Wunz Associates, LLC

Protecting the Water Environment

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August 20, 2015

William J. Hall, CPG, Director
Shale Gas Innovation and Commercialization Center
Ben Franklin Technology Partners
200 Innovation Blvd, State College, PA 16803

RE: Shale Gas Development-Summary of Shale Gas Wastewater Treatment and Disposal In Pennsylvania 2014

Dear Mr. Hall:

Thank you for this opportunity to update my 2012 report on shale gas wastewater production and treatment with data from 2014. I found the effort to be very interesting and informative.

In 2014, about 1.8 billion gallons, 42,919,000 barrels, of wastewater was produced. That is about the same amount as was produced in 2011. Most of this was "produced" water, the water that comes from wells after they are put into production. In 2011 the greater fraction was "frac" water.

The investigations I conducted in completing this report lead me to conclude that the effort made in the 2008-2010 time frame by both regulators and the industry to recycle and not discharge shale gas wastewaters was amazingly successful. Now, five years after adoption of the 25 PA Code 95.10 regulations, almost no wastewater is being discharged to surface waters, only about 1.1 percent, and very little is being disposed of by underground injection wells, about 7.9 percent. So, the industry, much to its credit, is recycling about 91 percent of the wastewater it produces. Much credit also goes to the members of the Water Resources Advisory Committee and the Department of Environmental Protection Bureau of Water Standards staff who in 2009 worked diligently with the industry to craft the regulations that have been so successful in promoting reuse.

I hope you will find this report satisfactory for your needs. I will be glad to answer any questions you might have.

Best wishes.

Very truly yours,
Wunz Associates, LLC

E. Charles Wunz, P.E., BCEE

Shale Gas Development

Summary of Shale Gas Wastewater Treatment and Disposal

In

Pennsylvania

2014

E. Charles Wunz, P.E., BCEE

August 20, 2015

Introduction

This report updates the author's May 2012 report entitled "Marcellus Shale Gas Development-A Summary of Marcellus Wastewater Treatment and Disposal" which described the generators, sources, volumes, treatment, recycling, and ultimate fate of waters produced as a result of Marcellus Shale development. The 2012 Report utilized data from 2011. This report utilizes 2014 data.

In 2014 shale gas production activities in Pennsylvania resulted in a reported 42,919,000 barrels (1,802,598,000 gallons), said another way, 1.8 billion gallons of wastewater. Over one half of the volume, about sixty-seven percent (67%) was what is called produced water and about twenty-nine percent (29%) was frac water. By far the largest amount of this wastewater, to the credit of the industry, was recycled for reuse in fracing activities.

In the original report, the content was exclusively focused on Marcellus shale development. Since 2011 Utica Shale has also been drilled in western Pennsylvania. Because the process of well development is similar between the Utica and Marcellus formations[1], they are considered to be similar in producing wastewater. Therefore, the reference to "Marcellus" in the previous version of this report has been removed in this update in favor of the words "shale", "horizontal", and "unconventional" which describe drilling in tight shale formations.

The 2012 report also focused on the hot issue of the time, frac water, the water that flows back after a well is fraced. This report is more focused on all the wastewater produced from the drilling, fracing, and operation of shale gas wells and it addresses the trend that produced water will inevitably become a larger and larger component of the total amount of water produced as frac water becomes proportionately less and less.

Recycling Rules!

Of the 1.8 billion gallons of wastewater reported to be produced, about 91 percent is recycled or stored for future recycling. Only about 162 million gallons are injected into deep geologic strata or discharged to surface waters. Only 7.9 percent is discharged to underground injection and a much smaller amount, only about 1.1 percent is discharged to surface water. This may be the industry's best state wide recycling effort anywhere in the country.

Trends

Reported wastewater production is static or slightly declining between 2011 and 2014. Much more water is being produced from operating wells (produced fluid or water) and less from fracing (frac fluid or water). The then-developing 2004 to 2009 business model for wastewater treatment has moved away from surface discharge which is no longer practiced except at two Pennsylvania locations and one each in West Virginia and Ohio and toward recycling. Recycling is accomplished through the reuse of the frac water in the next frac. Data

[1] Technical details are different, but for this report they can be considered to be the same in the production of wastewater.

show that the hauling of western Pennsylvania wastewater to permitted disposal wells in Ohio for disposal is a common practice, but a distant second choice to recycling.

In the future as the number of producing wells increase without a matching proportional increase in frac water needs, recycling treated wastewater to the next frac job will become more difficult. Recycling requires the demand for water, but the ratio of water demand to water production will be static or will decrease when proportionately fewer wells are being fraced and more wells are in production. This assumes an alternative use of the water cannot be developed. Alternatives to recycling, whether increased transport to Ohio's disposal wells, development of disposal wells in Pennsylvania, distillation, evaporation, or treatment and surface water discharge will likely be implemented if recycling becomes more difficult as proportionate demand for recycled water drops.

Well Development[2]

Well stimulation using fracing techniques injects large quantities (about 4 to 10 million gallons) of water[3] into a newly drilled gas well under very high pressure, usually in a series of stages. The target zone geologic formation fractures (cracks open) and a "proppant" is injected with the water to keep the fractures open[4]. When the pressure is released "frac" water flows back out of the well in a volume of about 15 to 30 percent of the water injected into the formation and the well continues to produce "production" water over its operating life. Later in this report the difference between frac water and production water is explained.

Well development activities and well operations actually produce a variety of liquid and solid wastes as well as the aforementioned frac waters. They include wastewaters from drilling, grouting, testing, and completion operations, production water, and from the installation of pipelines conveying the gas from the well. The liquid wastes, excepting pipeline waters, are collectively the subject of this report.

These shale gas wastewaters may be mixed at the time of transport, treatment, reuse, and final disposal. All of these wastewaters require some level of treatment prior to reuse[5], final disposal[6], or discharge. This Summary of Shale Gas Wastewater Treatment and Disposal reports the handling of wastewaters resulting from shale gas development and the variety of practices employed in their handling.

For the purposes of this report, the term "wastewater" means any waste which has not been discharged to the atmosphere and which is not a solid waste and has been reported in the data set analyzed to be a wastewater. This definition includes wastewaters that are heavily laden with both dissolved and suspended solids. The dividing line between solid wastes and wastewater has been clarified by the Pennsylvania Department of Environmental Protection (DEP) to reflect the long established definition that solid waste passes the "paint

[2] Well development includes fracing for which there are several spellings. This report uses "frac" and "fracing" which is pronounced "fracking."
[3] In Midwestern Canada fracing using propane has been demonstrated. Volumes of water used depend in part on the length of the horizontal bore being fraced. Over time, the length of horizontal bores has increased.
[4] Similar to timbers that support a mine shaft.
[5] For some reuse, dilution with clean water is sufficient "treatment."
[6] Injection in Class 2 disposal wells may require minimal treatment.

filter test[7]" required for delivery of solid waste to a landfill. In other words, wastewater includes any wastes that have sufficient free water in them to fail the paint filter test.

