Evaluation of Stray Natural Gas in the Amber Norrid Domestic Water Well Near Abandoned Oil Wells in Hanover Township, Washington County, Pennsylvania

Dominic DiGiulio, Ph.D.

Independent Consultant for the Center for Applied Environmental Science

September 8, 2023

Funding: Funding for this project was supplied by the Center for Applied Environmental Science, Environmental Integrity Project

About the Author: Dr. DiGiulio is a retired scientist from the U.S. Environmental Protection Agency. He has conducted research on: emissions of volatile organic compounds from abandoned wells, leakage of produced water, condensate, and drilling fluids from impoundments to groundwater, contamination of groundwater from hydraulic fracturing, subsurface methane and carbon dioxide migration (stray gas), intrusion of subsurface vapors into indoor air (vapor intrusion), gas flow-based subsurface remediation (soil vacuum extraction, bioventing), groundwater sampling methodology, soil-gas sampling methodology, gas permeability testing, and solute transport of contaminants in soil. He assisted in the development of EPA's original guidance on vapor intrusion and the EPA's Class VI Rule on geologic sequestration of carbon dioxide. He has served as an expert witness in litigation relevant to oil and gas development, testified before State oil and gas commissions on proposed regulation, and testified before Congress on the impact of oil and gas development on water resources. His consulting services have included reports on: storage of natural gas liquids in solution mined caverns, proposed oil and gas regulations in Colorado, impact to groundwater resources from Class II disposal wells in Ohio, Idaho, and Florida, produced water transport in barges along the Ohio River, proposed EPA regulation on discharge of produced water to surface water, and Bureau of Land Management leases in Wyoming, Montana, and Colorado.

Work experience and list of publications available at https://www.linkedin.com/in/dominic-digiulio-phd-79835bbb/ or at https://scholar.google.com/scholar?as_sdt=400007&q=Dominic+DiGiulio&hl=en

Contact Information: dom.c.digiulio@gmail.com

Background

The Norrid residence is located in Hanover Township, Washington County in southwestern Pennsylvania just northeast of Hillman State Park (**Figure 1)**. Surficial bedrock in Washington County consists of rocks of Pennsylvanian and Permian age (**Figure 2**). The Pennsylvanian rocks are represented by the Conemaugh and Monongahela Group formations which consist mainly of limestones, sandstones, shales, mudstones, and coal (Lentz and Neubaum, 2005; Ryder et al., 2012). Within the Monongahela Group are the non-marine Pittsburgh coal beds, which are regionally continuous in Pennsylvania (Markowski, 1998).

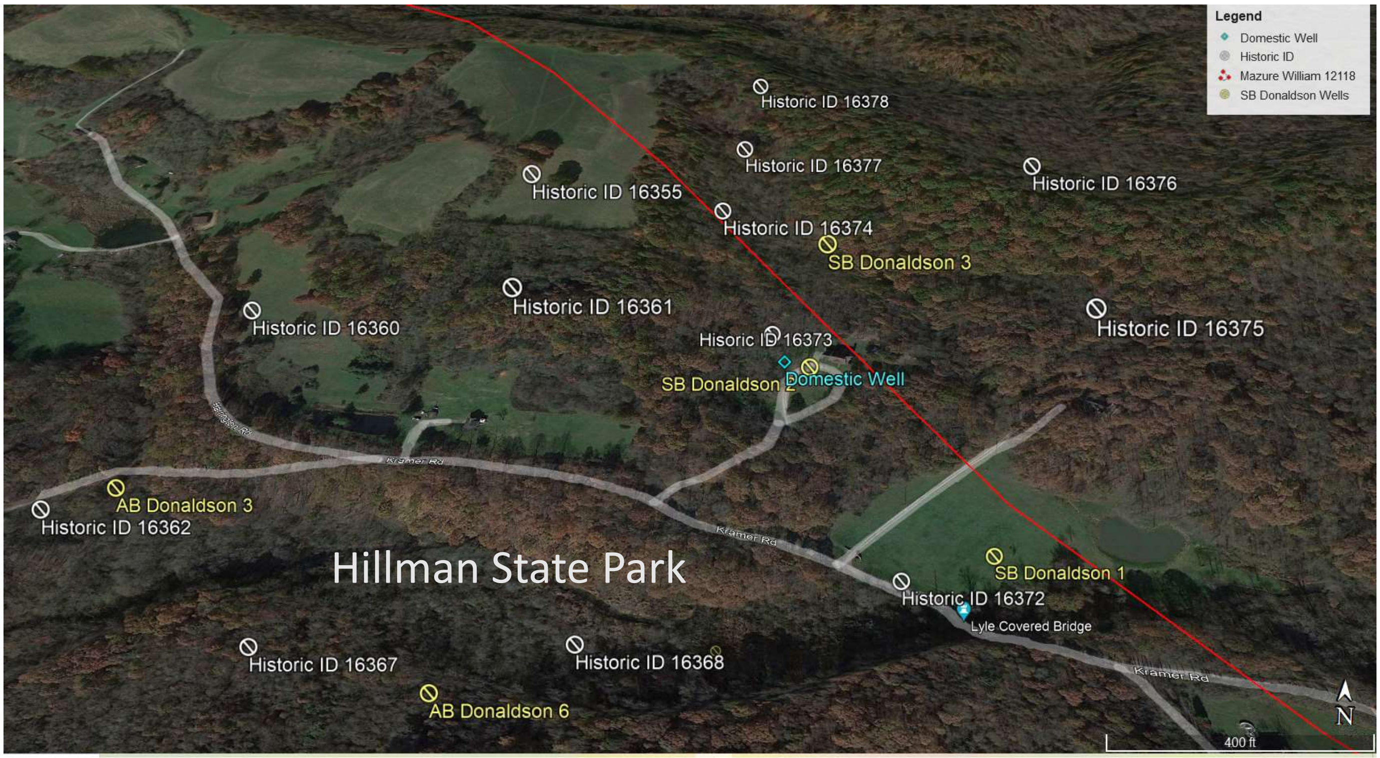


Figure 1. Schematic of AB and SB Donaldson abandoned wells, PADEP Historic wells and a surface trace (red line) (extends 2.6 miles) of Mazure William 12118 2H horizontal stimulated well in proximity to the Norrid domestic water well. Image from Google Earth Pro.

Approximately one-half of what is now Hillman State Park was strip mined (Pittsburgh coal beds) between the 1930s and 1960s. Casing from oil wells were cut and eventually covered with up to 100 feet of overburden (Sams et al., 2017). Pumpjacks and other infrastructure (e.g., pipes) remain at some locations in the park. During an aeromagnetic survey, Sams et al. (2017) identified 165 well-type magnetic anomalies indicative of abandoned wells.

The current land area of Hillman State Park includes part of the Florence-Five Points oilfield which was discovered in the late 1800s and fully developed by 1915 (Sams et al., 2017). The producing horizon was the Upper Devonian Venango Group (**Figure 3**) with well depths between 1800 to 2000 feet below ground surface (Sams et al., 2017).

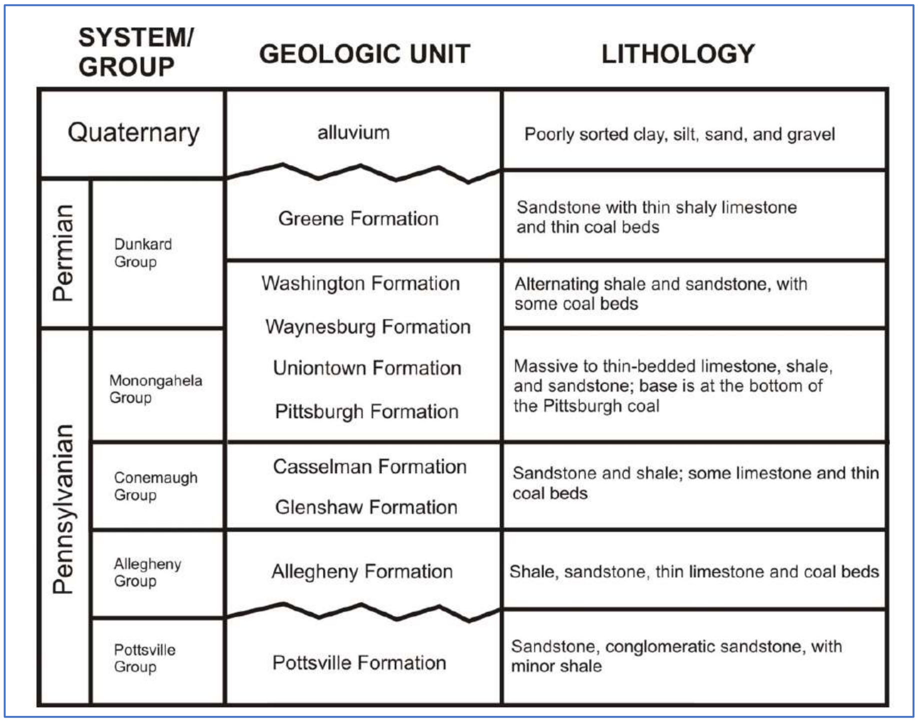


Figure 2. Generalized stratigraphic section of rocks in the subsurface in western Pennsylvania and eastern Ohio. Black flags indicate potential source rocks. Figure from Laughrey and Baldassare (1998). Figure from EPA (2016).

The Norrid residence and domestic water well are surrounded by a number of abandoned and historic wells (**Figure 1**). It is unclear from the Pennsylvania Department of Environmental Protection (PADEP) Oil and Gas Mapping portal (PADEP 2023f) precisely what historic wells are. A representative from the PADEP explained to Ms. Norrid in August 2023 that historic wells are essentially old and inaccurate coordinates of currently documented abandoned wells. Using this logic, Historic ID 16373 could be SB Donaldson 2 (**Figure 1**). However, there are a greater number of historic wells in the area than documented abandoned wells implying that coordinates of multiple historic oil wells could be a single documented abandoned well. Hence, this explanation may not be entirely accurate. Also, it is common knowledge in the area that "dry" wells were encountered and subsequently abandoned and thus never documented as abandoned wells (personal communication with Amber Norrid). Hence, the number of well penetrations in the vicinity of the Norrid residence could be greater than that indicated by documented abandoned wells alone. The PADEP estimates that there are approximately 200,000 abandoned oil and gas wells that remain unaccounted for in state records (Pelepko et al., 2017; PADEP, 2022). A summary of abandoned and historic wells in the vicinity of the Norrid residence is provided in **Tables 1** and **2**.

According to the PADEP Oil and Gas Inventory (PADEP 2023f), the Donaldson wells are listed as "*active*" (**Table 1**). However pursuant to Section 3203 of the 2012 Oil and Gas Act, 58 Pa. C.S. § 3203, a well is an *"abandoned well" if "equipment necessary for production, extraction or injection has been removed. . . ."* or *"that has not been used to produce, extract or inject any gas, petroleum or other liquid within the preceding 12 months…"* Hence, all of the Donaldson wells are abandoned wells. The listed spud date of 01/01/1800 appears to indicate that the spud date is unknown. However, according to a well completion report obtained by Ms. Norrid (**Attachment 1**), SB Donaldson 2 was completed on 11/6/1891.

Right to Know (RTK) requests on abandoned and historic wells listed in **Tables 1** and **2** were submitted to the PADEP on July 20, 2023. A final response received on August 22, 2023 provided state inspection reports on the AB and SB Donaldson wells indicating outstanding violations on all of these wells at the time of transfer of ownership to Prosperity Oil Company in October 1994. No information was provided on historic wells.

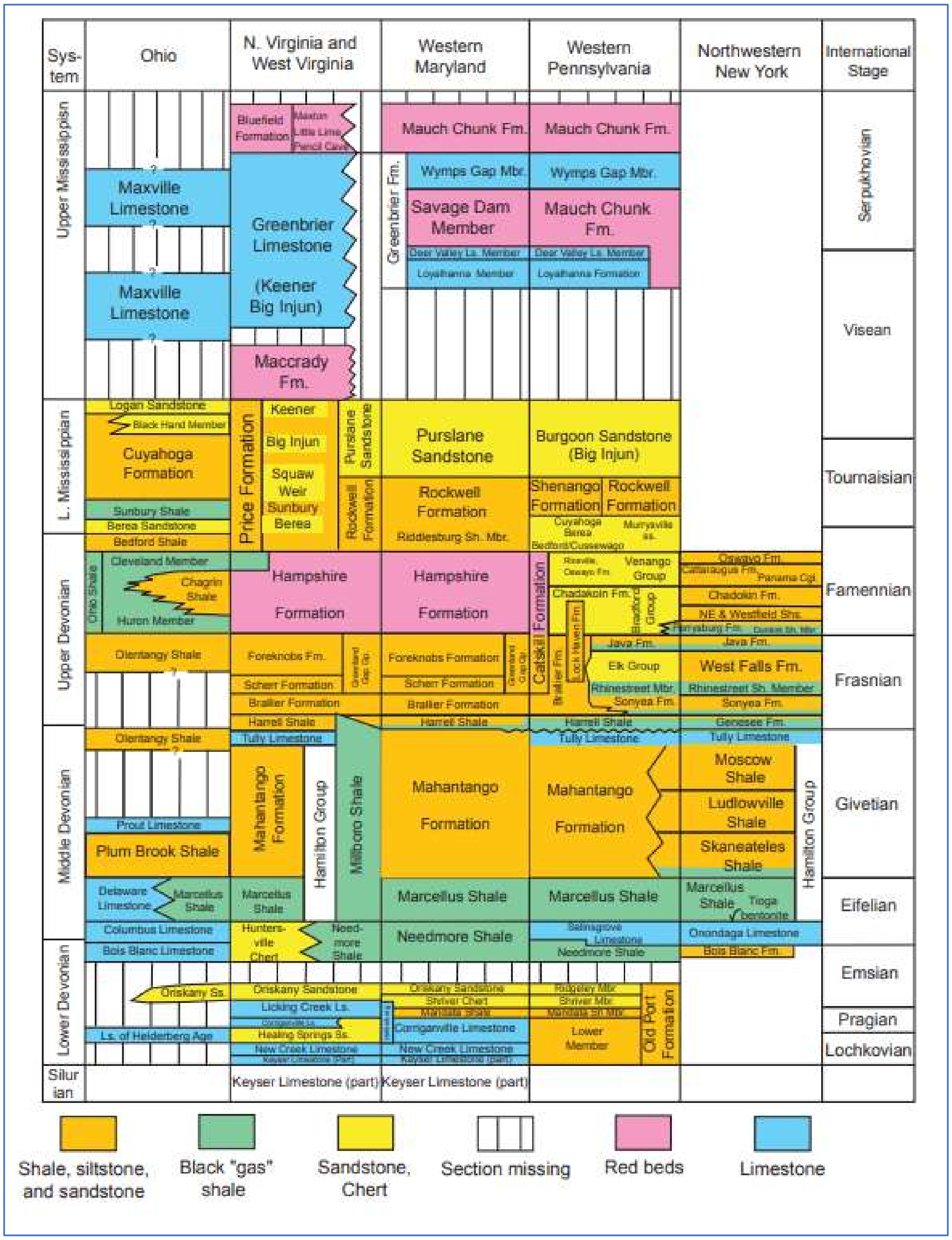


Figure 3. Generalized stratigraphic nomenclature for the Devonian Shale- Middle and Upper Paleozoic Formations in the northern part of Appalachian basin. Figure from the U.S. Geological Survey, https://pubs.usgs.gov/of/2006/1237/pdf%20tables/table2.pdf

