Gaps in Water and Waste Reporting for Oil & Gas Production: a Five-State Review

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For more information on this study go to: http://reporting.earthworksaction.org

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Earthworks is a nonprofit organization dedicated to protecting communities and the environment from the adverse impacts of mineral and energy development while promoting sustainable solutions.

Contents

Important acronyms used in this report

COGCC: Colorado Oil and Gas Conservation Commission
DEP: Department of Environmental Protection (applicable to PA and WV agencies)
NDIC: North Dakota Industrial Commission
RRC: Railroad Commission (of Texas)

bbl: barrel (of oil or fluid) = 42 gallons
FOIA: Freedom of Information Act Request
RTKL: Right to Know Law (Pennsylvania's version of FOIA)
SRB/SRBC: Susquehanna River Basin/ Susquehanna River Basin Commission
SWD: saltwater disposal

Introduction

In the past few years a number of state-specific analyses have been published with information on the lifecycle management of oil and gas water and wastes. (See Appendix A for a list of studies referenced in this report)

These investigations raise questions regarding where current and future water for hydraulic fracturing might come from, and the need to evaluate oil and gas water requirements in relation to other water users.

Several studies have taken a close look at the disposal of fluid wastes that are extracted from oil and gas wells – including near-term flowback of hydraulic fracturing fluids, and produced water that is extracted over the longer term. Such wastes pose management challenges because of their high volumes, but they also are a potential source of water to be re-used for other purposes if the fluids can be treated to achieve acceptable water quality. Understanding current disposal practice is necessary to plan and evaluate waste fluid management options.

What has become clear from reviewing the studies is that data challenges exist that make it difficult to perform detailed, accurate water and waste management analyses.[1]

Availability and access to data varies greatly from state to state. In some cases, there is no requirement for operators to report certain types of information; often the data are not presented in formats that would provide for ready data analysis (e.g., spreadsheets); and in some states data are only accessible via payment or freedom-of-information type requests.

And, when data are obtained, they are often incomplete or contain errors.

In 2013, researchers from Downstream Strategies and San Jose State University developed a report in collaboration with Earthworks to investigate water use and waste disposal requirements and practices in the Marcellus Shale. The resulting report[2] applied the concept of life cycle analysis to calculate the water footprint of the extraction phase of natural gas from Marcellus Shale.

In 2014, Earthworks set out to see if it was possible to perform similar water footprint lifecycle analyses for the shale oil plays in Colorado and Texas. We discovered it is not possible due to shortcomings in state reporting requirements and data collection.

As a result, this paper has been written to summarize some of the water-and-waste-related information gaps in Colorado and Texas. We also reviewed water and waste reporting requirements in North Dakota, as that state, similar to Colorado and Texas, has experienced high rates of drilling, combined with water challenges. We contrast the information available in those three states with water and waste data available in Pennsylvania and West Virginia.[3]

When we came across data in formats that were relatively accessible, we carried out analyses to demonstrate the type of information that could be generated from the data.

Ultimately, this report highlights where state reporting requirements and public disclosure could be improved so that regulators, academics, community planners, and non-governmental organizations can access the data needed to fully analyze and understand current and future water use and waste disposal requirements, and plan accordingly.

Findings

Table 1 provides an overview of reporting requirements and accessibility of data on oil and gas water and waste management in Colorado, Texas, North Dakota, Pennsylvania and West Virginia. The five categories of information in the table are addressed later in this paper in much greater detail, to provide the rationale for the "grade" applied to each state, as well as examples of the types of information that can be generated when the data are available.

Table. 1. Report card: state-by-state comparison of water use and waste disposal reporting requirements.

	CO	TX	ND	PA	WV
Water Management Plan					
Water Management Plan submitted by operator	F	F	F	C	C
Hydraulic Fracturing Water Use					
Report volume of all water used	B	B	B	B	B
Report sources of fresh water	F	F	F	C	C
Report volume of recycled water used	B	F	F	C	C
Report sources of recycled water	F	F	F	F	C
Hydraulic Fracturing Flowback Production and Disposal					
Report volume of flowback recovered	B	F	F	A	C
Report method(s) of flowback disposal	C	F	F	A	C
Report flowback waste disposal location	F	F	F	A	C
Produced Water Generation and Disposal					
Report volume of produced water from oil or gas wells	A	F	B	A	F
Report method(s) of produced water disposal	A	F	F	A	C
Report produced water disposal location	F	F	F	A	C
Underground Injection of Wastes					
Report volumes of fluid wastes disposed of through injection	A	A	B	A	C
Report source wells (i.e., wells sending wastes to disposal site)	B	F	C	F	C
Report transportation method of wastes to disposal site	B	F	C	F	F
Report volumes of different types of waste injected	F	A	F	F	F

Table Legend

A	REPORTING REQUIRED, DATA ACCESSIBLITY GOOD
	Data are accessible online, free of charge, in a format that is easy to utilize for analyses (e.g., downloadable database)
B	REPORTING REQUIRED, DATA ACCESSIBLITY MODERATE
	Data are accessible online, but: 1) The format is cumbersome (e.g., need to download documents or access data on a well-by-well basis – making it time-consuming to compile data for analysis); or 2) Users must pay to access online data.
C	REPORTING REQUIRED, DATA ACCESSIBLITY POOR
	Data are available from state agencies, but are not online, so public may need to file a FOIA-type request to obtain copies of data, or go to offices to view data. OR data are only partially available (due to lack of reporting requirements).
F	REPORTING NOT REQUIRED

Water Management Plans

	CO	TX	ND	PA	WV
Water Management Plan					
Water Management Plan submitted by operator	F	F	F	C*	C

* Note: the subset of PA wells located in the SRBC would receive a B-grade.