Shale Gas Wastewater Generation

Beginning with calendar year 2011 data, the DEP began to publish detailed summaries of the generation and handling of wastes generated by unconventional well drilling and operations[8]. These data are as reported by the wastewater producers to DEP. The DEP notes that the reliability of the data is not checked or guaranteed by DEP. The 2012 report analyzed data from the last six (6) months of 2011. This update examines 2014 data. The data are posted at:

https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/DataExports/DataExports.aspx

The data set examined for this report is the combined two 2014 data files (six months each) posted at the address above[9]. Each of the two files is an approximately 18,000 row comma delimited file with each row containing thirty-two (32) data cells (about 576,000 cells in each file, when combined about 1,152,000 cells total). Each of the approximately 36,000 rows in the two files describe a reported waste or wastewater transportation event which may a single partial truckload or an extended multi-truckload event all being delivered to the same destination. The date of such activity is not memorialized in the data set, beyond occurring in the calendar year. About one fifth of the DEP data files contain information on solid waste. These reports were deleted and not considered in this report on wastewater production. After the deletion of solid waste, about 30,000 rows of data remained for analysis.

With any huge self-reporting activity, some individual reports are likely to be erroneous. For example, in the data set one or two entries reflect delivery to facilities that are not permitted to receive wastes from unconventional wells; a few report the delivery of wastes to landfills in terms of barrels instead of tons. These reporting errors are not considered to be significant except for what we note in the following paragraph.

The largest reporting errors are associated with receiving facilities that hold or held both an NPDES discharge permit and WMGR 123 recycling permit. In one case, over one thousand deliveries are reported to Reserved Environmental Services (RES) operating under an NPDES permit. RES had an NPDES permit for discharge of shale gas wastewaters and storm water, but never constructed the facilities required to treat the shale gas wastewater to required levels for discharge. It never discharged shale gas wastewaters. So, all of those reported deliveries were made to RES, but it is operating under its WMGR permit and is recycling, not discharging. We corrected the data based on this understanding. Deliveries to Eureka Standing Stone and Eureka Williamsport likely exhibit the same confused permit reporting. We applied corrections based on somewhat limited additional information. But with that said, the data represent the best picture of shale gas

[7] EPA Method 9095B Paint Filter Liquids Test, 2004.

[8] In separate files, DEP reports the production of wastewater from conventional wells.

[9] At the time of writing of this report. The content of the data files may change and the website may be updated without notice by DEP.

wastewater generation in Pennsylvania and the use of this original data allows this Summary to be built on the actual reported data, not upon the summaries of data completed by others. With the corrections applied the data are believed to be very representative of wastewater movement and initial storage and treatment**.**

Wastes are characterized in eight (8) waste type groups in the 2015 Revision of the DEP "Oil and Gas Production and Waste Reporting Guide"[10]. They are[11]:

> **Produced Fluid:** Water and/or formation fluids, including brine, recovered at the wellhead after the flowback period. This waste type must be reported in barrels. The Pennsylvania residual waste code for this waste type is 802.
>
> **Drilling Fluid Waste**: Oil and gas drilling mud and other drilling fluids (other than fracing fluid and spent lubricant). This waste type must be reported in Barrels. The Pennsylvania residual waste code for this waste type is 803.
>
> **Fracing Fluid Waste**: Oil and gas fracturing/stimulation fluid waste and/or flowback. Flowback is defined as the return flow of water, fracturing/stimulation fluids, and/or formation fluids recovered from the well bore of an oil or gas well within 30 days following:
>
>> the release of pressures induced as part of the hydraulic fracture stimulation of a target geologic formation, or until the well is placed into production, whichever occurs first. This waste type must be reported in Barrels. The Pennsylvania residual waste code for this waste type is 804.
>
> **Basic Sediment**: Oil and gas production storage impurities/sediment from produced oil at storage tank battery. This waste type must be reported in Barrels. The Pennsylvania residual waste code for this waste type is 807.
>
> **Servicing Fluid**: Oil and gas production well maintenance and work over fluids and/or oil/water-based mud and foam. This waste type must be reported in Barrels. The Pennsylvania residual waste code for this waste type is 808.
>
> **Spent Lubricant**: Spent oil and gas drilling lubricants and/or spent plug drilling lubricants. This waste type must be reported in Barrels. The Pennsylvania residual waste code for this waste type is 809.
>
> **Wastes Reported in Tons and Not Typically Considered to be Wastewater**
>
> **Flowback Fracturing Sand**: Oil and gas drilling flowback fracturing sand. This waste type must be reported in Tons. The Pennsylvania residual waste code for this waste type is 804.

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[10] The Guide can be found at:
http://files.dep.state.pa.us/OilGas/BOGM/BOGMPortalFiles/OilGasReports/Greenport/Userguides/Oil%20and%20Gas%20Reporting%20Electronic%20Production%20and%20Waste%20Reporting%20Guide.pdf

[11] Copied directly from the Guide.

Drill Cuttings: Rock cuttings and related mineral residues generated during the drilling of an oil and gas well. This waste type must be reported in Tons. The Pennsylvania residual waste code for this waste type is 810.

Wastewater Characteristics Do Not Define Waste Type

Note that the difference between produced fluid (produced water) and fracing fluid waste (frac water) is time or event, but not characteristic, based. Unique water quality characteristics do not define either. Note also that the characterization of a waste into one of the eight (8) waste type groups does not determine its treatment method or its final disposal site. For example, Flowback Fracturing Sand might be saturated with water in which case it might not be delivered to a landfill and instead might be delivered to a WMGR 123 permitted facility for water removal before being delivered to a landfill. The units of measurement become confused as the sand is reported in tons, and the products resulting from WMGR 123 treatment would be reported in tons for the sludge delivered to a landfill and gallons stored, discharged (with additional permitting), recycled, or transported to a disposal well.

For reporting purposes, the Guide also provides the additional direction when a waste is not disposed of at a permitted facility:

Road spreading: Select the appropriate county/municipality combination that identifies the location of the road spreading.

On site disposal: If waste was disposed in pits, encapsulated, or land applied at the well site at which it was generated, select the appropriate on site disposal method. Revised 12/30/2013

Reuse: If waste was reused at another well site without being processed at a permitted facility (i.e., a facility operating pursuant to an individual or general permit), select "REUSE WITHOUT PROCESSING AT A PERMITTED FACILITY". Note that on site processing of waste pursuant to an approved "Request for Approval of Alternative Waste Management Practices" (form 5500-PM-OG0071) is not considered a permitted facility.

Temporary storage: If waste was temporarily stored at the well site at which it was generated pending processing, disposal, or reuse, select "TEMP ON SITE STORAGE PENDING DISPOSAL OR REUSE". Please note that final disposition of the waste will need to be reported for the reporting period in which it occurs. If this occurs, a double reporting of volume would result.