At some time prior to March 2021, Ms. Amber Norrid expressed concern to the PADEP regarding the presence of the two documented abandoned oil wells (SB Donaldson 2 and SB Donaldson 3) on her property (**Figure 1**) and their potential impact on her nearby domestic water well. She complained of low flow from the well, a sulfide odor, and black particles coming from well water at times. The Norrid domestic water well was installed in 2004 to a depth of 120 ft. The well has 7" casing to approximately 40 to 60 feet after which 5" perforated casing extends in an open borehole to 120 feet. The submersible pump was set at approximately 118 to 120 feet (personal communication with domestic well owners). Coordinates of the well are approximately 40°27'22" N and 80°22'35"W (from Amber Norrid). Given near surface mining of the Pittsburgh coal at Hillman State Park, the domestic well appears to penetrate Pennsylvanian age Monongahela and Conemaugh Groups, the latter of which is known to have thin coal beds (**Figure 2**). The Pittsburgh coal was not mined out beneath the Norrid residence.

Table 1. PADEP Oil and Gas Inventory of oil wells in the vicinity of the Norrid Residence. Well information obtained from the PA Oil and Gas Mapping portal (PADEP 2023f).

Permit Number	Well Name	Listed Spud Date	Well Status	Well Type	Configuration	Latitude	Longitude	County	Municipality
125-00880	A B Donaldson 3	1/01/1800	Active	Oil	Vertical Well	40.454956	-80.380972	Washington	Hanover Twp
125-00881	A B Donaldson 5	1/01/1800	Active	Oil	Vertical Well	40.453972	-80.377	Washington	Hanover Twp
125-00882	A B Donaldson 6	1/01/1800	Active	Oil	Vertical Well	40.453528	-80.378583	Washington	Hanover Twp
125-00883	S B Donaldson 1	1/01/1800	Active	Oil	Vertical Well	40.454641	-80.375202	Washington	Hanover Twp
125-00884	S B Donaldson 2	1/01/1800	Active	Oil	Vertical Well	40.456042	-80.376212	Washington	Hanover Twp
125-00885	S B Donaldson 3	1/01/1800	Active	Oil	Vertical Well	40.457587	-80.375862	Washington	Hanover Twp

Table 2. Listing of Historic Oil Wells in the vicinity of the Norrid Residence. Well information obtained from the PA Oil and Gas Mapping portal (PADEP 2023f).

Historic ID	Well Type	County	Municipality	Latitude	Longitude	MAP ID	Map Name
16373	Oil Well	Washington	Hanover, Twp	40.45636	-80.37646	WPA16407	WPA Burgettstown 2 Pittsburgh.tif
16375	Oil Well	Washington	Hanover, Twp	40.45672	-80.37386	WPA16409	WPA Burgettstown 2 Pittsburgh.tif
16361	Oil Well	Washington	Hanover, Twp	40.45645	-80.37847	WPA16395	WPA Burgettstown 2 Pittsburgh.tif
16355	Oil Well	Washington	Hanover, Twp	40.4579	-80.37847	WPA16389	WPA Burgettstown 2 Pittsburgh.tif
16374	Oil Well	Washington	Hanover, Twp	40.45781	-80.37677	WPA16408	WPA Burgettstown 2 Pittsburgh.tif
16376	Oil Well	Washington	Hanover, Twp	40.45836	-80.37391	WPA16410	WPA Burgettstown 2 Pittsburgh.tif
16377	Oil Well	Washington	Hanover, Twp	40.45886	-80.3765	WPA16411	WPA Burgettstown 2 Pittsburgh.tif
16378	Oil Well	Washington	Hanover, Twp	40.45979	-80.37628	WPA16412	WPA Burgettstown 2 Pittsburgh.tif
16360	Oil Well	Washington	Hanover, Twp	40.45644	-80.38052	WPA16394	WPA Burgettstown 2 Pittsburgh.tif
16362	Oil Well	Washington	Hanover, Twp	40.45472	-80.38135	WPA16396	WPA Burgettstown 2 Pittsburgh.tif
16367	Oil Well	Washington	Hanover, Twp	40.45376	-80.37965	WPA16401	WPA Burgettstown 2 Pittsburgh.tif
16368	Oil Well	Washington	Hanover, Twp	40.45395	-80.37782	WPA16402	WPA Burgettstown 2 Pittsburgh.tif
16372	Oil Well	Washington	Hanover, Twp	40.45444	-80.37583	WPA16406	WPA Burgettstown 2 Pittsburgh.tif

SB Donaldson 2 is located on a gently sloping wooded yard approximately 75 feet from the Norrid residence (PADEP 2023c, d) and approximately 120 feet from the domestic water well (PADEP, 2023d). At the surface, the well has an 8" driven open wooden conductor casing, 6" open metal casing, 4 ½" metal casing with an inverted 5 ½" swage attached to a vented casinghead, 2 3/8" tubing and rods and a 2" production line (PADEP, 2023d) **(Figure 4**). The well has no associated production equipment and is not attached to any flowline. An old rig engine remains **Figure 5**) located about 50 feet away from SB Donaldson 2. The PADEP noted that the well does not appear to have produced oil for many years or even decades (PADEP 2023d).

SB Donaldson 2 was completed at a depth of 1738 feet (**Attachment 1**). Apparently, the Pittsburgh Coal was observed near the surface and the Freeport Coal was observed at 259 feet during drilling. The well appears to have been completed in the "5th Sand", a common drillers term for an upper Devonian age Venango Group deposit (Coughlin, 2009).

Figure 4. Photograph of SB Donaldson 2 with Norrid residence in background approximately 75 feet from the well. From PADEP (2023d)

Figure 5. Photograph of old pump engine near SB Donaldson 2. From PADEP (2021a)

The well appears to have been developed with explosives as evidenced in language in the well record (*"torpedoed using a 189 ft shell, shot with 30 qts 11-8-1895. Well tubed 12-3-1895, flowing started at 10 barrels, shot with 100 qts 8-2-1898"*). The torpedo was the earliest successful enhanced oil recovery technology developed in the United States in the early 1860s and was commonly used in western Pennsylvania (ETHW). The technology was based on the controlled use of explosives in oil wells. Between 1860 and 1865, the most utilized explosive was black powder ignited with a fuse. After 1867, nitroglycerine was often used in place of gunpowder (ETHW). Apparently after the last round of explosives were used, 901 feet of pipe was pulled out from the well and replaced with 876 feet of 4 ½" casing and a packer presumably set at the base of casing.

Ms. Amber Norrid recently became aware of and obtained a schematic (**Attachment 2**) of a horizontal hydraulically fractured well (Mazure Williams 12118 2H) located beneath her land in the Marcellus Formation at a depth of 5840 feet. The Record of Notification to Drill and Operate a Horizontal Well was issued on 6/22/2018.

Given the coordinates of the landing point (40°28'16.91"N, 80°23'11.91"W) with a relative scale (-1289.01 feet local north, -1250.05 feet local east) and proposed bottom hole location (PBHL) (-13326.92 feet local north, 5155.34 feet local east) having an azimuth of 151.98°), on the Well Location Plat (6/2014), the horizontal leg extends 13,636 feet (2.58 miles) in the direction illustrated in **Figure 1**. If actually drilled as indicated on the Well Location Plat, the surface expression of the horizontal leg appears to be within 200 feet of the Norrid domestic water well. The date of stimulation is unknown.

Summary of PADEP Investigations

Between March 2021 and May 2023, the PADEP conducted seven inspections of abandoned oil well SB Donaldson 2 (**Table 3**). During this time period, the PADEP noted numerous violations of PADEP statutes including: (1) failure to plug the well upon abandoning it, (2) failure to plug the well to stop the vertical flow of fluids or gas within the well bore, (3) failure to submit an annual report on the compliance status of the well with the mechanical integrity requirements, (4) failure to operate the well to ensure that the integrity of the well is maintained and health, safety, environment and property are protected, and (5) venting gas to the atmosphere that poses a hazard to the public health and safety. After each inspection, the PADEP instructed the owners/operators of the well, to respond to the inspection reports within approximately 15 days of receipt. Prior to issuance of an order in May 2023 (PADEP 2023e), there is no record of any response to Notices of Violation over this more than two-year period.

The PADEP conducted open air (no enclosure) gas screening at the disconnected production line using either a Bascom Turner Gas Explorer EGA-411 or EGA-611 between March 2021 and May 2023. The Bascom Turner Gas Explorers were typically calibrated at least one month prior to use. Details on calibration (calibration gas and concentration) were not provided in inspection reports. The calibration gas was presumably methane in an inert gas mixture.

The catalytic combustion detector of the Bascom-Turner Explorers has a measurement range between 20 to 10,000 parts per million volume (ppmv) methane with a resolution and accuracy of ± 20 ppmv. Between the measurement range of 1% (1% =10,000 ppmv) to 5% methane, the thermal conductivity detector has a resolution of ± 0.05% and accuracy of ± 0.1%. Between the measurement range of 5% to 100% methane, the thermal conductivity detector has a resolution of ± 1.0% and accuracy of ± 2.0%. Readings are presented as ppmv gas or percent gas since compounds in addition to methane are present in natural gas (Bascom Turner).

The EGA 611 is also equipped with an electrochemical cell for measurement of carbon monoxide with a resolution of 1 ppmv and accuracy of ± 10 ppmv and an electrochemical cell for measurement of hydrogen sulfide with a resolution and accuracy of ± 1 ppmv (Bascom Turner). However, the PADEP did not conduct screening of CO and H_2S during site inspections.

Table 3. Notices of Violation issued for oil well SB Donaldson No. 2, Permit No. 37-125-00884

Inspection Date	Reference	Gas Level	Soil Screening	Cellar Screening	Sample Collection	Violations						
3/2/2021	PADEP 2021a	97%	no	yes	yes	OGA3211(H)	OGA3220(A)	78.91(a)	78.88(e)	78.121(A)	78.73(a)	78.74
6/28/2021	PADEP 2021b	15%	no	no	no	OGA3211(H)	OGA3220(A)	78.91(a)	78.88(e)	78.121(A)	78.73(a)	78.74
12/13/2021	PADEP 2021c	10%	yes	no	no	OGA3211(H)	OGA3220(A)	78.91(a)	78.88(e)	78.121(A)	78.73(a)	
3/2/2023	PADEP 2023a	99%	no	no	yes	OGA3211(H)	OGA3220(A)	78.91(a)	78.88(e)	78.121(A)	78.73(a)	78.74
3/20/2023	PADEP 2023b	99%	no	yes	no	OGA3211(H)	OGA3220(A)	78.91(a)	78.88(e)	78.121(A)	78.73(a)	78.74
4/24/2023	PADEP 2023c	93%	yes	yes	no	OGA3211(H)	OGA3220(A)	78.91(a)	78.88(e)	78.121(A)	78.73(a)	
5/11/2023	PADEP 2023d	45%	no	no	no	OGA3211(H)	OGA3220(A)	78.91(a)	78.88(e)	78.121(A)	78.73(a)	

OGA3211(H) - WELL PERMITS - LABELING - Failure to install, in a permanent manner, the permit number on a completed well.

OGA3220(A) - PLUGGING REQUIREMENTS - Failure to plug the well upon abandoning it.

78.91(a) - PLUGGING - GENERAL PROVISIONS - Upon abandoning a well, the owner or operator failed to plug the well to stop the vertical flow of fluids or gas within the well bore under 25 Pa. Code §§ 78.92—78.98 or an approved alternate method.

78.88(e) - OPERATING WELLS - MECHANICAL INTEGRITY OF OPERATING WELLS - Operator failed to submit an annual report to the Department identifying the compliance status of each well with the mechanical integrity requirements for structurally sound wells in compliance with 25 Pa. Code Section 78.73(c).

78.121(A) - WELL REPORTING – PRODUCTION REPORTING – Conventional operator failed to submit annual conventional production and status report for permitted or registered well.

78.73(a) - GENERAL PROVISION FOR WELL CONSTRUCTION AND OPERATION - Operator failed to construct and operate the well in accordance with 25 Pa. Code Chapter 78 and ensure that the integrity of the well is maintained and health, safety, environment and property are protected.

78.74 - VENTING OF GAS - Operator vented gas to the atmosphere that produced a hazard to the public health and safety.

Measurement of gas at the disconnected 2” production line varied from 10% to 99% gas (**Table 3**). During the May 2023 inspection, gas was not detected within the 8” wooden and 6” metal casing (PADEP 2023d). During the December 2021 inspection, gas venting from the production line had very little pressure and no detectable combustible gas within 4" from the disconnected production line (**Figure 6**) (PADEP, 2021c).

