersey timber (Forest Service, 2017). The extent of damage to the logging industry as a direct result of the Mariner East 2 and

PennEast pipeline development is unclear, but these pipelines could result in some economic reductions to the logging industry, particularly the PennEast pipeline, which will disturb over 800 acres of forest area. Without more data on the extent to which the pipelines affect forests used for commercial logging, we are unable to develop cost estimates for the loss in logging productivity.

Recreation

The proposed PennEast pipeline will cross protected lands, including lands preserved in fee or under conservation easements, and may reduce the value of the region's outdoor recreation industry. Common recreation activities in Pennsylvania's and New Jersey's protected areas include hiking, fishing, boating, hunting, and wildlife viewing. Wildlife-related recreation, which includes fishing, hunting, and wildlife-watching, was enjoyed by more than 4 million people in Pennsylvania and more than 2 million people in New Jersey in 2011 (U.S. Department of the Interior et al., 2011). These recreation activities are associated with an estimated $2.8 billion of trip-related, equipment, and other related expenditures in Pennsylvania, and $2.3 billion in New Jersey (U.S. Department of the Interior et al., 2011). A four-hour visit to New Jersey state parks and forests was estimated to provide between $17 and $26 of economic value (Mates and Reyes, 2004). A study in Pennsylvania found that for every dollar invested in state parks in 2010, $12.41 of income returned to the state (PA DCNR, 2012). Additionally, canoeing, kayaking, and rafting support $86 million in gear rental and trip sales in the DRB.

Importance of Preserved Land in Pennsylvania

A 2014 survey of nearly 600 Pennsylvania residents revealed a "strong desire to protect [the state's] wildlife, natural areas and resources." Many respondents "voiced concerns about the impacts of fracking, especially in terms of water pollution and forest fragmentation."

Overall, comments related to drilling and development reflected "concerns about the impacts of natural gas drilling on or near public land, more specifically forest fragmentation, water pollution and loss of open space." (PA DCNR, 2014)

The proposed PennEast pipeline route intersects 470 acres of recreational, conserved, or preserved land in the DRB, of which nearly 270 acres will be dedicated to the permanent ROW. The Mariner East 2 pipelines 18 acres of fee-protected land and conservation easements in the DRB, of which 9 acres are permanent. Some of the region's most popular outdoor recreational areas would be crossed by the PennEast pipeline including the Bear Creek Preserve, the Appalachian National Scenic Trail, Hickory Run State Park, the Lehigh River (which is a designated water trail and supports recreational kayaking and canoeing), Milford Bluffs, Horseshoe Bend Park, the Washington Crossing State Park, the Ted Stiles Preserve at Baldpate Mountain, and Weiser State Forest. Likely detrimental effects in these areas include poorer aesthetics during and after construction, and water, noise, and air pollution during construction. Figure 2 provides a map illustrating the protected areas and recreational trails that will be crossed by the Mariner East 2 and PennEast pipelines.

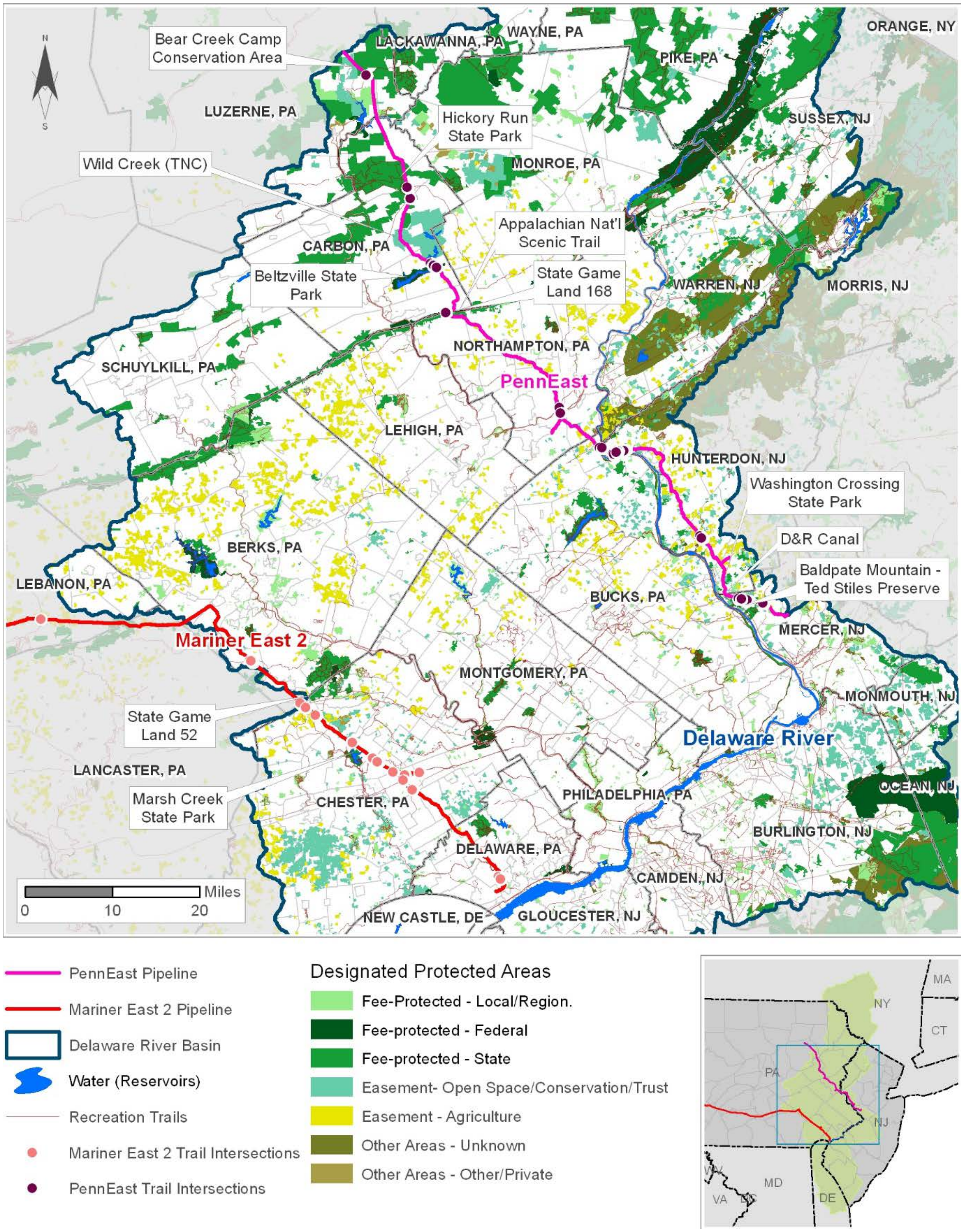


Figure 2. Map of Protected Area and Recreational Trail Crossings by Mariner East 2 and PennEast Pipelines

Wildlife Watching

Wildlife watching is a significant outdoor recreation activity in both states, generating approximately $1.3 billion in Pennsylvania and $1 billion in New Jersey in 2011 (U.S. Department of the Interior et al., 2011). These estimates include trip-related expenditures, equipment expenditures, and other expenses (such as membership dues). Nearly 4 million people participated in wildlife-watching activities in Pennsylvania in 2011 (U.S. Department of the Interior et al., 2011). During pipeline construction, short-term effects that disrupt wildlife habitat will likely halt wildlife-related recreation activities within the "buffer zone," the total distance from the disturbance where effects will be felt (Jordaan, et al., 2009). The buffer zone is defined as 100 meters (equivalent to approximately 328 feet) on either side of the areas cleared for the pipeline. Acute effects of blasting, noise from heavy machinery, and other construction activities have been shown to be highly disruptive to wildlife within this zone and may significantly reduce or eliminate wildlife-based activities during the construction period. Figure 3 is a map of wildlife-based recreation demand along each of the pipelines.

According to PennEast's EIS, the proposed pipeline route crosses multiple Important Bird Areas (IBAs). We estimate that the PennEast pipeline would cross or come within 100 feet of six IBAs, and Mariner East 2 crosses or comes within 100 feet of four IBAs in the DRB.

Table 8. Important Bird Areas in the DRB Affected by PennEast and Mariner East 2 Pipelines

IBA	State	Type
PennEast		
Hickory Run State Park	PA	State IBA
Kittatinny Ridge	PA	Global IBA
Musconetcong Gorge	NJ	State IBA
Everittstown Grasslands	NJ	State IBA
Sourland Mountain Region	NJ	Continental IBA
Baldpate Mountain	NJ	State IBA
Mariner East 2		
Hay Creek	PA	Continental IBA
Middle Creek Wildlife Management Area*	PA	Global IBA
Great Marsh	PA	State IBA
Upper Ridley/Crum	PA	State IBA

**Middle Creek Wildlife Management Area is located along the edge but outside the DRB.*

IBAs are identified by the National Audubon Society as critical habitat areas for birds. Notably, the PennEast Pipeline would cross Hickory Run State Park, which is a large area of contiguous forest that provides interior habitat for birds. The proposed PennEast pipeline route also passes through Baldpate Mountain, an IBA that supports numerous migrating and breeding bird species, including 28 species ranked by the American Bird Conservancy as birds of conservation concern (Washington Crossing Audubon Society, 2018). Pipeline construction through these sensitive bird habitats could result in wildlife displacement, disruptions to and elimination of nesting habitat, and long-term changes in habitat composition, particularly when in forested areas (FERC, 2017). In its EIS, PennEast identified 22 bird species listed by the U.S. Fish and Wildlife Service as migratory birds of concern that may be located in the project area.

Hunting

More than 700,000 people spent over 18 million days hunting in Pennsylvania in 2011, corresponding to nearly $1 billion of expenditures in the state. In the DRB alone, the economic value of hunting was estimated to be $114 million per year (Kauffman and Homsey, 2013). However, hunters, as well as wildlife and birdwatchers, may be forced into other tracts of land if populations of their target species diminish in the long term. Black bears have significant land requirements for their populations to thrive, and studies have shown that increased fragmentation via forest clearing and road construction in their habitat corresponds to diminished population sizes and increased mortality (Schoen, 1990). One study reported that bears have taken to avoiding roads and human disturbance (McGarigal, et al., 2005). As previously discussed, forest fragmentation increases edge forest and reduces core forest area. Some game species have been shown to prefer edge (such as deer and elk), and the ultimate long-term effect of pipeline development on hunting is unknown (McGarigal, et al., 2005).

Freshwater Fishing

Pipeline crossing construction has been shown to cause water quality degradation, including erosion and sedimentation, compromise biological habitat, and alter fish behavior and physiology (Levesque and Dube, 2007). Approximately 870,000 people participated in recreational freshwater fishing in Pennsylvania and 260,000 people New Jersey in 2011 (U.S. Department of the Interior et al., 2011). This equates to more than 10 million freshwater fishing days in the states combined. In total, recreational fishing in Pennsylvania generated nearly $500 million of expenditures and$1.1 billion in New Jersey (including expenditures related to saltwater fishing) in 2011 (U.S. Department of the Interior et al., 2011).

Pipeline development has been shown to disrupt fish habitat and is likely to disrupt recreational fishing activities during construction. (A more detailed discussion of the effects of the pipeline on fish habitats is included in *Chapter 3. Other Environmental Effects*.) Researchers have demonstrated that there is an economic value associated with recreational fishing. One study found the average marginal value of individual fish in recreational fishing waters was $16.82 in 2003 dollars (Johnston, et al., 2006). Another study examined the marginal value of water quality for recreational activity along the Monongahela River in Pennsylvania and found that residents valued improvements in water quality to meet standards for boating at $35, fishing at $42, and swimming at $55 (1999 dollars, per resident), respectively (Wilson and Carpenter, 1999). Yet another study estimated the cost of lost access to a fishing site to be $19 to $23 per trip (Melstrom et al., 2015). Therefore, degradation in water quality and fish habitat as a result of pipeline construction and operation is likely to result in economic losses associated with recreational use of waterways.

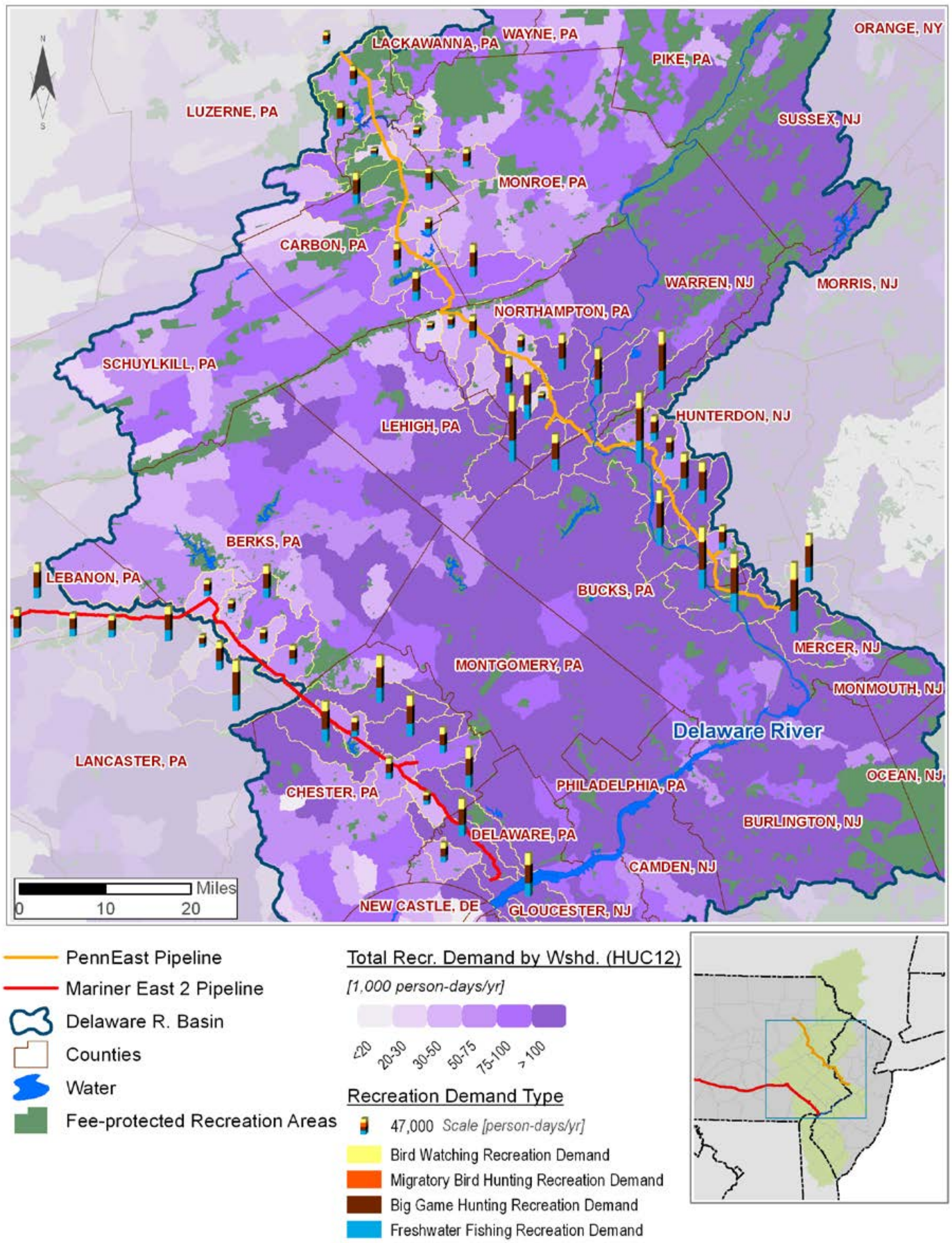


Figure 3. Map of Wildlife-based Recreational Demand in Watersheds Crossed by the PennEast and Mariner East 2 Pipelines

Value of Recreation per Person-Day

As demonstrated above, there are many ways to estimate the value of recreation. A common measure of recreational value is the value per person per day (per person-day) participating in a specific type of recreational activity. The U.S. Department of Agriculture's Forest Service estimated the economic value of a day of recreation for numerous outdoor-based recreation activities by geographic region. One potential use of these values is to estimate the costs associated with land management decisions.

Table 9. Estimated Value of Recreational Benefits in the Northeast Region

Recreational Activity	Average Value Per Person Day (2017 USD)
Bird Watching*	$73
Migratory Bird Hunting	$41
Big Game Hunting	$73
Freshwater Fishing	$58

Source: Rosenberger et al., 2017
**Average per person/day value for bird watching unavailable. This table uses the value for "Other Recreation."*

The Forest Service's estimates represent the "monetary measure of the economic benefits received by an individual or group doing that activity" (Rosenberger, et al., 2017). The net economic value of recreation is "measured as the maximum amount the individual is willing to pay to participate in the activity, less the actual cost incurred by the individual to participate in that activity." This measure of value is not the same as the economic impact of recreation, which refers to the economic activity generated by recreation (e.g., entry fees, equipment, subscriptions). The value represented in the Forest Service's per person-day estimates are sometimes called the "consumer surplus," or the net value to the consumer of the activity. Table 9 lists the consumer surplus value per person-day of recreation activities in the Northeast region. These values can be used to understand the cost implications of policies or land uses that disrupt recreation activities, such as may be the case with PennEast and Mariner East 2. If construction of these pipelines disturbs wildlife activity in the buffer zone, people may choose not to participate in these wildlife-based recreation activities and will lose the equivalent of the values represented in Table 9.

Property Value

Our review of current research did not uncover any proven relationship between natural gas pipelines and local property values. However, pipeline construction has clear effects on properties during construction, including noise, air and water pollution, and aesthetics, and residents near the Mariner East 2 pipelines have reported difficulty when trying to sell their properties during construction (Maykuth, 2018). A recent study surveyed realtors, home buyers, and appraisers as a means of estimating the effects of natural gas pipelines on property values and found that 68 percent of realtors believed a pipeline nearby would negatively affect property value (Phillips, et al., 2017). Of those, 56 percent believed a 5 to 10 percent decrease in value would result (Phillips, et al., 2017). Further, when asked about purchasing an otherwise desirable home that had a 36-inch transmission pipeline located on the property, 62.2 percent of homeowners determined that there was no price at which they would purchase the home, and 18.9 percent stated they would only purchase the property at an average of 21 percent below its market price (Phillips, et al., 2017). In addition to the detrimental effects of nearby natural gas pipelines on property values, the study also identified the effects compressor stations can have on local real estate. When considering total property value effects in the ROW, in the evacuation zone, and near the compressor station, this study estimated a one-time loss of property value equal to approximately $160 to $170 million. It also estimated an annual loss in property tax revenue equal to approximately $3 million (Phillips, et al., 2017).

A potential short- and long-term effect of the pipelines is the risk of sinkholes. In fact, numerous sinkholes near private homes have been linked to the Mariner East 2 pipeline (PA Senate, 2018). A number of bedrock types exist along the pipeline route that can, over time, be dissolved by water. Examples include limestone and other carbonate rocks, gypsum, and salt beds (Dumm, et al., 2016). When water percolates through these rock types, it can slowly dissolve the rock and create open spaces underground. When the space below can no longer support the ground above, it collapses, creating a sinkhole. Landscapes where the limestone bedrock has undergone dissolution are referred to as karst. Pennsylvania is one of the seven most at-risk states for sinkholes, given its underlying limestone and widespread mining in the past (Dumm, et al., 2016). Central and eastern Pennsylvania have significant amounts of carbonate bedrock, making these regions particularly vulnerable (PA DCNR, 2015). Also, when pipelines of any type are located underground, precipitation can percolate into the trenches the pipes are buried in and flow along them. This can cause slow subsidence and collapse of the land around the pipeline (PA DCNR, 2015).

A study of Florida real estate found that properties located within a 0.25-mile radius of a sinkhole sold for 9 percent less than those not located near one (Dumm, et al., 2016). In the short term, construction activities associated with horizontal directional drilling (HDD) can also lead to sinkholes in karst areas; these activities can include water impoundment in reservoirs and stormwater retention basins, vibrations from equipment, and any other activities that affect hydrology (Smith and Sinn, 2013). In a study in Florida, Smith and Sinn (2013) also describe how sinkholes can be induced by HDD drilling due to erosion of already weakened soils by drilling mud or by erosion of soil-filled cavities in karst areas. These may be areas where the bedrock has already undergone dissolution; the added stress of HDD can trigger sinkhole formation.

3. Other Environmental Effects

Key Findings

- The cost of GHG emissions associated with operation of Mariner East 2 at one pump station and from operations at the Marcus Hook facility will be approximately $260 million. Using a high impact SC-CO2, costs could be as high as $800 million for these facilities. These estimates do not include emissions associated with construction or many other pump stations along the pipeline and, therefore, underestimate of potential emissions from the Mariner East 2 pipelines.
- Six federally-listed and 25 state-listed species face habitat disruption from the PennEast pipeline's construction and operation activities.
- Pipeline ROWs contribute most to erosion and sedimentation in the natural gas development process, exceeding the erosion and sedimentation effects of well pads and roads.
- The PennEast pipeline will result in 135 stream crossing in the DRB, and the Mariner East 2 pipelines have 72 stream crossings in the DRB. The PennEast pipeline would cross 80 streams with high value designations, and Mariner East 2 crosses 30 streams with high value designations. These crossings pose concerns for stream health, as well as trout and long-tailed salamander populations during both construction and operation.
- Research indicates that open-cut, isolated, and horizontal directional drilling (HDD) stream crossing methods for pipeline construction have had damaging effects on channel morphology, water quality, and aquatic life and habitats. One study examined 54 HDD installations and concluded that half resulted in inadvertent returns (IRs) of drilling fluid. These IRs occurred most frequently within 200 feet of the HDD entry or exit point.

Greenhouse Gas Emissions

GHGs trap heat in the atmosphere by absorbing solar radiation after it reflects off of earth's surface. GHGs come from a variety of sources, both anthropogenic and natural, and they play an important role in temperature regulation on earth. Over time, increasing amounts of GHGs released into the atmosphere have driven alterations in global climate patterns, collectively referred to as global climate change. Carbon dioxide is the most common GHG emitted due to human activity, but other gases are considered GHGs, such as methane (CH_4), nitrous oxide (N_2O), and fluorinated gases. Methane is a more effective GHG than carbon dioxide; current research suggests that methane is 28 to 36 times more potent than carbon dioxide per unit mass over 100 years (U.S. EPA, 2017). Release of methane into the atmosphere can occur via a number of natural processes such as anaerobic decomposition in wetlands, but most comes from human activities, including natural gas production and raising livestock. In fact, a recent NASA study found that the increases in global methane emissions are largely due to the oil and gas industry (United Nations, 2018). Therefore, methane release as a result of the natural gas industry is acknowledged as a significant climate change concern (Alvarez, et al., 2018; United Nations, 2018; Marchese and Zimmerle, 2018).

Methane release as a result of pipeline leakage, rupture, or intentional blowdowns at compressor stations can escape into the atmosphere at significant rates (Alvarez, et al., 2018). The EPA Greenhouse Gas Inventory estimate of methane leakage due to transmission and storage equaled 1.4 teragrams per year (Tg/y) in 2015, but recent research estimated methane emissions from gas transmission and storage to be approximately 1.8 Tg/y (Alvarez, et al., 2018). This estimate is nearly 30 percent higher than EPA's estimate. The study found that overall national supply chain methane emissions equaled 13 Tg/y, or 2.3 percent of the gross gas production nationwide and approximately 60 percent higher than EPA's estimate (Alvarez, et al., 2018). There are also data from the federal PHMSA on Pennsylvania and New Jersey's methane emissions reported by pipeline operators from 2010-2017 that indicate specific leak and rupture events ranged in quantity from approximately 70 Mcf to 550,000 Mcf (Thompson, 2017). Natural gas is often characterized as a cleaner alternative to coal due to its low CO_2 emissions relative to coal when generating electricity. However, methane leakage from natural gas operations narrows this gap in emissions because of its greater global warming potential (GWP). As noted above, the GWP for methane is 28 to 36 times that of carbon dioxide over the span of 100 years (U.S. EPA, 2017). Furthermore, methane is a precursor to ozone, which is also a GHG.

In addition to methane leakage, the pipeline is expected to contribute GHG emissions from combustion activities during construction (e.g., combustion engines of construction vehicles and equipment) and operation of the pipeline and compressor station. These activities are expected to release CO_2, N_2O, and methane, as described in the previous section. N_2O has a GWP 265 to 298 times that of carbon dioxide over the same period. Finally, the PennEast pipeline will deliver an estimated 1.1 million dekatherms per day of natural gas to customers. Combustion of this gas will result in additional GHG emissions of 23.5 million short tons (21.3 million metric tons) per year of carbon dioxide equivalence (CO_2e) (FERC, 2017). CO_2e is a standard unit for measuring carbon footprints and is calculated by multiplying the mass of a given compound by its corresponding GWP.

EPA has estimated the SC-CO_2, which is an estimate of the dollar value of damage done by a ton of CO_2 emissions in a given year. First devised in 2010 by a working group of U.S. government agencies and since revised twice, the SC-CO_2 incorporates three different integrated economic models as well as the probability of rare yet costly catastrophic events (U.S. EPA 2016). The SC-CO_2 is a broad measure of the impact of CO_2 on society; it captures the changes in agricultural productivity, human health, property values, and energy system costs that result from increased emissions. The SC-CO_2 also increases over time, meaning that the SC-CO_2 will be higher in future years than it is now. This increase is partly due to the fact that gross domestic product (GDP) grows over time and many economic models remain proportional to GDP, but also because future emissions are expected to produce larger incremental damages as physical and economic systems become more stressed. In other words, the destructive potential of carbon emissions will grow over time, and the SC-CO_2 model is designed to take this compounding effect into account. Although it is as comprehensive as possible, the SC-CO_2 does not include every physical, ecological, and economic effect caused by carbon emissions because some damages are difficult to quantify or lack the necessary research. As a result, SC-CO_2 may underestimate the true social cost of carbon. EPA has estimated similar social costs for N_2O and CH_4. Over time, the social cost estimates associated with these gasses increases. The table below provides a selection of EPA's estimates.[3] The differences in GWP are reflected in the social cost estimates in Table 10.

Table 10. Social Cost of Greenhouse Gas Emissions

Gas	Year of Emission	Social Cost per metric ton (in 2017 USD)		
		Low (2.5% Discount rate)	Medium (3% Discount rate)	High (5% Discount rate)
Carbon Dioxide (CO_2)	2020	$12	$42	$62
Carbon Dioxide (CO_2)	2035	$18	$55	$78
Carbon Dioxide (CO_2)	2050	$26	$69	$95
Nitrous Oxide (N_2O)	2020	$4,700	$15,000	$22,000
Nitrous Oxide (N_2O)	2035	$7,400	$21,000	$29,000
Nitrous Oxide (N_2O)	2050	$11,000	$27,000	$37,000
Methane (CH_4)	2020	$540	$1,200	$1,600
Methane (CH_4)	2035	$900	$1,800	$2,300
Methane (CH_4)	2050	$1,300	$2,500	$3,100

Source: Interagency Working Group on Social Cost of Greenhouse Gasses, United States Government, 2016

Forest Fragmentation and Ecosystem Impacts

As discussed throughout earlier chapters, pipeline construction and operation have numerous effects on existing land uses and the various ecosystems they support. Disruption of the habitats in these areas will have negative effects on plant and animal species that live in the regions along the pipeline route. Deforestation for the ROW and access roads is a large component of the habitat disruption, and while the fragmentation may benefit edge species, those species that require deep forest to thrive will find their range diminished.

[3] Note that U.S. EPA has proposed changes to these cost estimates and has set an interim social cost of methane at $55 per metric ton in 2020. This represents approximately 4% of the cost established by EPA in the table above.

There are numerous federal and state threatened and endangered species that could be negatively affected by pipeline construction and long-term land use changes. Many of these species have specific habitat requirements and are already declining in population as a result of human development, climate change, and habitat loss. The permanent ROW of the proposed PennEast pipeline would degrade many acres of woodland and wetland habitat upon which these species depend.

Six federally listed species are located in areas that will be crossed by the pipeline (PennEast, 2016). These species are the endangered northeastern bulrush (*Scirpus ancistrochaetus*), the endangered Indiana bat (*Myotis sodalis*), the threatened northern long-eared bat (*Myotis septentrionalis*), the threatened bog turtle (*Glyptemys muhlenbergii*), the endangered dwarf wedgemussel (*Alasmidonta heterodon*), and the endangered rusty patched bumble bee (*Bombus affinis*). These species possess not only intrinsic value, but also value as contributors of ecosystem services. For example, northern long-eared bats are insectivores that prey directly on mosquitos, serving as a natural form of population control, and Indiana bats are known to consume at least six different species of agricultural insect pests (Kunz et al., 2011). Another federally endangered species, the rusty patched bumble bee, provides benefit through pollination. In the region, this bee species is known to pollinate a number of plants, such as the Prunus genus, which includes species such as plum, cherry, peach, and apricot trees (US Fish and Wildlife Service, 2018). In the DRB's aquatic ecosystems, the dwarf wedgemussel plays an important role as part of the food web and also as a natural water filter, removing pollutants and small particulate matter from the water as it filters for oxygen and food (US Fish and Wildlife Service, 2011).

PennEast, in consultation with the Pennsylvania and New Jersey U.S. Fish and Wildlife Service field offices, conducted field surveys to evaluate the potential effects of construction and operation of the PennEast pipeline on six endangered species. Table 11 lists these species and the potential impacts they face.

Table 11. Endangered and Threatened Species Along the PennEast Pipeline Route

Species	Federal Status	Location of Concern in the Project Area	Preferred Habitat	Potential Impacts
Indiana bat	Endangered	All counties	Caves or mines in the winter; dead/dying trees or trees with exfoliating bark in the summer	Indiana bat could be adversely affected by construction-related tree clearing possibly resulting in removal of maternity roost tree, change in characteristics to foraging habitat, mortality of bats roosting in a tree, and reduction of summer roosting habitat. Noise, vibrations, and lighting during construction could disturb bats during hibernation or lead to behavior changes during active season. (Survey did not capture any Indiana bats in PA or NJ.)
Dwarf wedgemussel	Endangered	Delaware River and tributaries	Muddy sand in shallow, clear waterbodies with slow to moderate currents	Inadvertent drill mud and drill fluid releases from HDD may impact waterbody habitat.

Species	Federal Status	Location of Concern in the Project Area	Preferred Habitat	Potential Impacts
Northern long-eared bat	Threatened	All counties	Caves or mines in the winter; dead/dying trees or trees with exfoliating bark in the summer	Northern long-eared bat could be adversely affected by construction-related tree clearing possibly resulting in removal of maternity roost tree, change in characteristics to foraging habitat, mortality of bats roosting in a tree, and reduction of summer roosting habitat. Noise, vibrations, and lighting during construction could disturb bats during hibernation or lead to behavior changes during active season. (Survey identified two hibernacula within 0.25 miles of the project and one hibernaculum just outside 0.25 miles of the project.)
Bog turtle	Threatened	Wetlands of Northampton and Carbon Counties in PA, and the Aquashicola watershed of Carbon County in PA.	Wetland bogs with deep organic soils and spring-fed hydrology; typically with open canopy and minimal woody species	Bog turtles could be injured or killed as a result of construction equipment and activity. Habitat disruption and alteration including changes to wetland hydrology and soil compaction during construction and operation of the pipeline.
Rusty patched bumble bee	Endangered	All counties in PA	Grasslands and tallgrass prairies with available flowers for food, underground cavities and aboveground grass clumps for nesting, and undisturbed soil for overwintering.	Colony destruction during construction, vegetation clearing, and ROW and road development. Noise, vibration, and lighting during construction may also cause disturbance to hibernating bees and/or behavior changes. However, long-term maintenance of the ROW could expand bee habitat.
Northeastern bulrush	Endangered	Carbon County in PA	Small wetlands, sinkholes, or wet depressions	Direct removal or destruction of plants during construction and alteration of habitat. Conversion of preferred forested wetland habitat to emergent habitat and potential adverse effects on groundwater hydrology from surface compaction.

Source: PennEast, 2016 and FERC, 2017

In addition to the six federally listed species, the PennEast EIS identified an additional 25 state-listed species that are threatened or endangered and may be found along the pipeline's proposed route. These include four mammals (northern flying squirrel, bobcat, Allegheny woodrat, eastern small-footed bat), six reptiles and amphibians (timber rattlesnake, eastern redbelly turtle, wood turtle, northern cricket frog, long-tailed salamander, southern gray tree frog), 11 birds (American kestrel, barred owl, bobolink, grasshopper sparrow, osprey, red-shouldered hawk, savannah sparrow, red-headed woodpecker, American bittern, vesper sparrow, long eared owl), and four invertebrates (brook snaketail, yellow lampmussel, tidewater mucket, triangle floater) (FERC, 2017). Many of these species depend on specialized habitat found in the DRB and will likely face additional stress from the pipeline's construction and operation.