Wastewater Characteristics

Shale Gas Wastewater varies in characteristic truck by truck, site by site, company by company, by time since the well was drilled and began producing, and geographically. A typical wastewater contains widely varying amounts of sand and gravel, oil and grease, dissolved and suspended solids containing multi-valence cations like iron, manganese, thorium, barium, strontium, radium, calcium, and magnesium, and single valence cations like sodium.

One of the best and most comprehensive characterizations of wastewater exists in the 2013 and 2014 NPDES and Clean Streams Law permit applications submitted for Eureka Resources, LLC – Standing Stone treatment facility located in Bradford County. Standing Stone is permitted as both a WMGR-123 recycling facility and as an NPDES permitted facility allowed to discharge to surface waters, in this case, the Susquehanna River.

The Standing Stone influent data (generally an average of four samples) are reported for Pollutant Groups 1 through 5 as follows:

POLLUTANT GROUP 1	AVERAGE CONCENTRATION		POLLUTANT GROUP 2	AVERAGE CONCENTRATION	
BOD	271	mg/l	Antimony, Total	not reported	ug/l
COD	42575	mg/l	Aresenic, Total	1	ug/l
HARDNESS	32507	mg/l	Berylium, Total	0.5	ug/l
TSS	532	mg/l	Cadmium, Total	0.5	ug/l
TDS	137267	mg/l	Chromium III	0.78	ug/l
Ammonia as N	134	mg/l	Chromium IV	not reported	
Nitrate-Nitrite as N	0.13	mg/l	Copper, Total	4.5	ug/l
Total Kjeldahl Nitrogen	123	mg/l	Lead, Total	0.5	ug/l
Phosphorus as P	0.29	mg/l	Mercury, Total	0.2	
Temperature	ɔt reported -ambient		Nickel, Total	0.86	ug/l
pH	not reported		Selenium, total	1.1	ug/l
Color	not reported		Silver, Total	0.5	ug/l
Fecal Coliform	not reported		Thallium, total	not reported	ug/l
Flouride	<100	mg/l	Zinc, Total	22.84	ug/l
Oil and Grease	5.5	mg/l	Cyanide, Total	0.005	mg/l
Bromide	712	mg/l	Cyanide, Free	not reported	ug/l
Chlorine, Total Residual	not reported		Phenols, Total	0.05	mg/l
Sulfate	1380	mg/l			
Sulfide	0.27	mg/l			
Sulfite	not reported				
Surfactant	7	mg/l			
Aluminum, Total	8.6	mg/l			
Barium, Total	5113	mg/l			
Boron, Total	3.9	mg/l			
Cobalt, Total	<0.5	mg/l			
Iron, Total	63.3	mg/l			
Iron, Dissolved	not reported				
Manganese, Total	10.3	mg/l			
Radioactivity	not reported				
Total Organic Carbon	1834	mg/l			
Radium, Total	not reported				
Magnesium	798	mg/l			
Molybedenum	<0.5	mg/l			
Tin, Total	not reported				
Titanium, Total	not reported				

POLLUTANT GROUP 3			POLLUTANT GROUP 5		ug/l
Acrolein	<50	ug/l	Acenaphthene (µg/L)	<26	ug/l
Acrylonitrite	<50	ug/l	Acenaphthylene (µg/L)	<26	ug/l
Benzene	<5	ug/l	Anthracene (µg/L)	<26	ug/l
Bromoform	<5	ug/l	Benzidine (µg/L)	<26	ug/l
Carbon Tetrachloride	<5	ug/l	Benzo(a)Anthracene (µg/L)	<26	ug/l
Chlorobenzene	<5	ug/l	Benzo(a)Pyrene (µg/L)	<26	ug/l
Chlorodibromomethane	<5	ug/l	3,4-Benzo-fluoranthene (µg/L)	<26	ug/l
Chrlroethane	<5	ug/l	Benzo(ghi)Perylene (µg/L)	<26	ug/l
2-Chloroethylvinyl Ether	<10	ug/l	Benzo(k)Fluoranthene (µg/L)	<26	ug/l
Chloroform	<5	ug/l	Bis(2-Chloro-ethoxy)Methane (µg/L)	<26	ug/l
Dichlorobromomethane	<5	ug/l	Bis(2-Chloroethyl)Ether (µg/L)	<26	ug/l
1,1 Dichloroethane	<5	ug/l	Bis(2-Chloro-isopropyl)Ether (µg/L)	<26	ug/l
1,2 Dichloropropane	<5	ug/l	Bis(2-Ethylhexyl)Phthalate (µg/L)	<26	ug/l
1,3 Dichloropropylene	not reported	ug/l	4-Bromophenyl Phenyl Ether (µg/L)	<26	ug/l
Ethylbenzene	<5	ug/l	Butyl Benzyl Phthalate (µg/L)	<26	ug/l
Methyl Chloride	not reported	ug/l	2-Chloronaphthalene (µg/L)	<26	ug/l
Methylene Chloride	not reported	ug/l	4-Chlorophenyl Phenyl Ether (µg/L)	<26	ug/l
1,1,2,2 Tetrachloroethan	<5	ug/l	Chrysene (µg/L)	<26	ug/l
Tetrachloroethylene	<5	ug/l	Dibenzo(a,h)Anthracene (µg/L)	not reported	
Toluene	11.1	ug/l	1,2-Dichlorobenzene (µg/L)	<5	ug/l
1,2 Trans-dichloroethyler	not reported	ug/l	1,3- Dichlorobenzene (µg/L)	<5	ug/l
1,1,1 Trichloroethane	<5	ug/l	1,4- Dichlorobenzene (µg/L)	<5	ug/l
1,1,2 Trichloroethane	<5	ug/l	3,3'-Dichlorobenzidine (µg/L)	<26	ug/l
Trichloroethylene	<5	ug/l	Diethyl Phthalate (µg/L)	<26	ug/l
Vinyl Chloride	<5	ug/l	Dimethyl Phthalate (µg/L)	<26	ug/l
			Di-n-Butyl Phthalate (µg/L)	<26	ug/l
POLLUTANT GROUP 4			2,4-Dinitrotoluene (µg/L)	<26	ug/l
2-Chlorophenol (µg/L)	<26	ug/l	2,6-Dinitrotoluene (µg/L)	<26	ug/l
2,4-Dichlorophenol (µg/L	<26	ug/l	1,4-Dioxane (µg/L)	<26	ug/l
2,4-Dimethylphenol (µg/l	<26	ug/l	Di-n-Octyl Phthalate (µg/L)	<26	ug/l
4,6-Dinitro-o-Cresol (µg/	not reported		1,2-Diphenylhydrazine (as Azobenzen	<26	ug/l
2,4-Dinitrophenol (µg/L)	<52	ug/l	Fluoranthene (µg/L)	<26	ug/l
2-Nitrophenol (µg/L)	<26	ug/l	Fluorene (µg/L)	not reported	
4-Nitrophenol (µg/L)	<52	ug/l	Hexachlorobenzene (µg/L)	7.59	ug/l
P-Chloro-m-Cresol (µg/L)	not reported		Hexechlorobutadiene (µg/L)	<53	ug/l
Pentachlorophenol (µg/L	<52	ug/l	Hexachlorocyclopentadiene (µg/L)	<26	ug/l
Phenol (µg/L)	<26	ug/l	Hexachloroethane (µg/L)	<26	ug/l
2,4,6-Trichlorophenol (µg	<26	ug/l	Indeno(1,2,3-cd)Pyrene (µg/L)	<26	ug/l
			Isophorone (µg/L)	<26	ug/l
			Naphthalene (µg/L)	6.84	ug/l
			Nitrobenzene (µg/L)	<26	ug/l
			N-Nitroso-di-methylamine (µg/L)	<38	ug/l
			N-Nitroso-di-n-propylamine (µg/L)	<26	ug/l
			N-Nitroso-di-n-phenylamine (µg/L)	<26	ug/l
			Phenanthrene (µg/L)	<26	ug/l
			Pyrene (µg/L)	<26	ug/l
			1,2,4-Trichlorobenzene (µg/L)	<5	ug/l