Figure 6. Photograph of SB Donaldson 2 with Bascom Turner EGA 411 4” above 2" production line venting gas at the wellhead. From PADEP (2021c)

During the December 2021 and April 2023 inspections, the PADEP also screened for gas above or in soils in the vicinity of SB Donaldson 2 (PADEP 2021c, 2023c), however, a description of the methodology used was not provided in the inspection reports. The PADEP reported no vegetative stress or oil stains in soils around the well. In March 2023, the PADEP screened the domestic water well headspace and noted 23% gas (PADEP, 2023b). The headspace of the water well was screened again in April 2023 with a reading of 80 ppmv (PADEP, 2023c). However, according to the homeowner, the well cap had been removed prior to measurement to allow venting. The PADEP reported that the water well had been disconnected from the house and is no longer in use (PADEP, 2023c). During inspections, the PADEP did not detect combustible gas in the cellar of the home.

During the March 2021 and 2023 inspections, the PADEP collected aqueous samples from the domestic water well. Purging time, purging rate, or water volume collected prior to sample were not provided in inspection reports. During both times, samples were analyzed for bacteria, major ions, some inorganic elements, light hydrocarbons, and volatile organic compounds (VOCs) (**Table 4**). During the March 2023 sampling event, gas samples from SB Donaldson 2 and the Norred domestic water were collected for light hydrocarbons and stable carbon isotopes of light hydrocarbons (**Table 5**).

On May 16, 2023, the PADEP issued an Order to the owners/operators of the SB Donaldson No. 2 and three other abandoned wells in the area (AB Donaldson No. 3, Permit No. 125-00880; SB Donaldson No. 1, Permit No. 125-00883; and SB Donaldson No. 3, Permit No. 125-00885) to do the following.

(1) Immediately commence an investigation of the stray gas migration incident at the Norrid residence as required by 25 Pa. Code § 78.89, and immediately take measures to address combustible gas in the water supply pursuant to the requirements of 25 Pa. Code § 78.89(d).
(2) After service of the order, submit a plan and schedule to plug all four wells within 30 days, commence plugging the wells within 60 days, and complete plugging of the wells with 180 days in accordance with the 2012 Oil and Gas Act and rules and regulations, including the requirements of Section 3220 of the 2012 Oil and Gas Act, 58 Pa. C.S. § 3220, and 25 Pa. Code §§ 78.91 – 78.98.

If the owners of the wells fail to comply fully with the order, the owners are required to pay the PADEP the costs of plugging the wells in accordance with 58 Pa. C.S. § 3254.1. To date, the owners of SB Donaldson 2 have not commenced a stray gas investigation or taken any action address combustible gas in the Norrid domestic water well.

As a result of inaction by the abandoned well owners, at the request of Ms. Amber Norrid, the Center for Applied Environmental Science at the Environmental Integrity Project agreed to provide technical assistance to the domestic well owners in interpreting PADEP inspection reports and sampling reports.

Table 4. Summary of analytical results from the March 2021 and 2023 sampling events for the Norrid domestic water well. Samples collected at the basement sink faucet.

Constituent	3/1/2021	3/2/2023
Bacteria		
E. Coli MPN	>200.5 cfu/100ml	< 1.0 cfu/100ml
Iron Bacteria	35000 cfu/ml	35000 cfu/ml
Slime Bacteria	440000 cfu/ml	67000 cfu/ml
Sulfur Bacteria	1400 cfu/ml	6000 cfu/ml
Total Coliform MPN	>200.5 cfu/100ml	1 cf/100 ml
General Parameters		
pH	7.6	7.9
Temperature	17.88C	19.22C
Turbidity	8.98 NTU	1.10 NTU
Total Suspended Solids	8 mg/L	<20 mg/L
Specific Conductance	240 umhos/cm	625 umhos/cm
Total Dissolved Solids	150 mg/L	354 mg/L
Hardness	108 mg/L	140 mg/L
Major Ions		
Alkalinity as CaCO3	101.2 mg/L	245.8 mg/L
Chloride	2.13 mg/L	48.72 mg/L
Sulfate	21.10 mg/L	27.97 mg/L
Calcium	30.80 mg/L	39.1 mg/L
Magnesium	7.62 mg/L	10.30 mg/L
Sodium	8.91 mg/L	86.6 mg/L
Potassium	1.50 mg/L	1.81 mg/L
Inorganics		
Iron	0.308 mg/L	<0.10 mg/L
Manganese	0.027 mg/L	0.033 mg/L
Strontium	0.306 mg/L	0.654 mg/L
Barium	0.065 mg/L	0.220 mg/L
Aluminum	301.0 µg/L	25.6 µg/L
Arsenic	<3.0 µg/L	<3.0 µg/L
Lithium	<20 µg/L	<25 µg/L
Selenium	<7.0 µg/L	<4.0 µg/L
Zinc	<30.0 µg/L	<30 µg/L
Bromide	<0.20 mg/L	0.255 mg/L
Light Hydrocarbons		
methane	<11.6 µg/L	15500 µg/L
ethane	<12.4 µg/L	282 µg/L
propane	<14.2 µg/L	17.4 µg/L
Volatile Organic Compounds (with the exception of BTEX components, only detections listed)		
Benzene	<0.50 µg/L	<0.50 µg/L
Toluene	<0.50 µg/L	<0.50 µg/L
Ethylbenzene	<0.50 µg/L	<0.50 µg/L
o-Xylene	<0.50 µg/L	<0.50 µg/L
m,p-Xylenes	< 1.00 µg/L	< 1.00 µg/L
Chloroform	<0.50 µg/L	2.0 µg/L
Tetrahydrofuran	<0.50 µg/L	4.62 µg/L

Table 5. Results of gas sample from SB Donaldsons 2 and gas from headspace of aqueous sample from Norrid basement sink. Samples collected on 3/2/2023.

Component	Basement Sink	SB Donaldson 2
Carbon monoxide	ND	ND
Helium	NA	0.0290%
Hydrogen	ND	ND
Argon	0.629%	0.0711%
Oxygen	4.61%	1.60%
Nitrogen	28.05%	6.73%
Carbon Dioxide	2.09%	0.096%
Methane	64.00%	89.18%
Ethane	0.588%	1.71%
Ethylene	ND	ND
Propane	0.0262%	0.294%
Propylene	ND	ND
Iso-butane	0.0036%	0.0210%
N-butane	0.0025%	0.0212%
Iso-pentane	0.0007%	0.0028%
N-pentane	ND	0.0009%
Hexanes +	0.0018%	0.245%
δ^{13}C-Methane	-51.45‰	-49.47‰
δD-Methane	-175.5‰	-203.4‰
δ^{13}C-Ethane	-31.8‰	-34.29‰
δ^{13}C-Propane		-27.78‰
δ^{13}C-Carbon Dioxide	-25.0‰	†

† Could not be resolved due to high methane concentration

Discussion of Existing Data

Total Coliform and E. Coli Bacteria

High levels of Total Coliform (>200.5 colony forming units (cfu)/100 ml most probable number (MPN)) and Escherichia Coli (E. Coli) (>200.5 cfu/100 ml MPN) were detected in the Norrid domestic well water during the March 2021 sampling event (**Table 4**). Total coliforms include bacteria that have been influenced by human or animal waste. E. coli is a subgroup of the fecal coliform group and comes from the feces of warm-blooded animals. Private water wells are not regulated under the Safe Drinking Water Act. However, for public supply wells, The U.S. Environmental Protection Agency Maximum Contaminant Level Goal (MCLG) for E. Coli is set at zero (EPA, 2023). Coliform bacteria are one of the most common water contamination problems in private water systems in Pennsylvania and throughout the United States. A 2006 survey of 450 private wells in Pennsylvania found coliform bacteria in approximately 35 percent and E. coli bacteria in about 15 percent of private wells (PSU, 2023). During the March 2023 sampling event, concentrations of Total Coliform and E. Coli were 1 cfu/100 MPN and < 1 cfu/100 ml, respectively (**Table 4**). Hence, the issue had been resolved, presumably by well treatment such as shock chlorination sometime after March 2021 (the well owners do not recall the date of well treatment).

Iron and Sulfur Bacteria

High levels (35,000 cfu/100 ml) of iron bacteria were detected during both sampling events. Iron bacteria are microorganisms that oxidize ferrous (Fe^{2+}) iron and reduced manganese (Mn^{2+}) in the presence of oxygen often causing a rusty fluffy or filamentous precipitate. While chemical treatments such as shock chlorination are very effective in treating Total Coliform and E. Coli, chemical treatments are only modestly effective against iron bacteria. Iron bacteria build up in thick layers, each forming a slime around bacterial cells that keeps disinfectants from penetrating beyond the surface cells. In addition, iron dissolved in water can react with disinfectants before they reach the bacterial cells. Chemical reactions occur far slower at the cool temperatures common in wells, and bacterial cells need a long exposure to the chemical for treatment to be effective. Even if chlorine kills all the bacterial cells in the water, bacteria in the groundwater can be drawn in by pumping or drift back into the well (EGLE, 2020). Iron bacteria can cause a sewage-like or swampy odor. The domestic well owners state that they have not observed a rusty precipitate in the toilet bowl or sink.

Based on field observation and geochemical modeling of a natural gas well blowout in the Oriskany Formation in northeastern Ohio in 1982, Kelly et al. (1985) surmised that addition of a large mass of methane to groundwater from an oil or gas well would result in reduction of iron (Fe^{3+}) and manganese (Mn^{4+}) oxides on aquifer sediment solids resulting in elevated aqueous concentrations of reduced iron (Fe^{2+}) and manganese (Mn^{2+}) in solution with potential subsequent decrease of reduced iron and manganese in solution depending on iron and manganese precipitation as carbonates and sulfides. Iron and manganese oxide depletion could eventually lead to low aqueous levels of reduced iron and manganese (Schout et al., 2018).

In the absence of oxygen, iron and manganese oxides in aquifer sediments can serve as electron acceptors for the oxidation of methane as described by Beal et al. (2009):

$$CH_4 + 4MnO_2 + 7H^+ \rightarrow HCO_3^- + 4Mn^{2+} + 5H_2O$$

$$CH_4 + 8Fe(OH)_3 + 15H^+ \rightarrow HCO_3^- + 8Fe^{2+} + 21H_2O$$

Aqueous iron concentration decreased from 0.308 mg/L to <0.10 mg/L between the March 2021 and 2023 sampling events, respectively (**Table 4**). Manganese levels remained approximately the same at 0.027 mg/L and 0.033 mg/L between the March 2021 and 2023 sampling events, respectively (**Table 4**). Iron and manganese concentrations in the Norrid domestic water wells are not excessively high. However, the relationship between oxidation and reduction (redox) conditions in domestic water wells can be confounded by in-well mixing of water from different flow pathways or fractures and gas-phase transport of methane. These factors are particularly relevant in the Appalachian Basin where most water wells are from open-borehole completions fed by fracture flow (Molofsky et al., 2015).

It is unclear whether iron and manganese oxide depletion has occurred on aquifer sediments. It is also unclear whether the presence of iron bacteria in the Norrid domestic water well is from high methane concentrations. During oxidation of methane, both of these reactions consume hydronium ion and produce bicarbonate resulting in an increase in pH and alkalinity as observed by Kelly et al. (1985). Both pH and alkalinity increased in the Norrid domestic water well between the March 2021 and 2023 sampling events (**Table 4**). However, it is unclear whether high concentrations of methane are a causative factor of increased pH and alkalinity or whether this is due to temporal variability or other factors not considered here.

Sulfur bacteria were also detected during the March 2021 and 2023 sampling events at 1400 and 6000 cfu/100 ml MPN, respectively (**Table 4**). Sulfur reducing bacteria occur naturally in groundwater and use sulfate as an electron acceptor in low oxygen environments producing hydrogen sulfide gas resulting in a rotten-egg type odor (PSU, 2023). Sulfate reduction is known to occur in groundwater having high methane concentrations (Kelly et al. 1985; Wolfe and Wilkin, 2016) through the following reaction (Beal et al. 2009):

$$CH_4 + SO_4^{2-} \rightarrow HCO_3^- + HS^- + H_2O$$

This reaction also increases alkalinity. Amber Norrid has complained about a "rotten egg" odor to her well water indicative of sulfate reduction. She has also complained about the presence of black particles which could be from iron sulfide precipitation. However, similar to the presence of iron bacteria, it is not known whether the presence of sulfur reducing bacteria is due to elevated methane levels in the Norrid well.

Major Ion Concentrations

Calculation of bicarbonate and carbonate concentrations were estimated from total alkalinity measurement using the U.S. Geological Society's (USGS) Alkalinity Calculation Methods (USGS, 2023). Major ion balances (milliequivalents per liter) (bicarbonate, carbonate, chloride, sulfate, sodium, potassium, calcium, magnesium) were 1.2% and 1.9% for the March 2021 and March 2023 sampling events, respectively. Generally, an ion balance less than 5 to 10% is considered acceptable. Hence, major ion analyses should be considered reliable.

An increase in major ion concentrations (**Figure 5**) and total dissolved solids (**Figure 6**) and a shift in major ion composition (**Figures 5 and 6**) occurred between the March 2021 and 2023 sampling events with enrichment in sodium and chloride during the March 2023 sampling event. This notable because methane was not detected (<11.6 µg/L) during the March 2021 sampling event but detected at 15,500 µg/L during the March 2023 sampling event. Hence, an increase and compositional shift in major ion concentration coincided introduction of methane into the well. Further sampling is necessary to determine whether sodium, chloride, and alkalinity have continued to increase.