Water Quality and Freshwater Habitats

The three primary stream characteristics affected by pipeline construction are channel morphology, water quality, and aquatic life health and habitat. Pipeline construction has been shown to change stream morphology by deposition of eroded sediment in the stream channel or by channel scour due to increased runoff associated with land clearing. Pipeline construction has also been shown to degrade water quality as a result of changes in temperature, dissolved oxygen, total dissolved solids (TDS), nutrients, turbidity, and more as a result of activity near, in, and/or below the waterway. Construction that modifies fish habitat and changes water quality will harm fish health. Suspended sediment in particular can reduce distribution and abundance of fish by damaging their gills (Levesque and Dube, 2007).

There are instances where the pipeline routes directly cross streams, lakes, wetlands, and other bodies of water. In these instances, risks of water contamination from construction are higher. Although there are a variety of methods of constructing stream crossings, any method (open-cut, isolated, or HDD) poses threats to the local aquatic ecosystem (Levesque and Dube, 2007). Open-cut water crossings involve digging a trench directly across the stream and its banks, laying the pipeline, and backfilling. This can be accomplished with either the "wet-ditch method," where construction occurs in the flowing stream, or the "dry-ditch method," in which flume pipes redirect the water through the excavated area and sandbag dams are created both up- and downstream of the construction to ensure dry conditions (PennEast Pipeline Company, LLC., 2014). Both methods cause a number of changes to the water quality and local ecosystems. Excavation of the streambed and the associated disruption and erosion of streambanks often result in altered stream morphology and elevated sediment levels downstream during construction and for a period of time afterwards (Reid and Anderson, 1999). This increased sedimentation has been shown to adversely affect downstream ecosystems that require lower water turbidity levels. Additionally, construction within the stream and along its edges negatively affects local ecosystems through habitat destruction. This can affect numerous organisms such as macroinvertebrate populations, which comprise the basis of the aquatic food chain (Reid and Anderson, 1999).

Stream crossing construction using HDD has resulted in many cases of groundwater and surface water contamination from the release of drilling fluids. As of November 2018, the Pennsylvania Department of Environmental Protection (PA DEP) has issued 94 notices of permit violations and nearly $13 million in fines to Sunoco for violations related to the Mariner East 2 pipeline. Among the violations are inadvertent returns (IRs) from HDD resulting in thousands of gallons of drilling fluids flowing into streams, lakes, and wetlands (PA DEP, 2018a). These IRs of drilling fluids have contaminated drinking water sources, as discussed in more detail in *Chapter 6. Case Study on the Real Impacts of the Mariner East 2 Pipeline*.

IR is a type of spill where drilling mud travels through weak points in the rock during drilling. Areas where there are subsurface cavities, fractures in the bedrock, or loose soils are most vulnerable to IR

(Litvak and Legere, 2018). A 2008 study conducted by the Gas Technology Institute found that of 54 HDD installations, half had experienced IRs (Skonberg et al., 2008). The study found that IRs occurred most frequently within 200 feet of the HDD entry or exit point, but PennEast only evaluated wells within 150 feet of the pipeline construction workspace (FERC, 2017). One example of an IR resulting from HDD occurred during construction of Energy Transfer Partners LP's (ETP) Rover pipeline. In April 2017, shortly after construction began, approximately two million gallons of drilling fluid spilled into wetlands in Ohio; ETP classified the spilled fluid as IRs as a result of HDD (Grzegorek, 2017). In response, Ohio EPA levied fines totaling $2.3 million (Grzegorek, 2017). In January 2018, another 150,000 gallons were lost down a borehole in the same wetlands area in Ohio during HDD (NRDC, 2018). After both of these incidents, the Federal Energy Regulatory Commission (FERC) halted construction of the pipeline (NRDC, 2018).

During construction, the disturbance of topsoil near surface water increases the likelihood of erosion and sedimentation of local waterways, markedly increasing suspended sediment concentrations in the water. Pipeline ROWs are the largest contributor to erosion and sedimentation in the natural gas development process, exceeding the erosion and sedimentation effects of well pads and roads (Habicht et al., 2015). One study found that when utilizing the trench excavation method, peak suspended sediment concentrations reached as high as approximately 2,700 nephelometric turbidity units (NTU) (Reid and Anderson, 1999). For comparison, the study identified eight states with numerical turbidity limits associated with instream construction permits. These states' allowable instantaneous exceedances ranged from 10 to 50 NTUs (typically outside of the mixing zone or post-construction).

Water habitats near or in the path of the pipelines may be damaged by changes in water quality and by disturbances to the benthic environment (Levesque and Dube, 2007). All downstream water systems, however, are put at risk by the pipeline. In the short term, suspended sediment loads spike during pipeline construction, which have been shown to harm freshwater organisms (Reid and Anderson, 1998). In the long term, pipeline water crossings have resulted in erosional problems, including permanent degradation of stream banks and riverbeds (Sawatsky et al., 1998). In fact, pipelines at water crossings are at a greater risk of rupturing because they are directly affected by flooding (Fogg and Hadley, 2007). Buried pipelines can become exposed due to river scour during flood events, bed and bank erosion, and river avulsion (the rapid abandonment of a river channel and the creation of a new river channel) in meandering channels (Sawatsky et al., 1998). Once exposed, the pipeline faces greater risks of corrosion and rupture, and there will be subsequent environmental and public safety consequences (Woidt Engineering and Consulting, 2017). Not only does a ruptured pipeline require remediation, which necessitates additional construction near the stream, but there may also be repairs to buffers such as articulated concrete blankets that cover the pipeline. These buffers can create a bump in the stream bottom, creating a barrier and altering the natural flow, which may fragment fish populations (Woidt Engineering and Consulting, 2017). Researchers conducted a preliminary inspection of PennEast's proposed stream crossings and determined that one third of the visited sites were deemed inadequate in their proposed cover depth, and one site was at risk of unstable channel scour, which could result in eventual pipeline rupture (Woidt Engineering and Consulting, 2017). Pipeline construction and operation therefore poses risks not only to the open water it crosses, but also to the downstream freshwater environments and the ecosystem services they provide.

The proposed PennEast pipeline has over 250 stream crossings, dozens of which are habitat for wild trout (Woidt Engineering and Consulting, 2017). We estimate that there will be 135 stream crossings for the PennEast pipeline and 72 stream crossings for the Mariner East 2 pipelines (see Table 12). These crossings pose concerns for stream health as well as the health of trout and long-tailed salamander populations during both construction and operation (Savant, 2018; Woidt Engineering and Consulting, 2017). In undisturbed streams, the substrate – or mix of stones, gravel, pebbles, and silt along the stream bottom – typically sorts by size, with smaller particles toward the bottom and larger gravel or stones on top (Woidt Engineering and Consulting, 2017). These larger stones require significantly stronger currents to move than the finer material underneath; this keeps the substrate intact. However, if the open trench method of pipeline installation is used and the substrate is not restored to the original sorted structure, smaller particles towards the top will be washed downstream much more easily. Flood events will mobilize significant amounts of sediment, deepening the stream channel and modifying flow. This condition has detrimental effects both upstream and downstream from the disturbed area, reducing water quality and harming local fish populations (Woidt Engineering and Consulting, 2017). HDD is often used as a stream crossing method to minimize these effects. However, HDD is not a perfect solution to these problems given the 50 percent IR rate estimated by one study (Skonberg et al., 2008).

Table 12. Mariner East 2 and PennEast Pipeline Stream Crossings in the DRB

Summary of Stream Crossings	Mariner East 2	PennEast
Total Stream Crossings	**72**	**135**
Crossings with HDD	*31*	*25*
Crossings without HDD	*41*	*110*
Crossings of Streams of High Value*	**30**	**80**
Crossings with HDD	*6*	*16*
Crossings without HDD	*24*	*64*
Crossings of Other Streams with Designation**	**38**	**23**
Crossings with HDD	*19*	*2*
Crossings without HDD	*19*	*21*
Crossings of Already Impaired Streams	**38**	**4**
Crossing of National Wetland Inventory Wetlands	**7**	**35**

Note: Stream crossings include roads.
** Streams of High Value include streams designated as EV or EQ in Pennsylvania and C1 in New Jersey.*
***Other Streams with Designation include CWF and TSF streams in PA not already classified as EV or EQ, and TM or TP streams in NJ not already classified as C1.*

Pennsylvania and New Jersey use stream designations to identify high quality streams or streams for designated uses. Stream designations vary depending on each state's regulations. In Pennsylvania, a stream can be classified as High Quality Waters (HQ) if its chemistry supports a healthy community of aquatic organisms. It can be classified as Exceptional Value Waters (EV) if it is located in a protected area, is of important recreational value, or is in near-perfect condition. Pennsylvania streams are also classified depending on whether they are protected for a designated aquatic life use. These uses are Warm Water Fishes (WWF), Trout Stocking (FSF), Cold Water Fishes (CWF), and Migratory Fishes (MF).

In New Jersey, streams are classified as FW2 if they are freshwater and not set aside for protection from all manmade influences. A category one water (C1) is one that is protected from anti-degradation. It is designated for protection from any measurable changes in water quality because of its significance for ecology, recreation, water supply, or fisheries. It is protected for its aesthetic value (e.g., color, clarity, scenic setting) and ecological integrity (e.g., habitat, water quality, and biological functions). Streams in New Jersey can also be classified as trout producing (TP) or trout maintenance (TM), or as non-trout waters (NT). As discussed above, pipeline construction and stream crossings have been demonstrated to result in erosion, sedimentation, changes in stream morphology, and degradation of water quality and habitats for aquatic species. Thirty-three of the impaired streams identified along the Mariner East 2 pipelines are impaired as a result of excessive siltation. Adding more sediment to those streams in runoff from the construction and long-term land use changes will cause even further impairment. Figure 4 includes a map of stream crossings in the DRB for each pipeline.

According to our analysis, PennEast and Mariner East 2 have or will cross many high-quality streams (see Figure 4). In addition to their socio-economic benefits, ecologically healthy streams are instrumental for successful water quality restoration efforts elsewhere in a watershed by providing an environmental support system. In 2008, the Delaware River Basin Commission (DRBC) designated the lower Delaware River as Special Protection Waters (SPW) with the goal of protecting existing high-quality waters from the adverse impacts of point source and nonpoint source discharges. The DRBC’s regulations prohibit any measurable change in the existing quality of SPW waters except towards natural conditions (DRBC, 2017b). Many of the streams crossed by the Mariner East 2 pipelines are already considered impaired for aquatic life due to siltation from urban runoff and stormwater sewers. Although crossings of high-quality streams are of significant concern, crossings of impaired streams are still a concern because any additional erosion and sediment contribution from the construction or long-term presence of the pipelines would further exacerbate the impairment.

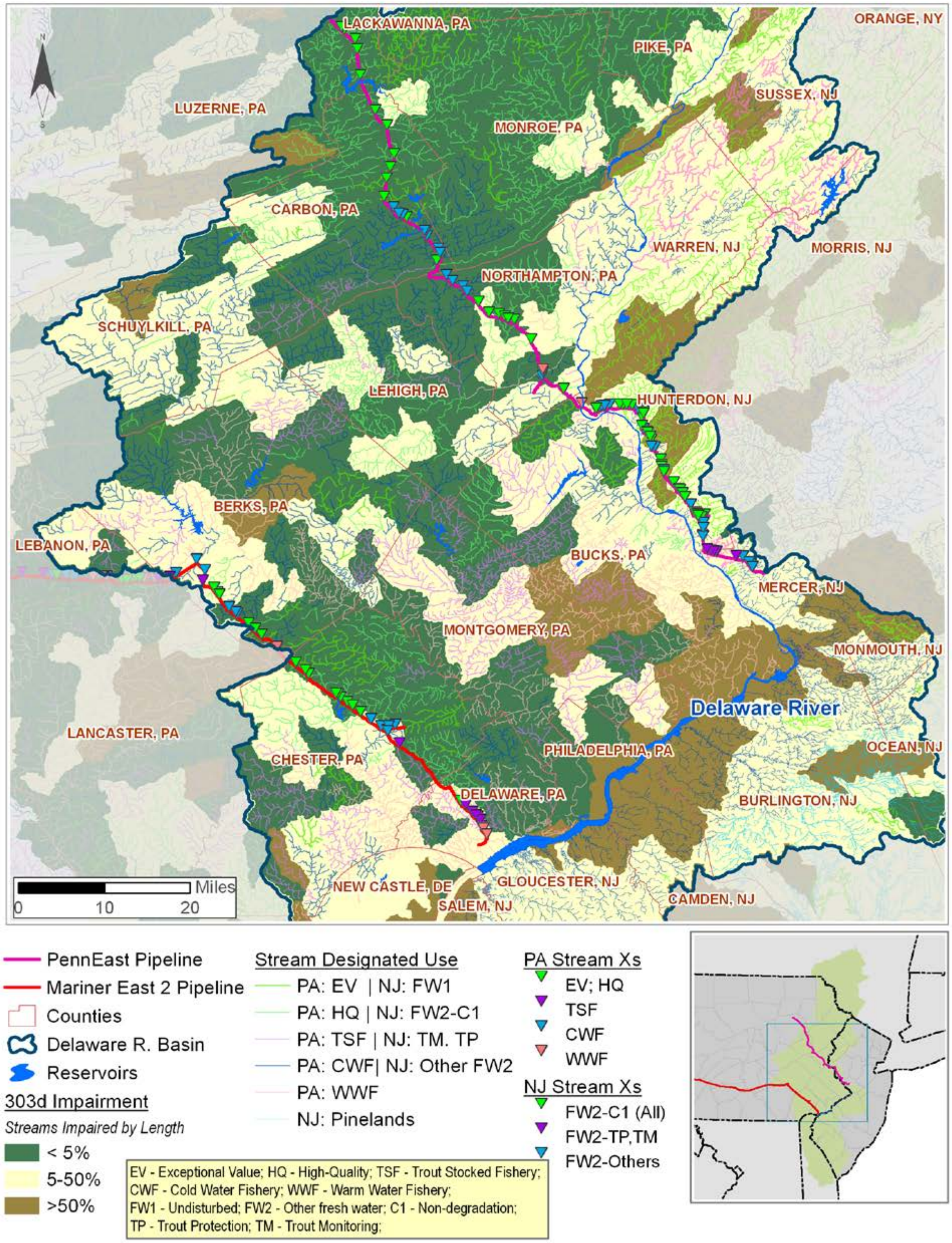


Figure 4. Map of Stream Quality and Pipeline Stream Crossings

4. Health and Safety

Key Findings

- Numerous studies indicate that the cost of water treatment is directly related to turbidity. Additional sediment loading to the Delaware River may lead to additional costs for surface water treatment systems in order to manage sedimentation. Measures may involve more frequent dredging to maintain clear waterways and adjustments to the water treatment infrastructure or processes to address turbidity.
- Overall, approximately 1.2 million individuals consume water from public water systems that could be at risk of contamination or degradation due to the PennEast and Mariner East 2 pipelines. Approximately 1,600 domestic wells could be at risk of contamination, and nearly 500 domestic wells are in close proximity to at least one of the pipelines.
- PennEast estimates that the gas-powered Kidder Compressor Station would emit approximately 90 tons of NOx, 17 tons of CO, 5 tons of SO2, 24 tons of PM10, 24 tons of PM2.5, and 2 tons of CH2O each year of continuous operation.
- An independent analysis estimated that the total emissions release related to the development at Marcus Hook to service the Mariner East pipelines will result in approximately 63 tons of NO_x, 163 tons of CO, 40 tons of SO_x, 14 tons of PM, and 13 tons of PM_{10} each year of operation.
- The pipelines risk catastrophic failure by ignition or explosion. Between 2005 and 2018, 29 fatalities and 133 injuries were sustained as a result of catastrophic failures of onshore gas transmission pipelines.

Drinking Water and Health Effects

Water quality degradation from pipeline activity has also affected drinking water. The DRB watershed provides drinking water for roughly eight million people living within the basin as well as approximately eight million more whose water is transported from the basin (Hanson and Habicht, 2016). Figure 5 shows the path of the Mariner East 2 and PennEast pipelines relative to drinking water sources, including those supplied by groundwater and surface water. If drinking water sources were to become contaminated, as has already resulted from the construction of Mariner East 2, or well supplies diminished, there could potentially be health implications for the population served by those sources.

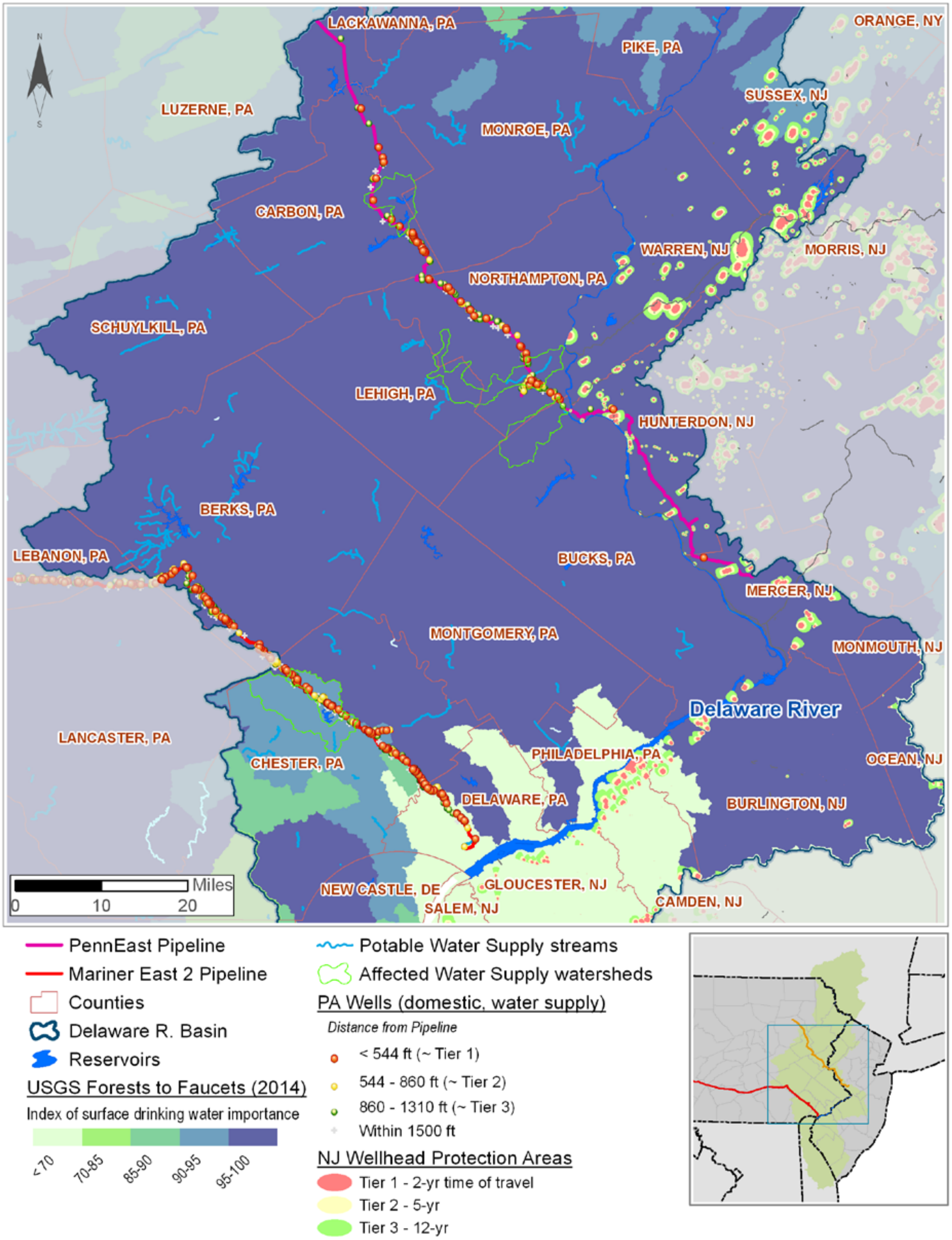


Figure 5. Map of Surface Water and Groundwater Sources Near the Mariner East 2 and PennEast Pipeline Routes

Furthermore, additional sediment added to waterways can accumulate in reservoirs and reduce the quantity of water available to water systems over time. Removing sediment from waterways and storage facilities (i.e., reservoirs) can be expensive and may disrupt the availability of quality source water. The discussion below identifies potential health problems and treatment costs that could result from chemical contamination and sedimentation in drinking water sources.

Sedimentation and Turbidity Impacts on Surface Water Sources

One of the primary potential effects of pipeline construction and operation is increased turbidity in local waterways. Turbidity refers to the “muddiness” or “cloudiness” of the water from suspended solids such as dirt, clay, silt, finely broken-down organic matter, algae, and other microorganisms (Dearmont et al., 1998). Turbidity increases as the amounts of these constituents in the water column increase. Activities such as deforestation and road construction are some of the most significant contributors to sedimentation and associated turbidity in forested watersheds (Warziniack et al., 2016). Sediment loading from streambank erosion also contributes to higher turbidity levels.

While increased turbidity has an aesthetic and ecological effect on impacted waterbodies, it also poses challenges for drinking water treatment systems that draw from those sources because it can mask other contaminants in the treatment process. This typically means additional or alternate treatment is needed to ensure public safety. These adjustments can include shorter filter run times, use of additional chemicals for coagulation and disinfection, and increased sludge production and removal, all of which may increase water system costs. For example, shorter filter run times require purchase of replacement filters more frequently. Also, increased chemical requirements result in increased chemical purchases; one study estimated that the additional chemical costs associated with elevated turbidity levels totaled approximately $74 per million gallons of water treated (Dearmont et al., 1998).

In addition to individual treatment components, numerous studies have evaluated the overall effects of land use change and related increased turbidity on overall water system treatment costs. For example, one study found that in northwestern Oregon, a one percent reduction in turbidity levels led to a 0.67 percent decrease in water treatment costs (Warziniack et al., 2016). Another study estimated that if ten percent of an average watershed were converted from forest to developed land, annual treatment costs would rise from $2.52 to $20.48 per million gallons of water treated (Warziniack et al., 2016). Table 13 provides several additional cost impacts cited in the literature. Although some of these sources may be dated, they demonstrate a widespread finding that increasing turbidity typically results in increased water treatment costs.

In addition to increasing turbidity, sedimentation also fills waterways reservoirs, necessitating expensive dredging. The Delaware and Raritan (D&R) Canal, managed by the New Jersey Water Supply Authority, faces significant costs to manage sedimentation in the waterway. Opened in June 1834, the canal was initially created for ease of goods transport through New Jersey (D&R Canal State Park, 2018). It now serves as a drinking water source for millions of central New Jersey residents who are supplied water originating from the Delaware River (New Jersey Water Supply Authority, 2017). Because its primary source is the Delaware River, the canal’s water is affected by watershed alterations in the DRB, such as increases in sediment load resulting from deforestation and road construction. Drinking water treatment systems that rely on the canal's water are therefore affected as well. The PennEast pipeline will further increase sediment levels in nearby waterways, not only because of the impacts of multiple stream and wetland crossings, but because its cleared and compacted ROW will further increase erosion and sedimentation.

Table 13. Effects of Changes in Turbidity on Water Treatment Costs in the Literature

Change in Turbidity	Effect on Costs	Source
10% reduction in soil erosion	4% reduction	Forster, Bardos, and Southgate, 1987
1% increase in turbidity	0.25% increase in chemical costs	Dearmont, McCarl, and Tolman, 1998
1% increase in turbidity	0.07% increase	Holmes, 1988
1% increase in TOC in the average watershed	0.46% increase	Warziniack et al., 2016
1% increase in TOC	$0.28 to $0.68 increase annually per million gallons treated	Warziniack et al., 2016
1% increase in forest cover	2% decrease in chemical treatment costs for systems in watersheds with 50% forested cover	Ernst et al., 2004

The cost of maintaining a nearly 200-year-old canal as a public water supply is significant, due in part to the increased transport of sediment into the streams feeding it as development in the watersheds increases. The PennEast pipeline would cross six major streams flowing into the D&R Canal and would traverse the streams' watersheds. Two of the creeks that PennEast is proposing to cross, the Lockatong Creek and the Wickecheoke Creek, provide the majority of the flow into the canal above Trenton. These creeks are "flashy", meaning they quickly reach flood stage after a few hours of steady rain, causing serious erosion and sedimentation. After a major storm, these streams become dangerous rapids. Such rapid response to storm events is due to the underlying geology combined with land uses in their watersheds that create impervious surfaces (Kologie, 2002). The erosion associated with these events can damage infrastructure. For example, Lower Creek Road in Delaware Township is in danger of collapsing into the Wickecheoke due to erosion.

The Lockatong Argillite, which is the predominant bedrock in the watersheds feeding the D&R Canal, has such low porosity and permeability that it acts as an impervious cover itself. This geology makes these watersheds particularly sensitive to increased amounts of impervious cover (Kologie, 2002), which is expected with pipeline construction. The clearing and regrading of slopes, the compaction created by heavy equipment, and the construction sites necessary for HDD and pipe storage will create a large amount of new impervious surface. This will promote degradation of sensitive creeks, many of which are sources for drinking water. By adding impervious surface to the local watersheds, construction of the PennEast pipeline would exacerbate the D&R Canal's sediment loading problems.

The costs documented to address sedimentation in the D&R Canal are significant. Regular and ongoing mitigation of sedimentation in the D&R Canal is conducted at the Prallsville Lock, which is cleaned of debris about once per month. Approximately 300 cubic yards of debris are removed annually, amounting to $200,000 in maintenance costs each year (USDA Natural Resource Conservation Service of the New Jersey Water Supply Authority, 2007). Once the debris is removed, it must be stored offsite, where the cost to dispose it is between $20 and $80 per cubic yard. Additionally, unpredictable natural events such as hurricanes and floods increase the flow of sediment and debris to the Canal (USDA Natural Resource Conservation Service of the New Jersey Water Supply Authority, 2007). The costs of events such as these could increase as there is more development in the watershed.

Vulnerability of Regional Watersheds

"The degradation caused by impervious cover in the watershed is serious and often irreversible. It includes increased flooding, lower dry weather flows, widening of the creeks and stream bank erosion and sedimentation, increase in water temperature and pollutant loading, declines in fish habitat, aquatic insect diversity, and a decline in wetland plant and animal community diversity."

- The Lockatong and Wichecheoke Watershed Management Plan, 2002

In 1985, 32 miles of the D&R Canal were dredged to remove 700,000 cubic yards of sediment (USDA Natural Resource Conservation Service of the New Jersey Water Supply Authority, 2007). The dredging effort cost approximately $20,100,000 and was expected to last 40 years (USDA Natural Resource Conservation Service of the New Jersey Water Supply Authority, 2007). Factored over its life expectancy, the dredging effort cost $1,205,000 annually. There is currently a new dredging project underway (New Jersey Water Supply Authority, 2017).

Once water reaches the intakes of the drinking water treatment plants served by the Canal, the increased sediment load affects the plants' ability to treat the water. Over the past 15 years, increased turbidity in the D&R Canal has necessitated increased chemical doses during water treatment and resulted in related increases in sludge created during treatment (USDA Natural Resource Conservation Service of the New Jersey Water Supply Authority, 2007). Poorer water quality during precipitation events used to affect the water treatment plants for two days; now the poorer water quality affects them for up to a week. Systems that draw water from the Canal typically spend $1,500,000 annually in treatment and waste residual (e.g. sludge) disposal costs (USDA Natural Resource Conservation Service of the New Jersey Water Supply Authority, 2007). In total, the cost of sedimentation in the D&R Canal is approximately $3 million each year. Additional sediment loading to the Delaware River is likely to increase the required frequency of dredging, may require costly water treatment adjustments for longer periods of time, and may increase the overall cost to manage sedimentation.

The North Brunswick Treatment Plant received EPA's Partnership for Safe Water Program's Director's Award in 2015 (American Water Contract Services Group, 2017). The award was granted for the system's optimization of facility operations and implementation of goals that are more stringent than those required by EPA and the state (American Water Contract Services Group, 2017). The plant received the award again in 2017. Because the Partnership for Safe Water's optimization goals require the system to produce water with lower finished water turbidity levels than required, changes in the source water quality entering the plant via the D&R Canal could reduce the North Brunswick Treatment Plant's ability to meet those goals.

Sedimentation in the D&R Canal

As sedimentation in the D&R Canal increases, the water depth decreases, allowing greater light penetration and providing increased habitat for aquatic weeds. Recently, hydrilla – an invasive aquatic plant – was found in the Canal and was determined to be reducing flow capacity and raw water quality. New Jersey Water Supply Authority initiated a 120-day herbicide treatment, to which New Brunswick Water Utility responded by implementing a temporary carbon-feed system to ensure a continued supply of safe drinking water (New Brunswick Water Utility, 2017)

Sedimentation and Turbidity Impacts on Groundwater Sources

In addition to surface water impacts, contamination of groundwater has been reported by homeowners near the Mariner East 2 pipeline. Water tests conducted by Sunoco revealed that well water had increased turbidity and elevated iron, affecting the taste and smell of the water (Burke, 2017). In response, Sunoco provided bottled water, water buffalos, and hotel rooms to affected households. The company also offered to connect households to a nearby public water system (PWS) and, according to news reports, offered a settlement of $60,000 to each household (Burke, 2017). Table 14 (next page) provides information on the estimated costs of these remediation actions.

Table 14. Alternative Water Supply Mechanisms and Associated Costs

Alternative Supply Mechanism	Description	Associated Costs	Source
Connection to a Municipal Source	If located close to an existing main, construction of new connection lines from the main to the affected residences and installation of water meters.	$10,000 - $50,000 $60,000	Hughes, 2015 Burke, 2017
	If not located close to an existing main, construction of a new water main to affected area and installation of connection lines to residences and new water meters.	$142.83 per foot for 6-10-inch diameter distribution mains $95.85 per foot for 6-10-inch transmission lines	U.S. EPA, 2010

Alternative Supply Mechanism	Description	Associated Costs	Source
Whole-House Treatment	Installation of a filtration device at a building's point of entry.	$2,120 - $5,782 per unit $1,149 - $2,298 per 500,000-gallon unit	Pelican Water Systems, 2019 Aquasana, 2019
Bottled Water	Replenishment of a well or an on-site water buffalo with water that is trucked in.	$150 - $300 per 2,500 gallons	ABC News, 2014

Note: Values have not been adjusted and are presented as reported in original publications.

Chemical or Harmful Substance Contamination of Groundwater Sources

NGL pipelines pose risks to drinking water through groundwater contamination. When NGL pipelines leak or break, the compounds they transport, such as benzene and propane, may leak into groundwater, where they may persist for some time. Referred to as volatile organic compounds (VOCs), these contaminants are of significant concern when found in drinking water. For example, while benzene – a human carcinogen – does eventually biodegrade in groundwater systems, the rate at which it does so varies and is heavily dependent on local factors such as oxygen and nutrient levels or presence of other hydrocarbons (Agency for Toxic Substances & Disease Registry, 2007). In 2013, an NGL pipeline spill in Parachute, Colorado contaminated local soil and groundwater, with levels of benzene 3,600 times above the state's health standard (Stokols, 2013). The spill required extensive remediation (Finley, 2013).

Homeowners relying on private wells may not test for certain contaminants – such as VOCs – that can reduce water quality. Residents may only detect water quality issues based on taste and odor, an approach that is not a reliable method for protecting public health. When wells are contaminated, installing treatment systems or relying on alternative water sources can minimize health effects. Treatment costs may increase depending on the type and extent of the contamination. In some cases, groundwater remediation may not be feasible, and it may be necessary for homeowners to connect to a nearby municipal water supply. In Dimock, PA, the estimated cost of extending the municipal water infrastructure to an affected neighborhood was $11.8 million (Dutzik, et al., 2012). This value does not include the costs in water fees homeowners incur once connected. Filtration is another potential solution to VOC contamination in groundwater. Filtration, typically using canisters containing activated carbon, can be installed at the home's point of entry or at one or more points of use, such as faucets or showerheads (Oregon Department of Human Services Public Health Division, Date Unknown). These filters require regular maintenance to ensure a continual supply of safe drinking water.

Although PWSs are required to test for VOCs, pipeline construction could exacerbate existing vulnerabilities. NJ American Water Company – Elizabethtown Division reported 88 well systems with high susceptibility to VOCs and 7 surface water systems with moderate susceptibility (NJ American Water Company – Elizabethtown Division, Date Unknown). Once municipal wellfields have been contaminated, PWSs must minimize health effects by installing new or enhanced treatment at the wells or in customers' homes, or they must provide alternative water supplies.