Any individual sample might yield results equal to the average reported or more or less.

A simple summary would be to state that wastewater contains oil and grease, other organics, dissolved and colloidal metals, hardness, and salt as well as settleable solids like drill cuttings and mud, sand, and gravel. The contaminants in wastewater together with the intended fate of the wastewater define, in large part, the treatment steps required. Additional water quality comments include a typical pH of less than 7 SU, usually in the range of 6 SU and a Langelier Index less than 1.0, making the water somewhat corrosive.

Current Treatment and Disposal Options

There are several options for treatment and disposal of wastewater including disposal in Class 2 disposal wells[12], recycling with treatment[13] on site, recycling with treatment off site, distillation and evaporation, and treatment and discharge. Storage is frequently an important component in the post-use, prior to re-use, schedule.

The Water Treatment Service Industry

If water does not remain on site and under the control of the producer, it can be transported to wastewater treatment facilities (WWTF's) or disposal well. Upon inspection, the WWTF either accepts the load on a tank truck or rejects it. When accepted, it becomes the WWTF's responsibility to treat it.

No wastewater received at any WWTF in Pennsylvania is presently known to be 'piped' in, although that is a likely future development, especially where a number of wells exist in close proximity. Rather, all wastewater is delivered by truck, and perhaps via rail in the future. These facilities may also be characterized as centralized wastewater treatment facilities (CWT's)[14], except with the detail that the EPA definition of a CWT includes a discharge to surface waters and many of the WWTF's recycle, but do not discharge. Both terms are used interchangeably in this report.

Treatment Requirements

In Pennsylvania, facilities which receive residual waste and have no liquid discharge are regulated in accordance with residual waste management regulations. Treatment and discharge facilities are primarily regulated under the Clean Streams Law and NPDES permit regulations. In Pennsylvania Class 2 disposal wells are regulated by the U.S. EPA. Regulation varies state to state. Ohio has primacy for regulation of its Class 2 disposal wells. Some facilities may hold both a residual waste permit and an NPDES permit.

[12] Mostly in Ohio.
[13] Treatment provided varies.
[14] CWT's are defined in U.S. EPA regulations 40 CFR 437.2 (c)

Treatment requirements for wastewater vary depending on the desired characteristics of the treated wastewater. If the wastewater is to be discharged to a POTW or to the surface waters of the Commonwealth, as a new source, then 25 PA Code 95.10 (and related chapters such as 92 and 92 (a)) applies.

If the wastewater is to be treated and then mixed with other waters to be used in the next frac job, then the treatment requirement is established by the gas company which might require minimal treatment or a higher level of treatment. If the wastewater is to be transported to Class 2 disposal wells in Ohio, then the wastewater must be treated to the standards established by those well operators.

The level of treatment provided to wastewater is critical not only for achieving the desired water quality, but also for the quality and quantity of the residuals, the sludges, produced. Higher levels of wastewater treatment result in the production of ever greater volumes of residuals.

Analysis of Shale Gas Wastewater Data 2014

Analysis of the data results in the following table of waste generation. Barrels are reported in the data set. Barrels have been converted to gallons in the following table as well. Rounding may result in minor arithmetic error.

2014 REPORTED WASTEWATER GENERATION					
Waste Type	**Barrels**	**Gallons**	**Daily Gallons**	**% of Total**	
Basic Sediment	834	35,028.00	96	0.002%	
Drilling Fluid Waste	1,663,600	69,871,200.00	191,428	3.876%	
Fracing Fluid Waste	12,421,740	521,713,080.00	1,429,351	28.942%	
Produced Fluid	28,817,104	1,210,318,368.00	3,315,941	67.143%	
Servicing Fluid	15,615	655,830.00	1,797	0.036%	
Spent Lubricant	107	4,494.00	12	0.000%	
Totals	42,919,000	1,802,598,000	4,938,625		

For comparison, the second half of 2011 data show the average daily volumes[15] of the then seven (7) different wastes reported at that time to DEP were as follows:

Reported Waste Generation Second Half 2011 Compared to 2014							
Type of Waste	2011 Daily Volume Barrels	2011 Daily Volume Gallons	2011 Percent of Total Wastewater Generation	2014 Daily Volume Gallons	2014 Percent of Total Wastewater Generation	Change from 2011 to 2014	
Brine (Produced Water)	27,622	1,160,124	22.82%	3,315,941	67.14%	294%	
Frac Fluid	65,298	2,742,516	53.95%	1,429,351	28.94%	54%	
Spent Lubricants	9	361	0.01%	12	0.00%	3%	
Servicing Fluid	N/A	N/A	N/A	1,797	0.04%	N/A	
Drilling Fluids	28,089	1,179,738	23.21%	191,428	3.88%	17%	
Basic Sediment	6	244	0.00%	96	0.00%	41%	
Total	121,023	5,082,983	100.0%	4,938,625	100.0%	97%	

Comparison of 2011 versus 2014 Data Sets

The data analyzed reports wastewater transfer events. It reflects but does not exactly define the date or dates that the wastewater was produced, rather when it was transported. Analysis of data over longer periods of time should reduce the impact of time difference between wastewater production and transport.

The analysis of 2011 second half data to 2014 data shows that it is obvious that Produced Fluid has over taken and passed, in terms of volume, the amount of Fracing Fluid Waste production. This is the likely outcome over time with ever more wells in production and relatively fewer wells being fraced[16].

Brine, now called Produced Fluid (or Water), is 294 percent of its volume in 2011. Drilling fluid in 2011 was about 620 percent of what it is today. Frac fluid in 2011 was about 180 percent of what it is today. Overall, the four liquid waste types in 2011 summed to just over 5,000,000 gallons per day, about 102 percent of the current volume. The types of wastes have changed in relative volumes, but the total volume has remained static despite reduced drilling.