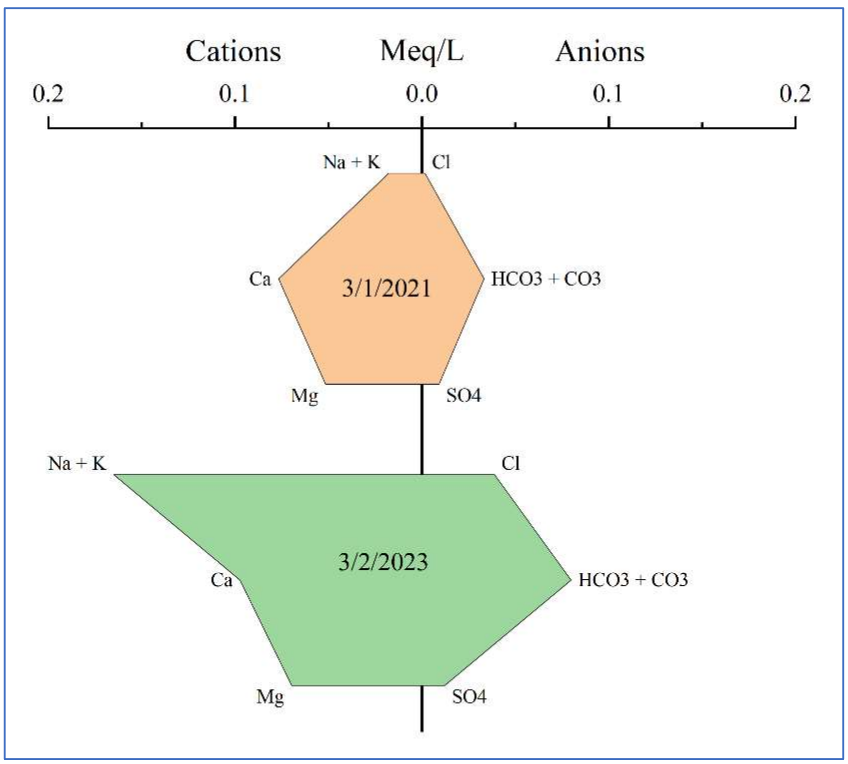


Figure 5. Stiff diagram of major ion concentrations in the Norrid domestic water well during the 3/1/2021 and 3/2/2023 sampling events. Note the increase in chloride (Cl), sodium (Na) + potassium (K) (primarily sodium), and bicarbonate (HCO3) + carbonate (CO3) (all bicarbonate) between the March 2021 and March 2023 sampling events. All concentrations in milliequivalents per liter (Meq/L).

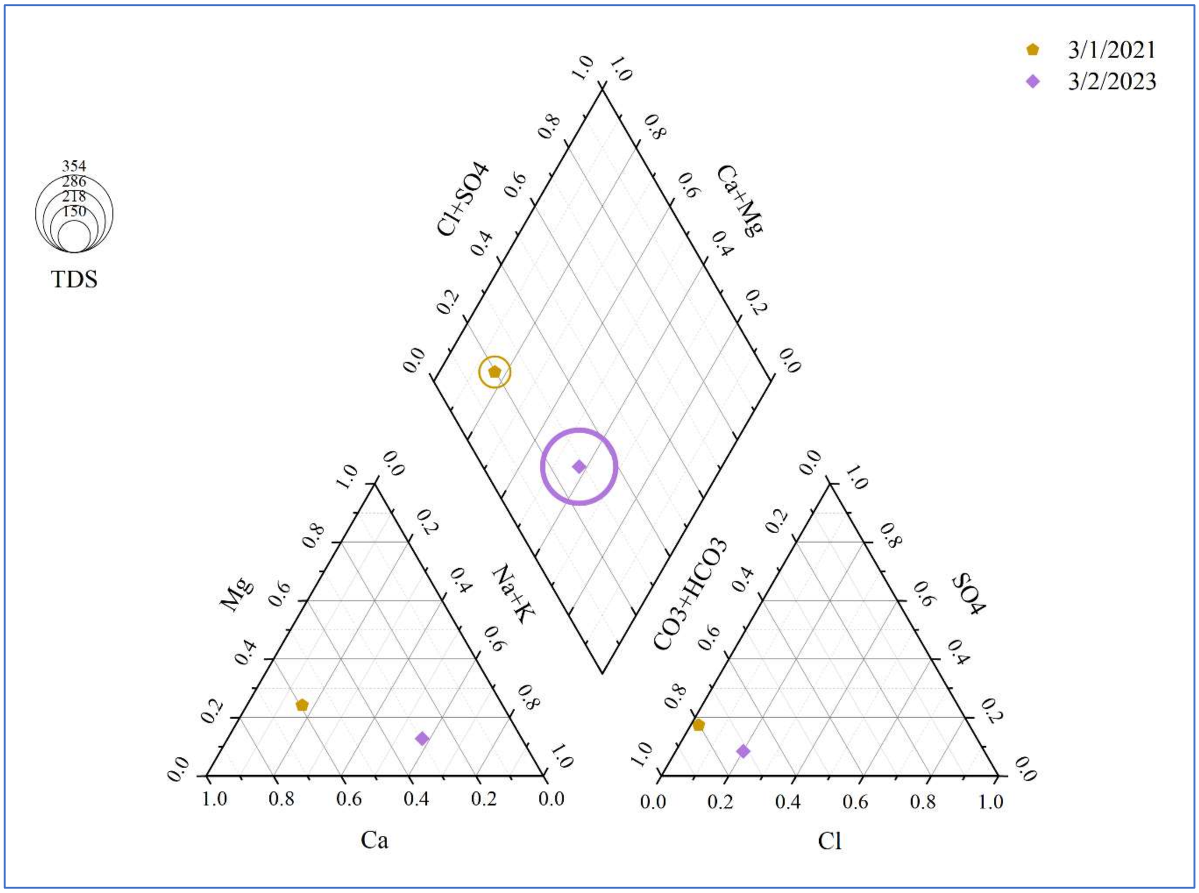


Figure 6. Piper diagram illustrating fractional composition (calculated as milliequivalents per liter) of major cations and anions in the Norrid domestic water well from the 3/1/2021 and 3/2/2023 sampling events. Note the increase in total dissolved solids (TDS) in mg/L.

It is very unlikely that an increase in methane from <11.6 µg/L to 15,500 µg/L could be due to temporal variability. Either there was an egregious methodological error during sampling by the PADEP during the March 2021 sampling event or a precipitating event occurred between the March 2021 and March 2023 sampling events which caused flow of methane to the domestic water well and a change in alkalinity and major ion concentrations. The date of hydraulic fracturing at the Mazure William 12118 2H is not known at present. The domestic well owners could not confirm (e.g., gas spurting at the faucet) that natural gas was present in their water well during the March 2021 sampling event.

Historical groundwater and spring water quality data for Washington County for parameters examined by the PADEP were obtained from EPA (2015). EPA provided a summary of data from Newport (1973), and the U.S. Geological Survey's (USGS) National Water Information System (NWIS) and National Uranium Resource Evaluation (NURE) databases. These data sources represent sampling events conducted before 2005 that pre-date unconventional gas development in Washington county. Examination of summary statistics of water quality information available from groundwater and springs relevant to analytes in the Norrid domestic water well (**Table 5**) indicates that while a shift in inorganic parameters occurred between the March 2021 and March 2023 sampling events, inorganic analytes detected in the Norrid domestic water well are within expected values in Washington County.

Table 6. Summary statistics of water quality information available in Washington County, PA from groundwater and springs relevant to analytes in the Norrid domestic water well.

Data Source	Parameter	Dissolved/ Total	Units	Mean	Median	Standard Deviation	Minimum	Maximum	N	Z[1]
NURE	pH			7.2	7.3	0.32	6.1	8.7	153	-
NWIS	pH			8.0	8.1	0.50	6.5	9.1	88	-
NURE	SPC		µS/cm	604	550	298	80	2050	153	0
NWIS	SPC		µS/cm	1238	675	1412	71	7000	97	0
NWIS	Alkalinity		mg/L	164	156	71	9	460	91	0
Newport (1973)	Sodium	dissolved	mg/L	87	33	122	8.2	440	14	0
NURE	Sodium	dissolved	mg/L	19	7	40	1.4	309	130	0
NWIS	Sodium	dissolved	mg/L	198	42	362	4.0	1700	48	0
Newport (1973)	Potassium	dissolved	mg/L	4.7	3.6	3.0	1.7	12	14	0
NWIS	Potassium	dissolved	mg/L	3.5	3.4	1.7	0.2	7.2	48	0
Newport (1973)	Calcium	dissolved	mg/L	94	69	124	2.8	506	14	0
NWIS	Calcium	dissolved	mg/L	74	66	30	19	160	69	0
Newport (1973)	Magnesium	dissolved	mg/L	26	18	35	2.1	141	14	0
NURE	Magnesium	dissolved	mg/L	10	7	10	1.0	73	123	0
NWIS	Magnesium	dissolved	mg/L	20	14	15	3.6	67	69	0
Newport (1973)	Chloride	dissolved	mg/L	45	17	72	1.4	220	14	0
NURE	Chloride	dissolved	mg/L	23	9	51	1.9	404	128	0
NWIS	Chloride	dissolved	mg/L	90	29	159	3.0	910	73	0
Newport (1973)	Sulfate	dissolved	mg/L	176	54	416	3.7	1600	14	0
NWIS	Sulfate	dissolved	mg/L	349	175	521	10	2600	91	0
Newport (1973)	Bicarbonate	dissolved	mg/L	340	316	181	45	867	14	0
NWIS	Bicarbonate	dissolved	mg/L	209	190	89	13	560	54	0
NWIS	Barium	dissolved	µg/L	51	13	70	9	183	6	0
NWIS	Strontium	dissolved	µg/L	1485	810	1800	445	6400	11	0
Newport (1973)	Iron	total	µg/L	771	700	639	70	2300	14	0
NWIS	Iron	total	µg/L	693	330	1278	<50	9200	79	1
NWIS	Iron	dissolved	µg/L	675	320	1383	130	9000	42	0
NWIS	Manganese	total	µg/L	107	60	126	<10	710	67	2
NURE	Manganese	dissolved	µg/L	131	62	176	7	903	71	0
NWIS	Manganese[2]	dissolved	µg/L	69	40	74	10	340	58	0
NURE	Br[3]	dissolved	mg/L	0.15	0.04	0.36	0.10	1.9	45	0

1 - Z is the number of locations with left-censored data; concentration values were set at ½ of the method detection limit or Reporting Level.

2 - Data base entries of "0" were not included in the statistical analysis.

3 - The NURE dataset provides results for bromine. It is likely that total bromine is present as bromide.

Volatile Organic Compounds

Benzene, toluene, ethylbenzene, and xylenes (BTEX) are commonly associated with natural gas from abandoned wells (DiGiulio et al., 2023). BTEX components were not detected in aqueous samples collected from the Norrid domestic water well and hence do not pose an inhalation risk from offgassing during showering or other use. The only detected volatile organic compounds detected were chloroform (2.0 µg/L) and tetrahydrofuran (4.62 µg/L) the cause of which are unknown.

Diesel Range Organics

Up until the mid-1980s to 1990s, it was common practice to dispose of diesel fuel-based drilling mud, produced water, and condensate on site in pits. During gas sampling of abandoned wells, DiGiulio et al.

(2023) noted the presence of pits in Oil Creek, Hillman, and Cornplanter State Parks in western Pennsylvania. It is reasonable to assume that a buried legacy pit exists somewhere in the vicinity of abandoned wells on the Norrid property. Biodegradation of petroleum in contaminated soils leads to the generation of polar degradation products that can be measured by diesel range organics (DRO) analysis in the absence of silica gel cleanup. DiGiulio and Jackson (2016) documented contamination of domestic wells from legacy pits using DRO analyses. As a precautionary measure, DRO analysis should be conducted at the Norrid domestic water well. Detection of DRO in well water should prompt a soils investigation on the Norrid property. Another precautionary measure would be collection of soil cores in the vicinity of abandoned wells.

Gas Compositional Plots

During the March 2023 sampling event, methane, ethane, and propane were detected at 15.5, 0.282, and 0.0174 mg/L, respectively. A methane concentration greater than 7 mg/L represents the lower threshold for a potential stray gas migration incident response (Pennsylvania Code, 2011). Matrix spike recoveries were low for light hydrocarbons indicating that sample results may be biased low.

The PADEP also submitted samples of water from the domestic water well and SB Donaldson to Isotech Laboratories for light hydrocarbon and isotopic analysis (results in **Table 5**). Analysis of gas from water was from headspace equilibrium using helium. Isotopic analysis of carbon and hydrogen is relative to the international standards Vienna Pee Dee Belemnite (VPDB) and Vienna Standard Mean Oceanic Water (VSMOW), respectively.

Thermogenic hydrocarbons form through the thermal decomposition of oil and organic matter dispersed in deep sedimentary rocks at temperatures exceeding 120°C and pressures exceeding 50 MPa. Thermogenic natural gas contains methane and other light hydrocarbons such as ethane, propane, butane, isobutane, pentane, isopentane. Coal is formed through geochemical and biochemical reactions transforming plant material into carbon-rich solids some of which produce hydrocarbons. There can be low single-digit percentages of ethane with little or no larger hydrocarbons such as propane or butane in coalbed gas in Pennsylvania (Kim 1973). Natural gas can also be produced by microbial communities in shallow sediments. This process can occur in relatively low temperatures, typically 60–80°C. The resulting shallow gas is commonly known as biogenic or microbial gas. Microbial methane forms via one of two predominant metabolic processes active in methanogenic bacteria - the reduction of CO_2 and fermentation of acetate. Some Upper Devonian gases might be mixtures of microbial and thermogenic hydrocarbons. Laughrey and Baldassare (1998) interpreted gases in the Pennsylvanian-age coals as mixtures of thermogenic gas, generated directly from Type III kerogens in the coals, and microbial gases generated by methanogenic bacteria in stagnant, anoxic groundwater in the coal-bearing strata. The Norrid domestic water wells have greater than 0.5% concentrations of C2+ hydrocarbons which indicates a thermogenic origin (Stahl, 1974; Whiticar, 1999; Whiticar et al., 1986). The presence of ethane, propane, iso-butane, butane, isopentane, and hexanes in gas from Norrid domestic water well (**Table 2**) indicates a thermogenic component of gas (e.g., mixed gas).

A plot of light hydrocarbon ratios (Pixler plot, Pixler, 1969) indicates that gas composition from SB Donaldson 2 is typical for abandoned wells at Hillman State Park. Gas from the Norrid domestic water well appears somewhat drier (higher molar ratios of methane to other light hydrocarbons) but somewhat wetter than coal-bed gas. Similar to the SB Donaldson well, the producing horizon at Hillman State Park was the upper Devonian Venango Group. The presence of a lighter molar ratio of light hydrocarbons in the Norrid domestic well could indicate mixed thermogenic gas from the Venango Group and coal-bed gas or mixed thermogenic gas from the Venango Group and biogenic gas. Data at Oil Creek and

Cornplanter State Park and other locations in western Pennsylvania are highlighted in **Figure 5** to illustrate how a Pixler Plot can be utilized to distinguish gas composition from apparent different source terms.