Some researchers have also identified the potential for arsenic contamination in some areas along the PennEast pipeline. The geology in areas along the proposed PennEast pipeline includes rock that is rich in arsenic, and there is some concern that disturbance of these areas could release arsenic into groundwater. A letter submitted to the FERC argued that arsenic migration is possible as a result of construction activities such as drilling and blasting, and potentially during operation of the pipeline. Release of arsenic could result from changes in the pH, oxygen, and carbon levels in soils around the pipeline (Onstott, 2014). The likelihood of contamination is a topic of considerable debate—PennEast has claimed that the project would result in no significant threat of arsenic contamination in groundwater. If groundwater does become contaminated with arsenic as a result of the pipeline, additional water treatment may be needed. The cost of arsenic removal can vary. In one study, total capital investment costs for arsenic management technology ranged from $14,000 to $305,000 (Wang and Chen, 2011). Normalized costs ranged from $477 to $6,171 per gallon per minute of design capacity, and unit costs of total capital investment spanned from $0.09 to $1.11 per 1,000 gallons of treated water (Wang and Chen, 2011). Additionally, costs typically decrease as the system size increases, so small systems may face steeper unit costs.

Researchers have also expressed concern that the PennEast pipeline would pass through areas with high concentrations of radium. A letter submitted to the FERC raises concerns that activities associated with the PennEast pipeline would exacerbate existing radium groundwater contamination by mobilizing radium associated with the bedrock (Barringer and Onstott, 2017). The mechanisms by which this could happen are 1) creating a reducing environment due to cathodic protection on the pipe, leading to the dissolution of iron hydroxides to which the radium is adsorbed (thereby releasing the radium into the water as well as arsenic if present), 2) promoting microbial growth due to increased temperature, which would also contribute to the dissolution of iron oxides and release of radium, 3) exposing fresh rock surface to groundwater due to fracturing of the rock, and 4) contributing barium to the groundwater; barium will compete with radium for sorption sites on minerals, which will and favor radium remaining in the groundwater. The authors suggest that studies be conducted to assess the potential effect of pipeline installation and maintenance activities on the levels of radium in groundwater wells.

Research has not yet been conducted to evaluate the potential for HDD activities to affect the integrity of nearby water wells, including effects on the cement, casing, or other components. However, HDD will induce vibrations. Should vibration from HDD damage a water well, it could potentially establish a conduit for migration of fluids along the wellbore, and the potable aquifer may no longer be isolated from other formations. A 1980 study on the effects of blasting for mining looked for cases of damage to water wells in Appalachia. The authors did not find evidence of degradation of water quality, although there was a potential for a transient drop in storage capacity as the blasting increased the size of fractures (Berger and Associates, 1980).

Pipeline Safety Risks

The PennEast Pipeline would transport natural gas, and the Mariner East 2 transports NGLs, a type of hazardous liquid. Both pipelines are at risk of leaks, ruptures, and explosion, putting people and structures in the immediate vicinity of the pipelines at risk. The U.S. Department of Transportation

Pipeline and Hazardous Materials Safety Administration (PHMSA) maintains a record of the natural gas and hazardous liquids pipelines in the U.S. These data are publicly available and include detailed records of the lengths of pipelines and the number of leaks of natural gas and releases from hazardous liquid pipelines, as reported by pipeline operators. Data for 2010 through 2017 indicate that approximately 1,000 releases of hazardous liquids and 6,500 leaks of natural gas have occurred in the 8-year period (Table 15). This translates to approximately 0.0028 releases or leaks per mile-year of natural gas pipelines and 0.00064 releases or leaks per mile-year of hazardous liquid pipelines.

Table 15. Historic Frequency of Natural Gas Leaks and Hazardous Liquids Releases for Onshore Transmission Pipelines (2010 – 2017)

	Hazardous Liquids Pipelines	Natural Gas Pipelines
Total Mile-Years of Pipeline	1,539,182	2,348,419
Total Releases or Leaks	986	6,488
Releases or Leaks per Mile-Year of Pipeline	0.00064	0.0028

Source: U.S. DOT Pipeline and Hazardous Materials Safety Administration (2019)
Notes: Releases or leaks associated with equipment have been excluded from this analysis because above-ground equipment is not necessarily correlated to the length of pipeline and counts of equipment were not included in the data set.

Pipeline failure can have devastating effects. These ruptures may occur for a variety of reasons, from physical disturbance to corrosion. Additionally, there are concerns that pipelines that cross streams, whether perennial, intermittent, or ephemeral channels, are at an increased risk of rupture due to floods and high flow events (Fogg and Hadley, 2007).

There is also a risk of catastrophic failure of natural gas pipelines by ignition or explosions. These events pose more significant immediate risks and may result in property damage, injury, or even loss of life. The probability of occurrence and severity of these events depend of factors such as the materials being transported, the type of pipeline failure, and the surrounding population and development density. A risk analysis of 20-inch Mariner East 2 pipeline estimated that the ignition probability ranges from 1.4 percent for a 50 mm release at 3.4 kg/s to 100 percent for a full bore release at 1,586 kg/s (G2 Integrated Solutions, 2018). From 2010-2017, four natural gas pipeline ruptures or leaks ignited in Pennsylvania, two of which then exploded. In one of those incidents, 12 people were evacuated and one was injured (Thompson, 2017). Most recently, Energy Transfer Partner's Revolution pipeline exploded on September 10, 2018, sending fire 150 feet into the air. The explosion destroyed one home (about 500 feet from where the blast occurred), two garages, a barn, and several vehicles. There were no injuries as a result of the blast, but 25 homes were evacuated (Phillips and Frazier, 2018). Between 2005 and 2018, 29 fatalities and 133 injuries were sustained as a result of catastrophic failures of onshore gas transmission pipelines. In the same timeframe, "significant incidents"[4] associated with pipeline transmission have resulted in a reported $170 million dollars in costs to public property (i.e., property not owned by the pipeline operator) (U.S. DOT, 2019).

NGLs, like those transported by the Mariner East 2 pipelines, are hydrocarbons such as ethane, propane, butane, and others (U.S. Energy Information Administration, 2012). NGLs differ from liquid natural gas (LNG), which is natural gas that has been cooled and pressurized until it becomes liquid (Colaneri, 2013). NGLs are extremely flammable and can pose combustion threats in a variety of situations. Because these vapors are denser than air, they do not dissipate as easily as natural gas and thus can travel significant distances, potentially meeting a source of ignition and igniting, flashing back, or exploding (Conoco Phillips, 2012). This can occur both indoors and outdoors, and the product can float and become reignited on the surface of water (Conoco Phillips, 2012). Besides the hazards posed by ignition or explosion itself, combustion can produce hydrogen sulfide, carbon monoxide, and other hazardous gases that pose risks to human health (Conoco Phillips, 2012). High concentrations of hydrogen sulfide can pose serious respiratory health risks, such as pulmonary edema and respiratory paralysis (Conoco Phillips, 2012). Acute symptoms associated with an NGL leak include headache, drowsiness, nausea, vomiting, disorientation, and fatigue, while longer-term effects from prolonged exposure may include skin and eye dryness or irritation (Conoco Phillips, 2012). Benzene, which is one of the components of NGLs, may also pose human health risks in a leak due to carcinogenicity (Conoco Phillips, 2012). More information regarding safety issues associated with the Mariner East 2 pipelines can be found in *Chapter 6. Case Study on the Real Impacts of the Mariner East 2 Pipeline*.

Air Quality and Health Effects

Pipelines require construction of a wide array of infrastructure types, from the pipeline itself to access roads, compressor stations, and more. These activities generate carbon dioxide (CO_2), particulate matter (PM), and nitrogen oxides (NO_x) from machinery such as diesel-powered trucks and off-road equipment. In large enough concentrations, combustion from these engines has the potential to reduce ambient air quality (Jackson, et al., 2014). The PennEast EIS also notes that carbon monoxide (CO), sulfur dioxide (SO_2), and harmful VOCs such as formaldehyde (CH_2O) will be emitted in association with pipeline construction and operation.

Once operable, the PennEast pipeline would use one new compressor station and tie into an existing compressor station in Lawrence Township, NJ. Natural gas-powered compressor engines can emit an array of pollutants, including CO_2, CO, NO_x, VOCs, PM, and potentially SO_2 (Jackson, et al., 2014). PennEast estimates that the gas-powered Kidder Compressor Station would emit approximately 90 tons of NO_x, 17 tons of CO, 5 tons of SO_2, 24 tons of PM_{10}, 24 tons of $PM_{2.5}$, and 2 tons of CH_2O each year of continuous operation (FERC, 2017). A study evaluating the potential effect of planned compressor

[4] The PHMSA defines "significant incidents" as those that include a fatality or injury requiring in-patient hospitalization; $50,000 or more in total costs; highly volatile liquid releases of 5 barrels or more or other liquid releases of 50 barrels or more, and liquid releases resulting in an unintentional fire or explosion.

stations in four DRB counties found that 20 planned compressor stations would result in significant increases in NO_x emissions for three of the four counties evaluated (Habicht et al., 2015). The study also found that compressor stations would be a long-term source of NO_x emissions. It is worth noting that the study evaluated smaller compressor stations for gathering pipelines. The 47,700 horsepower (hp) Kidder Compressor Station planned for PennEast would be much larger than a compressor station for a gathering line and could produce higher localized emissions than those estimated in the Habicht analysis.

Proximity to pipelines and compressor stations has the potential to pose chronic health risks associated with long-term leaks and pollution exposure. Humans may be exposed to harmful airborne substances used or emitted by natural gas facilities via inhalation and dermal absorption. Many chemicals used in the natural gas industry have been shown to cause cancer and other long-term health impacts (Steinzor, et al., 2013). Construction and operation of compressor stations can produce toxic VOCs, which can degrade air quality and may cause an array of acute health effects from short-term exposure. Combustion products also result in ground-level ozone when VOCs are exposed to heat and sunlight (Subra, 2012). Over the long-term, health effects include loss of coordination and damage to the liver, kidneys, and nervous system, and some VOCs are known carcinogens (SPEHP, 2015). Compressor stations also emit PM, which may pose respiratory risks. Short-term inhalation may exacerbate existing pulmonary and cardiovascular disease, while long-term exposure may increase risks of cardiovascular disease and death (SPEHP, 2015). A 2017 study of 56 operational compressor stations in New York state found that these compressor stations emitted an estimated 40 million pounds of pollutants composed of 70 different chemicals from 2008 to 2014 (Russo and Carpenter, 2017). The study also found that these chemicals are linked to 19 major categories of human disease. These chemicals pose health risks to otherwise healthy individuals, but some populations are at greater risk, such as infants, children, pregnant women, the elderly, those with compromised immune systems, and those already suffering from specific diseases or disorders (Russo and Carpenter, 2017).

Compressor Stations and Air Pollution

A 2017 study of 56 operational compressor stations in New York state found that the stations emitted an estimated 40 million pounds of pollutants composed of 70 different chemicals from 2008 to 2014 (Russo and Carpenter, 2017).

Compressor stations have been estimated as the largest source of emissions for most pollutants from oil and gas production in PA, representing more than 80 percent of VOC emissions, 50 percent of NO_x, 60 percent for PM, and between 0-60 percent for SO_2 (Jackson, et al., 2014).

While the health effects of high exposure to these pollutants are known, there is not enough scientific research to fully understand the link between natural gas development and adverse health effects (Werner et al., 2015). Some literature has identified health outcomes based on distances from natural gas activities, most often associated with the well pad (Habicht et al., 2015). Even less research has been done evaluating potential health effects associated with pipelines. A 2009 survey of 31 people attempted to identify negative health effects potentially resulting from natural gas facilities in Dish, Texas. The study suggests that some residents experienced illness and detected odors potentially related to these facilities. For example, odors that may be related to compressor stations included sulfur smell, odorized natural gas, ozone, and a smell resembling burnt butter. The study also identified seven reported health effects potentially related to compressor stations (Subra, 2009). It is difficult or impossible, given current research, to ascertain what health effects will occur as a direct result of the pipeline and compressor station. Nevertheless, the pipelines and compressor station will contribute to pollution in the DRB and will contribute to the cumulative effects of natural gas development in the region.

Some public health groups have also argued that emissions from compressor stations are not well represented, as they often use tons per year as their unit of measurement, but do not emit uniformly over time (SPEHP, 2015). This variability may result in instances of high emissions and localized risk to public health that are not captured in averages over time. One example is the periodic occurrence of scheduled and accidental blowdowns at compressor stations. These events release natural gas from the blowdown valve and can last up to three hours, venting 15 MCf of gas on average (SPEHP, 2015). Based on our analysis, we estimate that approximately 13 people live within a half mile of the Kidder Compressor Station, 31 live within 1 mile, and 243 live within 2 miles. These individuals could experience exposure to elevated levels of pollutants from the compressor station. Proximity to the compressor station is not an explicit prediction of health outcomes, but these distances provide approximations of the population that could be exposed to compressor station emissions. However, without additional data and research on health outcomes related to proximity to a compressor station, we are unable to reliably predict how the Kidder Compressor Station would affect the health of these nearby residents.

Facilities for the Mariner East 2 pipelines include the Twin Oaks and Marcus Hook end stations and the Beckersville pump station. The Beckersville pump station will operate using electric power, and Sunoco therefore estimates that emissions will be relatively low. We estimate that approximately 250 people live within half a mile of the Beckersville pump station, 540 live within 1 mile, and 2,900 live within 2 miles. We estimate that approximately 500 people live within half a mile of the Twin Oaks facility, 4,600 live within 1 mile, and 45,000 live within 2 miles. Due to the proximity of the Marcus Hook facility and the Twin Oaks facility, we estimate that these population estimates will strongly overlap with those for the Marcus Hook facility.

The facility at Marcus Hook is located in an area that is already heavily industrialized. Nevertheless, the facility will contribute air emissions and further reduce ambient air quality. An analysis completed by the Clean Air Council estimates that the total emissions release related to the development at Marcus Hook to service the Mariner East pipelines will result in approximately 63 tons of NO_x, 163 tons of CO, 40 tons of SO_x, 14 tons of PM, and 13 tons of PM_{10} each year (Minott et al., 2018).[5] In addition to these stations, there will be numerous other emissions sources associated with Mariner East 2, such as pipeline and facility construction-related emissions and fugitive emissions from leaks of NGLs from valves, flanges, and holes in the pipeline. To our knowledge, data on the magnitude of these emissions is not available. Because of these missing data, and because the operations of the Mariner East 1 and Mariner East 2 pipelines are so intertwined, we do not know the total quantity of emissions from the Mariner East 2 pipelines and are unable to estimate the effects of its construction and operation on public health.

Noise and Health Effects

Construction activities associated with the pipeline and its supporting infrastructure, as well as compressor stations during operation, generate noise pollution. During construction, the communities along the pipeline ROW and near above ground facilities and access roads will be affected by noise, poor aesthetic conditions, construction traffic, and other disruptions in the community. Exposure to high decibel levels can have deleterious effects; studies have shown that excessive noise has been associated with a variety of psychological and physical human health effects. These include sleep disturbance, tinnitus, and cognitive impairment in children (SPEHP, 2015). Long-term exposure to noise levels between 32 and 75 A-weighted decibels (dBAs) has been linked to hypertension, sleep disturbance, and poor academic performance (Passchier-Vermeer and Passchier, 2000). Increases in chronic noise exposure has also been linked to an increased risk of diabetes (Sorensen et al., 2013). Furthermore, research suggests that some groups are more vulnerable to noise exposure. For example, children, the elderly, the chronically ill, and people with hearing impairment are most at risk for health impacts related to noise exposure (Van Kamp and Davies, 2013).

The area surrounding the compressor station face long-term increases in ambient noise. The maximum allowable decibel level for a compressor station is 55 dBA day-night average sound level at any preexisting noise sensitive areas under federal regulations (PennEast Pipeline Company, LLC, 2015b). The PennEast noise modeling analysis for the Kidder Compressor Station suggests that the station will not significantly increase the ambient sound level in the surrounding area. However, there is limited research that examines noise exposure from compressor stations and their effect on nearby communities. A 2017 pilot study that examined residential noise exposure in homes near natural gas compressor stations found that indoor noise levels in homes less than 300 meters from the stations were higher on average than noise levels in homes more than 1,000 meters away (53.4 versus 42.2 dBA) (Boyle et al., 2017). Homes as far as 750 meters (approximately half a mile) from a compressor station

[5] Because the Mariner East and Mariner East 2 pipelines use the same equipment at the Marcus Hook facility, we are not able to develop specific emissions estimates for Mariner East 2 alone. The Clean Air Council estimated emissions for the two pipelines at Marcus Hook using 2009/2010 as the baseline years for calculating the emissions increase. The calculations also assumed that the application would be submitted in 2018, which is used as the starting point to estimate the five- and ten-year lookback periods.

had average indoor ambient noise levels of 51.2 dBA, approximately 9 dBA higher than homes more than 1,000 meters away.

According to our analysis, approximately 13 people will live within half a mile of the Kidder Compressor Station. Boyle et al. (2017) also found that residents in homes less than 300 meters from the nearest compressor station may also be exposed to low frequency noise, which has been associated with annoyance, poorer performance, and sleep disruption. The authors conclude that residents living near a compressor station "are potentially exposed to noise levels that are higher than the recommended U.S. EPA levels of 55 dBA (outdoor/daytime) and 45 dBA (indoor/night time)." Additional research is needed to fully understand the effects of compressor station noise on nearby communities and vulnerable populations, but these findings suggest that compressor stations may contribute more to ambient noise levels than previously thought.

5. Analysis of Costs Associated with the PennEast and Mariner East 2 Pipelines

Key Findings

- The pipelines will result in a present value loss of ecosystem services of approximately $11 million (Mariner East 2) and $43 million (PennEast) as a result of land cover changes in the DRB. These values are based on a limited analysis and do not fully capture all ecosystem services or the land cover changes along the full lengths of the pipelines. They likely underestimate the full cost of lost ecosystems along the pipeline routes.
- The present value cost of emissions associated with long-term operation of Mariner East 2 at one pump station and at operations at the Marcus Hook facility is approximately $260 million. The present value cost of emissions associated with construction and operation of the PennEast pipeline would be $470 million. If we assume a high impact cost of carbon, the combined present value costs of these emissions could be as high as $2.2 billion.
- Based on the area cleared for the pipeline in the ROW, we estimate that the total value of cleared land in one county alone is approximately $1.4 million.
- Overall, one quarter of the land the PennEast pipeline is proposed to pass through is protected or preserved under conservation easements. Total costs of the easement acreage cleared for the temporary and permanent ROW for PennEast and Mariner East 2 are approximately $4 million.
- Mariner East 2 and PennEast could cost recreation goers approximately $2.8 million in lost recreational enjoyment as the pipelines are constructed. The long-term effects of the ROW on recreation are unknown.

Summary

This chapter describes the methods used to estimate the environmental and social costs associated with the PennEast and Mariner East 2 pipelines. The analysis consists of seven distinct analyses that build on the descriptions of the effects in the previous chapter, our GIS analysis, and the assumptions defined in the PennEast EIS. The distinct analyses address ecosystem services, climate, water quality, recreation, property value, protected areas, and agricultural production.

Some of these analyses evaluate the stream of costs associated with the PennEast and Mariner East 2 pipelines over numerous years. To do so, we discounted future costs to calculate the present value, which represents all future costs in 2017 U.S. dollars (USD) and allows for comparison of dollar amounts from various years.

Key assumptions are used throughout the analysis:

- A discount rate of 3 percent is used as a basis for calculating the present value of costs that will be incurred over many years. A sensitivity analysis adjusts this discount rate to demonstrate the effects of this assumption on the final results.
- The pipelines would be constructed over the course of 13 months. This approximation is consistent with the estimates provided in the PennEast EIS. This represents an underestimate for the Mariner East 2 pipelines, for which construction has experienced delays.
- All values have been adjusted to 2017 USD.
- The route for the PennEast pipeline is based on the pipeline centerline accurate as of September 2016. Any changes to the pipeline route subsequent to that date are not captured in this analysis. The route for the Mariner East 2 pipelines is based on accurate and complete geospatial information made available by the PA DEP.

We also assume that the life of the pipeline infrastructure will be 50 years. This assumption is based on the long life of numerous existing pipelines, many of which are more than 60 years old. To our knowledge, there is no precedent for pipelines relinquishing the legal ROW, and we assume that the effects of the pipeline on land use would continue for as long as the pipeline is in place. Therefore, we believe that 50 years is a reasonable estimate for the lifespan of the pipeline for the purpose of this analysis. We also assume that the pipelines will operate for 50 years (from 2020 to 2070), which is primarily applicable to the GHG cost analysis. This assumption is based on the understanding that PennEast will likely operate the PennEast pipeline for as long as gas is produced and transmitted to the region. We explore the degree to which these assumptions affect the outcome of the analysis in the *Sensitivity Analysis* section of this report.

Some components of the analysis lacked sufficient data or information about the likelihood of events to allow monetary costs to be determined. In these instances, we developed qualitative descriptions of potential effects. When possible, we also provided a potential range of costs corresponding to these events.

The table below summarizes the results for each portion of the analysis. We estimated that the largest cost is attributable to the cost of GHG emissions resulting from the construction and operation of the PennEast pipeline. These costs are estimated to range from approximately $500 million (using the average SC-CO_2) to approximately $1.6 billion (using a high SC-CO_2). The cost of GHG emissions was also the highest type of cost for the Mariner East 2. Costs associated with the loss of ecosystem services was the next highest cost in the analysis. We estimated that the loss in ecosystem services will range from nearly $17 million to $130 million for PennEast and from $4.3 million to $33 million for Mariner East 2. A detailed description of each individual analysis is included in the sections that follow.

Table 16. Summary of Environmental and Social Costs of PennEast and Mariner East 2 Pipelines

Type of Cost	Estimated Costs (PV 2017 USD)		
	Low	Medium	High
PennEast Pipeline			
Ecosystem Services*	$17,000,000	$43,000,000	$130,000,000
GHG Emissions*	$470,000,000	$470,000,000	$1,400,000,000
Lost Recreation Days**	$2,000,000	$2,000,000	$2,000,000
Conservation Easements**	$4,000,000	$4,000,000	$4,000,000
Subtotal PennEast Costs	*$493,000,000*	*$519,000,000*	*$1,536,000,000*
Mariner East 2 pipelines			
Ecosystem Services*	$4,300,000	$11,000,000	$33,000,000
GHG Emissions*	$260,000,000	$260,000,000	$800,000,000
Lost Recreation Days**	$810,000	$810,000	$810,000
Conservation Easements**	$169,000	$169,000	$170,000
Subtotal Mariner East 2 Costs	*$265,000,000*	*$272,000,000*	*$834,000,000*
Total Cost	**$758,000,000**	**$791,000,000**	**$2,370,000,000**

**These estimates include future costs and use a 3 percent discount rate to estimate present value (PV).*
*** A range of unit cost estimates were not available for these types of costs. Therefore, the same estimate is used for low, medium, and high estimates.*
Note: All individual estimates have been rounded to two significant figures and subtotals rounded to the nearest million dollars.

Ecosystem Services

As previously mentioned in *Chapter 1. Potential Effects on Ecosystem Services Along the Pipeline Route*, several researchers have estimated the total value of ecosystem services in and around the DRB using the benefit transfer method. One study estimated the total present value of New Jersey's ecosystem services to be approximately $370 billion over 100 years at a 3 percent discount rate (in 2004 dollars) (Liu et al., 2010). Another study estimated ecosystem services in the DRB at approximately $21 billion per year, which is equivalent to a present value of approximately $683 billion over 100 years (all in 2010 dollars) (Kauffman, 2016). In addition to the state- and DRB-level analyses, there is a 2017 study that estimated the lost ecosystem services values associated with the full PennEast pipeline to range from approximately $6 million to $22 million during the construction year and an annual loss of about $3 million to $10 million following construction (in 2015 dollars; Phillips et al., 2017).

Each of these studies calculated a different aggregate ecosystem services value for each land type. In our analysis, we selected ecosystem services values from the literature that we believe best represent the land types in our analysis, and we included the most comprehensive range of ecosystem services appropriate. We also excluded: ecosystem services that might result in double-counting values estimated elsewhere in this report; values estimated for land types that had characteristics significantly different from those captured in this study; and values estimated in countries with significantly different economies. The final ecosystem services values used in our analysis fall within the range of values estimated by these other studies, but differences in assumptions and selection of ecosystem services values results in a broad range of potential values. These differences highlight the degree of uncertainty in ecosystem services values in our specific region of focus, but they consistently demonstrate that ecosystem services have significant value that should be considered in cost analyses of projects that disrupt land cover.

As other studies recognize, there are considerable gaps in the literature for ecosystem services in each land type, preventing us from creating comprehensive value estimates. For this reason, and because of the conservative assumptions we make throughout our analysis, we believe that our range of costs likely underestimates the true value of the land that will be disturbed by the pipelines.

We examined the disruption of land cover caused by construction and the permanent ROW to estimate the loss in ecosystem services attributable to the PennEast and Mariner East 2 pipelines. Land cover estimates are based on our GIS analysis, summarized in Appendix A. The analysis assumes that ecosystem services will be lost in part or entirely as a result of this disruption, with the extent of disruption depending on the amount of land cover affected. The acreage of land cover disruption is multiplied by the duration of disruption and the value of the ecosystem services associated with each type of land cover to estimate the value of the ecosystem service loss.

Ecosystem Services Values

Ecosystem services are grouped by type of ecosystem—forests, scrub/shrubs, cultivated land, etc. Table 17 provides the minimum, average, and maximum ecosystem services values for each ecosystem type. These estimated values are the sum of the value of each ecosystem service in each ecosystem type. For example, the total value of an acre of temperate or boreal forest is the sum of the values of air quality control, biodiversity, erosion control, soil fertility, climate control, and waste processing. When more than one estimated value is available for a given ecosystem service, the analysis uses the minimum, average, and maximum values of these ecosystem services in the calculations. For some ecosystem services, only one estimate was available for a given ecosystem. In these cases, the same ecosystem service value is used for the minimum, average, and maximum calculations. A detailed breakdown of the values for each ecosystem is included in Appendix B.

As previously discussed, ecosystems provide a wide range of services. To avoid double-counting values included in other portions of this analysis, some types of ecosystem services were excluded from these calculations. For example, costs associated with recreation value are included in the *Recreation* analysis. Therefore, these ecosystem services values were not included in the values developed in Table 17.

Table 17. Minimum, Maximum, and Average Ecosystem Services Values by Ecosystem Type

Ecosystem	Ecosystem Services Values (2017 USD/acre/year)		
	Minimum	Average	Maximum
Forests	$888	$2,239	$6,545
Woodland and Scrub/Shrub	$168	$244	$395
Inland Wetlands	$6,195	$10,825	$19,865
Cultivated	$1,389	$1,412	$1,436
Grasslands	$76	$124	$188
Barren	$0	$0	$0
Fresh water	$543	$543	$543

Note: Values have been adjusted from original studies to 2017 dollars per acre per year.

Construction

During construction, it is assumed that the ecosystem services provided by land covers in both the temporary and permanent ROWs will be lost entirely for one full year. According to the PennEast EIS, construction and ROW restoration will take 13 months. After construction is completed, the land cover in the temporary ROW will be allowed to regrow. A conservative regrowth estimate (i.e., one that results in underestimating costs) of one year is assumed for wetlands, grasslands, and freshwater (the PennEast EIS estimated three years for regrowth in non-forested areas). Table 18 provides the results of the cost estimates for one year of lost ecosystem services in the temporary and permanent ROW during PennEast construction. The largest loss is associated with forest area, with an estimated loss from approximately $710,000 to $5 million.

Table 18. Estimated Economic Loss from Disrupted Ecosystem Services During Construction of PennEast Pipeline

Ecosystem	Temporary and Permanent ROW Acreage	Loss (in 1,000s 2017 USD)		
		Minimum	Average	Maximum
Forested	800	$710	$1,790	$5,200
Shrub-Scrub	34	$5.7	$8.2	$13
Wetlands	19	$120	$200	$400
Agricultural	476	$660	$670	$680
Grasslands	217	$17	$27	$41
Developed, Barren, Other	173	$0.0	$0.0	$0.0
Water	3	$1.5	$1.5	$1.5
Estimated Total Loss		*$1,500*	*$2,700*	*$6,000*

Note: All estimates have been rounded to two significant figures

Using the same assumptions for the construction of the Mariner East 2 pipelines, Table 19 provides the estimated monetary loss associated with ecosystem services for Mariner East 2.[6] It is worth noting that Mariner East 2 has faced numerous construction delays, which may have resulted in even higher losses associated with ecosystem services during the construction phase of the project. (See the *Chapter 6. Case Study on the Real Impacts of the Mariner East 2 Pipeline* for more details on delays associated with Mariner East 2.)

Table 19. Estimated Economic Loss from Disrupted Ecosystem Services During Construction of Mariner East 2 pipelines

Ecosystem	Temporary and Permanent ROW Acreage	Loss (in 1,000s 2017 USD)		
		Minimum	Average	Maximum
Forested	204	$180	$1,300	$460
Shrub-Scrub	9	$1.5	$3.5	$2.1
Wetlands	1	$4.2	$10	$10
Agricultural	71	$98	$100	$100
Grasslands	47	$3.6	$8.8	$5.8
Developed, Barren, Other	123	$0.0	$0.0	$0.0
Water	0	$0.0	$0.0	$0.0
Estimated Total Loss		*$290*	*$1,500*	*$570*

Note: All estimates have been rounded to two significant figures.

Forests cleared in the temporary ROW will require decades to regenerate. The forest area that would be disrupted by the PennEast pipeline is largely deciduous broadleaf forest, which includes several hardwood trees including species of beech (*Fagus grandifolia*), oak (*Quercus sp.*), red maple (*Acer rubrum*), and eastern hemlock (*Tsuga canadensis*). The PennEast EIS indicates that the time required to restore woody vegetation along the pipeline to preconstruction conditions would be more than 30 years, and in some cases hundreds of years. We estimated the loss in ecosystem services during regrowth periods of 30, 100, and 150 years. We assumed that previously forested acreage provides the ecosystem services values of grassland as the forest regrows, and the difference in value between forest and grasslands is used for the lost value over time. For example, the minimum estimated values of forests are $888 per acre and for grasslands are $76 per acre. In year one of this analysis, the loss in ecosystem services is estimated to be the difference between these values, approximately $811. Over the 50-year regrowth period, this value is reduced proportionally each year until it is $0 in the 50th year. Because the ecosystem service values for scrub-shrub are so close to those for grasslands, we did not estimate a loss associated with regrowth of the scrub-shrub in the temporary ROW. We conducted the same analysis for Mariner East 2 using the same assumptions.

[6] Note that the Mariner East 2 pipelines have been under construction for more than two years, so this assumption likely underestimates the costs associated with lost ecosystem services during construction.

Table 20 provides estimated values of economic loss resulting from disrupted ecosystem services as forests regrow in the temporary ROW for the PennEast and Mariner East 2 pipelines. For PennEast, this loss amounts to a present value of least $4 million and as much as $76 million, depending on the ecosystem services values used and the regrowth period.

Table 20. Present Value of Long-Term Economic Loss from Forest in the PennEast and Mariner East 2 Temporary ROWs

Regrowth Period	Ecosystem Services Loss (PV in 1,000s 2017 USD)		
	Minimum ES Value	Average ES Value	Maximum ES Value
PennEast Pipeline			
30-year regrowth period	$4,100	$11,000	$32,000
100-year regrowth period	$8,400	$22,000	$66,000
150-year regrowth period	$9,700	$25,000	$76,000
Mariner East 2 pipelines			
30-year regrowth period	$820	$2,100	$6,400
100-year regrowth period	$1,700	$4,400	$13,000
150-year regrowth period	$1,900	$5,100	$15,000

Ongoing Operation

Ongoing operation of the pipeline will result in permanent land cover changes. To estimate the loss of ecosystem services for this land cover, we compared land cover from before pipeline construction to the likely land cover that would exist in the permanent ROW after construction. For a conservative estimate, we assumed that wetlands, grasslands, agriculture, and fresh water areas will return to their original land cover, and we assumed no change in their associated ecosystem services values in the long term. This is a conservative assumption given the numerous effects of pipelines on ecosystems, as described earlier in this report.

We assumed that land in the permanent ROW previously covered by forest, scrub/shrub, and grasslands would be replaced by some form of grass. The permanent ROW would be maintained periodically by the gas company and that grasslands will be degraded as a result of this maintenance. However, the effect of this degradation on the ecosystem services values for grasslands is unknown. For a conservative estimate, this analysis uses the full ecosystem services value for grasslands. Table 21 summarizes the change in land cover for the PennEast permanent ROW.