Transport of Shale Wastewaters to Other States

During 2014, shale wastewaters were disposed of at sites in three states, Pennsylvania, Ohio, and West Virginia. Solid wastes were delivered to those same states plus Utah, New York, and Michigan.

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[15] Assuming the data covered 184 days. Work day volumes would be 7/5 (no weekend work) or 7/6 (includes Saturday as a work day) of the results reported.
[16] Especially so given lower gas prices.

Centralized Wastewater Treatment Plants for Discharge

The reported facilities to which wastewater was delivered include:

1. Fairmont Brine Recycling in West Virginia 5,989 barrels. This is also a recycling facility.
2. Patriot Waste Treatment in Warren Ohio 103,747 barrels. This waste is discharged under a Municipal Industrial Pretreatment Program (MIPP) permit to the Warren, OH, sewage treatment plant. If located in Pennsylvania, it is believed that this discharge would not be 25 PA Code 95.10 compliant.
3. Waste Treatment Corporation in Warren, Pennsylvania 228,165 barrels. The DEP reports that reported deliveries to this facility were for recycle, for groundwater injection at "Bear Lake" injection wells, and not for discharge. Further DEP reports[17] that this facility no longer accepts wastewater from unconventional wells.
4. Three possibly incorrect reports of deliveries to Creekside, Fluid Recovery Service, Franklin, and the same company in Josephine, PA. These deliveries totaled 176 barrels.
5. Additional deliveries for discharge to surface water are not reported but likely occur at the Eureka facilities in Williamsport and Standing Stone, PA. The Williamsport discharge occurs through the Williamsport sewage treatment plant, is 95.10 compliant and varies averaging about 30,000 gallons per day[18]. The Standing Stone discharge is to the Susquehanna River and is discussed is some detail later in this report. Three Eureka facilities also hold WMGR-123 residual waste recycling permits. That is the source of the uncertainty.

Given the uncertainties in the above, only an estimate of surface water discharge can be made. The author's estimate is on the order of 460,000 barrels in 2014.

Centralized Treatment Plants for Recycle

A total of five (5) facilities fit into this category. They are located in Ohio and West Virginia, all outside of Pennsylvania. The total discharge is 50,576 barrels in 2014. They are:

1. Hanchin Recycling, Hopedale, OH 180 barrels.
2. Central Ohio Oil, Columbus OH 48 barrels.
3. Eureka Station Crosstex Energy, St. Mary, WV 4049 barrels.
4. Liquid Waste Solidification, Steubenville, OH 134 barrels.
5. Petrowater, Inc., Jefferson, OH 46,165 barrels.

These are out of state recycling facilities, hence, they are not regulated under WMGR-123.

Injection Wells

[17] This is from a phone conversation with Joel Fair of DEP NWRO on June 15, 2015.
[18] Confirmed in a telephone conversation with Jorgen Zimmerman of the Williamsport Sanitary Authority June 19, 2015.

A total of 3,392,707 barrels of wastewater was disposed of at fifty-five (55) disposal wells, almost all of which are located in Ohio. The two wells accepting the most wastewater were Adams No. 1, 230,942 barrels, in Coshocton, OH and RHOA No. 3, 243,960 barrels, in Jefferson, OH. Camp Creek Disposal in Camp Creek, WV received 240 barrels and the Irvin A-19 FMLY FEE A19 well in Mahaffey, PA received 147,913 barrels. These are the only two listed wells not located in Ohio.

Residual Waste Recycling Facilities Permitted under WMGR-123

DEP reports that there are a total of twenty-three (23) WMGR123 facilities holding active permits. They are reported in the following table.

	DEP REGION	PERMITTEE	MUNICIPALITY	COUNTY	PERMIT NO.	DATE PERMIT ISSUED	STATUS	PERMITTED FOR	PROCESS	DESIGN CAPACITY
1	NCRO	Hydro Recovery LP	Blossburg Borough	Tioga	WMGR123	10/4/2010	In Operation	Frac Production,	Chemical Precipitation	300,000 gpd
2	NCRO	EOG Resources Inc.	Lawrence Twp.	Clearfield	WMGR123 NC003	6/29/2011	In Operation	Frac Production &	Blending	3.15 million gpd
3	NCRO	Eureka Resources	2nd Street Facility City of Williamsport	Lycoming	WMGR123 NC005	7/14/2010 Amended	In Operation	Frac Production & Flowback Waters	Chemical Precipitation, and	820,000 gpd
4	NCRO	Chesapeake Energy	Stevens Twp.	Bradford	WMGR123 NC008	2/21/2012	In Operation	Frac Production &	Chemical Precipitation	50,400 gpd
5	NCRO	EXCO	Franklin Twp.	Lycoming	WMGR123 NC009	5/29/2012	In Operation	Frac Production &	Storage Only	300,000 gal
6	NCRO	Hydro Recovery LP: Antrim Facility	Duncan Township	Tioga	WMGR123 NC010	7/24/2012	Partial Operation-Frac	Frac Production &	Chemical Precipitation	720,000 gpd
7	NCRO	Eureka Resources: Reach Road (Catawissa Ave)	City of Williamsport	Lycoming	WMGR123 NC011	11/8/2012	Partial Operation-Storage	Frac Production & Flowback	Chemical Precipitation	420,000 gpd
8	NCRO	Seneca Resources Cherry Flats	Covington Twp.	Tioga	WMGR123 NC012	6/13/2012	In Operation	Frac Production & Flowback waters	Chemical Precipitation	30,000 gpd
9	NCRO	Hydro Recovery: Standing Stone Township	Standing Stone Township	Bradford	WMGR123 NC016	9/21/2012	In Operation	Frac Production & Flowback Waters	Storage/Chemical Treatment	1,015,600 gpd treatment; 2,013,200 storage
10	NCRO	SWEPI LP: Detweiler	Sulivan Township	Tioga	WMGR123 NC022	12/10/2012	In Operation	Storage/Flowback Waters		3,000,000 gallons
11	NCRO	Chespeake Appalachia LLC-Lamb's Farm Pad	Smithfield Township	Bradford	WMGR123 NC027	3/13/2014	In Operation		Storage	756,000
12	NCRO	Anadarko E&P Onshore LLC -	Seijas Water Treansfer	Bradford	WMGR123 NC028	3/21/2014	In Construction		Storage	3,000,000
13	NWRO	Highland Field Services LLC (HFS) - New owner		McKean	WMGR123 NW005	8/20/2012	In Operation	Frac & Gas Flowback	Chemical Precipition	600,000 gpd
14	NWRO	Caes, Clarion Altela Environmental Services, LLC		Clarion	WMGR123 NW006	10/5/2012	In Operation	Frac & Gas Flowback	Chemical Precipition	600,000 gpd
15	NWRO	RE GAS DEVELOPMENT LLC (BURGH WELL PAD FACILITY)		Butler	WMGR123 NW007	8/11/2013	In Operation	Frac & Gas Flowback	Storage	126,000 gpd
16	NWRO	Res Water - Butler LLC.; Renfrew		Butler	WMGR123 NW009	6/28/2013	In Operation	Frac & Gas Flowback	Chemical Precipition	420,000 gpd
	NWRO	WELL PAD FACILITY)		Butler	NW010	8/26/2013	In Operation	Flowback	Precipition	126,000 gpd
17	NWRO	Seneca Resources Corp - Clermont Storage Facility		McKean	WMGRN12 3W011	6/24/2014	In Operation	Frac & Gas Flowback	Storage and Blending	3,000,000 Total
18	NERO	Somerset Regional Water Resources	Hunter Road at SR29, Springville	Susquehanna	WMGR123 NE001	10/20/2010	In Operation	Tank cleanouts	Chemical Precipitation	250,000 gpd
19	NERO	Cabot Oil & Gas Corporation	Dimock Township, Springville	Susquehanna	WMGR123 NE002	5/2/2013	In Operation	Only Produced Water	Chemical Precipitation	WW-378,000 gpd; muds - 42,000 gpd
20	SCRO	CRS Reprocessing Services, LLC		York	WMGR123	2/14/2013	In Operation	Drilling Muds	Mechanical	
21	SWRO	Greene County Water Treatment, Inc	Franklin Twp	Greene	WMGR123 SW010	1/7/2013	In Operation	Frac Drilling Fluids	Chemical Precipitation	30,000 gallons/month
22	SWRO	Appalachian Water Services, LLC	Masontown Borough	Fayette	WMGR123 SW001	5/29/2013	In Operation	Frac Drilling Fluids	Chemical Precipitation	
23	SWRO	Reserved Env. Services	119 Old Route (119S)	Westmoreland	WMGR123 SW005	6/10/2010	In Operation	Frac Drilling Fluids	Chemical Precipitation	