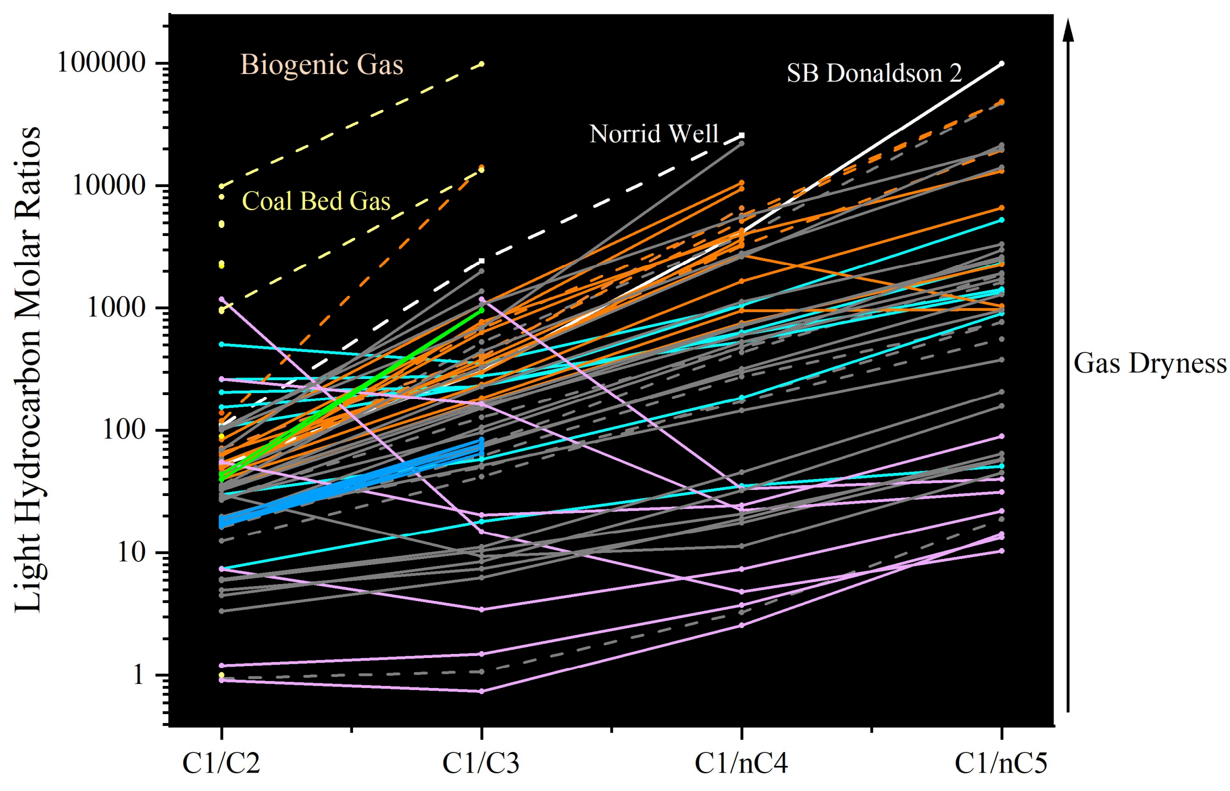


Figure 5. Pixler plot (Pixler, 1969) of gas from the Norrid Domestic water well (white dashed line), SB Donaldson 2 abandoned well (solid white line), and active and abandoned wells in western Pennsylvania from Upper Devonian age reservoirs unless otherwise noted. Active Pennsylvanian age coal bed gas wells (dashed yellow line, data from Laughrey and Baldassare, 1998, n=6 and Kim, 1973, n=4), abandoned wells at Oil Creek State Park (solid cyan line, data from DiGiulio et al., 2023, n=7), abandoned wells at Hillman State Park (solid orange lines, data from DiGiulio et al., 2023, n=11, dashed orange lines, data from Pekney et al., 2018, n=5) abandoned wells at Cornplanter State Park (solid violet lines, data from DiGiulio et al., 2023, n=7), other abandoned wells (solid gray lines, data from DiGiulio et al., 2023, n=23), active Upper Devonian wells (dashed gray lines, data from DiGiulio et al., 2023, n=7), active Upper Devonian-Lower Mississippian age wells (solid powder blue lines, data from Sharma et al., 2015, n=7), and active Marcellus Shale wells (light green solid lines, data from Sharma et al., 2015, n=2). C1 = methane, C2 = ethane, C3 = propane, nC4 = butane, and nC5 = pentane. Note that data points at C1/C2 without lines indicates that light hydrocarbon beyond ethane were not detected. Increasing gas dryness with increasing light hydrocarbon molar ratios and regions representative of coal bed and biogenic gas illustrated.

$\delta^{13}C$-CH_4 can be plotted with C1/(C2+C3) (C1 = methane, C2 = ethane, C3 = propane) ratios (Bernard Plot, Bernard et al., 1978) to distinguish biogenic, thermogenic and mixed gas. Typical reported ranges for $\delta^{13}C$-CH_4 and $\delta^{2}H$-CH_4 of methane produced by CO_2 reduction are between -110‰ to -60‰ and -150‰ to -250‰, respectively. Acetate fermentation produces methane with $\delta^{13}C$-CH_4 values ranging from -65‰ to -50‰ and $\delta^{2}H$-CH_4 values of -300‰ to -400‰ (Schoell, 1983, 1980; Whiticar, 1999; Whiticar et al., 1986). Typically, biogenic gas will consist mostly of methane and has a Bernard ratio > 500, while thermogenic gas often includes heavier hydrocarbons up to hexane (C6) and has Bernard ratio < 100. However, highly mature and dry thermogenic gas may have Bernard ratio high enough to be mistaken for biogenic gas. Again, SB Donaldson 2 is typical of Upper Devonian reservoir age abandoned wells in Hillman State while the Norrid domestic water well plots as a mixed thermogenic gas and coal-bed gas, or a mixed thermogenic gas and biogenic gas (**Figure 6**). Importantly, C1/(C2+C3) and $\delta^{13}CH_4$ values for thermogenic gas from the upper Devonian Venango Group at Hillman State Park (including SB Donaldson 2) are clustered clearly indicating a mixing trend of the Norrid domestic water well toward this cluster from either biogenic gas or coal-bed gas. Hence, at least some portion of gas in the Norrid domestic water well is from the upper Devonian Venango Group typical of oil wells at Hillman State Park.

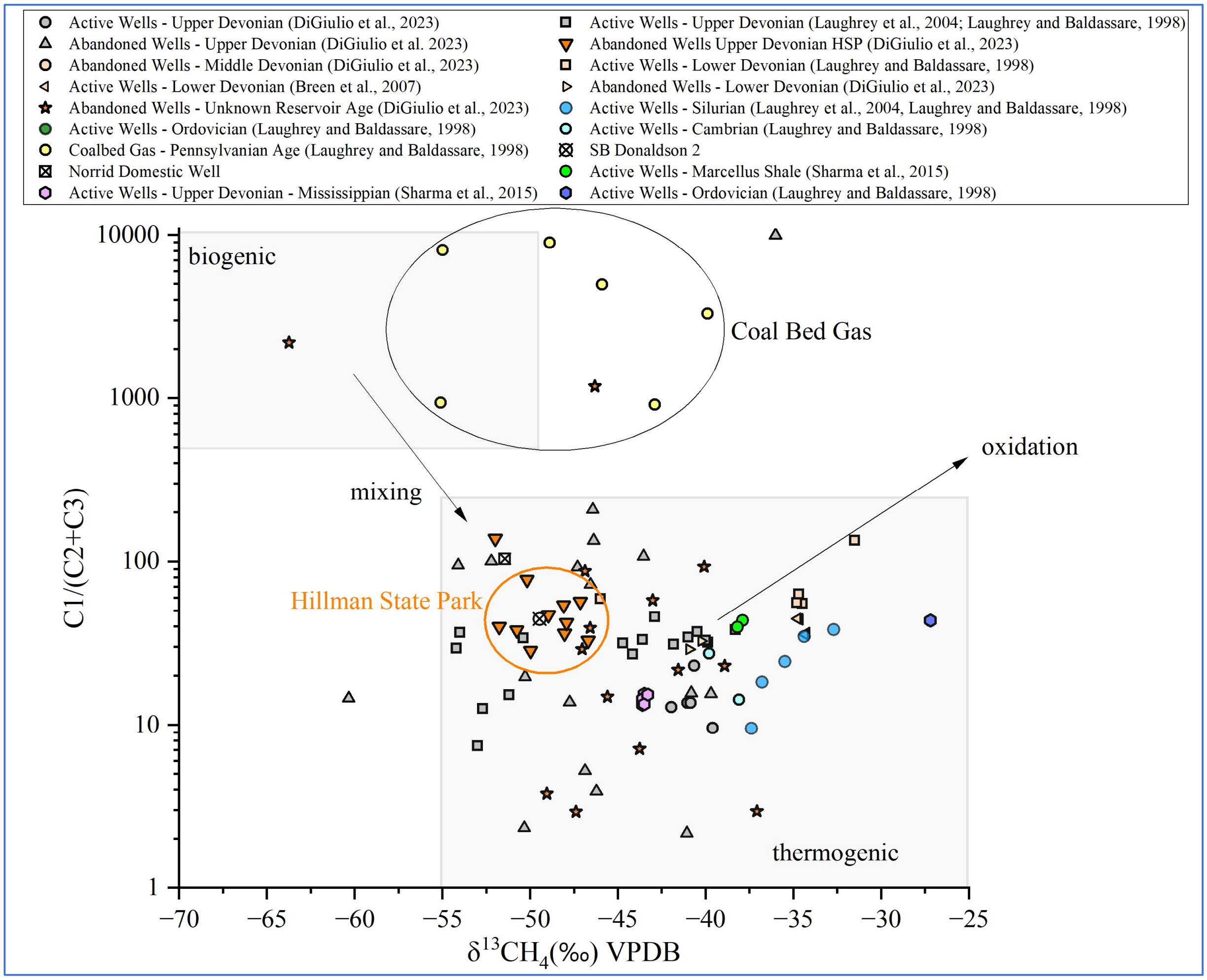


Figure 6. Bernard Plot of gas from the Norrid Domestic water well, SB Donaldson 2, oil and gas wells in western PA: active coal-bed gas wells (Laughrey and Baldassare, 1998), Upper Devonian active wells (Laughrey et al., 2004; Laughrey and Baldassare, 1998; DiGiulio et al., 2023), Upper Devonian abandoned wells (DiGiulio et al., 2023), abandoned wells of unknown reservoir age (DiGiulio et al., 2023), Lower Devonian active wells (Breen et al., 2007; Laughrey and Baldassare, 1998), Silurian active wells (Laughrey et al., 2004; Laughrey and Baldassare, 1998), Ordovician active wells (Laughrey and Baldassare, 1998), Cambrian active wells (Laughrey and Baldassare, 1998), active Upper Devonian – Mississippi wells (Sharma et al., 2015), and active Marcellus Shale Gas Wells (Sharma et al., 2015). C1 = methane, C2 = ethane, and C3 = propane. HSP denotes Hillman State Park.

Stable isotopes of carbon $\delta^{13}C$ and hydrogen ($\delta^{2}H$) can also be plotted (Schoell diagram, Schoell, 1980) to distinguish biogenic, thermogenic and mixed source gas. In this plot, gas from both SB Donaldson 2 and the Norrid domestic water well appear representative of coal bed or Upper Devonian thermogenic gas (**Figure 7**).

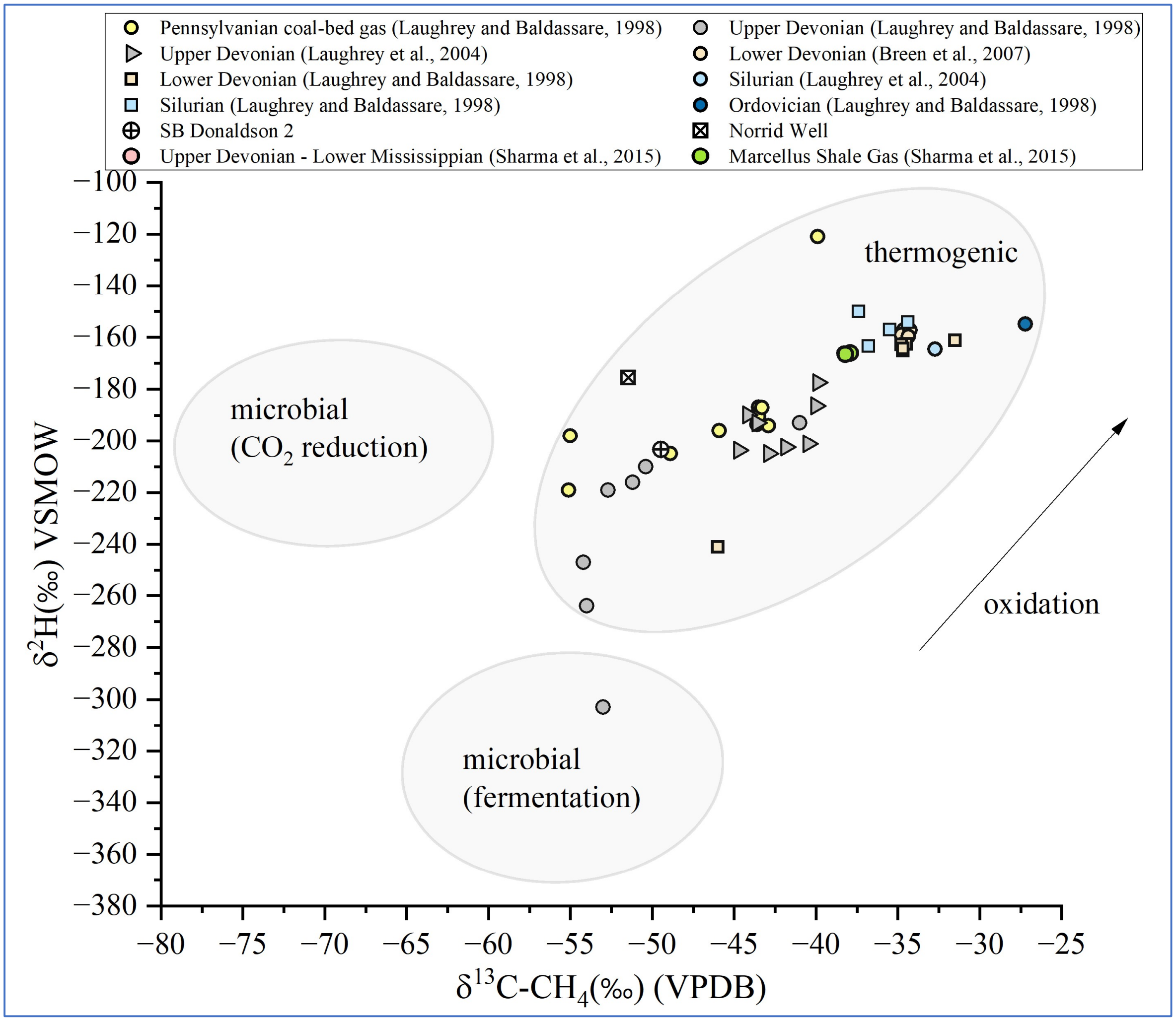


Figure 7. Schoell plot of gas from the Norrid Domestic water well, SB Donaldson 2, oil and gas wells in western PA: coal-bed gas (Laughrey and Baldassare, 1998), Upper Devonian active wells (Laughrey et al., 2004; Laughrey and Baldassare, 1998, Lower Devonian active wells (Breen et al., 2007; Laughrey and Baldassare, 1998), Silurian active wells (Laughrey et al., 2004; Laughrey and Baldassare, 1998), Ordovician active wells (Laughrey and Baldassare, 1998).