Table 21. Change in Land Cover in PennEast Permanent ROW

Original Land Cover	Land Cover After Construction	Mariner East 2 Acres	PennEast Acres
Forests	Grasslands (Degraded)	111	337
Shrub-Scrub	Grasslands (Degraded)	5	13
Inland Wetlands	Inland Wetlands	1	8
Agriculture	Agriculture	35	156
Grasslands	Grasslands (Degraded)	24	85
Barren	Barren	61	41
Fresh water	Fresh water	0	1

As illustrated in the table above, forest and shrub-scrub are the only land cover types that would undergo significant changes in the permanent ROW (according to our conservative estimate). Furthermore, the ecosystem services values estimated for shrub-scrub and grasslands do not differ substantially relative to other land cover types (Table 17). Accordingly, we estimated the permanent change in ecosystem services only for the conversion of forest to grassland. The results in Table 22 demonstrate that the long-term loss of ecosystem services from forest cover cleared in the permanent ROW could be significant, with present value ranging from approximately $2 million to $18 million for Mariner East 2, and from $7 million to approximately $55 million for PennEast.

Table 22. Estimated Loss in Ecosystem Services Values from Permanent Loss of Forest Cover

Ecosystem	Ecosystem Services Loss (2017 USD)		
	Minimum ES Value	Average ES Value	Maximum ES Value
Forests	$888	$2,239	$6,545
Grasslands	$76	$124	$188
Difference	*$811*	*$2,115*	*$6,357*
PennEast			
Estimated Annual Loss for 337 acres	$270,000	$710,000	$2,100,000
Present Value over 50 Years	$7,000,000	$18,000,000	$55,000,000
Mariner East 2			
Estimated Annual Loss for 111 acres	$90,000	$230,000	$710,000
Present Value over 50 Years	$2,300,000	$6,000,000	$18,000,000

Note: All estimates have been rounded to two significant figures.

Summary of Ecosystem Services

As demonstrated in Table 23, PennEast would result in a present value loss of ecosystem services ranging from $17 million to $130 million. The average present value loss is estimated to be $43 million, with the largest loss associated with the many years required for the forest to regrow in the temporary ROW. Mariner East 2 will result in a present value loss of ecosystem services ranging from $4 million to

$33 million, with an average present value loss of $11 million. Note that the costs associated with the Mariner East 2 pipelines are much lower than those for the PennEast pipeline in large part because only a fraction of the Mariner East 2 pipelines are located in the DRB.

Table 23. Summary of Ecosystem Services Loss from Pipeline Construction and Operation

Type of Loss	Ecosystem Services Loss (PV in millions 2017 USD)		
	Minimum ES Value	Average ES Value	Maximum ES Value
PennEast			
Loss of all ES during construction	$1.5	$2.7	$6
Loss of forest in permanent ROW	$7.0	$18	$55
Loss of forest quality in temporary ROW (100-year regrowth)	$8.4	$22	$66
Total	*$17*	*$43*	*$130*
Mariner East 2			
Loss of all ES during construction	$0.3	$0.6	$1.5
Loss of forest in permanent ROW	$2.3	$6.0	$18
Loss of forest quality in temporary ROW (100-year regrowth)	$1.7	$4.4	$13
Total	*$4.3*	*$11*	*$33*
Total Estimate Loss for both Pipelines	**$21**	**$54**	**$160**

Note: All estimates have been rounded to two significant figures.

Climate

We estimated the cost associated with GHG emissions for the construction and operation of the PennEast pipeline and Mariner East 2 pipelines. As described in *Chapter 3. Other Environmental Effects*, the PennEast pipeline is expected to contribute to GHG emissions as a result of methane leaks during pipeline operation and as a result of combustion activities during construction and operation of the pipeline and compressor station. Our analysis estimates costs based on PennEast's reported emissions projections for the construction and operation of the pipeline (FERC, 2017). Estimates of emissions associated with the Mariner East 2 pipelines were more difficult to identify and separate from emissions associated with the first Mariner East pipeline. We used emissions estimates associated with the Beckersville pump station (located in the DRB) and the Marcus Hook facility to approximate climate costs associated with the Mariner East 2 pipelines.

PennEast Emissions

PennEast evaluated the GHG emissions that would result from the pipeline's construction and operation. The estimates are presented as CO_2e as part of its report to the Federal Energy Regulatory Commission (FERC, 2017). To calculate CO_2e, PennEast multiplied the mass of a given compound by its corresponding GWP. As discussed previously, the GWP is the factor by which a GHG traps heat relative to CO_2 (FERC, 2017). PennEast computed the CO_2e for each of the constituent components of natural gas, and these values are summed to obtain the total CO_2e GHG emissions (FERC, 2017). As a part of these calculations, PennEast assumed forcing factors of 1 for CO_2, 25 for methane, and 298 for N_2O and applied these values to estimates for project facility and pipeline construction activity emissions (FERC, 2017: Table 4.10.1-5), compressor station operations emissions (FERC, 2017: Table 4.10.1-6), pipeline operation emissions (FERC, 2017: Table 4.10.1-8), and the project's overall potential operational emissions (FERC, 2017: Table 4.10.1-9). Table 24 summarizes PennEast's emissions estimates.

Table 24. CO_2e Emissions During Construction and Lifetime Operation of PennEast

Activity	Emissions of CO_2e	
	Upfront Emissions (tons)	Annual Emissions (tons/yr)
Project Facility and Pipeline Construction Activity	33,276	N/A
Compressor Station Operation	N/A	190,529
Combustion	*N/A*	*190,332*
Fugitive Leaks and Vents	*N/A*	*197*
Pipeline Operation	N/A	69,188
Combustion	*N/A*	*47,766*
*Fugitive Leaks and Vents**	*N/A*	*21,423*
Total	**33,276**	**259,717**

Source: FERC, 2017; Tables 4.10.1-5, 4.10.1-6, 4.10.1-8, 4.10.1-9
**PennEast's estimate uses an estimated rate of fugitive leakage of 1.55 standard cubic feet of natural gas per day per mile of pipeline, from EPA's 2014 reference document "Oil and Natural Gas Sector Leaks".*

In addition, PennEast estimates that an additional 21.3 million metric tons of GHGs (in the form of CO_2e) will be released each year as a result of downstream end-use of the gas delivered by the pipeline. These emissions are not considered part of the pipeline development and operation and are outside the scope of this cost assessment. Nevertheless, this represents a significant additional release of GHGs each year and should not be overlooked when evaluating energy procurement options.

Because PennEast reported these values in terms of CO_2e, we used the SC-CO_2 when calculating the costs of these emissions. As discussed previously, the SC-CO_2 is a metric that quantifies the present value of the total cost of a ton of CO_2 (or equivalent) emission over 100 years. This cost varies depending on the year in which the emission occurred because the SC-CO_2 increases over time due to GDP growth and larger incremental damages from increasingly stressed social systems. Our analysis uses EPA's SC-CO_2 estimates, which represent the average value in a modeled distribution of outcomes. As seen in Figure 6, the right tail of the distribution is long, meaning that the upper estimate of potential cost of CO_2 emissions is very high. Furthermore, recent scientific literature also suggests that the SC-CO_2 should be higher than estimated by EPA (Pindyck, 2019).

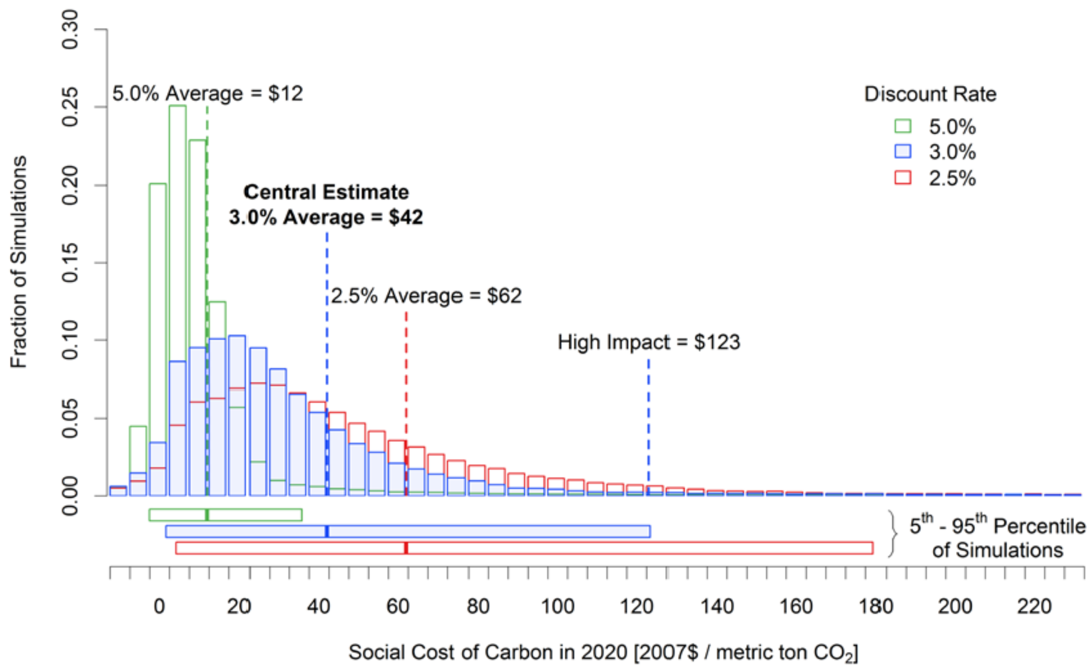


Figure 6. Modeled Distribution of SC-CO_2 Estimates

Source: U.S. Interagency Working Group on Social Cost of Greenhouse Gases, 2016, Figure ES-1: Frequency Distribution of SC-CO_2 Estimates for 2020

We assumed that the useful life of the PennEast pipeline will be 50 years, but EPA's SC-CO_2 estimates end at 2050. Therefore, we used the SC-CO_2 estimates for 2040 through 2050 to extrapolate the values for 2051-2070. Table 25 presents the SC-CO_2 by Year of Emission (in 2017 dollars) that we used for this analysis. For brevity, the table contains the value every ten years, but our calculations use EPA's annual cost estimates.

Table 25. Social Cost of Carbon per Metric Ton of CO_2e by Year of Emission (2017 USD)

Year	3% Discount Rate		Average Cost at 5% Discount Rate	Average Cost at 2.5% Discount Rate
	Average	High Impact (95th Percentile)		
2020	$49	$144	$14	$73
2030	$59	$178	$19	$86
2040	$70	$215	$25	$99
2050	$81	$249	$31	$112
2060*	$92	$283	$36	$125
2070*	$103	$316	$42	$138

Source: *U.S. EPA Social Cost of Carbon (2017), figures have been converted to 2017 USD per metric ton.*
*EPA's SC-CO_2 estimates end at 2050. Using that data, we extrapolated out these values.

EPA specifies that the "future monetized value of emission reductions in each year (the SC-CO_2 in year *t* multiplied by the change in emissions in year *t*) must be discounted to the present to determine its total net present value for use in regulatory analysis." (U.S. Interagency Working Group on Social Cost of Greenhouse Gases, 2016). EPA's average annual SC-CO_2 estimates were calculated using 5 percent, 3 percent, and 2.5 percent discount rates. Accordingly, our analysis calculates the present value of all future emissions using these same discount rates.

Table 26 provides our results for the present value of the SC-CO_2 of GHG emissions released from PennEast pipeline activities in 2017 dollars. The costs have been broken down by pipeline activity and estimated with a range of discount rates. Estimated emissions are smallest in construction activities and highest in compressor station operation. The total cost using the average SC-CO_2 ranges from $110 million with a 5 percent discount rate to $740 million with a 2.5 percent discount rate.[7] These estimates assume that methane has a forcing factor of 25 for CO_2 equivalency, which may be conservative and underestimate the actual costs associated with methane leakage. If we assume a high impact with a 3 percent discount rate, costs could be as high as $1.4 billion over the life of the pipeline.

Table 26. SC-CO_2 of PennEast Construction, Compressor Station Operation, and Pipeline Operation (Millions 2017 USD)

Activity	PV Cost of Carbon Using 3% Discount Rate		PV Cost of Carbon (Using Average Cost at 5% Discount Rate	PV Cost of Carbon (Using Average Cost at 2.5% Discount Rate)
	Using Average Cost	Using High Impact Cost (95th Percentile)		
Pipeline Construction	$1.6	$4.8	$0.5	$2.4
PV Operation – Compressor Station	$350	$1,000	$81	$550
PV Operation – Pipeline	$120	$370	$29	$190
Total	*$470*	*$1,400*	*$110*	*$740*

Note: All estimates have been rounded to two significant figures.

EPA's estimates of the SC-CO_2 do not include a low and high estimate at each of the discount rates, and we are unable to develop SC-CO_2 estimates for these values using the information provided in EPA's technical report. Therefore, our analysis is limited to the SC-CO_2 estimates EPA provided (as represented in Table 26). The results in Table 26 suggest that the price of carbon has a larger effect on the results than the uncertainty in the discount rate. The total present value of costs for EPA's average SC-CO_2 range from $110 million using a 5 percent discount rate to $740 million using a 2.5 percent discount rate, a difference of about $630 million. In contrast, the variation in the present value of costs using EPA's average and high SC-CO_2 under a 3 percent discount rate is approximately $930 million ($1.4 billion minus $470 million). Because recent scientific literature suggests that the SC-CO_2 should be

[7] Note that EPA did not provide the high impact value of SC-CO_2 at different discount rates. Therefore, we were unable to estimate the high impact cost of carbon at the 2.5 percent and 5 percent discount rates.

higher than estimated by EPA (Pindyck, 2019), there is reason to believe that EPA's average SC-CO_2 is a low estimate under any of the above discount rates.

Current scientific literature also suggests that the methane forcing factor is higher than that used by PennEast to calculate CO_2e. As noted previously, PennEast used a value of 25 for methane over a 100-year lifetime. While this value is within the possible range of forcing factor estimates, it is at the lower range of current estimates and may be outdated. IPCC's Fourth Assessment Report, published in 2007, provides the GWP for methane as 25. This estimate is consistent with that used by PennEast, but out of date. Additional EPA sources have included that value as well, citing the IPCC report. However, IPCC's more recent Fifth Assessment Report, published in 2013, updated methane's forcing factor to 28 as a low estimate and 34 as a high estimate over a 100-year lifetime, depending on whether climate-carbon feedbacks are included. Additional EPA sources cite similar values. Table 27 provides the ranges in IPCC and EPA publications.

Table 27. Methane Forcing Factor Estimates

Source	Low Estimate	High Estimate	Lifetime (years)
PennEast Environmental Impact Statement (2017)	25	25	100
IPCC Climate Change 2013 Fifth Assessment Report	28	34*	100**
EPA's Climate Change Indicators in the United States (2016)***	28	36	100
EPA's Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016****	25	25	100
EPA's Understanding Global Warming Potentials	28	36	100

*This value includes climate-carbon feedbacks.
**Over shorter timeframes this number increases: 84-86 over 20 years.
***Cites IPCC's 5th Report
****Cites IPCC's 4th Report
Sources: Myhre and Shindell, 2013; EPA, 2016; EPA 2018; EPA 2017

Based on PennEast's estimates in Table 24, the compressor station and pipeline will release 21,620 tons of CO_2e per year through fugitive leaks and vents. If we estimate that these CO_2e derive from methane using PennEast's applied forcing factor of 25, we calculate that a higher forcing factor of 36 would increase these CO_2e emissions to approximately 31,000 tons per year. This represents a 14 percent increase in PennEast's annual emissions from the pipeline, but this increase is minor when compared to the compressor station emissions (190,529 tons of CO_2e).

Mariner East 2 Emissions

To our knowledge, there is no comprehensive estimate of emissions associated with the construction and long-term operation of the Mariner East 2 pipelines. Furthermore, the Mariner East 1, 2, and 2X pipelines operate jointly using much of the same equipment and infrastructure. This makes it difficult to isolate emissions for the Mariner East 2 pipelines, which is the scope of this analysis. Sources of emissions connected with the Mariner East 2 pipelines include:

- Pipeline construction-related emissions from vehicles, drilling equipment, blasting, earthmoving (dust), etc.
- Facility construction-related emissions for pumping stations, valve stations, and terminal facilities
- Fugitive emissions from leaks of NGLs from valves, flanges, and holes in the pipes
- Operational emissions from running the pumping stations, including running the pumps, venting product, and launching "smart pigs"
- Operational emissions from the terminal facilities, most prominently the Marcus Hook facility

In addition, similar to the PennEast pipeline, the Mariner East 2 pipelines will result in downstream emissions from the portion of the NGLs that are burned and from the energy used to process the rest into plastics. We were able to collect data to estimate emissions associated with operation of one of the pump stations and the operational emissions from the Marcus Hook terminal facility.

CO_2e emissions from the Marcus Facility end station added by the Mariner East projects is equivalent to approximately 177,000 tons per year (Minott et al., 2018).[8] The Beckersville pump station, located in the DRB, will operate on electric power continuously at 1,750 hp (PA DEP, 2017a). Using a standard conversion of 0.746 kilowatts per hp, we estimate that the pump station will require 11.4 kilowatt hours each year. The U.S. Energy Information Administration estimates that on average in Pennsylvania, each megawatt hour of electricity generated emits 816 pounds of CO_2 (EIA, 2019). Assuming that these emissions stay relatively constant, and if we add 113 tons of CO_2e emissions annually from flaring (PA DEP, 2017a), we estimate that the pump station will generate 4,346 tons of CO_2 each year. We believe this to be a conservative estimate because the pumps are not the only electrical load at the pump stations.

Because all Mariner East pipelines share these facilities, we adjusted these estimates to reflect the burden of the Mariner East 2 pipelines based on throughput relative to that of Mariner East. We estimated that the Mariner East 2 pipelines will deliver approximately 80 percent of the throughput of all Mariner East pipelines (Hurdle, 2019). Therefore, we estimated that approximately 80 percent of the emissions from the pump station and Marcus Hook will be attributable to Mariner East 2. Table 28 summarizes these results.

---

[8] Because Mariner East and Mariner East 2 use the same equipment at the Marcus Hook facility, we are not able to develop specific emissions estimates for Mariner East 2 alone. The Clean Air Council estimated emissions for the two pipelines at Marcus Hook using 2009/2010 as the baseline years for calculating the emissions increase. The calculations also assumed that the application would be submitted in 2018, which is used as the starting point to estimate the five- and ten-year lookback periods.

Table 28. Estimated CO_2e Emissions for Mariner East 2 pipelines

Emissions Source	Total Estimated Annual CO_2e	CO_2e Associated with Mariner East 2
Beckersville Pump Station	4,346	3,464
Marcus Hook Facility	176,622	140,786

Using the same methodology applied to the PennEast GHG cost analysis, we estimated that operation of the Mariner East 2 facilities over 50 years will result in a present value social cost of at least $270 to $810 million at the average and high impact cost of carbon. We consider these estimates to underestimate the full cost of emissions because of the numerous emission sources we were unable to include in this analysis.

Table 29. SC-CO_2 of Emissions Associated with Mariner East 2 (Millions 2017 USD)

Activity	PV Cost of Carbon Using 3% Discount Rate		PV Cost of Carbon (Using Average Cost at 5% Discount Rate	PV Cost of Carbon (Using Average Cost at 2.5% Discount Rate)
	Using Average Cost	Using High Impact Cost (95th Percentile)		
Marcus Hook Facility	$260	$790	$60	$410
Beckersville Pump Station	$6	$20	$1	$10
Total	*$270*	*$810*	*$61*	*$420*

Note: All estimates have been rounded to two significant figures. Totals may not sum due to rounding.

Water Quality, Drinking Water and Health Effects

Contamination of Private Wells

As noted earlier in *Chapter 4. Health and Safety*, pipeline routes are often near private wells. If pipeline construction or operation activities contaminate a well's source water or diminish a well's supply, homeowners have limited options to ensure continued water supply.

In our analysis of the PennEast and Mariner East 2 pipelines, we identified drinking water wells along the pipeline routes and categorized them by distance to the well. The distance ranges, presented in Table 30, represent a three-tiered classification system. Each tier provides an estimate of the amount of time it would take for materials spilled at the surface to migrate to the well. Tier 1 represents two years, Tier 2 represents five years, and Tier 3 represents 12 years. Our analysis evaluated each well's maximum risk tier based on closest intersection with the pipelines. These tiers do not indicate certainty; a well located in Tier 1 will not necessarily be contaminated, and wells further than 1,310 feet will not necessarily remain uncontaminated. However, we believe these groupings provide a reasonable bundling of risk based on proximity. A recent study noted the New Jersey Department of Environmental Protection suggested a 1,000-foot monitoring radius from the pipeline (Phillips, et al., 2017). According to our analysis, approximately 1,600 domestic wells could be at risk of contamination, and nearly 500 domestic wells are within close range of one of the pipelines.

Table 30. Number of Drinking Water Wells in Proximity to Mariner East 2 and PennEast Pipelines

Pipeline	Number of Drinking Water Wells in Proximity to Pipeline			
	Tier 1: < 544 ft	Tier 2: 544 – 860 ft	Tier 3: 860 – 1,310 ft	Total Wells within 1,500 ft
Mariner East 2	205	129	368	785
PennEast (domestic)	273	129	292	792
Total Number of Wells	**478**	**258**	**660**	**1,577**

Given the numerous factors required to calculate the probability of a spill, it is not feasible to evaluate that probability or estimate the likely costs in this report. However, in the event that wells become contaminated through pipeline construction or operation activities, homeowners would lose their water source, possibly permanently. As described in the previous chapter, homeowners would be forced to connect with an existing system, install whole-home treatment systems that require replacement, or rely on bottled water. While alternative water provision incurs additional costs to homeowners, contamination of private wells may also affect home values. In one study, researchers determined a two to six percent depreciation in a home's value when its private, potable well is contaminated, which gradually increases again only once water quality has been remediated (Guignet et al., 2015). While this study primarily focused on nitrogen-based contamination, its findings suggest that when a home's private well is contaminated and rendered unusable, home value decreases. While we cannot predict the likelihood of well contamination, there are numerous examples of well contamination along portions of the Mariner East 2 pipeline. *Chapter 6. Case Study on the Real Impacts of the Mariner East 2 Pipeline* provides additional detail on the effects contaminated well water can have on homeowners.

High Turbidity at Water Treatment Systems

In addition to contaminating private wells, increased turbidity in surface water supplies can affect raw water quality and lead to increased costs for drinking water systems to mitigate the problem. There are a number of non-treatment approaches that systems may take, such as increased source water protection, implementation of watershed best management practices, selecting among different water sources, and regionalization. These alternatives may not always be feasible, so water systems may turn instead to treatment technologies to address turbidity. These processes can include increased or enhanced coagulation, flocculation, sedimentation, and filtration. As discussed in the previous chapter, changes in treatment can have corresponding effects on costs.

Table 31 details the number of PWSs (both surface water and groundwater) that our analysis identified as being located near the pipelines and that may be affected by construction and operation. Although information on source water intakes is not publicly available due to security concerns, we do know that the source water supplies are located in areas that will be affected by pipeline ROWs. The drinking water intakes must be subject to some risk of water contamination, but that risk is unknown. Depending on the source water type and location, intakes may be vulnerable to problems such as increased sedimentation, increased turbidity, and chemical contamination. Given the information on the potential cost implications of the water quality changes identified in the previous chapter, these systems may face increased costs for various treatment techniques. Additional expenses may range from costs associated with making operational changes to existing conventional treatment (e.g. increasing coagulant dose, reducing flows to allow greater settling during treatment, shortening filter run times) to costs of installing additional treatment (e.g. granular activated carbon).

We grouped water systems into two groups: "likely at risk" and "possibly at risk" of impact. Groundwater PWSs that are likely at risk are those for which a portion of the ROW falls within the groundwater influence zone (Tier 1, 2, or 3) for at least one of the source wells. If the ROW is located slightly beyond the Tier 3 zone, it is classified as a possibly at risk. Surface water PWSs that will likely be at risk are those with a pipeline clearing within the watershed that drains directly to a potable use stream or reservoir used by the system. Those that are possibly at risk have a credible potential for runoff from pipeline activities to affect the PWS's water supply, although it may be downstream. For example, PWSs that use the D&R Canal are considered possibly at risk.

Table 31. Number of Surface and Groundwater PWSs Near the PennEast and Mariner East 2 Pipelines

Pipeline	Number of PWSs Likely at Risk	Number of PWSs Possibly at Risk	Estimated Population Served at Risk	Estimated Population Served Possibly at Risk
Mariner East 2	2	1	*49,900*	*35,518*
PennEast	13*	8	*123,966*	*947,372*
Total	**7**	**9**	***173,866***	***982,890***

*Includes eight PWSs that purchase water from a likely impacted PWS
PWS population estimates from U.S. EPA's Safe Drinking Water Information System

Table 31 presents the number of PWSs that are likely or possibly at risk from pipeline activity as well as the number of individuals served by those PWSs. Along the Mariner East 2 pipelines, two PWSs will likely be at risk, and one is possibly at risk; these PWSs serve a combined population of approximately 85,000 individuals. The PennEast pipeline affects far more PWSs, with 13 likely at risk and eight possibly at risk. Of the 13 PWSs likely at risk, eight are at risk given their purchase of water from the City of Bethlehem PWS, a system whose sources – Wild Creek and Penn Forest Reservoirs – would likely face water quality changes due to pipeline activities. In total, the number of individuals likely or possibly facing direct effects on their drinking water from the PennEast pipeline totals approximately 1,071,000. Overall, approximately 1,157,000 individuals consume water that will likely or possibly be affected by the PennEast and Mariner East 2 pipelines.

Other Costs

Our analysis estimates that the largest costs associated with the pipeline are captured in the loss of ecosystem services, water quality and habitat degradation, and GHG emissions. Nevertheless, there are many other costs associated with the pipeline, as noted in the previous chapters. Although these costs are smaller in magnitude, they nevertheless demonstrate the breadth of detrimental effects the pipeline could have on the DRB region. Our analysis was able to monetize some of these costs, but it is challenging or impossible to estimate the monetary value of all costs.

Recreation

As previously described, the construction of the PennEast and Mariner East 2 pipelines will likely disrupt recreation activities in the region. We estimated the cost of this disruption by estimating the approximate loss in recreation days associated with pipeline construction and multiplying those lost days by the value of recreation (measured by the person-day value of each recreation activity).

We estimated that there are approximately 10 million person-days per year dedicated to freshwater fishing in the DRB, and approximately 1.3 million of those fishing days occur in a HUC-12 watershed crossed by the Mariner East 2 or PennEast pipelines (Table 32). Based on our analysis, the DRB supports nearly 14 million person-days of hunting each year (big game and bird hunting), and approximately 1.8 million of those person-days are spent in a HUC-12 watershed crossed by the Mariner East 2 or PennEast pipelines. Table 32 provides an estimated number of person-days of wildlife-based recreation in the DRB and in the watersheds that are or will be crossed by the Mariner East 2 and PennEast pipelines. These estimates are derived from EPA's EnviroAtlas database and provide an estimate of recreation demand in the region.

Table 32. Estimated Person-Days of Recreation per Year in the Delaware River Basin and Watersheds Affected by Mariner East 2 and PennEast Pipelines

Geographic Location	Estimated Person-Days of Recreation Activity per Year				
	Bird Watching	Bird Hunting	Big Game Hunting	Freshwater Fishing	Total
Delaware River Basin	7,200,000	500,000	13,200,000	9,900,000	30,800,000
HUC-12 Watersheds Crossed by PennEast	600,000	40,000	1,300,000	900,000	2,840,000
HUC-12 Watersheds Crossed by Mariner East 2	300,000	20,000	500,000	300,000	1,120,000

Source: EPA EnviroAtlas

To estimate the total recreation area disturbed by the pipeline, we calculated the total cleared area for the temporary and permanent ROWs plus the 100-meter "buffer zone" discussed previously in the *Recreation* section of the *Chapter 2. Potential Effects on Industries*. This is the land area that is expected to incur wildlife disruption resulting from the short-term effects of pipeline construction (e.g., noise and vibrations from blasting and digging). Next, we calculated the proportion of this disrupted area as a percentage of the total land area in the HUC-12 watersheds crossed by the pipelines. We then estimated the number of person-days of wildlife-based recreation lost along the pipeline route by applying this percentage to the total estimated person-days of recreation in the watersheds. For lack of more detailed recreation data, this analysis assumes that recreation activities are evenly distributed throughout each HUC-12 watershed.

It is possible that these recreation days would not be entirely lost. For example, a person that usually visits one of the areas affected by pipeline construction may choose to go to a different location.

However, the person is unable to visit the first-choice location, and additional travel or other expense may be incurred to reach an alternative location. It is also possible that some people may entirely avoid recreation activities in the area during pipeline construction because of possible reduction in enjoyment. Without more accurate data on exactly how construction will affect recreation decisions, a more precise analysis is not possible. It is important to note that this analysis does not estimate losses associated with hiking. We estimate that PennEast will cross a total of 16 recreational trails and Mariner East 2 will cross a total of 11 recreational trails (non-HDD). The costs associated with trail disruption and reduced aesthetics are not accounted for in our cost analysis.

We believe that our approach provides a reasonable approximation of the potential loss of recreation for bird watching, bird hunting, big game hunting, and freshwater fishing. Table 33 provides a summary of estimated lost recreation days by pipeline and recreation activity.

Table 33. Estimated Loss of Recreation Days Associated with Pipeline Construction

Recreation Activity	Total Recreation Days in Affected Watersheds	Loss in Recreation Days in the DRB	
		Mariner East 2*	PennEast
Bird Watching	910,000	6,000	13,000
Migratory Bird Hunting	60,000	-	1,000
Big Game Hunting	1,711,000	10,000	25,000
Freshwater Fishing	1,261,000	8,000	19,000
Total	*3,942,000*	*24,000*	*58,000*

**The lost recreation days for Mariner East 2 include those located in the Susquehanna River Basin directly adjacent to the DRB.*
Recreation days are represented as person-days.

We calculate the estimated cost of lost recreation associated with pipeline construction by multiplying the lost recreation days in Table 33 by the person-day recreation values identified in Table 9. The results (presented below in Table 34) suggest that Mariner East 2 and PennEast pipelines could cost recreation goers approximately $2.8 million in lost recreation enjoyment as the pipelines are constructed.

Table 34. Estimated Cost Associated with Lost Recreation Days in the DRB

Recreation Activity	Average Value per Person Day	Cost of Lost Recreation Days (1,000s 2017 USD)		
		Mariner East 2*	PennEast	Total
Bird Watching	$73	$210	$480	$690
Migratory Bird Hunting	$41	$7.5	$18	$26
Big Game Hunting	$73	$380	$920	$1,300
Freshwater Fishing	$58	$220	$550	$770
Total		*$810*	*$2,000*	*$2,800*

**The lost recreation days for Mariner East 2 include those located in the Susquehanna River Basin directly adjacent to the DRB.*
Note: All estimates are rounded to two significant figures. Totals may not sum due to rounding.

Loss represented in Table 34 does not include other economic losses associated with these recreation activities (such as travel costs, access fees, subscriptions, or equipment rentals). These estimates also do not account for losses associated with other recreation activities in the region (such as hiking) or the long-term detrimental effects the pipeline might have on recreation activities in the region. Therefore, these estimates can reasonably be considered lower-bound costs resulting from the pipelines.

Protected Areas

As discussed in *Chapter 2. Potential Effects on Industries*, the PennEast and Mariner East 2 pipelines will intersect numerous protected areas in Pennsylvania and New Jersey. Our analysis identified 89 distinct protected areas through which the pipelines pass, with the area affected totaling approximately 470 acres. Included in the 89 protected areas, our analysis identified:

- federal, state, and public lands
- hunting areas
- farm easements, and
- other privately held conserved land.

Notably, PennEast will result in approximately 40 acres of total (temporary and permanent) cleared land in Hickory Run State Park, 100 acres in PA State Game Lands, and 50 acres in the Nature Conservancy's Wild Creek. See Figure 2 for a map of protected areas crossed by the pipelines.

Protected Areas Crossed by PennEast

Overall, one quarter of the land the PennEast pipeline is proposed to pass through is protected. The pipeline would cross 69 properties with agricultural, open space, recreation, and other types of conservation easements.

These protected lands provide a number of important services to the region, such as habitat, agricultural production, recreation, and more. These services – which constitute much of the value of protected lands – are accounted for in the ecosystem services portion of this analysis. However, additional investment has been made to protect these lands for conservation through public acquisition or the purchase of easements.

According to our analysis, the PennEast pipeline crosses 69 properties with agricultural, open space, recreation, and other types of conservation easements. Conservation easements are purchased, typically by conservation organizations or government, to preserve land for a specific conservation purpose. These easements represent an investment by the conservation organizations or public to protect the land. Conservation easement costs can vary based on location, zoning, development potential, nature of the easement, and current market conditions. We estimated the value of land protected in fee or through easements in the counties crossed by the pipelines to calculate a cost associated with the disruption of this protected land. We collected historic data from the Trust for Public Land's Conservation Almanac to estimate the per acre cost of these easement and fee-protected lands. These estimates are summarized in Table 35.