DEP was kind enough to provide the table which is reformatted for this report, but otherwise unchanged prior to complete Department review. The author's review notes the erroneous listing of Hydro Recovery Standing Stone. This is likely Eureka Standing Stone. Also, Eureka notes its 2nd Street facility has a capacity of 420,000 gpd.

A total of nineteen facilities are reported receiving a total of 11,597,000 barrels in 2014 as listed below:

VOLUME BARRELS	PERMIT NO.	FACILITY
7,540	WMGR 123 NC024	AQUATECH WASTE PROCESSING, LAWRENCEVILLE,TIOGA CO
420	WMGR 123 SW011	ASPEN JOHNSTOWN RESIDUAL WASTE OPERATION
37,935	WMGR 123 NW006	CAES WATER TRMT & RECYCLING FAC
4,000	WMGR 123 NW005	CARES MCKEAN WATER TRMT & RECYCLING FAC
1,040	WMGR 123 NC012	CHERRY FLATS CS CONCENTRATOR
49,230	WMGR 097 R017	CLEAN EARTH INC WILLIAMSPORT DRILLING MUD PROC FAC
310,940	WMGR 123 NC119	EUREKA RESOURCES LLC WILLIAMSPORT WATER TREATMENT[19]
275,540	WMGR 123 NC018	EUREKA RESOURCES STANDING STONE TWP FACILITY
29,740	WMGR 123 SW010	GREENE COUNTY WATER TREATMENT LLC
2,361,700	WMGR 123 NE002	HIBBARD TANK PAD
2,065,860	WMGR 123	HYDRO RECOVERY LP BLOSSBURG FACILITY
2,305,340	WMGR 123 NC010	HYDRO RECOVERY LP ANTRIM FACILITY
760,420	WMGR 123 NW009	RES WATER BUTLER
2,109,100	WMGR 123 SW005	RESERVED ENV SVC HEMPFIELD TWP RESIDUAL WASTE OPER
445,480	WMGR 123 SW001	RONCO WASTE PROCESSING FACILITY
248,990	WMGR 123 NC008	SHARER TEMP CENTRALIZED FLUIDS PROCESSING FACILITY
5,310	WMGR123NE003	SHASKAS SOUTH PAD
305,640	WMGR123NE001	SOMERSET REGIONAL WATER RESOURCES
172,990	WMGR123D001X	TERRAQUA RESOURCE MANAGEMENT

Again, there is some uncertainty associated with the total volumes recycled. Since two of these facilities also hold NPDES permits, the ultimate fate of the wastewater once delivered to the facility is not known. Some or all may have been discharged at the two Eureka facilities. Nonetheless, that amount of wastewater accepted by these facilities for recycling dwarfs what could have been discharged by the two Eureka facilities. Conversely, the RES facility in Hempfield Township, Westmoreland County is a WMGR-123

[19] The 2014 data export files available on the DEP website do not contain data allowing the tracking of wastewater deliveries to the two Eureka facilities located in Williamsport, PA. Deliveries are reported only to the South Second Street facility and not to the Reach Road facility. So, this table reports the sums reported deliveries to both facilities.

holder but is frequently listed as an NPDES facility with surface water discharge. Where misreported, delivery data for RES was moved over into this category of facility. The Clean Earth Inc. facility in Williamsport operates under WMGR 097. This is a permit granted to research and development facilities on a temporary basis.

The largest WMGR-123 treatment and recycling entity is Hydro Recovery, LLC which operates two facilities north of Williamsport near Blossburg, PA. Together, those two facilities are reported to have received 4,771,000 barrels in 2014. They are opening another facility in Hanover Township, Washington County this summer.

Adjustments applied in this report result in an assumed 11,210,000 barrels treated for recycling.

Reuse without Processing at a Permitted Facility

This is the most common handling of wastewater generated from unconventional wells. It involves the storage and reuse of wastewater at the well site by the producer. Transportation and treatment costs are minimized. A total of 27,651,510 barrels of wastewater were handled in this way.

Storage Pending Reuse

This reflects the wastewater that has been stored on site pending reuse. It amounts to 112,577 barrels in 2014.

Wastewater Handling in 2014

The data for 2014 are summarized in the following table:

Wastewater Produced from Unconventional Wells 2014

	Barrels	Gallons	Barrels Daily	Gallons Daily
Number of Wells 6,890				
Treatment Methods				
Treatment and Discharge	460,000	19,320,000	1,260	52,932
Centralized Waste Treatment for Recycle	50,576	2,124,192	139	5,820
Injection Wells	3,392,707	142,493,694	9,295	390,394
Residual Waste Processing Facilities	11,210,300	470,832,600	30,713	1,289,952
Residual Waste Transfer Facility	41,397	1,738,674	113	4,763
Reuse W/O Processing at a Permitted Treatment Facility	27,651,510	1,161,363,420	75,758	3,181,818
Road Spreading	0	0	0	0

Storage Pending Disposal or Reuse	112,577	4,728,234	308	12,954
Totals	42,919,000	1,802,601,000	117,586	4,938,632

As stated before, the data set reports of Treatment and Discharge Facilities (NPDES and MIPP Discharges) result in the potential greatest error in the data for several reasons. The first is that some deliveries are to a treatment facility[20] that operates under a WMGR permit, but also holds, but does not use, an NPDES permit. That reporting was corrected for this report and RES discharge data was moved to RES WMGR-123 recycle. The reporting error for Eureka Standing Stone seems to be the reverse in that it actually does hold an NPDES permit and uses it, but is reported as a Residual Waste Processing Facility.