For most gas deposits in basins throughout the world methane is isotopically the lightest hydrocarbon, followed by ethane, propane, butane, and pentane (Chung et al., 1988). This trend can be observed in a "natural gas plot" by plotting the inverse of the carbon number (methane = 1, ethane = 2, propane = 3, etc.) and the carbon isotope ratio (Chung et al., 1988). Reversals of carbon isotope ratios may indicate the presence of more than one source terms for hydrocarbons (Chung et al., 1988). Isotope reversals are observed within the Marcellus gas (**Figure 8**), but not within the Upper Devonian/Lower Mississippian gas (Burruss and Laughrey, 2010; Baldassare et al., 2013). A pronounced downward (more negative) deviation from a straight line after ethane as indicated by the Norrid domestic water well (**Figure 8**) may indicate the presence of mixed microbial and thermogenic gas (Chung et al., 1988).

Natural gas plots for the SB Donaldson 2 and Norrid domestic water well indicate that they are isotopically dissimilar (**Figure 8**). It is interesting that the $\delta^{13}C$ value for ethane in the Norrid domestic water well is higher than that observed for the SB Donaldson well and nearly all other available values for active oil and gas well in western Pennsylvania. This likely indicates preferential oxidation of nonmethane alkanes as observed by Schout et al. (2018).

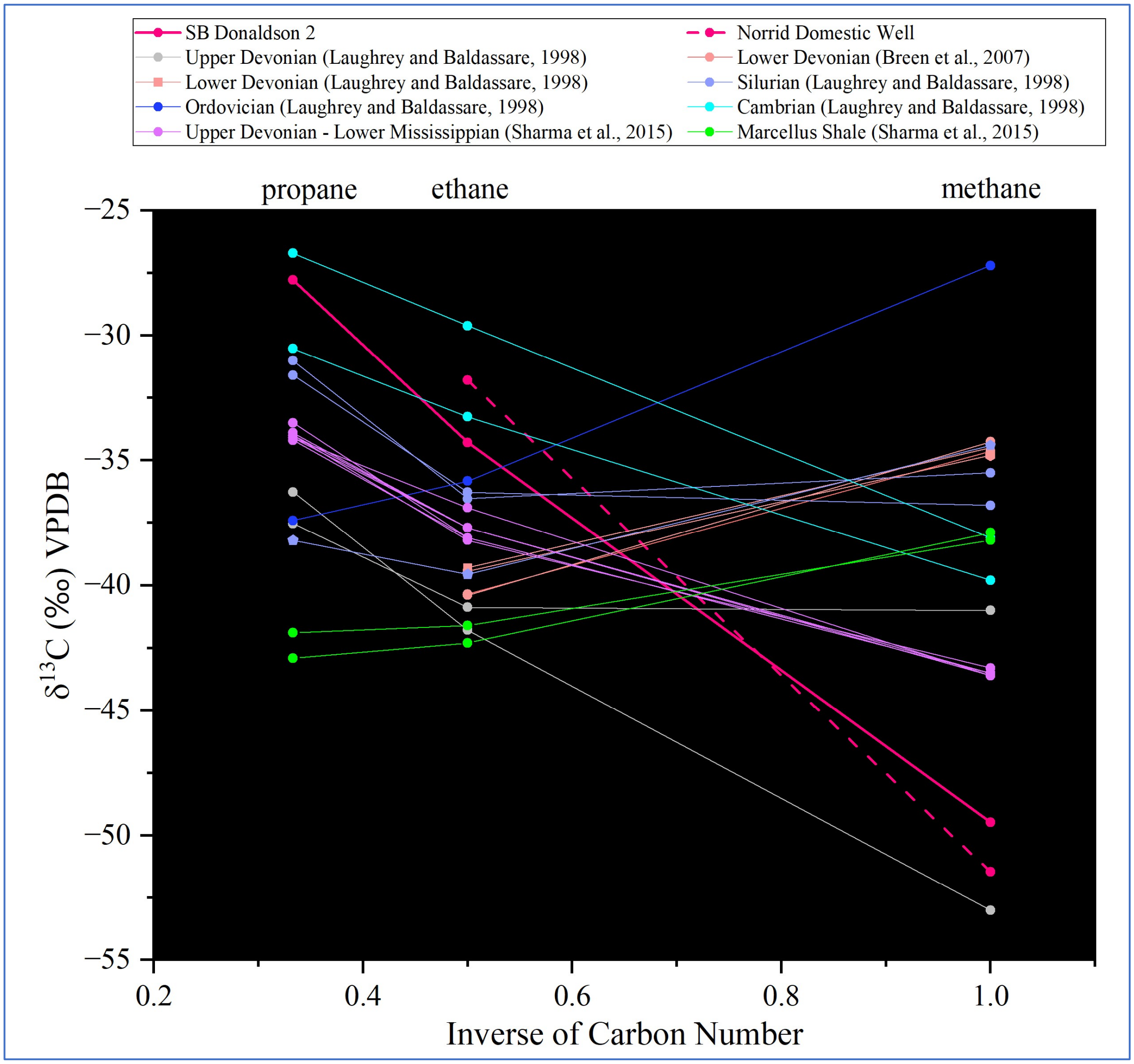


Figure 8. Natural gas plot from the Norrid Domestic water well, SB Donaldson 2, oil and gas wells in western PA: Upper Devonian active wells (Laughrey and Baldassare, 1998), Lower Devonian active wells (Breen et al., 2007; Laughrey and Baldassare, 1998), Silurian active wells (Laughrey and Baldassare, 1998), Ordovician active wells (Laughrey and Baldassare, 1998).

Gas compositional plots illustrated here clearly indicate that stray gas in the Norrid domestic well is a mixture of thermogenic and coal bed gas or a mixture of thermogenic and biogenic gas. Carbon-14 analysis (not conducted here) is a more definitive method to distinguish microbial versus thermogenic gas. Radiogenic ^{14}C activity is typically expressed as percent modern, where 100% modern is defined as ^{14}C activity of atmospheric carbon dioxide in the year 1950. Methane formed before 1950, would have ^{14}C activity less than 100% modern. Methane formed after 1955 would have ^{14}C activities greater than

100% modern because of testing of nuclear bombs. Thermogenic methane formed with coal or petroleum will contain no ^{14}C activity because these materials were generated millions of years ago.

Given that there is no cement outside casing at the SB Donaldson well or any other nearby abandoned wells, stray gas migration to the Norrid well should not be considered unusual or unexpected. Stray gas migration is believed to be due to lack of cement outside casing in non-producing but gas-containing strata overlying reservoirs (as is apparently the case here), defects in cement during setting, poor bonding between cement and casing or cement and boreholes, drilling induced fractures outside boreholes (Dusseault et al., 2000; Dusseault and Jackson, 2014). Importantly, between 1987 and 2013, there were 133 confirmed cases of stray gas migration to water wells in Pennsylvania attributed to abandoned wells (Pelepko et al., 2017). Hence, stray gas migration from oil and gas wells into water wells is not unusual in Pennsylvania. Gas migration from abandoned wells into buildings and residences has resulted in emergency plugging actions (Pelepko 2019, 2020) and contributed to explosions in Pennsylvania (Baldassare and Laughrey, 1997; PADEP, 2009) and elsewhere (Chilinger and Enders, 2005).

The lack of an exact isotopic match between the Norrid domestic water well and SB Donaldson 2 indicates that gas containing strata of different isotopic composition from the target reservoir is contributing to stray gas in the Norrid domestic water well. SB Donaldson 2 and other uncemented abandoned wells in the area are essentially function as conduits for upward mixing of gas from targeted reservoirs and overlying gas bearing strata. Hence, it is likely that SB Donaldson 2 and other abandoned wells in the area caused stray gas migration into the Norrid domestic water well.

Recommended Treatment of Norrid Domestic Well

The Norrid domestic water well at times does not provide sufficient yield for consistent domestic use (personal communication with Amber Norrid). This could be due to at least three possible factors: (1) insufficient aquifer recharge, (2) collapse or sloughing of formation materials at the base of the well creating a low permeability skin around the base of the slotted 5” casing, and (3) gas locking of the submersible pump. A first step in investigating this issue is to determine depth to groundwater and drawdown during sustained use. Knowledge of pumping rate and drawdown could be used to estimate hydraulic conductivity and to evaluate excessive drawdown. If this testing is not definitive, the submersible pump and internal perforated casing could be pulled from the well and the base of the well could be inspected with a borehole camera or at least tagged with a water level meter to determine the extent of sloughing or borehole collapse.

If low well yield is due to gas locking of the submersible pump, a gas shroud could be installed around the submersible pump (**Figure 9**). In some cases, the installation of a shroud on the pump has reduced gas levels enough so that no further treatment was necessary (Michigan Water Well Manual, 2023). The shroud seals to the top of the submersible pump motor below the intake and extends 5 to 10 feet above the top of the pump. The water then must travel upward and over the top of the shroud and downward to the pump intake. The dissolved gases will have a tendency to continue upward rather than follow the water to the intake, allowing gases to escape from vented well (Michigan Water Well Manual, 2023). If the casing is 5 inches or larger with a 4-inch submersible pump, a gas shroud can be easily fabricated from 4-inch thin wall plastic pipe. A few submersible pump manufacturers have shrouds available for 4-inch wells. A 3-inch submersible pump with a thin-wall plastic shroud can also be used in a 4-inch well. It is important that a tight seal be made between the pump motor and the bottom of the shroud, since leakage will cause gaseous water to enter the pump intake. The bottom of the shroud must seal at the top of the motor to allow for proper motor cooling. Drillers have sealed the shroud to the motor by wrapping tape around the shroud or by slitting the thin-wall plastic near the bottom and clamping the shroud to the motor (Michigan Water Well Manual, 2023).

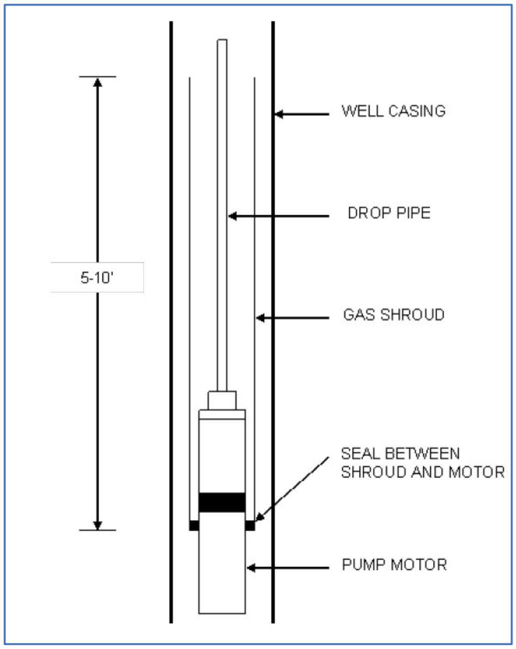


Figure 9. Gas shroud on submersible pump. Figure from Michigan Water Well Manual (2023).

The concentration of methane in water entering a household from a domestic water well will be dependent upon the methane concentration in groundwater surrounding the screened interval of the well, the vertical location of the submersible pump, the pumping rate, and hydraulic conductivity of the formation surrounding the water well. The pumping rate and hydraulic conductivity of the surrounding formation determine drawdown in the well during pumping. At the commencement of pumping, water is removed from the submersible pump casing. Combined downward and upward flow then occurs in blank casing above and below a pump inlet, respectively as drawdown occurs in the well. In the screened interval, radial flow occurs from the surrounding formation and mixes with water initially in the borehole and screen. This mixed water then undergoes upward flow in the casing to the pump inlet. As drawdown stabilizes, all of the water entering the pump inlet is from the surrounding formation. Hence, water entering the household is some mixture of stagnant water in casing above the pump inlet which has been ventilated and water directly from the surrounding formation which has higher concentrations of methane (DiGiulio and Jackson, 2016). Thus, while use of a gas shroud and venting will promote the release of methane from the water well, it may not negate the need for an aeration system (Mantel, 2013).

A gas removal system that has worked effectively in Michigan is use of a vented storage tank with a spray bar mechanism (**Figure 10**). The spray bar is a length of pipe with small holes drilled in it to disperse the water. Water from the well is sprayed upward through the spray bar into the vented tank and gas is liberated and exits through a vent pipe at the top of the tank. A float switch is used in the vented tank to control the well pump (Michigan Water Well Manual, 2023). The vent line should terminate above the roof line of the building and screened and turned down to prevent insects and debris from entering. It is recommended that a flap-type check valve be installed on the vent line to allow the tank to vent to the outside only. This will minimize the intake of airborne bacteria, spores, pollen, etc., into the vent line. In addition, the check valve will place the tank under negative pressure when the second pump is operating, further increasing the liberation of gas from the water.