Table 35. Estimated Cost of Protected Land in Pennsylvania and New Jersey

County, State	Average Easement Cost Per Acre	Average Fee Cost Per Acre
Berks County, PA	$3,000	$11,000
Bucks County, PA	$9,000	$36,000
Carbon County, PA	$5,000	$14,000
Chester County, PA	$10,000	$28,000
Delaware, PA	$7,000	$14,000
Luzerne County, PA	$4,000	$7,000
Hunterdon, PA	$6,000	$19,000
Northampton County, NJ	$9,000	$10,000
Mercer, NJ	$11,000	$16,000

Source: The Trust for Public Land's Conservation Almanac, www.conservationalmanac.org

Applying these values to the acres of land disrupted in each county in the DRB, we estimate that PennEast and Mariner East 2 will result in a loss of approximately $4 million. These costs are summarized in Table 36. We estimate that Mariner East 2 disrupted only 18 acres of easement or fee-protected land in the DRB, totaling approximately $170,000 in cost (not included in table). However, only a small portion of Mariner East 2 is located in the DRB, and while outside the scope of this analysis, the costs associated with land along the entire pipeline could be significantly larger.

Table 36. Estimated Loss in Conservation Easement and Fee-Protected Land for PennEast

State	Easement		Fee		Total Protected Land	
	Acres	Cost	Acres	Cost	Acres	Cost
PA	99	$600,000	180	$1,700,000	278	$2,300,000
NJ	165	$1,300,000	27	$400,000	192	$1,700,000
Total	*264*	*$1,900,000*	*206*	*$2,100,000*	*470*	*$4,000,000*

Although the easements will still be in place after pipeline construction, the purpose of the easements has been overridden by the pipeline. With the pipelines' construction, land that was once a large, unfragmented forest home to game species, migratory birds, recreational opportunities, and more, would be split by with a wide swath of permanently-cleared right-of-way. The fundamental purpose of an easement is to preserve the land from residential or industrial development through a financial investment; the development of a permanent ROW through an easement would defeat this purpose and the public's and organizations' investment. These lands were preserved because they have high value ecosystems or agricultural soils. Construction of a pipeline through these preserved areas is a change of use that the easements are expressly intended to prevent. Therefore, we assume that the investment to protect the acreage with easements has been essentially lost. In addition, the losses in the ROW can diminish the value of the surrounding land under easement, such as through ecosystem fragmentation. This loss is not included in our analysis and would be in addition to the figures in Table 36.

Property Value

We conducted an analysis of the value of parcels crossed by the pipeline in Hunterdon County, NJ to estimate the value of land cleared for the pipeline. Comparing Hunterdon County Parcels data for 2018 against our GIS maps of the PennEast pipeline, we estimated that land will be cleared on approximately 180 parcels to accommodate the pipeline in Hunterdon County. The collective value of those parcels is approximately $29 million (Table 37). Based on the area cleared for the pipeline in the ROW, we estimate that the total value of land cleared for the pipeline in one county alone is approximately $1.4 million.

Table 37. Value of Parcels Cleared for PennEast in Hunterdon County, NJ

Parcel Type	Number of Parcels in ROW	Parcel Area affected by ROW (Acres)	Total value of all parcels with any clearing	Total land value of cleared area	Land value of cleared areas as a percentage of total parcel value
Residential	50	43	$17,100,000	$950,000	5.6%
Farm	97	298	$1,900,000	$120,000	6.3%
Commercial	6	12	$6,900,000	$160,000	2.3%
All other	26	38	$3,200,000	$190,000	5.9%
Total	*179*	*391*	*$29,100,000*	*$1,420,000*	*4.9%*

Source: Hunterdon County Parcel Data (2018)

It is important to note that this does not represent a loss in property value. Rather, it demonstrates that the collective value of the land the pipeline will disrupt is high. The actual loss of property value associated with the pipeline could be higher or lower than the value of areas cleared for the ROW. Additionally, these data represent Hunterdon County parcels only. The pipeline will pass through the heart of other counties in the DRB including Carbon and Northampton Counties (PA) and may also cross parcels in short segments within Bucks County (PA), Mercer County (NJ), and Luzerne County (PA).

Sensitivity Analysis

The cost analyses above rely on assumptions and are accompanied by some degree of uncertainty. We conducted a sensitivity analysis, which involves the adjustment of key assumptions to determine the effect of these assumptions on the outcome. When possible, our cost estimates already incorporate an evaluation of sensitivity through the use of a range of cost values. For example, the ecosystem services estimates use low, medium, and high values from the literature for each ecosystem. That analysis also demonstrated the effect of low, medium, and high forest regrowth periods on the results. Our sensitivity analysis in this section will examine the effect of the discount rate on the results and the effect of a shorter operation period on the GHG cost estimates.

We use a discount rate of 3 percent in this analysis to calculate the present value of future streams of costs. The discount rate was used for cost analysis of lost ecosystem services in the permanent ROW, lost ecosystem services during forest regrowth in the temporary ROW, climate effects from GHG emissions, and the expected value of mortality risk. None of the other cost analyses in this report evaluate costs over time. As previously described, the discount rate accounts for the time value of money so that we can compare costs over time. There is no consensus on the “correct” discount rate. We chose 3 percent for this analysis because it is commonly used to represent the social discount rate. However, discount rates can range from 2.5 percent to 7 percent. We applied 2.5, 5, and 7 percent discount rates in our sensitivity analysis below. The sensitivity analysis under different discount rates for the cost of GHG emissions has already been conducted in the *Climate* section of this chapter.

Our low-end estimates using a 7 percent discount rate are approximately $9.8 million for PennEast and $2.4 million for Mariner East 2. On the other end of the range, our estimates using a 2.5 percent discount rate range from $19 million to approximately $140 million for PennEast and $4.7 million to $36 million for Mariner East 2.

Table 38. Estimated Costs Associated with Lost Ecosystem Services at Varying Discount Rates

Discount Rate	Low	Medium	High
PennEast			
2.5%	$19,000,000	$47,000,000	$140,000,000
3%	$17,000,000	$43,000,000	$130,000,000
5%	$12,400,000	$31,000,000	$92,000,000
7%	$9,800,000	$24,400,000	$72,000,000
Mariner East 2			
2.5%	$4,700,000	$12,000,000	$36,000,000
3%	$4,300,000	$11,000,000	$33,000,000
5%	$3,100,000	$8,000,000	$24,000,000
7%	$2,400,000	$6,200,000	$18,000,000

Using the results of this sensitivity analysis, we calculated the total range of costs under a 2.5, 3, and 5 percent discount rate. Because the GHG emissions estimates can only be conducted using a 2.5, 3, and 5 percent interest rate for the average SC-CO_2, we were unable to develop an overall analysis at the 7 percent discount rate. Additionally, the high SC-CO_2 estimate was only available at the 3 percent discount rate, so our sensitivity analysis below uses the average SC-CO_2 estimate for the low, medium, and high value estimates.

Figure 7 presents the results for the PennEast cost analysis. Estimates range from approximately $130 million for the low estimate under a 5 percent discount rate to approximately $890 million for the high estimate under a 2.5 percent discount rate. It is important to remember that this range does not account for the high value estimate of the SC-CO_2, which is estimated to be much larger than the average $SC\text{-}CO_2$. Consequently, we consider the high estimate at the low discount rate to be well within the reasonable range of potential costs of the PennEast pipeline.

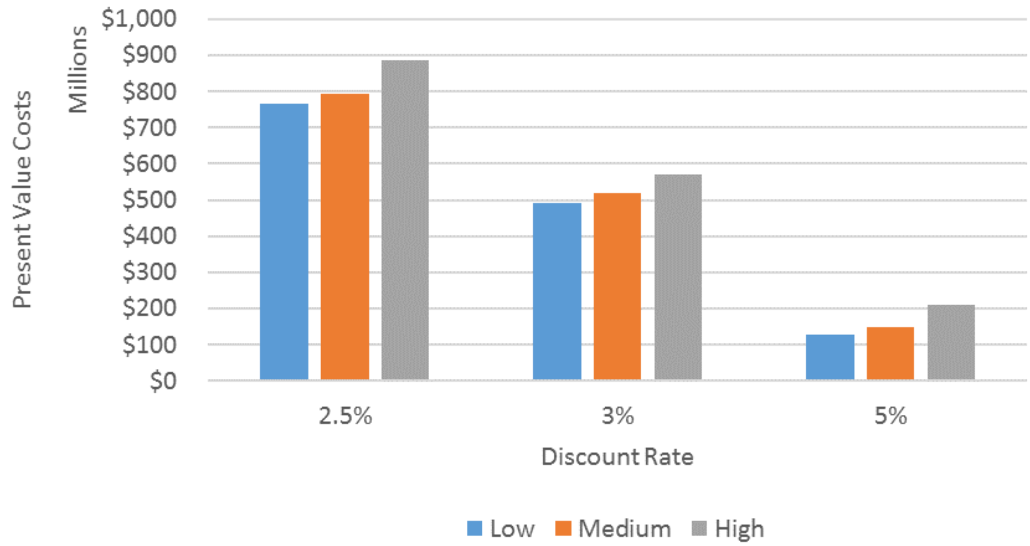


Figure 7. Estimated Low, Medium, and High Present Value Costs for PennEast Using Three Discount Rates (Using Average $SC\text{-}CO_2$ Estimates, 2017 USD)

Figure 8 presents the results for the Mariner East 2 cost analysis. Estimates range from approximately $65 million for the low estimate under a 5 percent discount rate to approximately $460 million for the high estimate under a 2.5 percent discount rate.

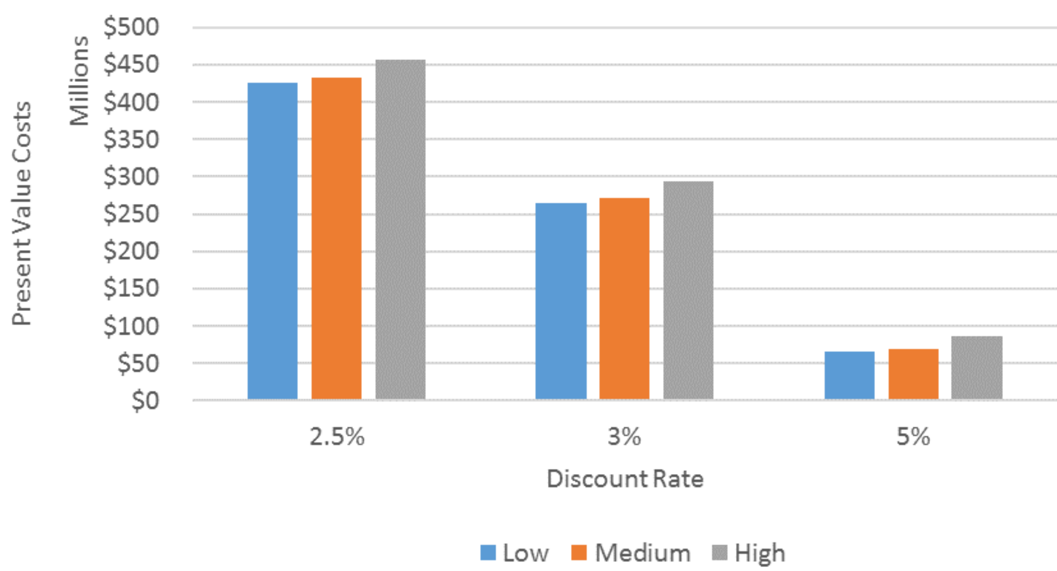


Figure 8. Estimated Low, Medium, and High Present Value Costs for Mariner East 2 Using Three Discount Rates (Using Average $SC\text{-}CO_2$ Estimates, 2017 USD)

Finally, we calculated the sensitivity of our analysis to the assumption that each pipeline will operate for 50 years. Table 39 summarizes the results for each pipeline for 50-year and 30-year operating periods. As demonstrated in the table, a shorter operating period has fewer GHG emissions and results in a lower overall cost associated with these GHG emissions. However, because costs in future years are discounted (in this case using a 3 percent discount rate), the reduction in cost is less than the reduction in the operating period. Therefore, even under a shorter operating period, the costs of GHG emissions associated with the pipelines are still large.

Table 39. Estimated Costs Associated with GHG Emissions Under Different Operation Assumptions

Years in Operation	Average Cost of CO_2	High Impact Cost of CO_2 (95th Percentile)
PennEast		
50	$470,000,000	$1,400,000,000
30	$330,000,000	$1,010,000,000
Mariner East 2		
50	$260,000,000	$810,000,000
30	$180,000,000	$560,000,000

The largest degree of uncertainty is the effect of GHG emissions from the PennEast and Mariner East 2 pipelines on climate change, but recent scientific literature suggests that the estimates for the SC-CO_2 included in this analysis may reflect a lower-bound estimate. We consider our analysis using EPA's average SC-CO_2 estimates to be a conservative estimate. In other words, we have reason to believe that the actual cost of GHG emissions from the pipeline could be much greater than estimated in this analysis. Furthermore, these estimates do not include downstream emissions resulting from burning the fuel, which would be much greater in magnitude.

There is no question that uncertainty results in a very high range of potential costs for these pipelines. However, we believe the average estimate under a 3 percent discount rate (approximately $790 million) to be a reasonable expected outcome for several reasons. First, this report describes many environmental and social costs that we were unable to monetize or otherwise estimate. Notably, we recognize the following unknown costs as potentially significant:

- Pollution and sediment loading in freshwater streams will likely degrade aquatic habitats, potentially causing short- and long-term damage to aquatic life and possibly damage to commercial and recreational fishing activities. While we have estimated potential disruption of freshwater fishing in the buffer areas during construction, we have not estimated long-term effects on fishing as a result of the pipelines.
- Pollution and sediment loading in waters designated as public water supplies may result in additional treatment costs at public water systems. Sediment in public water supplies is known to be of great concern and cost to drinking water systems, and research demonstrates that pipeline construction contributes to sediment loading in nearby streams. Increases in sediment

loading may limit the storage capacity of streams and reservoirs, necessitating more frequent, costly dredging.

- Community disruption, including damaged private wells, sinkholes, reduction in property values, noise and other construction-related and long-term problems have not been included in the monetary estimates in this analysis. Nevertheless, as demonstrated in the Mariner East 2 case study, these problems are real and have been documented as a result of the construction of the Mariner East 2 pipeline.

6. Case Study on the Real Impacts of the Mariner East 2 Pipeline

Key Findings

- As of February 2019, there have been approximately 240 inadvertent returns of drilling fluid to land and water along the Mariner East 2 pipeline route, and the PA DEP had issued 94 notices of permit violations.
- As of March 2018, seven sinkholes and 386 surface depressions had been found within 1,500 feet of a Mariner East 2 HDD site, and approximately 38 percent of the planned HDD segments occur in carbonate rock areas, which are susceptible to sinkholes.
- There have been environmental damages to streams of at least $13 million in value, as estimated based on PA DEP fines levied on Sunoco. Also, well contamination has been estimated at $60,000 per contaminated household based on compensation offered by Sunoco.
- An independent risk analysis found safety risks to be elevated when the three Mariner East pipelines are co-located along the ROW route, with the risk of mortality exceeding 1 in 100,000 per year for outdoor exposure along the pipelines' routes. This risk is greater than the risk of mortality as a result of exposure to smoke, fire, or flames (which is approximately 1 in 121,000 per year).
- In the event of a pipeline leak, residents are to evacuate on foot uphill, upwind, away from the pipeline, to a distance no less than half a mile. All potential ignition sources are to be avoided during a leak event. At least one community is considering installation of its own leak detection equipment as well as emergency notification systems that include air raid horns and strobe lights as a means of warning residents of an NGL leak.

Overview

Since its construction began, Mariner East 2 has been the source of great contention and has sparked significant concern among residents and land owners. Construction associated with the Mariner East 2 pipelines has contaminated drinking water sources, been connected to sinkhole formation in residential neighborhoods, contaminated local waterways and wildlife areas, and caused significant disruption to nearby communities and homeowners. Sunoco Pipeline LP, the company building and operating Mariner

East 2, has faced permit violations, legal battles, monetary fines, state and federal penalties, and extensive public opposition. The numerous unintended consequences of the pipeline's construction – such as sinkholes and IRs of drilling fluids – have made Mariner East 2 a prominent source of concern for pipeline development. Repeated violations of permit requirements and orders from the PA DEP have culminated in temporary construction halts on Mariner East 2. Also, a temporary hold was issued on all clean water permit approvals for ETP and its subsidiaries (including Sunoco) who operate multiple pipelines in the region.

This case study draws from publicly available information and direct communication with homeowners to identify and describe the consequences of Mariner East 2 pipeline construction activities.[9] This case study focuses on the damaging effects of the pipelines that have been incurred and costs that have been documented.

Water Quality and Ecosystem Impacts

As discussed earlier in *Chapter 3. Other Environmental Effects*, pipeline construction and operation pose several potential risks to surface water ecosystems and drinking water sources. Increased sedimentation, well integrity, arsenic migration, and contamination by drilling fluid can have long-term implications for surface water ecosystems, drinking water treatment, and source water viability. Many of these potential risks have materialized into actual costs during the construction of the Mariner East 2 pipelines.

The construction of the Mariner East 2 pipelines includes 39 sections of HDD in the DRB, totaling approximately 19 miles in length. As of February 2019, the 20-inch Mariner East 2 pipeline had resulted in approximately 240 IRs of drilling fluid to land and water along the pipeline route, and the PA DEP had issued 94 notices of permit violations (PA DEP, 2019a). Also, over 150,000 gallons of drilling fluid have been spilled during construction of the 20-inch Mariner East 2 pipeline (PA DEP, 2019a). These contamination events have polluted private drinking wells, wetlands, and waterways.

Construction on the 20-inch Mariner East 2 pipeline was first suspended in July 2017 when numerous households in Chester County, PA experienced contamination of their private wells, evidenced by withdrawal interruption and/or a cloudy color in the water (Maykuth, 2017a; PA DEP, 2017b). Several mitigating actions were needed to ensure that the affected homes had access to water and to compensate them for the damages:

- Sunoco provided bottled water to about a dozen affected homes and provided hotel accommodations for five affected families (Rettew, 2017a; Maykuth, 2017b)
- As a long-term remediation strategy, Sunoco also agreed to pay to connect approximately 30 affected homes to the local municipal water supply (Maykuth, 2017a; Weiss, 2017)
- Sunoco paid $60,000 to homeowners for new water connections to cover municipal water costs, releasing Sunoco from several claims such as "causes of action, damages, liabilities, and losses"

[9] Information in this case study is accurate as of April 20, 2019.

(Rettew, 2017b). Many homeowners accepted this settlement, but at least one did not, citing his belief that affected residents should not have to agree to the settlement in order to have access to clean water (Rettew, 2017b; Phillips, 2017a).

Some homes required only the addition of a small service line from an existing main, but other affected homes were located farther away, necessitating construction of a new 1,600-foot main (Maykuth, 2017a). Construction of this water main was more time intensive and costly than the addition of service lines. In this case, a group of about 30 homes were near enough to municipal service to construct a new main. However, in other areas along the pipeline, some homes were too far from municipal service for a new connection. When wells on these properties were permanently damaged, homeowners lost their drinking water supply and have relied indefinitely on bottled water or large water buffalos (replenished by trucks approximately three times per week). In addition to financial costs, the need to treat contaminated water or use alternative water sources can be challenging to homeowners. Lack of a viable water supply can also reduce property values and decrease a homeowner's ability to sell the property (discussed in more detail in the following section).

PA DEP suspended Sunoco's construction permits a second time in January 2018 after the company failed to follow its permit conditions and contaminated additional private wells in Cumberland County, PA (PA DEP, 2018b). In addition to IRs and groundwater contamination, several of Sunoco's permit violations were issued in response to the company conducting HDD activities at sites for which HDD was not authorized, including at sites designated as Exceptional Value Waters, High-Quality Waters, Migratory Fish Waters, or Class A Wild Trout Waters.

One of the consequences of Sunoco's HDD activities in Cumberland County was the loss of a farmer's well water. The well of Ralph Blume, a Cumberland County, PA farmer, was contaminated by diverted water from the pipeline construction process, which turned the well water yellow and "slimy." After using this water, Mr. Blume broke out into a rash, which he believes was caused by the water contamination. He drilled a new water well, but the water drawn from this new well was also unusable because it tested positive for magnesium and sulfur, and it appeared black as it ran out of the faucet. The source of these contaminants is unknown. According to Mr. Blume, the cost to dig the new well was about $7,000, and additional costs of about $10,000 would be needed to install, operate, and maintain necessary filtration treatments. In addition to the loss of potable water, Mr. Blume's farm suffered damage as a result of the pipeline construction. During construction, pipeline workers removed the topsoil, put it into a pile, and covered it with hay to prevent erosion. Mr. Blume noted that this process introduced an invasive weed called foxtail and will result in the complete loss of farmable

Contaminated Well Water in Cumberland County, PA

This cup holds contaminated water from Ralph Blume's private well.

Photo credit: Ralph Blume

land in that field until the weeds can be effectively eliminated, which may take years (R. Blume, personal communication, March 28, 2019).

Pipeline Construction in Cumberland County, PA

Construction activity on farmland degraded the quality of the land, according to land owner Ralph Blume.

Photo credit: Ralph Blume

In response to Sunoco's repeated permit violations and contamination of surface and groundwaters, the PA DEP issued Sunoco a fine of $12.6 million in February 2018 – one of the largest civil penalties ever in the state (PA DEP, 2018c). PA DEP determined that the $12.6 million penalty would go to the Clean Water Fund and the Dams and Encroachments Fund to award grants for projects that "reduce or minimize pollution and protect clean water in the 85 municipalities along the length of the pipeline corridor" (PA DEP, 2018d). Funded projects ranged from stormwater runoff management at a local high school in Berks County and streambank stabilization in Dauphin County, to floodplain restoration in Lancaster County and water system improvements in Lebanon County (Blanchard, 2018). Despite the magnitude of this historic fine, Sunoco continued to violate its permit conditions, conducting activities that resulted in "unpermitted discharge of drilling fluids to wetlands, wild trout streams, and High-Quality Waters at a number of locations…in violation of its permits and the Clean Streams Law" (PA DEP, 2018e). These continued activities resulted in two additional fines by the PA DEP, one for $355,000 in May 2018 and a second for $148,000 in August 2018 (PA DEP 2018e and f). These fines can be considered a proxy for the environmental costs incurred as a result of the pipeline construction activities, but they do not address the contamination issues of numerous private drinking water wells.

Most recently in February 2019, the PA DEP suspended all reviews of clean water permit applications from ETP and its subsidiaries (including Sunoco) due to ET's failure to comply with an order issued in October 2018 to address issues including erosion and "sediment-laden discharges into waterways," stemming from ET's Rover pipeline (PA DEP, 2019b). This continued failure to address water-related issues points to a systemic problem and suggests that ongoing operations continue to put DRB waterways at risk.

Because construction of the Mariner East 2 pipelines is still ongoing, the full ramifications of construction and operation of the pipeline cannot be known, and risks remain. For example, the path of the Mariner East 2 pipelines is near three public water supplies—Downingtown Water Authority and

Aqua Pennsylvania of West Chester and Aqua Pennsylvania of Uwchlan—putting residents in all three municipalities at risk of contamination (Table 40). Through a combination of surface water and groundwater sources, these three PWSs serve approximately 85,000 people. No damaging effects have been reported for any PWSs yet, but and at least one aquifer feeding private wells in Chester County was punctured by Sunoco's operations (Phillips, 2017a). With the continued construction and ultimate operation of the Mariner East 2 pipelines, these three public water supplies remain at risk of damage. Our analysis indicates that Mariner East 2 could damage each of these water systems if something went wrong. As explained previously in *Chapter 5. Analysis of Costs Associated with the PennEast and Mariner East 2* Pipelines, we estimated that a groundwater source is likely at risk if part of the pipeline ROW falls within the groundwater influence zone. If a pipeline is in close proximity to the groundwater influence zone (about 500 ft) of a well, then we determined that the well is possibly at risk of being damaged as a result of the pipeline. Wells located beyond the groundwater influence zone may also be at risk, but our analysis focuses on the groundwater influence zone as we believe that it represents the greatest possibility of risk.

For surface water sources, we estimated that a water source is at risk when there is pipeline clearing within the watershed that drains directly to a potable use stream with an intake or reservoir with public supply use. Downingtown Water Authority's water, which is drawn from East Branch Brandywine Creek and Marsh Creek River, is most at risk because the pipeline ROW travels through the watersheds that drain to these streams.

Table 40. Public Water Systems at Risk from Mariner East 2 pipelines

Water System Name	Approximate Population Served	Source Water Type	At Risk	Affected Source
Downingtown Water Authority	9,900	Surface water, wells	Yes	East Brach Brandywine Creek, Marsh Creek Reservoir
Aqua PA - West Chester	40,000	Surface water, wells	Probable	Brandywine Creek
Aqua PA - Uwchlan Division	35,000	Surface water, wells	Possible if wells near pipeline	Wells, purchased surface water

Safety Concerns

As previously noted, the Mariner East 2 pipelines transport hazardous highly volatile liquids (HVLs) in the form of NGLs, which include ethane, propane, and butane. Upon depressurization, these HVLs vaporize from the liquid state to an extremely flammable or explosive gas. Some residents have indicated that this long-term pipeline risk is of much greater concern than the temporary concerns about construction activities and water contamination (E. Friedman, personal communication, January 24, 2019; Phillips, 2017b). Potentially fatal hazards resulting from ignition of HVLs along the pipeline include jet fires, pool fires, flash fires, and vapor cloud explosions. Asphyxiation around an HVL release is also a fatal risk. These risks were so concerning to the communities along the pipeline that it resulted in Pennsylvania municipalities, nonprofit organizations, and individuals across the state raising funds for an independent study of the risks posed by the pipeline in Delaware and Chester Counties, Pennsylvania (Quest

Consultants Inc., 2018). The modeling analysis considered wind speed and the size of the rupture to estimate the maximum hazard distances for a leak, rupture, or explosion on the Mariner East 2 pipelines. The study estimated that the flammable vapor cloud could spread downwind from the leakage site in an oblong shape and that the cloud could extend from 120 feet (created by a quarter-inch hole) to 2,130 feet (created by a complete rupture) from the leakage site. The distance and shape of the cloud would also depend on atmospheric conditions.

Overall, the study found elevated risks when the three pipelines are co-located along the ROW route, with the risk of mortality exceeding 1 in 100,000 per year for outdoor exposure along the pipelines' routes. This risk is greater than the risk of mortality as a result of exposure to smoke, fire, or flames (which is approximately 1 in 121,000 per year) (Quest Consultants, Inc., 2018). The study found that pipeline valve stations pose the highest risk, with the risk of mortality due to a pipeline release exceeding 1 in 10,000 per year for those in the immediate area around valve stations. This risk is approximately equal to the risk of dying in a motor vehicle accident (Quest Consultants Inc., 2018). According to our analysis, approximately 5,000 people live within 2,130 feet of a single valve on the Mariner East 2 pipelines in the DRB. There is also one elementary school within approximately 600 feet of a valve station (Quest Consultants Inc., 2018). The Quest analysis concluded that risks are also elevated at HDD entry/exit points (and lowered along HDD sections due to the depth of the pipeline).

A second risk analysis drew similar conclusions. For a person on the centerline of Mariner East 2, the risk of mortality is 1 in 161,290.[10] This analysis evaluated only the risk associated with the body of the pipeline and did not incorporate the risk associated with valves or other nearby pipelines, which could increase risk estimates (G2 Integrated Solutions, 2018). The findings from the Quest and G2 analyses demonstrate that the risk level for the Mariner East 2 pipelines is within range of other common risks. According to the analysis, a full bore rupture with "neutral" atmospheric conditions (winds of 4.5 meters per second) and early ignition (at 2 minutes) would result in a flammable vapor cloud extending 500 meters (0.3 miles) from the centerline. If ignited, the vapor cloud explosion would result in a shockwave that would be fatal to anyone located in an area of approximately 150,000 square meters (equivalent to about 37 acres). However, the G2 study also determined that a fatal thermal impact zone could extend to more than a mile from the site of the blast under some circumstances.[11] While the probability of such

[10] The Quest Consultants, Inc. and G2 Integrated Solutions studies both estimate the risk associated with continuous outdoor exposure (24-hours per day, 7-days per week) and should be considered a maximum individual risk level. The authors claim that this assumption is consistent with common quantitative risk assessment methodology.

[11] The large fatal thermal impact zone can result if there is a high pressure release, a stable atmosphere with winds at 1.5 meters per second, and a long ignition delay. This is a worst-case scenario. The G2 study uses an early ignition delay for most of its analyses, "justified by the argument that in a populated, urban area such as Delaware County, a dispersing flammable NGL cloud is more likely to ignite sooner rather than later due to the likely presence of numerous ignition sources."

an event is extremely low, the consequences in densely the populated communities along Mariner East 2 would be devastating.

Leak protocol and evacuation methods for the Mariner East 2 pipelines indicated that in the event of a leak on the pipeline, residents, if aware that the leak exists, are to evacuate on foot uphill, upwind, away from the pipeline, to a distance no less than half a mile. Because of the well-known dangers associated with an NGL leak, all potential ignition sources are to be avoided during a leak event, including vehicles, cellphones, land lines, doorbells, electric garage openers, and more (Hurdle, 2018a). Current notification systems rely on a reverse 911 system, yet residents are directed not to use cell phones, leading to confusion and formal complaints from residents (Hurdle, 2018a). At least one community is considering installation of its own leak detection equipment as well as emergency notification systems that include air raid horns and strobe lights as a means of warning residents (E. Friedman, personal communication, January 24, 2019). These costs may be significant, and the warning system's presence may have a detrimental effect on property values.

Property Value

Homeowners located along the path of the pipeline have expressed significant concerns about the effect of pipeline construction and operation on their property values. In addition to well contamination discussed above, the occurrence of sinkholes and the general risks of being located near the pipeline are among homeowners' primary concerns. As described earlier in the *Property Value* section, Pennsylvania's karst geology makes it more susceptible to sinkholes than other regions. In West Whiteland Township in Chester County, PA, numerous sinkholes have opened along the ROW of Mariner East 2 construction (Sasko, 2018). As of March 2018, seven sinkholes and 386 surface depressions had been found within 1,500 feet of a Mariner East 2 HDD site (Fractracker Alliance, 2018). There are 230 HDD segments for the entire Mariner East 2 pipelines. As of March 2018, approximately 38 percent of the planned HDD segments would be located in areas with carbonate bedrock, which is susceptible to sinkholes (Fractracker Alliance, 2018). Additionally, about 40 percent of instances of IRs of drilling fluids had occurred in carbonate rock areas (Fractracker Alliance, 2018).

Numerous news articles dating back several years have highlighted the detrimental effects of pipeline construction on property values near the Mariner East pipelines. From sinkholes appearing in backyards spanning 15 feet wide and 20 feet deep, to loss of water wells that residents have relied on for years, residents have lodged numerous complaints about the construction activities. In at least one instance, a sinkhole opened deep enough to reveal the Mariner East I pipeline, prompting the Public Utility Commission to shut down operation in the face of "potentially catastrophic risk to public safety" (Sasko, 2018).

Many residents have taken further steps to protect their families and properties from the risks associated with the Mariner East 2 pipelines. Residents in Chester County, Pennsylvania filed a class action lawsuit against Sunoco in March 2018 alleging that pipeline construction opened up sinkholes; damaged their property; caused cracks in in the foundations, walls, and chimneys of their homes; and damaged driveways. The lawsuit also alleged negative impacts of construction on the plaintiffs' quality of life, including reduced "use of quiet enjoyment of their property" and detrimental effects on home values (Rettew, 2018).

The complaints alleged in the lawsuit stem in part from Sunoco's use of HDD in areas that are typically not recommended for that type of drilling (Sasko, 2018). For example, areas susceptible to sinkholes or located near faults or fractures could face an increased risk of incidents due to HDD, but the drilling practice is claimed to have been used by Sunoco in such vulnerable locations (Sasko, 2018). The lawsuit alleged that the company knew or ought to have known about the potential fissure beneath one of the plaintiff's properties (Sasko, 2018). A year after it was initially filed, the lawsuit was settled out of court.

There appears to be inconclusive evidence in the scientific literature on the effects of transmission gas lines on nearby property values, as noted earlier in this report. However, anecdotal accounts of attitudes, perceptions, and priorities of prospective and recent homebuyers suggest that there may be a real cost to property values that is not reflected in the market.

Sinkholes in Thornbury Township Caused by Construction Activity

Sinkholes appeared in numerous yards shortly after pipeline construction began.