Eureka Williamsport Second Street effluent is discharged to the Williamsport Sanitary Authority, but can also be recycled.

These wastewater data also presume that a generator knows that his waste will be either recycled or discharged when he makes the waste report or that he changes his report when a decision is made to recycle instead of discharge, etc. Also, data set reporting ends at delivery to the first permitted facility and then, if additional reporting is appropriate, falls on the permitted facility to make appropriate reporting under its permit if the waste is then, for example, hauled to a disposal well instead of being recycled. This problem is always true with the waste delivered to a Residual Waste Transfer Facility. Its final fate is not reported in this data set, but is probably available from the data sets the Transfer Facility provides to DEP under its permit reporting obligations. Similarly, WMGR-123 only requires that the permittee maintain data regarding the fate of its treated wastewater.

The data set also does not report on the sludge that might be generated during the treatment process which is then hauled to a landfill.

In the case of Eureka Standing Stone, some reconciliation can be attempted. It is reported to have received 164,883.68 barrels or 6,925,128 gallons of wastewater in 2014. It discharged only 3,310,594 gallons of wastewaters in 2014[21], and the difference is not reported in the data set analyzed, but may exist in reporting Standing Stone does to comply with its WMGR permit.

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[20] Reserved Environmental Services, LLC in Mount Pleasant, Pennsylvania

[21] Based on analysis of EDMR's from DEP website for NPDES Permit No. PA0232351

Summary of Wastewaters 2011

In contrast to 2014, in 2011, the ultimate disposal methods were:

2011 Disposal Method	Daily Volume	Units	Number of Facilities
Brine or Industrial Wastewater Treatment Facility	77,304	barrels	
Injection Wells	9,994	barrels	42 of which 5 were in WV, 3 in PA, and 34 in Ohio
Landfill	2,710	tons	32
Landfill[22]	8.6	barrels	4
Publicly Owned Treatment Plant	69.8	tons	2[23]
Stored, Ultimate Disposal Method Not Determined[24]	37.8	barrels	Not Applicable
Reuse Other Than Spreading[25]	33,611	barrels	Not Applicable

Chapter 95.10 New Source Compliant Facilities

The DEP adopted 25 PA Code 95.10 in August, 2010. It established new effluent limitations for new and expanding Marcellus wastewater treatment facilities planning to discharge to surface waters.

Among other limitations, the maximum concentrations established under 95.10 for total dissolved solids are 500 mg/l and total chlorides are 250 mg/l. The removal of sodium chloride necessary to meet those limits requires crystallization, evaporation, and condensation (distillation), or reverse osmosis. The treatment needed to accomplish this is very expensive to build and operate.

As long as wastewater recycling[26] could be accomplished in new frac jobs, recycling would be less expensive than implementing those treatment technologies needed for new source compliance and, therefore, no such treatment facilities were constructed to meet the 95.10 standards. Beginning in 2013, one facility was constructed. Eureka Resources LLC reports that it has constructed the only new facility compliant with the new 95.10 regulations for surface water discharge in Standing Stone Township, Bradford County.

[22] It is assumed that all of this material was solidified at the landfill before final disposal, but may be misreported.
[23] Reynoldsville and Johnstown
[24] It is not known if any of the materials reported here were subsequently disposed of by another method and so reported.
[25] Probably for the next frac.
[26] With storage to meet the inevitable inequities in supply of and demand for recycled water.

On October 1, 2013, Eureka became authorized through the issuance of NPDES Permit No. PA 0232351 to discharge from its new facility located in Standing Stone Township, Bradford County, at a rate up to 0.168 million gallons per day into the Susquehanna River . A total of twenty parameters are regulated and/or monitored. The effluent limitations and monitoring requirements of the permit are as follows:

Total Nitrogen	Report	lbs	Total Monthly
Total Phosphorus	Report	lbs	Total Monthly
2,4,6-Trichlorophenol	Report	lbs/day	Average Monthly
2,4,6-Trichlorophenol	Report	lbs/day	Daily Maximum
2,4,6-Trichlorophenol	0.106	mg/L	Average Monthly
2,4,6-Trichlorophenol	0.155	mg/L	Daily Maximum
2-Butanone	Report	lbs/day	Average Monthly
2-Butanone	Report	lbs/day	Daily Maximum
2-Butanone	1.85	mg/L	Average Monthly
2-Butanone	4.81	mg/L	Daily Maximum
Acetone	Report	lbs/day	Average Monthly
Acetone	Report	lbs/day	Daily Maximum
Acetone	7.97	mg/L	Average Monthly
Acetone	30.2	mg/L	Daily Maximum
Acetophenone	Report	lbs/day	Average Monthly
Acetophenone	Report	lbs/day	Daily Maximum
Acetophenone	0.0562	mg/L	Average Monthly
Acetophenone	0.114	mg/L	Daily Maximum
Ammonia-Nitrogen	Report	lbs/day	Average Monthly
Ammonia-Nitrogen	Report	lbs/day	Daily Maximum
Ammonia-Nitrogen	10	mg/L	Average Monthly
Ammonia-Nitrogen	20	mg/L	Daily Maximum
BOD5	Report	lbs/day	Average Monthly
BOD5	Report	lbs/day	Daily Maximum
BOD5	53	mg/L	Average Monthly
BOD5	163	mg/L	Daily Maximum

Chloride	Report	lbs/day	Average Monthly
Chloride	500	mg/L	Daily Maximum
Chloride	Report	lbs/day	Daily Maximum
Chloride	250	mg/L	Average Monthly
Dissolved Iron	7	mg/L	Instantaneous Maximum
Flow (mgd)	Report	MGD	Average Monthly
Flow (mgd)	Report	MGD	Daily Maximum
o-Cresol	Report	lbs/day	Average Monthly
o-Cresol	Report	lbs/day	Daily Maximum
o-Cresol	0.561	mg/L	Average Monthly
o-Cresol	1.92	mg/L	Daily Maximum
Oil and Grease	Report	lbs/day	Average Monthly
Oil and Grease	15	mg/L	Average Monthly
Oil and Grease	30	mg/L	Instantaneous Maximum
p-Cresol	Report	lbs/day	Average Monthly
p-Cresol	Report	lbs/day	Daily Maximum
p-Cresol	0.205	mg/L	Average Monthly
p-Cresol	0.698	mg/L	Daily Maximum
pH	6	S.U.	Minimum
pH	9	S.U.	Maximum
Phenol	Report	lbs/day	Average Monthly
Phenol	Report	lbs/day	Daily Maximum
Phenol	1.08	mg/L	Average Monthly
Phenol	3.65	mg/L	Daily Maximum
Pyridine	Report	lbs/day	Average Monthly
Pyridine	Report	lbs/day	Daily Maximum
Pyridine	0.182	mg/L	Average Monthly
Pyridine	0.37	mg/L	Daily Maximum
Total Barium	Report	lbs/day	Average Monthly
Total Barium	Report	lbs/day	Daily Maximum