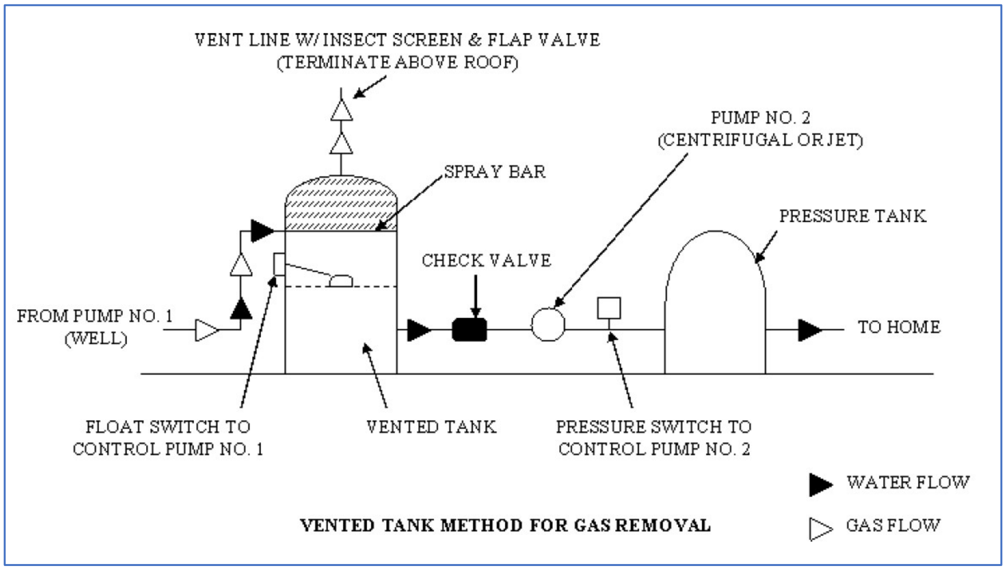


Figure 10. Vented tank for gas removal. Figure from Michigan Water Well Manual (2023).

Aeration devices require routine maintenance. An upgradient whole house filter may need to be installed to prevent plugging. Disinfection equipment may also be recommended since some aeration units can allow bacterial growth in the water system (PSU, 2023). Though not required, chlorination is typically recommended with a reservoir tank.

Recommended Minimum Plugging Requirements at SB Donaldson 2

Pennsylvania regulations state the following. § 78.92 (a) (1), 78.93 (a) (1), 78.94 (a) (1), 78.95 (a) (1). The retrievable production casing shall be removed by applying a pulling force at least equal to the casing weight plus 5,000 pounds or 120% whichever is greater. If this fails, an attempt shall be made to separate the casing by cutting, ripping, shooting or other method approved by the Department, and making a second attempt to remove the casing by exerting a pulling force equal to the casing weight plus 5,000 pounds or 120% of the casing weight, whichever is greater.

§ 78.93 (3) After it has been established that the surface casing or coal protective casing is free and can be retrieved, the surface or coal protective casing shall be retrieved by applying a pulling force at least equal to the casing weight plus 5,000 pounds or 120% whichever is greater. If this fails, an attempt shall be made to separate the casing by cutting, ripping, shooting or other method approved by the Department, and making a second attempt to remove the casing by exerting a pulling force equal to the casing weight plus 5,000 pounds or 120% of the casing weight, whichever is greater.

§ 78.91 (h) In lieu of the plugging requirements of §§ 78.92—78.95 and 78.97, an operator may cement a well from the total depth or attainable bottom to the surface.

Since there is no cement behind casing, to mitigate stray gas migration, it is recommended that all well casing be removed to the extent possible even if this involves milling or cutting sections of casing. Afterwards, the wellbore should be cemented to the surface rather than installing individual plugs. To mitigate stray gas migration, it is necessary to have a formation wall to wall barrier throughout the wellbore.

Summary and Recommendations

Compositional and isotopic analysis of the gas from the Norrid domestic water well indicates a mixture of thermogenic gas from the Upper Devonian Venango Formation and coal bed or biogenic gas from overlying deposits. The most likely cause of gas in the Norrid domestic water well is from SB Donaldson 2 and other nearby abandoned wells. These abandoned wells lack cement outside casing and act essentially as conduits for gas migration from the Venango Formation and overlying gas bearing units. It is perplexing that methane and other light hydrocarbons were detected at high levels during the March 2023 sampling but not detected during the March 2021 sampling event. Differences in concentration are well beyond what would be expected from temporal variability. Lack of detection of light hydrocarbons during the March 2021 sampling event could be due to poor well purging or sampling procedures. The PADEP did not include any information on sampling procedures in inspection reports. Alternatively, detection of light hydrocarbons during the March 2023 sampling event could have been due to a precipitating event. While concentrations of major ions are well within expected values in Washington County, there was a definitive shift in major ion concentrations, especially sodium and chloride, between the March 2021 and March 2023 sampling events. The horizontal leg of a production well in the Marcellus Shale appears to be within 200 lateral feet of the Norrid domestic water well. The dates of well stimulation are unknown. Hypothetically, hydraulic fracturing could have caused wellbore communication in one or more abandoned wells in overlying formations. However, this is speculation lacking any definitive information or data. Also, gas in the Norrid domestic water well does not appear to be from the Marcellus Shale.

Information submitted in this report should be sufficient to justify plugging abandoned wells, SB Donaldson 2 and SB Donaldson 3 on the Norrid property. Properly plugging these abandoned wells may ultimately reduce gas concentrations to safe levels. In the meantime, water entering the household should be treated with an aeration system and construction of the domestic well may need to be modified as outlined in this report.

References

Baldassare, F.J.; Laughrey, C.D. 1997. Identifying the sources of stray methane by using geochemical and isotopic fingerprinting. *Environmental Geosciences*, 4, 2, 85–94.

Baldassare, F.J.; McCaffrey, M.A.; Harper, J.A. 2014. A geochemical context for stray gas investigations in the northern Appalachian Basin: Implications of analyses of natural gases from Neogene-through Devonian-age strata. *The American Association of Petroleum Geologists Bulletin* 98, 2, 341–372 341.

Bascom-Turner. Gas-explorer model specifications and price list. https://www.bascomturner.com/_files/ugd/9a5810_2b30bb86858742ce8e9b64128837a4e3.pdf

Beal, E.J.; House, C.H.; Orphan, V.J. 2009. Manganese- and iron-dependent marine methane oxidation. *Science* 325:184–187.

Bernard, B.B., Brooks, J.M., Sackett, W.M., 1978. Light hydrocarbons in recent Texas continental shelf and slope sediments. *Journal of Geophysical Research: Oceans* 83, C8, 4053–4061.

Breen, K.J.; Révész, K.; Baldassare, F.J.; McAuley, S.D. 2007. Natural gases in ground water near Tioga Junction, Tioga County, North-Central Pennsylvania - Occurrence and use of isotopes to determine origins, 2005, U.S. Geological Survey Scientific Investigations Report 2007-5085.

Burruss, R.C.; C.D. Laughrey, C.D. 2010. Carbon and hydrogen isotopic reversals in deep basin gas: Evidence for limits to the stability of hydrocarbons. *Organic Geochemistry* 41, 1285–1296.

Chilingar, G. V.; Endres, B. 2005. Environmental hazards posed by the Los Angeles Basin urban oilfields: an historical perspective of lessons learned. *Environmental Geology* 47, 302−317.

Chung, H.M.; Gormly, J.R.; Squires, R.M. 1988. Origin of gaseous hydrocarbon in subsurface environments: Theoretical considerations of carbon isotope distribution. *Chemical Geology*, 71, 97-103.

Coughlin, M. F. 2009. Subsurface mapping and reservoir analysis of the Upper Devonian Venango and Bradford groups in Westmoreland County, Pennsylvania. Graduate Theses, Dissertations, and Problem Reports. 4452. https://researchrepository.wvu.edu/etd/4452

DiGiulio D.C., Jackson R.B. 2016. Impact to Underground Sources of Drinking Water and domestic wells from production well stimulation and completion practices in the Pavillion, Wyoming Field. *Environmental Science & Technology* 50, 4524-4536.

DiGiulio, D.C.; Rossi, R.J.; Lebel, E.D.; Bilsback, K.R.; Michanowicz, D.R.; Shonkoff, S.B.C. 2023. Chemical Characterization of Natural Gas Leaking from Abandoned Oil and Gas Wells in Western Pennsylvania. *ACS Omega*. 8, 22, 19443-19454.

Dusseault, M. B.; Gray, M. N.; Nawrocki, P. A. 2000. Why oil wells leak: Cement behavior and Long-Term Consequences. *Society of Petroleum Engineers* p 64733.

Dusseault, M.; Jackson, R. 2014. Seepage pathway assessment for natural gas to shallow groundwater during well stimulation, in production, and after abandonment. *Environmental Geosciences* 21, 107−126

Department of Environment, Great Lakes, and Energy (EGLE), Drinking Water Laboratory, https://www.michigan.gov/egle/-/media/Project/Websites/egle/Documents/Programs/DWEHD/Water-Well-Construction/iron-bacteria-in-wells.pdf?rev=4d80d804ca214567930e03739fa37141

ETHW. Torpedoes (Well shooting). https://ethw.org/Torpedoes_%28Well_shooting%29

Kelly, W.R., G. Matisoff, and J.B. Fisher. 1985. The effects of a gas well blow out on groundwater chemistry. *Environmental Geology & Water Science* 7, no. 4: 205–213.

Kim, A.G. 1973. The Composition of Coalbed Gas. United States Department of the Interior, Bureau of Mines, Report of Investigations 7762.

Laughrey, C.D.; F. J. Baldassare, F.J. 1998. Geochemistry and origin of some natural gases in the Plateau Province, Central Appalachian Basin, Pennsylvania and Ohio. *The American Association of Petroleum Geologists*, 2, 317–335.

Laughrey, C.D.; Billman, D.A.; Canich, M.R. 2004. Petroleum geology and geochemistry of the Council Run gas field, north central Pennsylvania. *The American Association of Petroleum Geologists Bulletin*, 88, 2, 213–239.

Lentz, L.J. and Neubaum, J.C. 2005. A study of coal availability in the Hackett 7.5-minute quadrangle, Washington County, Pennsylvania. Pennsylvania Geological Survey.

Mantel, B. Methane mitigation procedures for private wells. 2013. Annual Midwest Workshop in Environmental Health, March 18, 2013. https://odh.ohio.gov/wps/wcm/connect/gov/578ee624-050b-4c48-abf8-0050e1fb26bd/Methane+Mitigation+Procedures+for+Private+Wells.pdf?MOD=AJPERES&CONVERT_TO=url&CACHEID=ROOTWORKSPACE.Z18_M1HGGIK0N0JO00QO9DDDDM3000-578ee624-050b-4c48-abf8-0050e1fb26bd-mn4g2Ed

Markowski, A.K. 1998. Coalbed methane resource potential and current prospects in Pennsylvania. *International Journal of Coal Geology*, v. 38, p. 137-159.

Michigan Department of Environment, Great Lakes, and Energy. Drinking Water and Environmental Health Division. Environmental Health Section. Source Water Unit Well Construction Program, August 2023. https://www.michigan.gov/-/media/Project/Websites/egle/Documents/Programs/DWEHD/Water-Well-Construction/Water-Well-Manual.pdf?rev=6a20f28815644913a502a27450fefb86

Molofsky, L.J.; Connor, J.A.; McHugh, T.E.; Richardson, D.D.; Woroszlyo, C.; Alvarez, P.J. 2016. Environmental Factors Associated with Natural Methane Occurrence in the Appalachian Basin. *Groundwater* 54, 5, 656-668.

Montana State University (MSU). Total Coliform and E. coli Bacteria. https://waterquality.montana.edu/well-ed/interpreting_results/fs_totalcoliform_ecoli.html

Newport, T.G. (1973). Summary of ground-water resources of Washington County, Pennsylvania. Pennsylvania Geological Survey, Water Resource Report 38, 32 pp.

Pekney, N.J.; Diehl, R.J.; Ruehl, D.; Sams, J.; Veloski, G.; Patel, A.; Schmidt, C.; Card, T. 2018. Measurement of methane emissions from abandoned oil and gas wells in Hillman State Park, Pennsylvania. *Carbon Management* 9(2), 165-175.

Pelepko, S.; Byron, L.A.; Beattie, S.; Catalano, D.; Swank, R. 2017. Pennsylvania legacy well integrity and emissions study: Part 1. Geological Society of America. Joint 52nd Northeastern Annual Section / 51st North-Central Annual Section Meeting - 2017.

Pelepko, S. 2019. PIOGATECH Well Plugging Workshop: Well plugging regulatory viewpoint. Pennsylvania Independent Oil and Gas Association. April 25, 2019. Accessed 7/6/2022. https://pioga.org/wp-content/uploads/2019/05/Well-Plugging-Workshop_Pelepko-DEP.pdf.

Pelepko, S. 2020. CCAC Abandoned and Orphan Oil and Gas Wells in Pennsylvania, October 27, 2020. Accessed 7/6/2022 https://files.dep.state.pa.us/Energy/Office%20of%20Energy%20and%20Technology/OETDPortalFiles/Climate%20Change%20Advisory%20Committee/2020/10-27-20/Presentation_Abandoned%20Wells_Pelepko_20201027.pdf

Pennsylvania Department of Environmental Protection (PADEP 2009). Stray Gas Migration Associated with Oil and Gas Wells (PADEP Technical Advisory Board) DRAFT Report, 2009. Accessed 7/6/2022. http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/TechnicalAdvisoryBoard/2009/Stray%20Gas%20Migration%20Cases.pdf.

Pennsylvania Department of Environmental Protection (PADEP 2022). Abandoned and Orphan Oil and Gas Wells and the Well Plugging Program. Accessed 1/16/2022. http://www.depgreenport.state.pa.us/elibrary/PDFProvider.ashx?action=PDFStream&docID=1419023&chksum=&revision=0&docName=ABANDONED+AND+ORPHAN+OIL+AND+GAS+WELLS+AND+THE+WELL+PLUGGING+PROGRAM&nativeExt=pdf&PromptToSave=False&Size=411528&ViewerMode=2&overlay=0

Pennsylvania Department of Environmental Protection (PADEP 2021a). Inspection Report. Complaint Record No. 354946. Inspection Record No. 3174126. March 2, 2021.