Photo credit: Eric Friedman

Unaticipated problems encountered during drill pullback of the Mariner East 2 pipeline highlight the extent of disruption that pipeline construction has on nearby residents. In Media, PA, pipeline pullback activity began in mid-June 2018 and continued 24 hours a day, seven days a week, for approximately four months. Pipeline pullback typically occurs over one to two days. The pullback entailed large lights shining throughout the night into nearby apartments and loud noise and vibrations throughout the day and night. One resident at nearby Tunbridge Apartments, who is retired and thus was present in her apartment for the majority of this time, noted she was largely unable to sleep for the duration of the pullback. She was unable use her patio or open her windows due to continual noise, light, and presence of construction workers, some of whom slept in their work vehicles. This resident experienced numerous hardships, such as emotional distress, anxiety, loss of sleep, pain and suffering, and loss of the tranquility of her home. To compensate for the disturbance, Sunoco offered residents payments of $500 per day or payments for living expenses such as hotels should they choose to leave during this time. One resident received payments totaling $20,000, although Sunoco did not cover the full duration of the drilling. (Lori Bartholomew, personal communication, April 15, 2019). If we assume that all 114 residential units in Tunbridge Apartments were paid $500 per day for 40 days, that equals $2.3 million dollars in compensation. In addition to the Tunbridge Apartments, there appear to be several other residential buildings near the drilling location. These include other apartment buildings, a senior living home, and numerous residential houses. These are not included in our analysis but may have also suffered from the pipeline construction similarly to the Tunbridge residents' experience.

Problems with Drill Pullback in Delaware County, PA

Mariner East 2 passes through Media, PA, where the pipeline construction process included HDD activities. Pipe installation in the HDD process is accomplished in the "pullback" phase, during which a prefabricated pipeline is pulled back through the drilled tunnel to the drilling rig. This process typically occurs on a 24-hour basis for one to two days, generating considerable noise and vibration. In Media, the pullback phase for one HDD site operated continually for approximately four months. Sunoco purportedly compensated nearby homeowners $500 for each day of the process. (Lori Bartholomew, personal communication, April 15, 2019)

Recent buyers in the area also noted that they would not have purchased their homes if they had known about Sunoco's purchase of easements (Maykuth, 2018). One buyer was unaware that the previous owners had sold easements to Sunoco and no longer wanted to remain in the newly purchased home. However, a lawyer advised that the cost to contest the sale would not be worthwhile (Maykuth, 2018). His home is now valued at ten percent less than his purchase price according to a real estate website (Maykuth, 2018). Nearby, a valve station located approximately 1,000 feet from Glenwood Elementary School has worried parents and may be influencing property values in the school's catchment area. One broker noted that this area's home prices have lagged behind home prices near other elementary schools in the same district by about seven percent (Maykuth, 2018). Additionally, these homes – which had previously sold seven days faster than those in other areas of the school district – now sell two days more slowly (Maykuth, 2018).

At least two families have moved out of the area to ensure that their children would not attend Glenwood Elementary School (Thomas Smith, personal communication, April 14, 2019; Allison Chabot, personal communication, March 29, 2019). One of these families was living next door to an HDD pad and described the activity as producing "deafening sounds from jamming in the pipe." After measuring the noise level inside their home, they found it similar to that of a factory room floor where people typically wear earplugs. Because of the safety risks posed by the valve station near the elementary school, the ongoing construction next door, and the mental and emotional toll of the pipeline's risks, the family decided to move despite the fact that they were unable to put their house on the market and subsequently let it go into foreclosure (A. Chabot, personal communication, March 29, 2019).

The Mariner East 2 pipelines also raise concerns regarding insurance rates and availability. At least one community has encountered difficulty with general liability coverage. A subdivision of Thornbury Township was approved as a cluster design for conditional use, where homes are set on relatively small lots and a large portion of the total lot is preserved as undeveloped space. The homeowners' association (HOA) maintains liability insurance for the preserved space, which Sunoco seized for the pipeline's ROW. The HOA asked the insurance company about potential premium increases due to the new pipeline and was notified by a representative of Community Association Underwriters of America in March 2016 that if Mariner East 2 is constructed through the community's open space, the association would no longer be eligible for liability insurance given the risk involved (E. Friedman, personal communication, January 24, 2019). At this time, the HOA's insurance has not been revoked, but Mr. Friedman remains concerned about the risk of losing liability insurance and the future viability of his community's HOA. Homeowners have expressed similar concerns for the future costs and availability of homeowner's insurance.

Thornbury Township, PA

Preserved open space in preserved subdivision used for Mariner East 2 pipeline.

Photo Credit: Eric Friedman

Litigation

In response to the safety and environmental concerns surrounding Mariner East 2, communities and individuals have invested countless hours in efforts they believe necessary to protect their homes and families. For example, one self-employed homeowner became involved in the organizations opposing the pipeline and estimates that she lost 15 to 20 percent of her annual income due to the time and effort she expended on activities related to the pipeline (A. Chabot, personal communication, March 29, 2019). These communities and individuals also initiated numerous legal actions against Sunoco in an effort to reclaim lost value associated with property, safety, and environmental quality. West Goshen Township (Chester County, PA) has documented its own legal struggle with Sunoco since 2014 in response to what it claims is a breach of the township's and Sunoco's "mutual Settlement Agreement to ensure the safe and efficient operation of the projects through [the township's] community" (West Goshen Township, 2019). Due to safety concerns about the location of Sunoco's initially proposed facilities, West Goshen Township filed a complaint against Sunoco. The township and Sunoco reached a settlement agreement in May 2015 that, in part, identified the location of automated valve locations for the pipeline and established procedures for notifying the township of any changes. The township later discovered that Sunoco had changed the location of that valve station without providing the required notice to the township. In response, the township filed a lawsuit against Sunoco in March 2017.

West Goshen Township claims that the pipeline has resulted in significant losses for the community. Failure of Sunoco to construct the pipeline within the planned parameters resulted in the loss of an approximately $35 million development project. According to West Goshen Township, an unauthorized location of valve stations near the development "scuttled" the project that would have "provided a nearby independent living facility accessible to retired Township residents." The Township also estimates that loss of the project will also result in the loss of approximately $400,000 in road improvements and over $100,000 in income from permit fees, earned income, and real estate taxes (West Goshen Township, 2019). These losses, along with an estimated $700,000 in legal costs, and "countless Township staff hours" to fight Sunoco since 2014, have resulted in a significant toll on the community.

Another lawsuit by Delaware Riverkeeper Network against Sunoco argues that the company failed to obtain a NPDES permit following discharges and thus violated the Clean Water Act (Hurdle, 2018b). An additional lawsuit involves a criminal investigation by the Chester County, PA District Attorney into Sunoco's construction activities. The District Attorney's office cited the appearance of sinkholes, well contamination, environmental violations and fines, and an explosion caused by another ETP pipeline in nearby Beaver County all as causes for the investigation (Chester County District Attorney's Office, 2018). Based on its findings, the District Attorney's office could charge Sunoco employees with "causing or risking a catastrophe, criminal mischief, environmental crimes, and corrupt organizations" (Chester County District Attorney's Office, 2018). Some of the suits have also targeted the state government, such as one suit in which three environmental groups claimed PA DEP did not adequately enforce protections against spills (Hopey, 2018).

These lawsuits demonstrate that communities believe that due to Sunoco's repeated violations of its permit requirements and the actual damaging effects of the Mariner East 2 pipelines on private property, they must provide their own oversight to protect their land, water, and safety - oversight that Sunoco has failed to deliver.

Summary of Costs

In addition to the potential costs estimated in *Chapter 5. Analysis of Costs Associated with the PennEast and Mariner East 2* Pipelines, Sunoco has incurred numerous additional costs that are not accounted for in the original construction cost estimates, as have the communities situated along its path. Environmental, social, and legal costs have been incurred by many parties, but because the breadth and scale of these costs is so large, a complete itemization of these costs is not available. Table 41 summarizes some of these costs as well as those that have been discussed throughout this chapter.

Table 41. Summary of Costs Associated with the Mariner East 2 Pipeline

Water quality and environment	• Environmental damages to streams of at least $13 million, based on PA DEP fines levied against Sunoco • Well contamination estimated at $60,000 per contaminated household (based on compensation offered by Sunoco) • Potential future costs of contaminated public water supplies or private wells (not monetized)
Litigation and safety	• Litigation expenses of at least $700,000 for one Township plus costs of other known litigation actions (associated costs for these are unknown) • Lost time associated with the need for community members and local governments to identify and oversee potential problems from the pipeline • Potential long-term costs of leak warning systems • Potential unknown long-term costs associated with pipeline failure • Undocumented costs to residents of moving or adjusting lifestyles to avoid the pipeline • Nearly $200,000 in private and public funds to address the safety risks posed to communities • Nearly $200,000 in legal fees to file formal complaints and petitions for emergency relief before the Pennsylvania PUC
Noise and vibrations	• Typical noise pollution from pipeline construction (not monetized) • Lost time associated with the need for community members and local governments to identify and oversee potential noise- and vibration-related problems from the pipeline • Excessive noise and vibration from the pullback phase of HDD affecting an estimated 114 residential units at one apartment complex. Information from residents suggests that Sunoco paid an estimated $2.3 million for these issues.

Property value	• Loss of property value due to sinkholes, property damage, other safety risks, and general proximity to the pipeline • Potential effects of pipeline proximity to homes on mortgage underwriting practices and associated difficulties in obtaining a loan for a property near the pipeline • Potential effect of pipeline on availability or cost of homeowner's insurance

It is worth noting that some of these costs have been paid by Sunoco (e.g., environmental fines and compensation to homeowners for well contamination and noise violations), meaning that they are no longer costs borne by the community or local governments. However, this assumes that the amounts of the fines and compensation were commensurate with the true costs of the problems resulting from the pipeline. This may not be the case given the time and legal fees needed to pursue these violations and resulting fines. Furthermore, these costs were unanticipated and, in some cases, the direct result of permit violations. Given the repeated failure of Sunoco to abide by its permit requirements, it inevitably raises the suspicion that the region is likely to face similar costs and consequences of unapproved siting or construction in the future.

Conclusions

This case study has demonstrated examples of the various ways in which the Mariner East 2 pipeline has had a detrimental effect on the environment and communities along the pipeline route. Due to the ongoing risks associated with pipeline operation, the full ramifications of the Mariner East 2 pipelines for safety, water quality, and property values may not be known for years to come. Nevertheless, it is evident that the pipeline has been costly to the DRB region while providing limited compensation to those who have been directly affected by its short-term and potential long-term effects. Although Sunoco has compensated homeowners for several of the more tangible losses (e.g., well contamination, excessive noise from a malfunctioning pullback phase), there are numerous other damages that have not been documented or monetized and that have gone unpaid by Sunoco, as identified earlier in this chapter.

The information and personal accounts collected and reported in this case study demonstrate the breadth of problems that have occurred as a result of the pipeline. Potentially more concerning is the pattern of Sunoco's permit violations and disregard for legal agreements, which have been thoroughly documented by the PA DEP, the media, and communities such as West Goshen Township. With this record, communities remain concerned that their safety is at risk due to the long-term operation of the pipeline.

7. Analysis of Job Creation by PennEast Pipeline and Other Energy Sources

Key Findings

- One of the claimed benefits of PennEast is that it will create jobs, but data indicate that other energy procurement options have greater job creation at the same level of investment.
- One study determined that the PennEast economic impact analysis likely overestimated the job creation potential of the pipeline by two thirds.
- Even using a relatively high jobs factor, all the renewable energy or energy conserving options evaluated would be expected to create more jobs than PennEast – from 2,744 to 13,719 additional jobs for the same level of investment.
- There are currently higher levels of employment associated with energy efficiency than electric generation in New Jersey and Pennsylvania, and more people are working in solar generation than other types of generation.

A major argument for the construction of the PennEast pipeline was its potential for job creation (PennEast Pipeline, 2018). An economic impact analysis completed for the pipeline company estimated that there would be 12,160 temporary jobs created during design and construction over a period of 5 to 7 months, and 98 jobs would be created to support ongoing operations (Econsult and Drexler University, 2015). In 2015, the Goodman Group conducted an independent jobs analysis of the PennEast pipeline and determined that the PennEast economic impact analysis likely overestimated the job creation potential of the pipeline by two thirds (Goodman and Rowan, 2015). We use the results from Goodman and Rowan (2015) to inform our analysis, but we do not conduct our own critique of the jobs analysis for the PennEast pipeline.

In this chapter we will compare these numbers 1) with job creation for a sample set of other pipelines, and 2) with rough estimates of the number of jobs that could potentially be created in conventional and renewable energy and energy efficiency given a similar investment as that for the pipeline, and 3) with the current employment situation in Pennsylvania and New Jersey.

Comparing PennEast Employment with Other Pipelines

One measure of employment that allows comparison across projects and types of projects is the number of jobs created per million dollars of investment. Goodman and Rowan's independent jobs analysis of the PennEast pipeline examined employment estimates in studies for four other natural gas pipeline projects in the Northeastern U.S. These studies provided the total number of jobs created[12] during design and construction per million dollars of investment, as shown in Table 42, along with the cost of construction and other information, as available. The comparison by Goodman and Rowan shows that the estimate for jobs per million dollars of cost for the PennEast pipeline is much higher than for any of the other pipelines, and it is 3.4 times the weighted average of all four.

Table 42. Job Creation Estimates for PennEast and Four Other Natural Gas Pipelines.

Pipeline	Cost of Construction (USD millions)	Construction Jobs (direct)	Construction Jobs (indirect)	Direct Jobs/ Million $ Construction Cost	All Construction Jobs/ Million $ Construction Cost
PennEast Jobs Analysis*	$1,193	2,500	9,660	2.1	10.2-10.7[13]
Northeast Supply Link**	$325	-	-	-	3.9
Northeast Energy Direct**	$1,300	1,360	1,033	1.0	2.0
Constitution**	$683	1,300	275	1.9	1.5
Atlantic Sunrise**	$2,099	-	-	-	3.9
Weighted average for other pipelines **					3.0

*Sources: *Econsult and Drexler (2015); **Goodman and Rowan (2015).*

Comparing PennEast Employment with Other Energy Investments

New Jersey and Pennsylvania have both made commitments to reduce GHG emissions by 80 percent by 2050 (Office of Governor Tom Wolf, 2019; NJ DEP, 2019). Key elements of the plans to achieve these targets include energy conservation and greater use of renewable energy. With that in mind, we offer a comparison of the number of jobs that could be created if the same investment made in the PennEast Pipeline was made in projects that were in alignment with the states' GHG reduction goals.

In Table 43 we provide estimates of the number of jobs created by the PennEast pipeline, fossil and renewable electric generation, and several energy saving options. The employment multiplier in the first row of Table 2 is the PennEast job creation estimate from Table 42, and the second estimate for natural gas pipelines is the weighted average of the multipliers from the four other pipelines, also presented in Table 42. The remaining employment multipliers are taken from a study by Polin, Heintz, and Garrett-Peltier (2009), which used a national input-output model (IMPLAN) to estimate the direct, indirect,

[12] Total number of jobs created includes direct, indirect, and induced jobs. This definition of total jobs is consistent with that used for the PennEast estimate by Econsult and Drexler University (2015).

[13] The number depends on the estimate for the duration of construction, which may range from 5 to 7 months.

induced and total employment for $1 million in investment. Input-output models tend to provide large estimates for induced employment, so Polin, et al. instead used a dynamic empirical model for those multipliers, resulting in a more conservative employment multiplier. The job estimates we show are intended to provide a rough estimate of potential employment, not a region-specific employment analysis.

Table 43. Estimates for Job Creation Factors and Jobs Created for the Same Investment as the PennEast Pipeline.

Investment	Source	Employment Multiplier (Jobs/$1 Million)	Jobs Created for a $1.19 billion investment*
PennEast Pipeline		10.2	12,169
Average of other pipelines	Goodman and Rowan (2015)	3.0	3,579
Oil & Natural Gas	Polin et al. (2009)	5.9	6,204
Coal Generation	Polin et al. (2009)	6.9	8,232
Solar Photovoltaic Generation	Polin et al. (2009)	13.7	16,344
Wind Generation	Polin et al. (2009)	13.3	15,867
Smart Grid	Polin et al. (2009)	12.5	14,913
Building retrofits	Polin et al. (2009)	17.4	20,758
Mass transit	Polin et al. (2009)	21.7	25,888

**Calculated by Cadmus by multiplying the employment multiplier by 1,193 (which represents $1,193 million, the cost of the PennEast pipeline).*

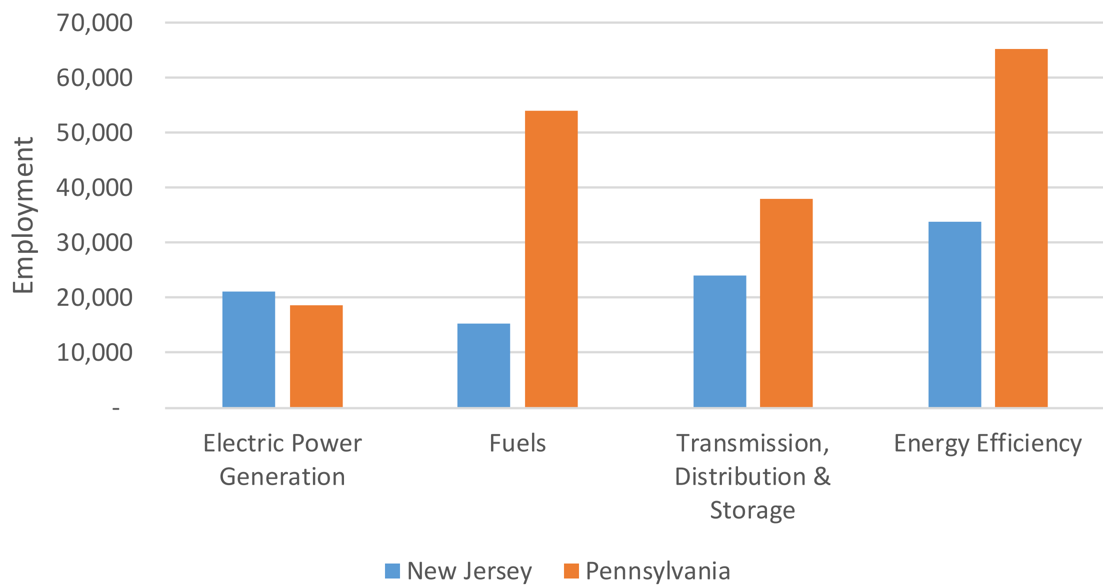
The table shows that even using the relatively high jobs factor from Econsult and Drexler (2015), all the renewable energy or energy conserving options would be expected to create more jobs – from 2,744 to 13,719 additional jobs for the same level of investment. This was estimated by multiplying the employment multiplier by the cost of the PennEast pipeline ($1.193 billion). It is clear that from an employment point of view, energy investments in efficiency, conservation, renewable generation, and mass transit would provide greater employment benefits and help the states to meet their GHG reduction goals. If PennEast's employment numbers are, in fact, overstated, then the relative benefit of these alternative energy investments would be even greater.

To make a comparison of the relative importance of an investment of the scale of the PennEast pipeline to employment in New Jersey and Pennsylvania, we provide employment numbers related to traditional energy and energy efficiency. As of 2017, there were about 270,000 traditional energy and energy efficiency jobs in New Jersey and Pennsylvania.[14] Traditional energy employment includes jobs in electric power generation, fuels, and transmission, distribution, and storage (TD&S). There were about 61,000 jobs in New Jersey in these categories and about 110,000 in Pennsylvania. The percentage of traditional energy employment to total employment is 1.5 percent in New Jersey and 1.9 percent in Pennsylvania, compared to the national average of 2.3 percent (NASEO, 2018). For energy efficiency

[14] To count as a job, the person doing the work need not be involved in that activity for all the time they are working, so this estimate cannot be interpreted as fulltime equivalents (FTEs).

employment, the numbers of jobs are about 34,000 for New Jersey and 65,000 for Pennsylvania. Energy efficiency employment includes jobs related ENERGY STAR® products and efficient lighting, HVAC systems and renewable heating and cooling, and advanced materials and insulation.

Figure 9 shows employment in the three categories for traditional energy and energy efficiency for both states. In both New Jersey and Pennsylvania, the highest employment category is energy efficiency, which reflects the high employment multiplier for those types of investments relative to the others.



Source: NASEO, 2018

Figure 9. Employment in Traditional Energy and Energy Efficiency in New Jersey and Pennsylvania

The breakout for electric generation is shown in Figure 10. New Jersey has more solar employment than any category in either state, at almost 9,000 jobs. The second largest category for New Jersey is "other," which includes hydroelectric, oil, and other unspecified generation. For Pennsylvania, nuclear and solar employment are the largest categories, followed by natural gas and coal. These data show that there are currently higher levels of employment associated with energy efficiency than electric generation in New Jersey and Pennsylvania, and that more people are working in solar generation than other types of generation. One reason is that there are more jobs in these categories for a given level of investment, as seen in Table 43.

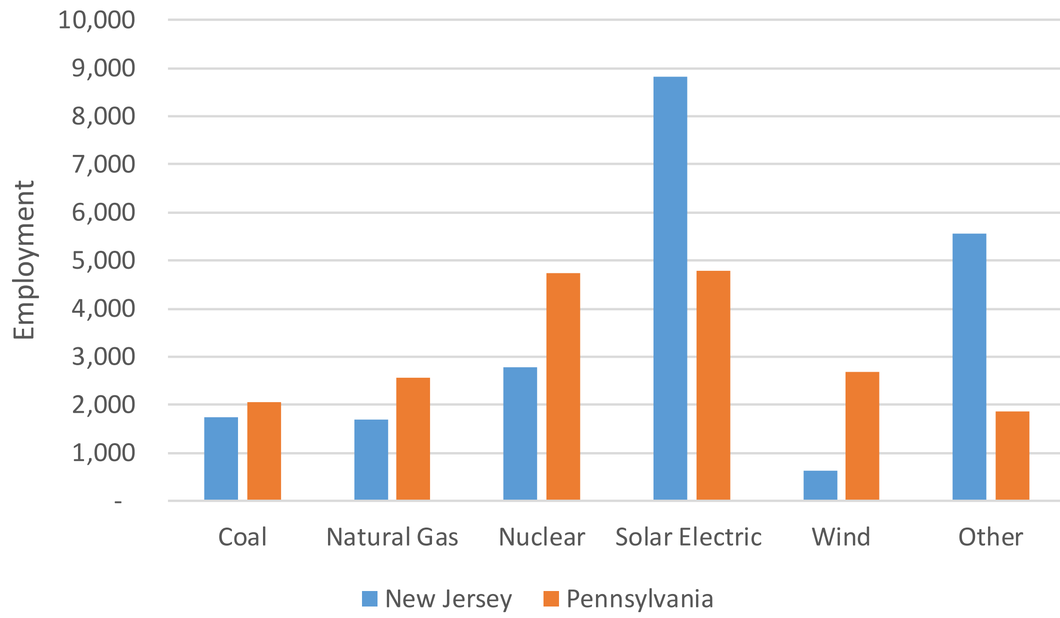


Figure 10. Employment Figures for Electric Generation Types in New Jersey and Pennsylvania

Summary

The data and analysis presented in this chapter show that while there are some employment benefits associated with the construction of the PennEast pipeline, there are other related types of investments that would provide many more jobs at any given level of investment. Even when comparing employment benefits against PennEast's high employment estimates, other types of investments still perform better in terms of job creation. For those who are interested in the employment benefits of investments in the energy sector, the best options are investments in energy efficiency, renewable energy and mass transit. There are already many jobs in New Jersey and Pennsylvania related to renewable energy and energy efficiency, and there is solid growth in these activities. These options also have the added benefits of reducing GHG emissions, improving air quality, and avoiding other environmental costs explored elsewhere in this report.

8. References

ABC News. (2014, July 24). With wells drying up residents turn to water trucks. Retrieved from https://abc30.com/news/with-wells-drying-up-residents-turn-to-water-trucks/218373/

Agency for Toxic Substances & Disease Registry. (2007). Toxicological Profile for Benzene. Retrieved from https://www.atsdr.cdc.gov/toxprofiles/tp.asp?id=40&tid=14#bookmark10

Alexander, R. B., Boyer, E. W., Smith, R. A., Schwarz, G. E. & Moore, R. B. (2007). The Role of Headwater Streams in Downstream Water Quality. Journal of the American Water Resources Association. 44(1), 41-59. doi: 10.1111/j.1752-1688.2007.00005.x. Retrieved from https://www.ncbi.nlm.nih.gov/pmc/articles/PMC3307624/

Alvarez, R., et al. (2018). Assessment of methane emissions from the U.S. oil and gas supply chain. Science. 361(6398), 186-188.

American Water Contract Services Group. (2018, April). Township of North Brunswick Water Utility Consumer Confidence Report for Water Delivered in 2017. Retrieved from https://www.northbrunswicknj.gov/images/water/2017ccr.pdf

Anielski, M. and Wilson, S. J. (2005). Counting Canada's natural capital: assessing the real value of Canada's boreal ecosystems. Canadian Boreal initiative, Pembina institute.

Aquasana. (2019). Whole House Filter System: 500,000 Gallon Well Water Rhino. Retrieved from https://www.aquasana.com/whole-house-water-filters/500k-gallon-well-water

Barrow, C. J. (1991). Land degradation. Cambridge University Press, Cambridge, UK.

Barringer, J.L. and Onstott, T.C. (2017). Docket No. CP15-558-000: Proposed PennEast Pipeline Project: Response to "Attachment C Response to T.C. Onstott Stockton Comments" by Dr. Michale Serfes. Submitted to the Federal Energy Regulatory Commission January 26, 2017.

Berger & Associates, Inc. (1980, November). Survey of Blasting Effects on Ground Water Supplies in Appalachia. U.S. Department of the Interior. Retrieved from https://www.osmre.gov/resources/blasting/docs/WaterWells/BergerBlastingEffectsWaterWells1980.pdf

Blanchard, S. (2018, October 17). PA Awards Water Quality-Related Grants Funded by $12.6M Penalty Against Sunoco. StateImpact Pennsylvania. Retrieved from https://wskg.org/news/pa-awards-water-quality-related-grants-funded-by-12-6m-penalty-against-sunoco/

Blumenthal, B. (2018, September). A solution in search of a problem: Analysis shows no need for PennEast pipeline. New Jersey Conservation Foundation. Retrieved from https://rethinkenergynj.org/wp-content/uploads/2018/09/NJCF_Sept2018_PennEastReport_SolutionInSearchOfProblem_FINAL.pdf

Boyle, M. D., Soneja, S., Quirós-Alcalá, L., Dalemarre, L., Sapkota, A. R., Sangaramoorthy, T., et al. (2017). A pilot study to assess residential noise exposure near natural gas compressor stations. PLoS ONE 12(4): e0174310. Retrieved from https://doi.org/10.1371/journal.pone.0174310

Brenner-Guillermo, J. (2007). Valuation of ecosystem services in the Catalan coastal zone. Marine Sciences, Polytechnic University of Catalonia.

Burke, M. (2017, August 5). After Sunoco pipeline drilling taints private Chester County wells, critics worry: What's next? The Philadelphia Inquirer. Retrieved from http://www2.philly.com/philly/news/after-sunoco-pipeline-drilling-taints-private-chester-county-wells-critics-worry-public-water-may-be-at-risk-20170805.html

Chester County District Attorney's Office. (2018, December 19). Chester County District Attorney Opens Criminal Investigation Into Mariner East Pipeline. Press Release. Retrieved from http://www.chesco.org/DocumentCenter/View/47921/PipelineCriminalInvestigation

Colaneri, K. (2013, December 17). Safety concerns arise over cross-state natural gas liquids pipeline. StateImpact Pennsylvania. Retrieved from https://stateimpact.npr.org/pennsylvania/2013/12/17/safety-concerns-arise-over-cross-state-natural-gas-liquids-pipeline/

ConocoPhillips. (2012, April 2). Natural Gas Liquids Safety Data Sheet. Retrieved from https://stateimpact.npr.org/pennsylvania/2013/12/17/safety-concerns-arise-over-cross-state-natural-gas-liquids-pipeline/

Costanza, R., d'Arge, R., de Groot, R., Farber, S., Grasso, M., Hannon, B., Limburg, K., Naeem, S., O'Neill, R. V., Paruel, J., Raskin, R. G., Sutton, P., & van den Belt, M. (1997). The value of the world's ecosystem service and natural capital. Nature, 387: 253-260.

Crable, A. (2014, August 12). Lancaster County farmer says crop yields never the same after gas pipelines. Lancaster Online. Retrieved from https://lancasteronline.com/news/local/lancaster-county-farmer-says-crop-yields-never-the-same-after/article_7ba7f6b0-2246-11e4-bba8-001a4bcf6878.html

D&R Canal State Park. (2018). A Historic Place. Retrieved from https://www.dandrcanal.com/index.php/history

De la Cruz, A. & Benedicto, J. (2009). Assessing Socio-economic Benefits of Natura 2000: a Case Study on the ecosystem service provided by SPA PICO DA VARA / RIBEIRA DO GUILHERME. Output of the project Financing Natura 2000: Cost estimate and benefits of Natura 2000.

Dearmont, D., McCarl, B. A., & Tolman, D. A. (1998). Costs of water treatment due to diminished water quality: A case study in Texas. Water Resources Research, 34(4), 849-853. Retrieved from https://agupubs.onlinelibrary.wiley.com/doi/pdf/10.1029/98WR00213

Delaware River Basin Commission (DRBC). (2013). State of the Basin 2013: Living Resources. Retrieved from https://www.nj.gov/drbc/programs/basinwide/sotb2013/living_resources.html

DRBC. (2017a). Basin Information. Retrieved from https://www.state.nj.us/drbc/basin/

DRBC. (2017b). Special Protection Waters (SPW). Retrieved from https://www.nj.gov/drbc/programs/quality/spw.html

Delaware River Basin Source Water Collaborative. (2019). The Delaware River Basin. Retrieved from http://www.delawarebasindrinkingwater.org/

Delaware Valley Regional Planning Commission and Green Space Alliance. (2011). Return on Environment: The Economic Value of Protected Open Space in Southeastern Pennsylvania. Retrieved from https://www.dvrpc.org/Products/11033A/

Donaghy, P., Chambers, S. & Layden, I. (2007). Estimating the economic consequences of incorporating BMP and EMS in the development of an intensive irrigation property in central Queensland.

Dumm, R., Sirmans, G. S., & Smersh, G. (2016). Sinkholes and Residential Property Prices: Presence, Proximity, and Density.

Dutzik, T., Ridlington, E., & Rumpler, J. (2012). The Costs of Fracking: The Price Tag of Dirty Drilling's Environmental Damage. Retrieved from https://www.ourenergypolicy.org/wp-content/uploads/2012/10/The-Costs-of-Fracking-vOH.pdf

Econsult Solutions, Inc. & Drexel University School of Economics. (2015, February 9). PennEast Pipeline Project Economic Impact Analysis. Retrieved from http://penneastpipeline.com/DrexelEconomicStudy/

Eggert, K. (2016). Speaking for the Trees: Preventing Forest Fragmentation in Pennsylvania's Marcellus Shale Region through Pipeline Siting. Vermont Journal of Environmental Law, 17(3): 372-393.

Ernst C., Gullick R., & Nixon, K. (2004). Protecting the Source: Conserving Forests to Protect Water. American Water Works Association, 30(5).

Evans, J.S. & Kiesecker, J. M. (2014). Shale gas, wind and water: Assessing the potential cumulative impacts of energy development on ecosystem services within the Marcellus Play. *PLoS ONE*, 9(2): 1-9. e89210.

Federal Energy Regulatory Commission (FERC). (2017). PennEast Pipeline Project: Final Environmental Impact Statement. Docket No. CP15-558-000.

Finley, B. (2013). Colorado absorbs 179 oil and gas spills as Parachute cleanup continues. The Denver Post. Retrieved from https://www.denverpost.com/2013/06/22/colorado-absorbs-179-oil-and-gas-spills-as-parachute-cleanup-continues/

Fisher, D., Fisher, D., and Fisher, D. (2000). Gas Pipelines: Are They a Detriment or an Enhancement for Crops? Journal of the ASFMRA.

Fogg, J. & Hadley, H. (2007). Hydraulic considerations for pipelines crossing stream channels. Bureau of Land Management Technical Note 423.

Forest Service, Northern Research Station. (2017). Pennsylvania Forests 2014. United States Department of Agriculture. Resource Bulletin NRS-111.

Forster, D. L., Bardos, C. P., & Southgate, D. D. (1987). Soil erosion and water treatment costs. Journal of Soil and Water Conservation, 42(5), 349-352.

FracTracker Alliance. (2018, March 12). Mariner East 2: More Spills & Sinkholes Too? Retrieved from https://www.fractracker.org/2018/03/me2-spills-sinkholes/

G2 Integrated Solutions. (2018). Mariner East 2 Pipeline and Existing Adelphia Pipeline Risk Assessments. Retrieved from http://www.westtownpa.org/wp-content/uploads/2018/12/g2-me2-adelphia-risk-assessment-v2-1.pdf

Gibbons, D. C. (1986). The economic value of water. Resources for the Future, Washington D.C., USA.