Total Barium	10	mg/L	Average Monthly
Total Barium	20	mg/L	Daily Maximum
Total Copper	Report	lbs/day	Average Monthly
Total Copper	Report	lbs/day	Daily Maximum
Total Copper	0.757	µg/L	Average Monthly
Total Copper	0.865	µg/L	Daily Maximum
Total Dissolved Solids	Report	lbs/day	Average Monthly
Total Dissolved Solids	500	mg/L	Average Monthly
Total Dissolved Solids	Report	lbs/day	Daily Maximum
Total Dissolved Solids	1000	mg/L	Daily Maximum
Total Iron	2.1	lbs/day	Average Monthly
Total Iron	4.2	lbs/day	Daily Maximum
Total Iron	1.5	µg/L	Average Monthly
Total Iron	3	µg/L	Daily Maximum
Total Strontium	Report	lbs/day	Average Monthly
Total Strontium	Report	lbs/day	Daily Maximum
Total Strontium	10	mg/L	Average Monthly
Total Strontium	20	mg/L	Daily Maximum
Total Suspended Solids	Report	lbs/day	Average Monthly
Total Suspended Solids	Report	lbs/day	Daily Maximum
Total Suspended Solids	216	mg/L	Daily Maximum
Total Suspended Solids	61.3	mg/L	Average Monthly
Total Zinc	Report	lbs/day	Average Monthly
Total Zinc	0.42	mg/L	Average Monthly
Total Zinc	Report	lbs/day	Daily Maximum
Total Zinc	0.497	mg/L	Daily Maximum

The limits reflect that the discharge is into the Susquehanna River and its water quality classification, location of the discharge relative to water intakes, other nearby discharges, and standard NPDES permit writing policy.

So, the Standing Stone NPDES permit provides a measure of what is allowed in a discharge to surface waters. These limits can be contrasted to the much more stringent limits if the intent were to be "de-listed," that is no longer considered a waste. With de-listing the water could be stored or used without needing to comply with a waste management permit.

APPENDIX A:

The following maximum concentrations were derived from drinking water standards, water quality standards for rivers and streams, and typical values observed in fresh water rivers and streams.

Constituent	Limit
Aluminum	0.2 mg/L
Ammonia	2 mg/L
Arsenic	10 μg/L
Barium	2 mg/L
Benzene	0.12 μg/L
Beryllium	4 μg/L
Boron	1.6 mg/L
Bromide	0.1 mg/L
Butoxyethanol	0.7 mg/L
Cadmium	0.16 μg/L
Chloride	25 mg/L
COD	15 mg/L
Chromium	10 μg/L
Copper	5 μg/L
Ethylene Glycol	13 μg/L
Gross Alpha	15 pCi/L
Gross Beta	1,000 pCi/L
Iron	0.3 mg/L
Lead	1.3 μg/L
Magnesium	10 mg/L
Manganese	0.2 mg/L
MBAS (Surfactants)	0.5 mg/L
Methanol	3.5 mg/L
Molybdenum	0.21 mg/L
Nickel	30 μg/L
Nitrite-Nitrate Nitrogen	2 mg/L
Oil & Grease	ND
pH	6.5-8.5 SU
Radium-226 + Radium-228	5 pCi/L (combined)
Selenium	4.6 μg/L
Silver	1.2 μg/L
Sodium	25 mg/L
Strontium	4.2 mg/L
Sulfate	25 mg/L
Toluene	0.33 mg/L
TDS	500 mg/L
TSS	45 mg/L
Uranium	30 μg/L
Zinc	65 μg/L

The delisting requirements are much more stringent than the discharge limits.

The Eureka Standing Stone Design-Prototype of the Future?

With a reduction in the number of wells being drilled and fraced and an increase in the number of wells in production thereby producing production fluids, the ability to reuse production and frac fluids decreases. There will likely be a time when recycling demand is not sufficient to meet the need for reuse. What happens to the shale wastewaters if they cannot be reused?

Standing Stone addresses that question by providing additional treatment steps to the end of what might be termed a conventional shale wastewater treatment plant. The typical plant is capable of removing petroleum products, high solids materials, hardness, and metals to the point required for reuse. Standing Stone does the same, but also adds after that level of treatment mechanical vapor recompression (MVR) crystallization to produce a low total dissolved solids "distilled" water, an almost dry salt containing mainly sodium chloride, and a high concentration brine. The water fraction can be reused. The concentrated brine is discharged to an approved reuse or to an underground injection well. The salt might be reused or transported to an appropriately licensed landfill for final disposal.

An additional step then provides for treatment of the distillate, clean water, fraction in a membrane bioreactor (MBR) followed by reverse osmosis and discharge to surface water compliant with an NPDES permit.

This is not entirely new technology. Clean Streams, LLC constructed a distillation treatment facility in Williamsport which opened in 2011 and which used Altela, Inc. technology. MBR's are widely used in municipal wastewater treatment and reverse osmosis is a standard method for removing ions from water. Perhaps the changing economies of "store and reuse" versus treatment and discharge or treatment and evaporate will bring more applications similar to Standing Stone.

A review of the EDMR's on the DEP website reveals that Standing Stone reports compliance with its NPDES permit effluent limitations. However, the discharge volumes have been considerably less than the design. It is not known if this is a result of recycling rather than discharging the wastewater or if demand has not yet grown to the point that there would need to be larger discharges. Discharges in June through November 2014 (December has no report) were 7,900, 8,011, 21,120, 17,100, 18,080, and 36,500 gallons per day on average.

Insight into the Standing Stone operation is provided by a paper Eureka presented to the Society of Petroleum Engineers entitled, "A Sustainable Choice for Water Treatment/Recycling When Injection is Not an Option or Water Supply is Limited" in May 2015. The paper concludes that efforts to create delisted water and salt products are very difficult and highly dependent on control of pre-treatment processes so that a constant feed to evaporation and crystallization equipment is achieved.

Conclusion

In the three years since the writing of the 2012 report, produced water has passed frac water in its volume of production and the practice of recycling of wastewater on site without treatment at a permitted facility and recycling by treatment at a permitted facility have come to dominate the shale gas wastewater industry. Treatment and discharge occurs only at a few sites, but may become more important as more produced water proportionately has to be treated and less treated water is needed for fracing. New treatment facilities are being constructed, Hydro

Recovery Antrim started operation in 2013 and Eureka Standing Stone in 2014. More facilities are planned.

All of this is occurring as the amount of wastewater being produced is more or less level.