Pennsylvania Department of Environmental Protection (PADEP 2021b). Inspection Report. Inspection Record No. 3220296. June 28, 2021.

Pennsylvania Department of Environmental Protection (PADEP 2021c). Inspection Report. Complaint Record No. 354946. Inspection Record No. 3295888. December 13, 2021.

Pennsylvania Department of Environmental Protection (PADEP 2023a). Inspection Report. Complaint Record No. 370355. Inspection Record No. 3523916. March 1, 2023.

Pennsylvania Department of Environmental Protection (PADEP 2023b). Inspection Report, Complaint Record No. 370355, Inspection Record No. 3544706. March 20, 2023.

Pennsylvania Department of Environmental Protection (PADEP 2023c). Inspection Report, Complaint Record No. 370355, Inspection Record No. 3544694. April 24, 2023.

Pennsylvania Department of Environmental Protection (PADEP 2023d). Inspection Report, Inspection Record No. 3555253. May 11, 2023.

Pennsylvania Department of Environmental Protection (PADEP 2023e). Order. The 2012 Oil and Gas Act. In The Matter of: Prosperity Oil Co., Inc., Route 2, Box 119, Administrative Code West Finley, PA 15377; Club Zed Investments, Inc. 14917 Lee Highway, Gainesville, VA 20155; Reedville Investment Revocable Living Trust, 272 Bridge Creek Circle, Reedville, VA 22539; Estate of Thomas O. Nutt, Jr./II. May 16, 2023.

Pennsylvania Department of Environmental Protection (PADEP 2023f). PA Oil and Gas Mapping portal. Accessed July 17, 2023. https://gis.dep.pa.gov/PaOilAndGasMapping/OilGasWellsStrayGasMap.html

Pennsylvania Department of Environmental Protection (PADEP 2023g). Methane Gas and Water Wells. https://www.dep.pa.gov/Business/Energy/OilandGasPrograms/OilandGasMgmt/Documents/5600-FS-DEP2690.pdf

Penn State University Extension (PSU) 2022. Methane Gas and Its Removal from Water Wells. https://extension.psu.edu/methane-gas-and-its-removal-from-water-wells

Penn State University Extension (PSU) Total Coliform. https://extension.psu.edu/coliform-bacteria

Penn State University Extension. Hydrogen Sulfide (Rotten Egg Odor) in Water Wells. https://extension.psu.edu/hydrogen-sulfide-rotten-egg-odor-in-water-wells

Pixler, B.O. Formation Evaluation by Analysis of Hydrocarbon Ratios. 1969. *Journal of Petroleum Technology* 21, 665-670.

Ryder, R.T., Trippi, M.H., Swezey, C.S., Crangle, R.D., Jr., Hope, R.S., Rowan, E.L., and Lentz, E.E. 2012. Geologic cross section C–C' through the Appalachian basin from Erie County, north-central Ohio, to the Valley and Ridge province, Bedford County, south-central Pennsylvania. U.S. Geological Survey Scientific Investigations Map 3172.

Sams, J. I., 3rd; Veloski, G.; Diehl, J. R.; Hammack, R. W. 2017. Methods and challenges to locating legacy wells in western Pennsylvania: Case study at Hillman State Park. *Environmental Geosciences* 24 (2), 95−112.

Schoell, M., 1980. The hydrogen and carbon isotopic composition of methane from natural gases of various origins. *Geochimica et Cosmochimica Acta* 44 (5), 649–661.

Schoell, M., 1983. Genetic characterization of natural gases. *The American Association of Petroleum Geologists* 67, 2225–2238.

Schout, G.; Hartog, N.; Hassanizadeh, S.M.; Griffioen, J. 2018. Impact of an historic underground gas well blowout on the current methane chemistry in a shallow groundwater system. *PNAS*, 115, 2, 296-301.

Sharma, S., Bowman, L., Schroeder, K., Hammack, R. 2015. Assessing changes in gas migration pathways at a hydraulic fracturing site: Example from Greene County, Pennsylvania, USA. *Applied Geochemistry* 60, 51–58.

Stahl, W., 1974. Carbon isotope fractionations in natural gases. *Nature* 251, 134–135

U.S. Environmental Protection Agency. Revised Total Coliform Rule and Total Coliform Rule. https://www.epa.gov/dwreginfo/revised-total-coliform-rule-and-total-coliform-rule

U.S. Environmental Protection Agency. 2015. Retrospective Case Study in Southwestern Pennsylvania EPA 600/R-14/084 | May 2015 | www.epa.gov/hfstudy

United States Geological Survey. Alkalinity Calculation Methods. https://or.water.usgs.gov/alk/methods.html

U.S. Geological Survey (2013a). National Water Information System. Available at http://waterdata.usgs.gov/nwis

Whiticar, M.J., 1999. Carbon and hydrogen isotope systematics of bacterial formation and oxidation of methane. *Chemical Geology* 161, 291–314.

Whiticar, M.J., Faber, E., Schoell, M., 1986. Biogenic methane formation in marine and freshwater environments: CO2 reduction vs. acetate fermentation-isotope evidence. *Geochimica et Cosmochimica Acta* 50, 693–709.

Wolfe, A.L.; Wilkin, R.T. 2017. Evidence of Sulfate-Dependent Anaerobic Methane Oxidation within an Area Impacted by Coalbed Methane-Related Gas Migration. *Environmental Science & Technology* 51, 1901−1909

Attachment 1: SB Donaldson 2 Well Record

COMPANY—Well Records.

Farm. | Well No. 2. Donaldson, S. B. Farm.

Co. | Lease No. Twp. Co.

189 | Commenced Drilling 189 Completed 11-6- 1891.

ract | Total Depth Feet at per foot. Contract

Drilling Contractor

Tool Dresser. | Driller. Tool Dresser.

" | " "

189 | Rig Commenced 189 Completed 189

Well. | New or S. H. transferred from Well.

Builder. | Builder.

wing through Casing, " Tubing, mping, | Production first hours barrels. {Flowing through Casing, " " Tubing, Pumping,

hor, 20 Quarts. | Torpedoed 189 ft. Shell, ft. Anchor, Quarts.

Result of Shot

HT.	FEET.	Strata DESCRIPTION.	TOP.	BOTTOM.	Casing SIZE.	WEIGHT.	FEET.
		Pittsburgh Coal,			10		
		Crinoidal Limestone,			8¼		
		"Hurry Up" Sand,			8		
	128'	Freeport Coal,			7⅝		259'
		Ferriferous Limestone,			6¼		851'
		Salt Sand,			6		
	810'	Red Rock,			5⅝		
		Mountain Limestone,			5		
		"Big Injun" Sand,			4¼		
	[illegible]	"Squaw" Sand,			2" Tubing		1730'
	[illegible]50	Gas "					
		"Gantz" " } 100 Foot. 100 Ft.	1711	1728			
		50 Foot "					
		Gordon Stray, or Boulder,			Cave at		feet.
		Gordon Sand,			"		"
		Fourth "			"		"
		Fifth "			Salt Water,		"

Ferriferous Limestone,			6¼	851'
Salt Sand,			6	
Red Rock,			5⅝	
ountain Limestone,			5	
" Big Injun " Sand,			4¼	
" Squaw " Sand,			2" Tubing	1730'
Gas "				
" Gantz " " } 100 Foot. 100 Ft.	1711	1728		
50 Foot "				
Gordon Stray, or Boulder,			Cave at	feet.
Gordon Sand,			"	"
Fourth "			"	"
Fifth "			Salt Water,	"
Total depth	1738		"	"
			"	"
			Gas,	"
Water Well, feet.			"	"
			"	"

eral Remarks :

Shot with 30 qts. 11-8-1895. Well tubed 12-3-1895,
flowing started at 10 barrels. Reported 1-23-96, owing to poor
quality 7⅝" casing was not pulled.
Shot with 100 qts. 8-2-1898.
" " 110 " 8-2-1899. Results good, but not cave
badly. Mossett Pumping Packer on tubing at 901' - 1" pipe
under barrel & 1" pipe.
Jan-1, 1910, Pull 901' pipe out and put 876' - 4½" casing.
Larkins Wall Packer 6¼ x 4½".

...ed 189

Well.

Builder.

barrels. {Flowing through Casing, / " " Tubing, / Pumping,

...ell, ft. Anchor, 20 Quarts.

Casing

Size.	Weight.	Feet.
[illegible]		
[illegible]		
[illegible]		
[illegible]		128'
[illegible]		
[illegible]		
[illegible]		810'
[illegible]		
[illegible]		
		1665
		1650
		feet.
		"
		"
		"
		"
		"
		"
		"
		"

Rig Commenced 189 Completed 189

New or S. H. transferred from Well.

Builder.

Production first hours barrels. {Flowing through Casing, / " " Tubing, / Pumping,

Torpedoed 189 ft. Shell, ft. Anchor, Quarts.

Result of Shot

Strata			Casing		
Description.	Top.	Bottom.	Size.	Weight.	Feet.
Pittsburgh Coal,			10		
Crinoidal Limestone,			8¼		
"Hurry Up" Sand,			8		
Freeport Coal,			7⅝		259'
Ferriferous Limestone,			6¼		851'
Salt Sand,			6		
Red Rock,			5⅝		
Mountain Limestone,			5		
"Big Injun" Sand,			4¼		
"Squaw" Sand,			2" Tubing		1730"
Gas "					
"Gantz" " } 100 Foot. 100 Ft.	1711	1728			
50 Foot "					
Gordon Stray, or Boulder,			Cave at		feet.
Gordon Sand,			"		"
Fourth "			"		"
Fifth "			Salt Water,		"
Total depth	1738		"		"
			"		"
			Gas,		"
Water Well, feet.			"		"
			"		"

General Remarks :

Shot with 30 qts. 11-8-1895. Well tubed 12-3-1895, flowing started at 10 barrels. Reported 1-23-96, owing to poor quality 7⅝" casing was not pulled.
Shot with 100 qts. 8-2-1896.

Attachment 2. Well Location Plat for Mazure William 12118

8000-PM-OOGM0002 6/2014

WELL LOCATION PLAT

Page 4 Cross Section

Applicant/Well Operator Name	DEP ID#	Well (Farm) Name	Well #
Range Resources - Appalachia, LLC	141142	MAZURE WILLIAM 12118	2H

WELL PLAN

RANGE RESOURCES

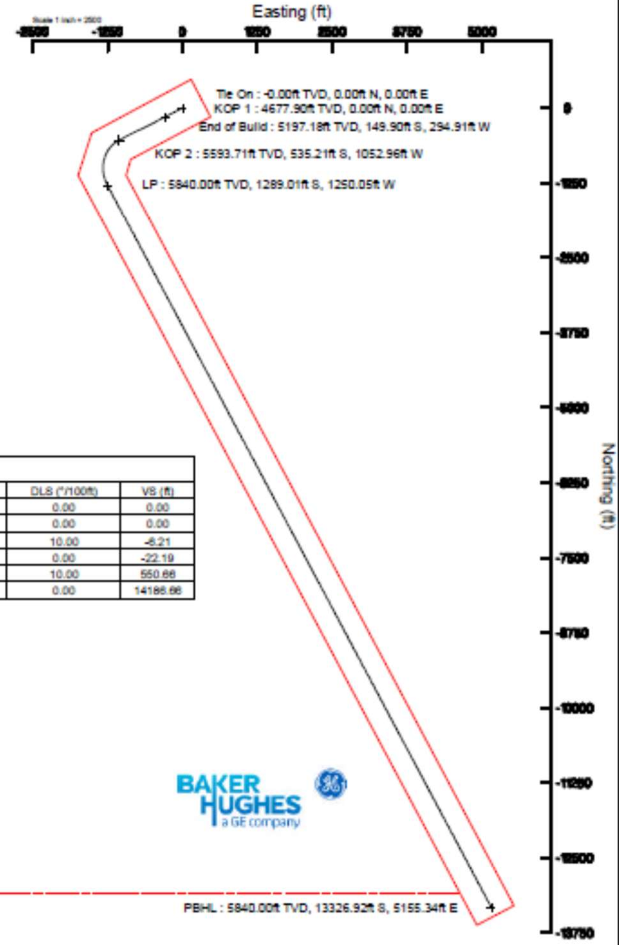
DEP Use Only	Permit #

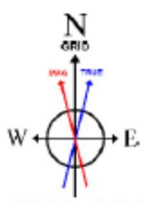
Operator Name: Range Resources - Appalachia, LLC

Well/Farm Name: MAZURE WILLIAM 12118

			Latitude	Longitude
KOP:	TVD: 4677.90	TMD: 4677.90	40°28'30.01"N	80°22'56.24"W
Landing Point:	TVD: 5840.00	TMD: 7175.91	40°28'16.91"N	80°23'11.91"W

Notes:





BGGM (1900.0 to 2020.0) Dip: 67.38° Field: 52448.7 nT
Magnetic North is 8.99 degrees West of True North (at 09/Jun/2018)
Grid North is 1.71 degrees West of True North
To correct azimuth from True to Grid add 1.71 degrees
To correct azimuth from Magnetic to Grid subtract 7.28 degrees

Well Profile Data

Design Comment	MD (ft)	Inc (°)	Az (°)	TVD (ft)	Local N (ft)	Local E (ft)	DLS (°/100ft)	VS (ft)
Tie On	0.00	0.000	243.056	0.00	0.00	0.00	0.00	0.00
KOP 1	4677.90	0.000	243.056	4677.90	0.00	0.00	0.00	0.00
End of Build	5327.90	65.000	243.056	5197.18	-149.90	-294.91	10.00	-6.21
KOP 2	6266.17	65.000	243.056	5593.71	-535.21	-1052.96	0.00	-22.19
LP	7175.91	90.000	151.982	5840.00	-1289.01	-1250.05	10.00	550.66
PBHL	20811.91	90.000	151.982	5840.00	-13326.92	5155.34	0.00	14186.66