Goodman, I. & Rowan, B. (2015). Expert Report on the PennEast Pipeline Project Economic Impact Analysis for New Jersey and Pennsylvania. Retrieved from https://www.kingwoodtownship.com/ktdocuments/NJCF_PennEastEconomicReport.pdf

Goulden, M. L., et al. (1996). Exchange of Carbon Dioxide by a Deciduous Forest: Response to Interannual Climate Variability. Science, 271, 1576-1578.

Gren, I. M., Groth, K. H., & Sylven, M. (1995). Economic values of Danube floodplains. Journal of Environmental Management, 45(4), 333-345.

Gren, I.M. & Soderqvist T. (1994). Economic valuation of wetlands: a survey. Beijer International Institute of Ecological Economics. Beijer Discussion Paper series No. 54, Stockholm, Sweden.

Grzegorek, V. (2017, September 21). Ohio EPA Raises Fines on Rover Pipeline to $2.3 Million, Company Still Refuses to Pay. Cleveland Scene. Retrieved from https://www.clevescene.com/scene-and-heard/archives/2017/09/21/ohio-epa-raises-fines-on-rover-pipeline-to-23-million-company-still-refuses-to-pay

Guignet, D., Northcutt, R., & Walsh, P. (2015). The Property Value Impacts of Groundwater Contamination: Agricultural Runoff and Private Wells. National Center for Environmental Economics. Retrieved from https://www.epa.gov/sites/production/files/2016-03/documents/2015-05.pdf

Hamza, M. A. & Anderson, W. K. (2005). Soil compaction in cropping systems: A review of the nature, causes and possible solutions. Soil & Tillage Research, 82, 121-145.

Habicht, S., Hanson, L., & Faeth, P. (2015, August). The Potential Environmental Impact from Fracking in the Delaware River Basin. CNA.

Hanson, L. & Habicht S. (2016, May). Cumulative Land Cover Impacts of Proposed Transmission Pipelines in the Delaware River Basin. CNA. Retrieved from https://williampennfoundation.org/sites/default/files/reports/CAC-Report%20-CNA-PipelinesSIX.pdf

Holmes, T. P. (1988). The offsite impact of soil erosion on the water treatment industry. Land Economics, 64(4), 356-366.

Hopey, D. (2018, February 28). More lawsuits flow against Mariner East construction. Pittsburgh Post-Gazette. Retrieved from https://www.post-gazette.com/news/environment/2018/02/28/Pipeline-lawsuits-flow-Sunoco-Marcellus-Utica-shale-gas/stories/201802280220

Hughes, J. (2015, May 26). How much does it cost to connect to a water and wastewater system? University of North Carolina Environmental Finance Center. Retrieved from http://efc.web.unc.edu/2015/05/26/connecting-water-system/

Hurdle, J. (2019). Mariner East: A pipeline project plagued by mishaps and delays. StateImpact Pennsylvania. Retrieved from https://stateimpact.npr.org/pennsylvania/tag/mariner-east-2/

Hurdle, J. (2018a, November 20). Residents urge PUC to halt Mariner East operation, hold hearing on emergency plans. StateImpact Pennsylvania. Retrieved from https://www.post-gazette.com/news/environment/2018/02/28/Pipeline-lawsuits-flow-Sunoco-Marcellus-Utica-shale-gas/stories/201802280220

Hurdle, J. (2018b, June 13). Suit accuses Sunoco of violating federal Clean Water Act. StateImpact Pennsylvania. Retrieved from https://stateimpact.npr.org/pennsylvania/2018/06/13/suit-accuses-sunoco-of-violating-federal-clean-water-act/

Industrial Economics, Inc. (2011). Economic Valuation of Wetland Ecosystem Services in Delaware. Retrieved from http://www.dnrec.delaware.gov/Admin/DelawareWetlands/Documents/Economic%20Evaluation%20of%20Wetland%20Ecosystem%20Services%20in%20Delaware.pdf

Interagency Working Group on Social Cost of Greenhouse Gasses, United States Government. (2016). Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866. May 2013, Revised August 2016.

Jacobson, M. (2004). Timber Harvesting in Pennsylvania: Information for Citizens and Local Government Officials. Pennsylvania State University, College of Agricultural Sciences, School of Forest Resources.

Jackson, R., et al. (2014). The Environmental Costs and Benefits of Fracking. Annual Review of Environment and Resources.

Johnson, N., Gagnolet, T., Ralls, R., & Stevens, J. (2011). Natural Gas Pipelines: Excerpt from Report 2 of the Pennsylvania Energy Impacts Assessment. The Nature Conservancy publication.

Johnston, R. J., Ranson, M. H., Besedin, E. Y., & Helm, E. C. (2006). What Determines Willingness to Pay per Fish? A Meta-Analysis of Recreational Fishing Values. Marine Resource Economics, 21, 1-32.

Jordaan, S. M., Keith, D. W., & Stelfox, B. (2009). Quantifying land use of oil sands production: a life cycle perspective. Environmental Research Letters, 4.

Kauffman. (2011). Socioeconomic Value of the Delaware River Basin in Delaware, New Jersey, New York, and Pennsylvania.

Kauffman, G. (2016). Economic Value of Nature and Ecosystems in the Delaware River Basin. Journal of Contemporary Water Research & Education, 158, 98-119.

Kauffman, G. & Homsey, A. (2013). Economic Value of Marcellus Shale Gas in the Delaware Basin. Oil and Gas, 1(1).

Keeler, B. L., et al. (2012). Linking water quality and well-being for improved assessment and valuation of ecosystem services. Proceedings of the National Academy of Sciences of the United States of America, 109(45), 18619-18624. doi: 10.1073/pnas.1215991109.

Kologie, C. (2002, June 28). The Lockatong and Wickecheoke Watershed Management Plan. Retrieved from https://rucore.libraries.rutgers.edu/rutgers-lib/19975/PDF/1/play/

Krieger, D. J. (2001). Economic Value of Forest Ecosystem Services: A Review. The Wilderness Society, Washington, D.C.

Kroeger, T. & Manalo, P. (2006, July 26). A Review of the Economic Benefits of Species and Habitat Conservation. Conservation Economics Program, Defenders of Wildlife.

Kunz, T., Braun de Torrez, E., Bauer, D., Lobova, T., & Fleming, T. (2011). Ecosystem services provided by bats. Annals of the New York Academy of Sciences. ISSN 0077-8923. https://www.bu.edu/cecb/files/2009/08/Kunz-et-al.-Ecosystem-Services_ANYAS-2011.pdf

Lander, G. (2016, September 12). PennEast Analysis of Alternatives. Skipping Stone. Retrieved from https://rethinkenergynj.org/wp-content/uploads/2016/09/PennEast-Analysis-of-Alternatives_Skipping-Stone_Sept-12-2016.pdf

Lant, C. L. & Roberts, R. S. (1990). Greenbelts in the cornbelt: riparian wetlands, intrinsic values and market failure. Environment and Planning, 22(10), 1375-1388.

Levesque, L., & Dube., M. (2007). Review of the effects of in-stream pipeline crossing construction on aquatic ecosystems and examination of Canadian methodologies for impact assessment. Environmental Monitoring Assessment, 132, 395-409. doi: 10.1007/s10661-006-9542-9.

Litvak, A. & Legere, L. (2018, October 23). The lessons of Mariner East 2. Pittsburgh Post-Gazette. Retrieved from https://newsinteractive.post-gazette.com/mariner-east-2-pipeline-horizontal-directional-drilling/

Liu, S., Costanza, R., Troy, A., D'Aagostino, J., & Mates, W. (2010). Valuing New Jersey's Ecosystem Services and Natural Capital: A Spatially Explicit Benefit Transfer Approach. Environmental Management. doi: 10.1007/s00267-010-9483-5. Retrieved from https://esanalysis.colmex.mx/Sorted%20Papers/2010/2010%20AUS%20USA%20-CS%20USA%20NJ,%203F%20Econ.pdf

Loomis, J. & Ekstrand, E. (1998). Alternative approaches for incorporating respondent uncertainty when estimating willingness-to-pay: The case of the Mexican spotted owl. Ecological Economics, 27(1), 29-41.

Loomis, J., Kent, P., Strange, L., Fausch K., & Covich, A. (2000). Measuring the total economic value of restoring ecosystem services in an impaired river basin: results from a contingent valuation survey. Ecological Economics, 33(1), 103-117.

Lord, B. (2013). Size and Economic Impact of Pennsylvania's Wood Products Industry. Report submitted to Pennsylvania Forest Products Association.

Marchese, A. & Zimmerle, D. (2018). The U.S. natural gas industry is leaking way more methane than previously thought." PBS News Hour. Retrieved from https://www.pbs.org/newshour/science/the-u-s-natural-gas-industry-is-leaking-way-more-methane-than-previously-thought

Mates, W. & Reyes, J. (2004). Economic Value of New Jersey State Parks and Forests. New Jersey Department of Environmental Protection, New Jersey.

Maykuth, A. (2018, June 1). "How Sunoco's Mariner East Pipeline is Affecting Real Estate Prices in PA's Chester and Delaware Counties." The Inquirer. Retrieved from http://www2.philly.com/philly/business/energy/sunoco-mariner-east-me2-pipeline-chester-delaware-county-real-estate-home-prices-pa-20180601.html

Maykuth, A. (2017a, July 11). Sunoco agrees to extend public water to homes with tainted wells. The Inquirer. Retrieved from http://www.philly.com/philly/business/energy/west-goshen-says-sunoco-violated-mariner-east-agreement-20170711.html

Maykuth, A. (2017b, July 7). Water-contamination complaints force Sunoco to suspend Chesco pipeline construction. The Inquirer. Retrieved from http://www.philly.com/philly/business/energy/water-contamination-complaints-force-sunoco-to-suspend-chesco-pipeline-construction-20170707.html

McGarigal, K., Cushman, S., & Regan, C. (2005, August 12). Quantifying Terrestrial Habitat Loss and Fragmentation: A Protocol. Department of Natural Resources Conservation, University of Massachusetts.

Melstrom, R. T., Lupi, F., Esselman, P. C., & Stevenson, R. J. (2015). Valuing Recreational Fishing Quality at Rivers and Streams. Water Resources Research, 51, 140-150. doi: 10.1002/2014WR016152.

Meyer, J. L., et al. (2003, September). Where Rivers are Born: The Scientific Imperative for Defending Small Streams and Wetlands. American Rivers and Sierra Club. September 2003.

Meyerhoff, J. & Dehnhardt, A. (2004). The European Water Framework Directive and Economic Valuation of Wetlands: the restoration of floodplains along the river Elbe. Working Paper on Management in Environmental Planning.

Ministerie van Landbouw, Natuur en Voedselkwaliteit. (2006). Kentallen waardering natuur, water, bodem en landschap. Hulpmiddel bij MKBA's. Eerste editie. Witteveen en Bos, Deventer, the Netherlands.

Minott, J., Bomstein, A., & Ahlers, C. (2018, August 14). Clean Air Council's Post-Hearing Brief. Clean Air Council v. Commonwealth of Pennsylvania Department of Environmental Protection and Sunoco Partners Marketing & Terminals, L.P. Permittee. EHB Docket No. 2016-073-L. Retrieved from http://ehb.courtapps.com/efile/documentViewer.php?documentID=43190

Myhre, G. & Shindell, D. (2013). IPCC Climate Change Fifth Assessment Report. Chapter 8: Anthropogenic and Natural Radiative Forcing. Intergovernmental Panel on Climate Change. Retrieved from https://www.ipcc.ch/site/assets/uploads/2018/02/WG1AR5_Chapter08_FINAL.pdf

National Association of State Energy Officials. (2018, May). Energy Employment by State. Retrieved from http://www.emnrd.state.nm.us/ECMD/documents/USEER2018_StateFacts.pdf

National Park Service (2012). Delaware River Basin National Wild and Scenic River Values: Pennsylvania, New York, and New Jersey. U.S. Department of the Interior.

National Soil Erosion-Soil Productivity Research Planning Committee. (1981). Soil erosion effects on soil productivity: A research perspective. Journal of Soil and Water Conservation, 36(2), 82-90.

Natural Resources Defense Council. (2018, February 26). Following Spills, Ohio Wants to Reroute the Rover Pipeline but Lacks the Muscle. Retrieved from https://www.nrdc.org/stories/following-spills-ohio-wants-reroute-rover-pipeline-lacks-muscle

New Brunswick Water Utility. (2017). Water Quality Report 2017. City of New Brunswick, New Jersey. Retrieved from http://thecityofnewbrunswick.org/water-utility/wp-content/uploads/sites/12/2018/05/New_Brunswick_WQR_2017_v10.pdf

New Jersey American Water Company – Elizabethtown Division. (Unknown). Source Water Assessment Summary. Retrieved from http://state.nj.us/dep/swap/reports/sumdoc_2004002.pdf

New Jersey Department of Environmental Protection, Office of Air Quality, Energy & Sustainability. (2019). Climate Change. Accessed on March 13, 2019 from https://www.nj.gov/dep/aqes/climate/

New Jersey Division of Fish & Wildlife. (2018). New Jersey's Endangered & Threatened Wildlife. Department of Environmental Protection. Retrieved from https://www.nj.gov/dep/fgw/tandespp.htm

New Jersey Water Supply Authority. (2017). Canal Dredging. Retrieved from http://www.njwsa.org/canal-dredging.html

Office of Governor Tom Wolf. (2019, January 8). Governor Wolf Establishes First Statewide Goal to Reduce Carbon Pollution in Pennsylvania.

Onstott, T. (2014). Docket No. PF15-1-000: Comments Regarding PennEast Pipeline Project: Arsenic and Earthquakes. Submitted to the Federal Energy Regulatory Commission February 24, 2014.

Oregon Department of Human Services Public Health Division. (Unknown). VOCs and well water: What you need to know. Retrieved from https://www.oregon.gov/oha/PH/HEALTHYENVIRONMENTS/TRACKINGASSESSMENT/ENVIRONMENTALHEALTHASSESSMENT/Documents/vocs_in_well_water_final_for_web.pdf

Panagos, P., Standardi, G., Borrelli, P., Lugato, E., Montanarella, L., & Bosello, F. (2018). Cost of agricultural productivity loss due to soil erosion in the European Union: From direct cost evaluation approaches to the use of macroeconomic models. Land Degradation and Development, 29(3), 471-484.

Passchier-Vermeer, W. & Passchier, W. F. (2000). Noise exposure and public health. Environmental Health Perspectives, 108(Suppl 1), 123-131. doi: 10.1289/ehp.00108s1123.

Pelican Water Systems. (2019). Whole House Filter & Salt Free Softener. Retrieved from https://www.pelicanwater.com/water-softeners/water-filter-and-salt-free-softeners/

PennEast Pipeline Company, LLC. (2018, January 20). After Three Years, PennEast Pipeline Approved by Federal Energy Regulatory Commission: Families and Businesses Will Receive Safe, Clean, Reliable and Affordable Energy. Retrieved from http://penneastpipeline.com/three-years-penneast-pipeline-approved-federal-energy-regulatory-commission/

PennEast Pipeline Company, LLC (2016, December). PennEast Pipeline Project Revised Applicant-Prepared Draft Biological Assessment.

PennEast Pipeline Company, LLC. (2015a). PennEast Pipeline Project Resource Report 1. FERC Docket No. PF15-1-000

PennEast Pipeline Company, LLC. (2015b). PennEast Pipeline Project Resource Report 8. FERC Docket No. PF-__-000.

PennEast Pipeline Company, LLC. (2014). How We Cross Rivers and Streams. Retrieved from https://penneastpipeline.com/wp-content/uploads/2014/12/PennEast_Crossing_Rivers.pdf

PA Department of Conservation and Natural Resources (PA DCNR). (2015). Sinkholes in Pennsylvania.

PA DCNR. (2014). Pennsylvania's Statewide Comprehensive Outdoor Recreation Plan 2014-2019. Appendix C: Pennsylvania Outdoor Recreation Online Surveys.

PA DCNR. (2012). The Economic Significance and Impact of Pennsylvania State Parks: An Updated Assessment of 2010 Park Visitor Spending on the State and Local Economy. Retrieved from http://www.docs.dcnr.pa.gov/cs/groups/public/documents/document/dcnr_007019.pdf

PA Department of Environmental Protection (PA DEP). (2019a). PPP/Mariner East II Project Overview Information. Retrieved from https://www.dep.pa.gov/Business/ProgramIntegration/Pennsylvania-Pipeline-Portal/Pages/Mariner-East-II.aspx

PA DEP (2019b, February 8). Department of Environmental Protection Issues Hold on All Energy Transfer Clean Water Permit Approvals and Modifications Due to Non-Compliance. Retrieved from http://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21634&typeid=1

PA DEP. (2018a). Pennsylvania Pipeline Portal: Mariner East II. Accessed November 20, 2018 at https://www.dep.pa.gov/Business/ProgramIntegration/Pennsylvania-Pipeline-Portal/Pages/Mariner-East-II.aspx

PA DEP. (2018b, January 3). DEP Suspends Mariner East 2 Construction Permits. DEP Newsroom. Retrieved from http://www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21371&typeid=1

PA DEP. (2018c, February 8). DEP Issues $12.6 Million Penalty to Sunoco, Lifts Suspension Order Following Stringent Compliance Review. DEP Newsroom. Retrieved from http://www.ahs.dep.pa.gov/NewsRoomPublic/SearchResults.aspx?id=21393&typeid=1

PA DEP. (2018d, April 17). Wolf Administration Announces Use of Mariner East 2 Fine. DEP Newsroom. Retrieved from http://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21442&typeid=1

PA DEP. (2018e, May 3). DEP Levies Additional $355,000 Penalty Against Sunoco for Mariner East 2 Violations. DEP Newsroom. Retrieved from http://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21456&typeid=1

PA DEP (2018f, August 6). DEP Assesses $148,000 Penalty Against Sunoco for Mariner East 2 Violations in Berks, Chester and Lebanon Counties. DEP Newsroom. Retrieved from http://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21523&typeid=1

PA DEP. (2017a, September 21). Sunoco Pipeline LP/Beckersville Station/Mariner East Permit Review Memo. Air Quality Program. Retrieved from http://files.dep.state.pa.us/RegionalResources/SCRO/SCROPortalFiles/Community%20Info/AQ/Sunoco%20Pipeline%20LP/Sunoco%20Pipeline%20LP%20-%20Beckersville%20Pump%20Station%20–%209-21-17%20DEP%20Review%20Memo%20and%20Draft%20State-Only%20Operating%20Permit%2006-03164.pdf

PA DEP. (2017b, July 25). DEP Announces Accountability Actions for Mariner East 2 Violations, Environmental Hearing Board Issues Temporary Partial Halt to Drilling. DEP Newsroom. Retrieved from http://www.ahs.dep.pa.gov/NewsRoomPublic/articleviewer.aspx?id=21249&typeid=1

PA Game Commission. (2018). Endangered & Threatened Species. Retrieved from https://www.pgc.pa.gov/Wildlife/EndangeredandThreatened/Pages/default.aspx

PA Senate. (2018, March 5). Dinniman: More Sinkholes May Mean Another Halt to Mariner II Pipeline. Retrieved from http://www.pasenate.com/dinniman-more-sinkholes-may-mean-another-halt-to-mariner-ii-pipeline/

Perrot-Maître, D. & Davis, P. (2001). Case studies of markets and innovative financial mechanisms for water services from forests. Forest Trends, working paper.

Phillips, S. (2017a, July 14). Sunoco halts drilling in Chester County where pipeline construction damaged drinking water wells. Retrieved from https://stateimpact.npr.org/pennsylvania/2017/07/14/sunoco-halts-drilling-in-chester-county-where-pipeline-construction-damaged-drinking-water-wells/

Phillips, S. (2017b, July 31). Democratic lawmakers ask FERC to investigate Mariner East 2 pipeline builder. StateImpact Pennsylvania. Retrieved from https://stateimpact.npr.org/pennsylvania/2017/07/31/democratic-lawmakers-ask-ferc-to-investigate-mariner-east-2-pipeline-builder/

Phillips, S. and Frazier, R. (2018). Natural gas pipeline blast in Beaver County prompts evacuation. Retrieved from https://stateimpact.npr.org/pennsylvania/2018/09/10/natural-gas-pipeline-blast-in-beaver-county-prompts-evacuation/

Phillips, S., Wang, S., & Bottorff, C. (2017). Economic Costs of the PennEast Pipeline: Effects on Ecosystem Services, Property Value, and the Social Cost of Carbon in Pennsylvania and New Jersey. Key-Log economics LLC. January 2017.

Phillips, S., Silverman, R., & Gore, A. (2008). Greater than zero: toward the total economic value of Alaska's National Forest wildlands. The Wilderness Society, Washington, D.C..

Pimentel, D., Harvey, C., Resosudarmo, P., Sinclair, K., Kurz, D., McNair, M., Crist, S., Sphpritz, P., Fitton, L., Saffouri, R., & Blair, R. (1995). Environmental and economic costs of soil erosion and conservation benefits. Science, 267, 1117-1123.

Pimentel, D., et al. (1997). Economic and environmental benefits of biodiversity. BioScience, 47(11), 747-757. doi: 10.2307/1313097.

Pindyck, R. (2019). The social cost of carbon revisited. Journal of Environmental Economics and Management, Vol. 94. Retrieved from https://www.sciencedirect.com/science/article/abs/pii/S0095069617307131

Polin, R., Heintz, J., & Garrett-Peltier, H. (2009). The Economic Benefits of Investing in Clean Energy: How the economic stimulus program and new legislation can boost U.S. economic growth and employment. Center for American Progress and Political Economy Research Institute, University of Massachusetts, Amherst. June 2009. Retrieved from https://www.researchgate.net/publication/46474466_The_Economic_Benefits_of_Investing_in_Clean_Energy_How_the_Economic_Stimulus_Program_and_New_Legislation_Can_Boost_US_Economic_Growth_and_Employment

Postel, S. & Carpenter, S. (1997). Ecosystem services: their nature and value. Island Press, Washington, D.C.

Quest Consultants Inc. (2018, October 19). Del-Chesco United for Pipeline Safety. Retrieved from https://stateimpact.npr.org/pennsylvania/2018/10/19/full-mariner-east-pipeline-risk-assessment-report-released/

Rausser, G. C. & Small, A. A. (2000). Valuing research leads: bioprospecting and the conservation of genetic resources. UC Berkeley: Berkeley Program in Law and Economics. Journal of Political Economy, 108(1), 173-206.

Reid, S. M. & Anderson, P. G. (1999). Effects of Sediment Released During Open-Cut Pipeline Water Crossings. Canadian Water Resources Journal, 24(3), 235-251. doi: 10.4296/cwrj2403235. Retrieved from https://doi.org/10.4296/cwrj2403235.

Reid, S. M. & Anderson, P. G. (1998). Suspended sediment and turbidity criteria associated with instream construction activity: An assessment of biological relevance. Summary of report prepared by Golder Associates Ltd (Calgary) for the InterState Natural Gas Association of America.

Rettew, B. (2018, March 26). Class action lawsuit filed against Sunoco pipeline claims negligence. Daily Times. Retrieved from https://www.delcotimes.com/news/class-action-lawsuit-filed-against-sunoco-pipeline-claims-negligence/article_9e10eab8-a0dd-554e-9ab7-399e6acc8d59.html

Rettew, B. (2017a, July 12). Uwchlan residents discuss Mariner East 2 pipeline, water problems. Daily Local News. Retrieved from https://www.dailylocal.com/news/national/uwchlan-residents-discuss-mariner-east-pipeline-water-problems/article_b5b63390-5da0-5bae-9f7d-7f1f535e6a30.html

Rettew, B. (2017b, November 3). W. Whiteland couple taking on Sunoco Pipeline project, but can they win? Daily Local News. Retrieved from https://www.dailylocal.com/news/national/w-whiteland-couple-taking-on-sunoco-pipeline-project-but-can/article_e9857069-66f1-5028-b98b-4019a27ef73b.html

Rosenberger, R. S., White, E. M., Kline, J. D., Cvitanovich, C. (2017). Recreation economic values for estimating outdoor recreation economic benefits from the National Forest System. Gen. Tech. Rep. PNWGTR-957. Portland, OR: U.S. Department of Agriculture, Forest Service, Pacific Northwest Research Station. 33 p.

Russo, P. N. & Carpenter, D. O. (2017, October 12). Health Effects Associated with Stack Chemical Emissions from NYS Natural Gas Compressor Stations: 2008-2014. Institute for Health and the Environment.

Sala, O. E. & Paruelo, J. M. (1997). Ecosystem services in grasslands. In: Daily, G. (ed), "Ecosystem services: their nature and value" Island Press, Washington, D.C.

Sasko, C. (2018, March 22). “I’m Terrified”: Life on the Front Lines of the Sunoco Pipeline. Philadelphia Magazine. Retrieved from https://www.phillymag.com/news/2018/03/22/sunoco-mariner-east-pipeline-sinkholes/

Sawatsky, L., Bender, M., & Long, D. (1998). Pipeline exposure at river crossings: Causes and cures. International Pipeline Conference, Vol. 1, ASME 1998.

Schoen, J. W. (1990). Bear Habitat Management: A Review and Future Perspective. Bears: Their Biology and Management, Vol. 8, 143-154.

Schwartz, A. & Kocian, M. (2015). Beyond Food: The Environmental Benefits of Agriculture in Lancaster County, Pennsylvania. Report prepared by Earth Economics.

Sheeder, S. A. & Evans, B. M. (2004). Estimating nutrient and sediment threshold criteria for biological impairment in Pennsylvania watersheds. Journal of American Water Research Association, 40, 881-888.

Shi, P., Xiao, J., Wang, Y., & Chen, L. (2014). Assessment of ecological and human health risks of heavy metal contamination in agriculture soils disturbed by pipeline construction. International Journal of Environmental Research and Public Health.,11(3), 2504-2520. doi: 10.3390/ijerph110302504

Skonberg E., Tammi C., Desilets, A., & Srivastava, V. (2008, December). Inadvertent Slurry Returns during Horizontal Directional Drilling. Retrieved from https://www.researchgate.net/publication/295339340_Inadvertent_Slurry_Returns_during_Horizontal_Directional_Drilling

Smith, T. J. and Sinn, G. C. (2013). Induced Sinkhole Formation Associated with Installation of a High-Pressure Natural Gas Pipeline, West-Central Florida. Retrieved from http://digital.lib.usf.edu/SFS0052010/00001/pdf

Sorensen, M., Andersen, Z.J., Nordsborg, R. B., Becker, T., Tjonneland, A., Overvad, K., et al. (2013). Long-Term Exposure to Road Traffic Noise and Incident Diabetes: A Cohort Study. Environmental Health Perspectives, 121(2), 217-22. PMID 23229017.

Southwest Pennsylvania Environmental Health Project (SPEHP). (2015). Summary on Compressor Stations and Health Impacts.

Steinzor, N., Subra, W., & Sumi, L. (2013). Investigating links between shale gas development and health impacts through a community survey project in Pennsylvania. New Solutions, 23(1), 55-83.

Stokols, E. (2013). Parachute creek contamination spreads, spurs calls for more regulations, fines. Fox News Denver. Retrieved from https://kdvr.com/2013/04/09/parachute-creek-contamination-spreads-spurs-calls-for-more-regulations-fines/

Subra, W. (2012, October). Toxic Exposure Associated with Shale Development. Subra Company and Earthworks Board.

Subra, W. (2009, December). Health Survey Results of Current and Former DISH/Clark Texas Residents. Earthworks. Retrieved from https://earthworks.org/cms/assets/uploads/archive/files/publications/DishTXHealthSurvey_FINAL_hi.pdf

Swinton, S. M., Lupi, F., Robertson, G. P., & Hamilton, S. K. (2007). Ecosystem services and agriculture: Cultivating agricultural ecosystems for diverse benefits. Ecological Economics, 64, 245-252. doi: 10.1016/j.ecolecon.2007.09.020.

The Trust for Public Land, Conservation Almanac. (2019). Retrieved from http://www.conservationalmanac.org/secure/

Thompson, J. (2017). A map $1.1 billion in natural gas pipeline leaks. High Country News. Retrieved from https://www.hcn.org/issues/49.22/infographic-a-map-of-leaking-natural-gas-pipelines-across-the-nation

United Nations. (2018, January 19). NASA Confirms Methane Spike Is Tied to Oil and Gas. United Nations Framework Convention on Climate Change. Retrieved from https://unfccc.int/news/nasa-confirms-methane-spike-is-tied-to-oil-and-gas

U.S. Department of Agriculture (USDA). (2017a). Land Value 2017 Summary.

USDA. (2017b). 2017 State Agricultural Overview: Pennsylvania. Retrieved from https://www.nass.usda.gov/Quick_Stats/Ag_Overview/stateOverview.php?state=PENNSYLVANIA

USDA. (2017c). National Agricultural Statistics Service: Quick Stats. Retrieved from https://quickstats.nass.usda.gov/

USDA Natural Resources Conservation Service. (2007). Lockatong and Wickecheoke Creek Watershed Sediment and Phosphorus Source Report. USDA Natural Resources Conservation Service for NJ Water Supply Authority.

U.S. Department of the Interior, U.S. Fish and Wildlife Service, & U.S. Department of Commerce, U.S. Census Bureau. (2011). National Survey of Fishing, Hunting, and Wildlife-Associated Recreation.

U.S. Department of Transportation Pipeline and Hazardous Materials Safety Administration (U.S. DOT PHMSA). (2019). Pipeline Significant Incident 20 Year Trend. Data retrieved March 9, 2019 from https://www.phmsa.dot.gov/data-and-statistics/pipeline/pipeline-incident-20-year-trends

U.S. Energy Information Administration (EIA). (2019). State Electricity Profiles, Pennsylvania Electricity Profile 2017. Retrieved from https://www.eia.gov/electricity/state/pennsylvania/index.php

U.S. EIA. (2017). Appalachia region drives growth in U.S. natural gas production since 2012. Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=33972

U.S. EIA. (2012, April 20). What are natural gas liquids and how are they used? Retrieved from https://www.eia.gov/todayinenergy/detail.php?id=5930

U.S. Environmental Protection Agency (EPA). (2019, April 29). EnviroAtlas. Retrieved from https://www.epa.gov/enviroatlas

U.S. EPA. (2018). Inventory of U.S. Greenhouse Gas Emissions and Sinks 1990-2016. Retrieved from https://www.epa.gov/sites/production/files/2018-01/documents/2018_complete_report.pdf

U.S. EPA. (2017). Greenhouse Gas Emissions: Understanding Global Warming Potentials. Updated February 14, 2017. Retrieved from https://www.epa.gov/ghgemissions/understanding-global-warming-potentials

U.S. EPA. (2016). Climate Change Indicators in the United States. Fourth Edition. Retrieved from https://www.epa.gov/sites/production/files/2016-08/documents/climate_indicators_2016.pdf

U.S. EPA. (2010, April). 2007 Drinking Water Infrastructure Needs Survey and Assessment, Modeling the Cost of Infrastructure.

U.S. Fish and Wildlife Service. (2018, June 20). Rusty Patched Bumble Bee (Bombus affinis): Plants Favored by the Rusty Patched Bumble Bee. Retrieved from https://www.fws.gov/midwest/endangered/insects/rpbb/plants.html

U.S. Fish and Wildlife Service. (2011, December). Dwarf wedgemussel: Alasmidonta heterodon. Retrieved from https://www.fws.gov/asheville/pdfs/DwarfWedgeMussel_factsheet.pdf

U.S. Interagency Working Group on Social Cost of Greenhouse Gases. (2016, August). Technical Support Document: Technical Update of the Social Cost of Carbon for Regulatory Impact Analysis Under Executive Order 12866.

Van der Ploeg, S., Wang, Y., Gebre Weldmichael, T., & de Groot, R. S. (2010). The TEEB Valuation Database – a searchable database of 1310 estimates of monetary values of ecosystem services. Foundation for Sustainable Development, Wageningen, The Netherlands.

Van Kamp, I. & Davies, H. (2013). Noise and health in vulnerable groups: a review. Noise Health. PMID 23689296. Retrieved from http://www.ncbi.nlm.nih.gov/pubmed/23689296

Veldman, J. W., et al. (2015). Where tree planting and forest expansion are bad for biodiversity and ecosystem services. BioScience, 65(10), 1011-1018. doi: 10.1093/biosci/biv118

Walsh, R. G., Loomis, J. B., & Gillman, R. A. (1984). Valuing option, existence, and bequest demand for wilderness. Land Economics, 60(1), 14-29.

Wang, L. & Chen, A. (2011). Costs of Arsenic Removal Technologies for Small Water Systems: U.S. EPA Arsenic Removal Technology Demonstration Program. EPA/600/R-11/090

Warziniack, T., Sham, C. H., Morgan, R., & Feferholtz, Y. (2016). Effect of Forest Cover on Drinking Water Treatment Costs.

Washington Crossing Audubon Society (2018). PennEast Pipeline Threatens Baldpate Mountain Important Bird Area. Accessed November 11, 2018 at https://www.washingtoncrossingaudubon.org/penneast-pipeline/penneast-threatens-baldpate/

Weiss, H. (2017, July 13). Sunoco to Pay to Resolve Cloudy Water Caused by Pipeline Drilling. Philadelphia Magazine. Retrieved from https://www.phillymag.com/business/2017/07/13/sunoco-mariner-east-2-pipeline-drilling-water-contamination-chester-county/

Werner, A. K., Vink, S., Watt, K., & Jagals, P. (2015). Environmental Health Impacts of Unconventional Natural Gas Development: A Review of the Current Strength of Evidence. Science of the Total Environment, 505C, 1127-1141. doi: 10.1016/j.scitotenv.2014.10.084.

West Goshen Township (2019). Sunoco Mariner I & Mariner II Documents and Litigation Information. West Goshen Township, Chester County, PA. Website accessed February 18, 2019 at https://www.westgoshen.org/sunoco-mariner-i-ii-information-litigation/

Wilson, M. A. & Carpenter, S. R. (1999). Economic Valuation of Freshwater Ecosystem Services in the United States: 1971–1997. Ecological Applications, 9(3), 772-783. doi: 10.1890/1051-0761(1999)009[0772:EVOFES]2.0.CO;2

Woidt Engineering and Consulting (2017, December). PennEast Pipeline Trout Habitat Protection Review. Prepared for Trout Unlimited.

Zeph, E. & Mowery, M. (Unknown). Economic Value of Pennsylvania State Parks and Forests.

Appendix A - Pipeline Geospatial Analysis Methods

The Pipeline Routes

This study investigates two pipeline projects preparing for construction within the Delaware River Basin: 1) The Mariner East 2 Pipelines and 2) the PennEast Pipeline.

Methods to Estimate Pipeline Cleared Areas

The Mariner East 2 pipelines have accurate and complete geospatial information made available by the Pennsylvania Department of Environmental Protection (PADEP) that was suitable for direct use for impact analysis. All new land clearing was contained in polygon shapefile [1], with attributes distinguishing permanent rights-of-way, temporary rights-of-way, facility footprint, and other spaces such as spoil space. The same source [1] also had the pipeline centerline including HDD and borehole sections in polyline format, and facilities as points. Using the combination of these datasets, we were able to complete the bulk of analyses. We used the attribute information in the polygon shapefile to categorize all of the clearing areas as permanent or temporary.

The PennEast pipeline does not have readily accessible geospatial files. Instead, the pipeline project has an online, view-only webmap [2] of the current pipeline route, and relatively detailed (1in = 2000 ft) portable document format (pdf) maps [3]. The pdf maps also show the clearing areas for construction and facilities, but do not the limits of the permanent ROW. In addition, the pdf maps show the roads. The New Jersey Conservation Foundation provided a file with the pipeline centerline accurate as of September 2016. In order to develop these maps into usable geospatial data, we employed a combination of methods:

1. **Correct centerline where deviations appear**: We used the online map [2] and pdf maps [3] to validate the centerline accuracy. Where there were noticeable deviations, we digitized the route alteration by either projecting the relevant pdf map into GIS and tracing the route, or using basemaps to hand digitize segments based on contours, roads and other landmarks.
2. **Digitize access roads**: We used the pdf maps and online map to locate proposed roads used during construction, and digitized them in ArcGIS. (Either by georeferencing the pdf map and tracing, or using basemaps.) We digitized all roads longer than roughly 500 feet, and used attributes to denote if they were permanent or temporary.
3. **Buffer the centerline to approximate workspaces in the right-of-way (ROW)**: Georeferencing and tracing all construction work areas would far exceed the scope of this project. Instead, we used an asymmetric buffer method to estimate the pipeline ROW areas. We sliced the pipeline route into segments and created attribute fields to keep track of left and right (relative to the direction of travel) buffer distances in units of feet. We identified segments of the pipeline that had HDD sections, abnormally wide ROW (such as a drilling pad upon an HDD approach), or ROW constrictions. We then buffered the entire ROW (except HDD segments) with an equal 15-ft buffer to model the permanently-cleared area (30-ft total width) specified in PennEast Environmental Impact study documents, and a 25-ft equal buffer for the permanent ROW (50-ft total width). Then, to model the construction

ROW, we used an asymmetric buffer to buffer 25-ft on the non-working side of the pipeline, and 75-ft (i.e. 50-ft past the permanent ROW) on the construction side. We used the left and right buffer attribute information to keep track of which side appeared to be the construction or working side based on the pdf and online maps, and set the left and right buffers to 25 and 75 accordingly. We also buffered the HDD approach sections with an equal 100-ft buffer, for a total width of 200-ft, which was the average width based on a random sample of six HDD approach sections on the pdf maps within the DRB. In addition to the pipelines, we buffered all of the construction access roads (that we previously digitized in step 2 above) with a 15-ft equal buffer for a total road ROW width of 30 feet.

4. **Erase already-cleared areas, and ensure non-overlapping layers**: Since the PennEast pipeline runs along several adjacent pipeline, and shares a portion of its ROW, there will not be new clearing along the entire route. We used a dataset with existing pipeline routes, and buffered all active pipelines by 25-ft (for a 50-ft permanent ROW). Then, we erased that buffer from all of the PennEast buffers. Additionally, we erased the permanent ROW of from the Construction ROW to create non-overlapping shapes representing the cleared areas for the permanent and temporary construction ROWs.
5. **Digitize additional facilities and work areas off the main ROW**: The pdf and online maps for the PennEast also show several larger areas for facility siting, additional temporary work space, and equipment storage. We georeferenced the relevant maps, and traced these areas to capture them, and used attribute information to assign them to either permanent or temporary clearing.
6. Merge all temporary and permanent workspace areas into a master file representing temporary and permanent clearing.

Thus, the process for estimating the clearing for the PennEast pipeline is much more intensive than for the Mariner East 2 pipelines, but it is the most accurate representation possible without manually digitizing the information in the pdf maps.

Pipeline Data Sets for Analysis

We used four main data sets for analyzing pipeline impacts. These include the line features for the pipeline centerline, the cleared areas for the pipeline ROW (and other workspaces), a series of distance buffers around pipeline centerline and facilities, and a buffer from the edge of clearing on the cleared areas. The summaries describe these datasets and note their uses for analysis.

1. **Pipeline centerline** – The polyline features for the pipeline centerline are used for intersection analysis with other linear features (e.g., streams, trails), and distance analysis (e.g., drinking water wells). In some cases, road centerline features may also be used. We have flagged HDD sections to distinguish crossings that may pass under a resource of interest.
2. **Cleared areas** – We aggregated all of the work areas and categorized them as either permanent or temporary. Primarily, these areas include the permanent and temporary ROWs. But there are additionally some facilities (e.g., compressor stations) that may be permanent, and some areas (e.g., additional temporary workspace or wareyards) that are temporary.
3. **Centerline buffer** – We buffered the pipeline centerline to enable determination of total resources (e.g., population) within certain distances of the pipeline. The buffers we used were

400 ft, 1/4 mile (1320 ft), and 1/2 mile (2640 ft). The 400-ft distance corresponds with the pipeline study corridor used by the PennEast project proponents. The 1320-ft distance roughly corresponds with the distance for explosive hazard or impacts from spills. The 2640-ft distance roughly approximates the immediate evacuation area in case of a pipeline incident. Additionally, we buffered permanent pipeline facilities (e.g., compressor stations, valve stations) by 2130-ft, a distance that corresponds with health risks due to air emissions and noise.

4. **Cleared area plus buffer** – We buffered the cleared areas dataset by an additional 100 meters beyond the edge of clearing. This buffer approximates the core to edge forest transition boundary for newly cleared forest edges. For analyses that concern species abundance, this buffer area defines the approximate zone that species highly sensitive to habitat alteration due to changes in noise, light, or vegetative cover may be affected by pipeline construction.

Methods for Pipeline Impact Analysis

The following sections briefly layout for each analysis conducted to assess the potential impacts of pipeline construction. For each type of analysis, we present a box that summarized the impact type, which pipeline dataset was used, data sources for other data used in the analysis, a description of the method, and output metrics. The analyses are broken down by category including land use and land cover change, agricultural loss of use, protected areas and recreation, population and private property, water sources, drinking water impacts, and surface water quality.

Land Use and Land Cover Change

The most basic impact of the pipeline will be land use change and temporary loss of use of land designated for clearing, either permanent or temporary for construction.

Impact type	Cleared are by land use type
Pipeline data	Cleared areas
Data Source	Cropland Data Layer (2017) [4]
Method description	We intersected the cleared area dataset with counties within the DRB to allow post-processing and tabulation by county. Then, we tabulated the intersection of the pipeline cleared areas with the cropland data layer. Since the cropland data layer somewhat underrepresents forest cover, we applied the adjustment factors in Hanson (2016) [5]to adjust forest cover for land use codes representing forest, shrub-scrub, grassland, developed –open space, developed- low density, cultivated areas, and pasture/hay. Other land uses had minimal forest cover.
Metrics	Total area [ac] of land cover disturbed by class in each county, municipality affected by construction.

Impact type	Land cover change caused by pipeline construction
Pipeline data	Cleared areas
Data Source	High-resolution land cover layer (2013) [6]
Method description	The HLRC divides land cover into 7 main land cover classes on a 1m resolution. (We simplified the impervious land cover classes into one single class.) We intersected the pipeline rights of way with the high resolution land cover dataset, and tabulated the area by land cover class within each clearing type. The HRLC is a true land cover dataset, and does not indicate land use. Therefore, the values from the Cropland Data Layer above are considered more relevant to land use breakdown of the pipeline cleared areas.

Metrics	Total area [ac] of land cover disturbed by class in each county, municipality affected by construction.

Agricultural Loss of Use

Impact type	Loss of use of agricultural lands due to pipeline clearing
Pipeline data	Cleared areas
Data Source	Cropland Data Layer (2017) [4]
Method description	Tabulate intersection between cleared area types (permanent, temporary) and land use codes for crops in the CDL. Calculate areas affected by crop types. Assume that 50% of Hay and 25% of grass/pasture lands are in active agricultural use (100% for all other crops).
Metrics	Total area [ac] of land cover disturbed by crop type. Identify top 5 crops affected.

Protected Areas and Recreation

Impact type	Protected areas affected by pipeline construction
Pipeline data	Cleared areas (temporary and permanent)
Data Source	National Gap Analysis Program (GAP) [7] National Conservation Easements Database (NCED) [8] New Jersey Conservation Foundation geospatial data
Method description	There are several categories of protected areas. Typically, they break down into 2 main categories: 1) fee-protected (often public, but occasionally private) parks, recreation areas, wilderness areas, or other protected areas, and 2) easements or others restrictions designed to preserve land, often as open space or agricultural land. In some cases, protected areas can fall under multiple classifications, such as when a private land-owner protects a parcel, and later sells or donates it a government agency to operate as a park. As a result, there is often some overlap across the primary data sources used to identify the protected areas. For this analysis, we conducted an initial step to use a spatial join to unite all protected areas affecting a given parcel of land. This created a single dataset encompassing all protected areas. We used geoprocessing and manual editing in ArcGIS to ensure that parcel boundaries were coincident. (In many cases, the spatial projections of boundaries were off by a few feet.) After the completion of spatial joining and boundary rectification, we intersected the pipeline cleared areas with the full protected areas dataset. We summarized the parcels using a hierarchy of fee-protected lands then easements. In cases where the same parcel of land occurred in multiple source databases as an easement, we defaulted to New Jersey Conservation Foundation parcels first, and then whichever databases had the most detail on the parcel and the finest scale breakdown. (Some databases aggregate all land managed by a single entity into a single shape, while others may break it down into smaller parcels held by individual owners. We defaulted to the finest scale information available.) In the summarization, we separate fee-protected areas into federal, state, local/regional, and other (private, etc.). For easements, we distinguish open space or conservation easements and agricultural easements.
Metrics	# of designated preserved areas (parcels) affected by pipeline construction by type [fee-protected, easement] Area [ac] of preserved areas affected by pipeline construction by type [fee-protected, easement]

Impact type	Reduced recreational opportunity, hunting and fishing
Pipeline data	Cleared areas plus 100 meter buffer
Data Source	U.S. EPA EnviroAtlas [9-12]
Method description	Enviroatlas is a dataset available at the HUC-12 watershed scale for the entire U.S. Among the metrics available are estimated recreational days [person-days per year] in four outdoor recreational categories (big game hunting,

	bird hunting, bird watching, freshwater fishing). Construction activities can affect wildlife is areas beyond the limits of clearing through noise, visual impacts, runoff, and air emissions. 100 meters is a standard distance accepted for delineating edge forests from more biologically diverse core forests. We used the limits of clearing plus 100 meters to define a zone of reduced wildlife activity that will result in lower ability to recreate. We divided the total clearing plus buffer area by the total area of each HUC-12 watershed to determine a "reduction factor" for the recreation days supported. We multiplied the reduction factor by the total days of recreation in each category for each HUC-12 to determine the number of lost recreational opportunity per year.
Metrics	Reduced recreational days [person-days per year] for: • Big Game Hunting • Bird Hunting • Bird Watching • Freshwater Fishing

Impact type	Reduced recreational opportunity, hiking and trails
Pipeline data	Centerline, road features
Data Source	Explore PA trails DCNR (2018) [13] NJ State Park trails (2018) [14] PA Chapter 93 Designated Use Streams (2017) [15]
Method description	This analysis uses a simple intersect method to determine where pipelines cross existing trails. The "Intersect" tool in ArcToolbox returns the intersections as points when two polyline feature classes (e.g. pipelines and trails) are intersected.
Metrics	# of trail crossings of pipeline centerline

Affected Populations and Property

Impact type	Population potentially affected by pipeline operations
Pipeline data	Centerline and major facilities buffers (buffers at 400 ft, 0.25 mi, and 0.5 mi)
Data Source	EPA Dasymetric population of the United States [16]
Method description	The EPA's dasymetric population dataset takes 2010 census data at the census block level (finest level for more areas) and apportions the population to a 30-m pixel raster based on land use and slope. Each pixel has an estimated population value. This gives a much finer assessment of populations in areas that do not have even land uses or population density across the census block. We used a zonal statistics calculation to compute the total population within each buffer "zone" from the pipeline.
Metrics	Population within given buffer distances of the pipeline (computed by county and municipality) Population within 2130 ft, and 0.5 miles of pipeline facilities (compressor stations, offloading terminals, valves, etc.)

Impact type	Population potentially affected by pipeline operations
Pipeline data	Centerline and major facilities buffers (buffers at 400 ft, 0.25 mi, and 0.5 mi)
Data Source	EPA Dasymetric population of the United States [16]
Method description	The EPA's dasymetric population dataset takes 2010 census data at the census block level (finest level for more areas) and apportions the population to a 30-m pixel raster based on land use and slope. Each pixel has an estimated population value. This gives a much finer assessment of populations in areas that do not have even land uses or population density across the census block. We used a zonal statistics calculation to compute the total population within each buffer "zone" from the pipeline.
Metrics	Population within 2130 ft, and 0.5 miles of pipeline facilities (compressor stations, offloading terminals, valves, etc.)

Impact type	Impacts to private property
Pipeline data	Pipeline cleared areas
Data Source	Hunterdon County, NJ parcels
Method description	We intersected the PennEast pipeline cleared areas with parcels in Hunterdon County, NJ. (Under the scope of this analysis, it was impractical to acquire and analyze all parcels in all counties along the pipelines' route.) We determined the number of parcels with any clearing. Then, we estimated the property value of cleared areas by multiplying the area cleared in each parcel by the land value per acre for the parcel. (We assume pipeline clearing does not damage improvements.) We also totaled the total land value (including improvements) for all parcels with any clearing.
Metrics	# of parcels impacted by type (residential, commercial, other) Value of land area affected by clearing ($M) Total value of parcels with any clearing ($M)

Drinking Water Impacts

Impact type	Drinking water wells potentially affected, New Jersey
Pipeline data	Pipeline centerline
Data Source	NJ Wellhead protection areas, non-community water systems [17] NJ Wellhead protection areas, community water systems [18]
Method description	NJ publishes GIS files containing water system well head protection areas using a modeled, three tier classification. Tier 1-3 represent a 2-yr, 5-yr, and 12-yr time of travel to the well for materials spilled on the surface. We determined the intersection of the pipeline with maximum risk tier for each well.
Metrics	# of wells in each dataset by maximum risk tier (Tier 1 is highest) intersecting the pipeline centerline

Impact type	Drinking water wells potentially affected, Hunterdon County
Pipeline data	Pipeline centerline
Data Source	Hunterdon county parcels [19] NJ Community Water System service area polygons [20]
Method description	We determined drinking water wells potentially affected in Hunterdon county based on the locations of residential parcels without water service relative to the location of pipelines. We identified parcels without water service as those classified as either residential (2) or a farm residence (3A), and located outside of a community water service area. Typically, these parcel types will meet their water needs with a well drilled on the property. (Unlike PA, NJ does not publish records of well drilling locations.) We determined the potential risk to these parcels with a 3-tiered scale based on the NJ Wellhead protection area tiers (2-yr, 5-yr and 12-yr time of travel). The relevant distances are Tier 1: 544 ft, Tier 2: 860 ft, Tier 3: 1310 ft. Using the NJ Non-community water system wellhead protection area polygons, we computed the median radius of the Tier 1, 2, and 3 polygons. We then completed a "Near" analysis to determine the distance from each qualifying residential parcel without water service to the pipeline. We computed the number within each of the 3 threshold radii for the tiers.
Metrics	# of Hunterdon County parcels likely to use wells within Tier 1, 2, and 3 distances of pipeline

Impact type	Drinking water wells potentially affected, Pennsylvania
Pipeline data	Pipeline centerline

Data Source	Pennsylvania Groundwater Information System (2018) [21]
Method description	We determined drinking water wells potentially affected in Pennsylvania based on the locations of wells drilled relative to the location of pipelines. We obtained the locations of wells in a tabular form from Pennsylvania's Groundwater Information System (PaGWIS). We downloaded the "Well Construction" data package for each county along the PennEast and Mariner East 2 pipeline routes in the DRB. We scrubbed the dataset to get an accurate well count. We selected only wells for which the "Type of Activity" was "NEW WELL" or blank, and for which the "Well Use" was "WITHDRAWAL" or blank, and "Water Use" was "COMMERCIAL", "DOMESTIC", "INSTITUTIONAL" or blank. We also used the PA Well ID to identify and remove duplicate records. We brought the scrubbed dataset into GIS using the "Add X-Y data" tool based on latitude and longitude. We determined the potential risk to these parcels with a 3-tiered scale based on the NJ Wellhead protection area tiers (2-yr, 5-yr and 12-yr time of travel). Using the NJ Non-community water system wellhead protection area polygons, we computed the median radius of the Tier 1, 2, and 3 polygons. We then completed a "Near" analysis to determine the distance from each qualifying residential parcel without water service to the pipeline. We computed the number within each of the 3 threshold radii for the tiers. The relevant distances are Tier 1: 544 ft, Tier 2: 860 ft, Tier 3: 1310 ft. Due to potential uncertainty in well locations, and groundwater conditions, we also identified all wells out to a 1500-foot distance from the pipeline.
Metrics	# of Pennsylvania wells within Tier 1, 2, and 3 distances of the PennEast and Mariner East 2 pipelines.

Surface Water Quality – Stream Crossings and Sedimentation

Impact type	Surface water quality – Stream crossings impacts (NJ)
Pipeline data	Pipeline centerline, Roads
Data Source	Surface water classification of New Jersey [22]
Method description	Intersect pipeline centerlines and road lines with stream line features from the surface water classification of New Jersey dataset. Using the intersect tool in ArcGIS, we set the output type to "point" to mark the intersection of the stream lines and the pipeline (or road). After intersecting, we tabulated the number of stream crossings by surface water classification. All of the stream crossings affected freshwater streams in the all other freshwaters category (FW2). That is, none were classified as FW1 (freshwater with no man-made discharge), or saline waters. Additionally, none of the stream crossings occurred in watersheds that are currently under a New Jersey TMDL rule. We separately tabulated stream crossings that use HDD versus other crossing methods.
Metrics	# Stream crossings (HDD and non-HDD) of Category 1 protection waters (FW2-TPC1,FW2-TMC1, FW2-NTC1). # Stream crossings (HDD and non-HDD) of Freshwater trout monitoring waters without category protections status (FW2-TM) # Stream crossings (HDD and non-HDD) of Freshwater non-trout waters without category protections status (FW2-NT)

Impact type	Surface water quality – Stream crossings (PA)
Pipeline data	Pipeline centerline, Roads
Data Source	Pennsylvania Integrated List – Attaining (2014) [23] Pennsylvania Integrated List – Non-Attaining (2015) [24] Pennsylvania Chapter 93 Designated Use Streams (2017) [15]
Method description	Pennsylvania assesses the quality of streams based on whether they attain minimum standards for their designated uses, and also has classifications to flag certain types of streams with higher values or specific types of fisheries. We used a merge and spatial join to combine three datasets into a single geospatial data layer. Because streams can have multiple uses, some stream segments had multiple features perfectly aligned with each other. We flagged these features to make sure to avoid double counting in summary totals. Using the combined geospatial data layer, we intersected pipeline centerlines and road lines with stream line features. Using the intersect tool in ArcGIS, we set the output type to "point" to mark the intersection of the

	stream lines and the pipeline (or road). After intersecting, we tabulated the number of stream crossings by designated use and use attainment status.
Metrics	# of total stream intersections, and crossings with HDD # of stream intersections with Exceptional Value (EV) or High Quality (HQ) classification # of stream intersections with Cold Water Fishery (CWF) or Trout use designations # of streams with Warm Water Fishery (WWF) or other designations not previously listed # of stream intersections with potable water supply designated use # of stream intersections with recreation designated use # of stream intersections with impairments (any type) # of stream intersections with impairments cause by sedimentation or siltation

Appendix A References

[1] Sunoco Pipeline LP (2016). Dec 8, 2016. Geospatial. *PA Pipeline Project (PPP)/Mariner East II Shapefiles: PPP_PA_Workspace_Centerline_111116.zip*. ESRI Shapefile. Pennsylvania Department of Environmental Protection (PADEP). http://files.dep.state.pa.us/ProgramIntegration/PA%20Pipeline%20Portal/Shapefiles%2012-8-16/.

[2] Penn East Pipeline Company LLC. 2018. "PennEast Pipeline Proposed Route." PennEast Pipeline. Accessed 15 Nov 2018. http://penneastpipeline.com/proposed-route/.

[3] Penn East Pipeline Company LLC, and Mott McDonald. 2018. *Current Proposed Route (Detailed View).* Accessed Sep 24, 2018. http://penneastpipeline.com/docs/proposed-route-19.pdf.

[4] USDA NASS (2017). 2017. Geospatial. *Cropland Data Layer* Raster Grid. U.S. Department of Agriculture, National Agricultural Statistics Service. https://nassgeodata.gmu.edu/CropScape/.

[5] Hanson, L. 2016. *Counting the trees in – and outside of – the forest: A best estimate of forest cover in the Delaware River Basin.* CNA for the William Penn Foundation.

[6] University of Vermont Spatial Analysis Laboratory (2016). Jul 15, 2016. Geospatial. *High-Resolution Land Cover Delaware River Basin, 2013*. Raster Grid. University of Vermont Spatial Analysis Laboratory. http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=3208.

[7] USGS (2016). Version 1.4 May 2016. Geospatial. *Protected Areas Database of the United States (PAD-US), National Gap Analysis Project - Pensylvania, New Jersey*. ESRI Geodatabase. U.S. Geological Survey, Department of the Interior. https://gapanalysis.usgs.gov/padus/data/download/.

[8] U.S. Endowment for Forestry and Communities, Ducks Unlimited, and The Trust for Public Land (2018). Sep 6, 2018. Geospatial. *National Conservation Easement Database*. ESRI Geodatabase. https://www.conservationeasement.us/.

[9] EPA (2016). Jun 13, 2016. Geospatial, Tabular. *EnviroAtlas - Migratory Bird Hunting Recreation Demand by 12-Digit HUC in the Conterminous United States*. ESRI Geodatabase. United States Environmental Protection Agency. https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7Bbf7112ad-58f7-40c4-9343-e70ab97f8af2%7D.

[10] EPA (2016). Jun 13, 2016. Geospatial, Tabular. *EnviroAtlas - Big Game Hunting Recreation Demand by 12-Digit HUC in the Conterminous United States*. ESRI Geodatabase. United States Environmental Protection Agency. https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7Bed43f10b-cf7f-4e09-b54e-33b1e4517b6d%7D.

[11] EPA (2016). Jun 13, 2016. Geospatial, Tabular. *EnviroAtlas - Bird Watching Recreation Demand by 12-Digit HUC in the Conterminous United States*. ESRI Geodatabase. United States Environmental Protection Agency.

https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7Bcf08727d-e248-43cb-8f4f-6d0055f5d99d%7D.

[12] EPA (2016). Jun 13, 2016. Geospatial, Tabular. *EnviroAtlas - Freshwater Fishing Recreation Demand by 12-Digit HUC in the Conterminous United States*. ESRI Geodatabase. United States Environmental Protection Agency. https://edg.epa.gov/metadata/catalog/search/resource/details.page?uuid=%7B28db3b57-618c-4257-bb4a-4946e9c1e8c4%7D.

[13] PA DCNR (2018). 2018. Geospatial. *Explore PA trails - Trails (line)*. ESRI shapefile. Pennsylvania Department of Conservation and Natural Resources. http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1550.

[14] NJSPS, and NJDEP (2018). Feb 21, 2018. Geospatial. *New Jersey State Park Service Trails*. ESRI Shapefile. New Jersey State Park Service, New Jersey Department of Environmental Protection. http://njogis-newjersey.opendata.arcgis.com/datasets/a36e0ae5cffb441abdb2adfd26356fb1_4.

[15] PADEP (2017). 2017. Geospatial. *Streams Chapter 93 Designated Use*. ESRI Shapefile. Pennsylvania Department of Environmental Protection. http://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=1098.

[16] EPA (2016). Feb 8, 2018. Geospatial. *EnviroAtlas - Dasymetric Population for the Conterminous United States*. Raster Grid. U.S. Environmental Protection Agency. https://catalog.data.gov/dataset/enviroatlas-dasymetric-population-for-the-conterminous-united-states.

[17] NJGWS. Apr 26, 2018. Geospatial. *DGS02-2 Well Head Protection Areas For Public Community Water Supply Wells In New Jersey*. ESRI Shapefile. New Jersey Geological and Water Survey. DGS02-2. https://www.state.nj.us/dep/njgs/geodata/dgs02-2.htm.

[18] NJGWS. Feb 19, 2015. Geospatial. *DGS04-5 Well Head Protection Areas For Public Non-Community Water Supply Wells In New Jersey.* ARC/INFO. New Jersey Geological and Water Survey. DGS02-2. https://www.state.nj.us/dep/njgs/geodata/dgs04-5.htm.

[19] NJOGIS (2017). 2017. Geopatial and tabular. *Hunterdon County tax parcels*. ESRI shapefile and dbase table. New Jersey Office of GIS, New Jersey Department of Treasury. Accessed Sep 24, 2018. Current dataset link: https://www.arcgis.com/home/item.html?id=406cf6860390467d9f328ed19daa359d.

[20] NJDEP (2017). Apr 18, 2018. Geospatial. *New Jersey Public Community Water Purveyor Service Areas.* ESRI Shapefile. New Jersey Department of Environmental Protection, Bureau of Safe Drinking Water. http://njogis-newjersey.opendata.arcgis.com/datasets/5d6bc04cd97c41259c4f4af83bdd886d_15.

[21] PA DCNR (2018). 2018. Tabular. *PA Groundwater Information System - Water Well Data*. comma separated value. Pennsylvania Department of Conservation and Natural Resources. https://www.dcnr.pa.gov/Conservation/Water/Groundwater/PAGroundwaterInformationSystem/Pages/default.aspx.

[22] NJDEP BGIS (2007). Sep 30, 2007. Geospatial. *Surface Water Quality Classification of New Jersey.* ESRI Shapefile. New Jersey Department of Environmental Protection, Bureau of GIS. https://gisdata-njdep.opendata.arcgis.com/datasets/surface-water-quality-classification-of-new-jersey.

[23] PADEP (2014). 2018. Geospatial. *Integrated List Attaining*. ESRI Shapefile. Pennsylvania Department of Environmental Protection. https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=887.

[24] PADEP (2014). 2018. Geospatial. *Integrated List Non Attaining*. ESRI Shapefile. Pennsylvania Department of Environmental Protection. https://www.pasda.psu.edu/uci/DataSummary.aspx?dataset=888.

Appendix B – Ecosystem Services Values

The table below identifies the ecosystem services values used in the cost analysis of this report. If more than one study was available for a given ecosystem service and biome, then we calculated a minimum, average, and maximum value for that ecosystem service. In many cases, only one potentially relevant study was available for an ecosystem service for that particular biome. In those cases, the same value is used for the minimum, average, and maximum estimate. When two values were available for an ecosystem service in a given biome, the “average” value is the average of the two available values. All values have been converted to 2017 USD.

Biome	Ecosystem Service	Number of Values	Min of $/acre (2017$)	Average of $/acre (2017$)	Max of $/acre (2017$)
Cultivated	BioControl	1	$15.75	$15.75	$15.75
	Erosion	2	$28.28	$51.70	$75.12
	Genepool	1	$1,078.09	$1,078.09	$1,078.09
	Pollination	1	$10.50	$10.50	$10.50
	Soil fertility	1	$119.31	$119.31	$119.31
	Waste	1	$136.95	$136.95	$136.95
	Total		***$1,388.88***	***$1,412.30***	***$1,435.72***
Forests [Temperate and Boreal]	Aesthetic	1	$319.83	$319.83	$319.83
	Air quality	1	$261.42	$261.42	$261.42
	BioControl	2	$2.63	$11.03	$19.43
	Climate	5	$2.85	$581.86	$2,809.61
	Cultural service [general]	1	$1.05	$1.05	$1.05
	Erosion	1	$64.07	$64.07	$64.07
	Genepool	6	$0.00	$631.57	$2,534.64
	Genetic	1	$10.50	$10.50	$10.50
	Pollination	1	$210.05	$210.05	$210.05
	Soil fertility	1	$6.30	$6.30	$6.30
	Waste	3	$8.97	$54.17	$96.31
	Water	3	$0.07	$86.92	$211.63
	Total		***$887.73***	***$2,238.77***	***$6,544.84***
Fresh water	Various	1	$1.11	$1.11	$1.11
	Waste	1	$11.10	$11.10	$11.10
	Water	1	$530.90	$530.90	$530.90
	Total		***$543.11***	***$543.11***	***$543.11***
Grasslands	Aesthetic	1	$17.34	$17.34	$17.34
	BioControl	1	$15.75	$15.75	$15.75
	Climate	4	$0.03	$1.21	$3.68
	Erosion	4	$15.97	$31.05	$70.70
	Pollination	1	$16.80	$16.80	$16.80

Biome	Ecosystem Service	Number of Values	Min of $/acre (2017$)	Average of $/acre (2017$)	Max of $/acre (2017$)
	Soil fertility	1	$3.68	$3.68	$3.68
	Waste	3	$4.13	$35.52	$57.24
	Water flows	1	$2.63	$2.63	$2.63
	Total		***$76.32***	***$123.98***	***$187.81***
Inland Wetlands	Aesthetic	3	$39.81	$920.20	$1,868.49
	Climate	2	$4.01	$83.66	$163.31
	Cultural service [general]	2	$5.25	$580.00	$1,154.75
	Extreme events	5	$113.95	$1,679.88	$4,745.58
	Genepool	5	$8.07	$86.57	$228.98
	Nursery	1	$4.84	$4.84	$4.84
	Soil fertility	1	$113.99	$113.99	$113.99
	Waste	6	$26.89	$1,141.56	$5,033.36
	Water	2	$2,003.36	$2,248.07	$2,492.78
	Water flows	2	$3,874.39	$3,966.55	$4,058.72
	Total		***$6,194.57***	***$10,825.33***	***$19,864.81***
Woodlands/ Scrub-Shrub	Air quality	1	$26.14	$26.14	$26.14
	Climate	1	$125.71	$125.71	$125.71
	Erosion	1	$15.97	$15.97	$15.97
	Waste	4	$0.07	$75.94	$227.59
	Total		***$167.88***	***$243.76***	***$395.40***