Water management plans are required in Pennsylvania and West Virginia, but not in Colorado, Texas or North Dakota.

Colorado, Texas, North Dakota

Despite the fact that oil and gas producing regions in Colorado and Texas have experienced high water stress conditions in the past few years,[4] the agencies overseeing oil and gas development in those states don't require operators to:

- plan for where they will obtain water,
- share with the public the ultimate source of that water, or
- assess the potential impacts of their usage on the water sources being tapped.

North Dakota does not require water management plans either, despite the fact that "finding cost-effective sources of fresh water for oil development in the Bakken play is becoming increasingly difficult."[5]

Pennsylvania

As part of the permit application process for unconventional wells, the Pennsylvania DEP requires operators to submit a Water Management Plan (WMP) for Unconventional Gas Well Development (Form OOGM0087). Operators must:

- "specify from where the water would be withdrawn
- demonstrate that the proposed withdrawal would not harm water quantity or quality for other uses or users,
- cause no adverse impacts to water quality in the watershed as a whole, and
- include a reuse plan for water used to hydraulically fracture wells."[6]

But the WMPs are not available online. The public must submit a Right-to-Know Law request, or request a file review, which allows parties to view (and copy) documents in DEP offices.

Water use for natural gas wells located in the Susquehanna River Basin is governed by the Susquehanna River Basin Commission (SRBC). Operators of these wells don't file a WMP, but they do submit "Consumptive Water Use Permit" applications to, and must be granted an approval by, SRBC before they may withdraw water. Based on the application and the review, the SRBC may grant an approval, which includes information such as "the maximum daily quantity of consumptive water use; metering, monitoring and reporting requirements; daily monitoring of quantities; sources of water transported to and from the site; and the fate of flowback and produced fluids in the first 30 days after hydraulic fracturing."[7]

According to SRBC, its permit reviews are science-based, and take into consideration cumulative impacts and timing and location of withdrawals to ensure that impacts on aquatic ecosystems are minimized.[8] A list of water sources approved for natural gas development, as well as approval documents, can be found on the SRBC web site on a company-by-company basis.[9]

West Virginia

West Virginia DEP requires that horizontal well permit applications include a water management plan if the operator estimates the well will require more than 210,000 gallons of water for drilling, hydraulic fracturing or stimulating. Practically all wells hydraulically fractured in West Virginia exceed this limit.[10]

In these plans operators must:

- identify the type of water source (e.g., surface water, groundwater, reused "frac water"),
- identify the specific location of the water source,
- identify the anticipated volume to be withdrawn,
- identify the expected timing of water withdrawal,
- identify all existing water uses within one mile downstream of a location where they will withdraw surface water, and
- ensure that enough in-stream flow remains to protect identified downstream uses.[11]

These water management plans are not available on the DEP web site; but may be obtainable through a FOIA request.

Hydraulic Fracturing Water Use

Volume and type of water usage

	CO	TX	ND	PA	WV
Hydraulic Fracturing Water Use – Volumes					
Report total volume of fluid or water used	B	B	B	B	B
Report volumes of fresh versus recycled water used	B	F	F	C	C

Pennsylvania, West Virginia and Colorado require operators to report the volumes of recycled water used for hydraulic fracturing operations. Texas and North Dakota do not differentiate between fresh and recycled water in their reporting requirements.

Generally, data on water usage for hydraulic fracturing are publicly available for wells in all states in this review, but "publicly available" often does not mean "easily publicly accessible", as is discussed below. Furthermore data are usually not in a format that facilitates any kind of public analysis of that data.

FracFocus

Colorado, North Dakota, Texas and Pennsylvania require operators to file hydraulic fracturing reports on the publicly accessible FracFocus web site. These filings include information on volumes of water used to fracture-stimulate oil and gas wells. West Virginia only requires operators of "natural gas horizontal wells" to file with FracFocus.[15]

It is possible to use FracFocus data to determine water used to fracture a limited set of wells. Earthworks looked at FracFocus data for wells that had hydraulic fracturing treatments in Weld County, Colorado in 2013. According to data filed by operators with FracFocus, there were 1,216 wells in the county that performed 1,235 hydraulic fracturing treatments that year. Cumulatively, these wells used 2.98 billion gallons of water (71 million barrels) during hydraulic fracturing operations.[16]

It is important to note that the data on water volumes reported to FracFocus represent the total amount of water used as the carrier fluid for the hydraulic fracturing job, and that the volume may include fresh water, produced water,

The FracFocus web site is cumbersome: data must be examined in pdf-format, on a well-by-well basis, and is therefore "of limited usefulness for researchers who desire data for numerous wells."[12]

When external interests, including the non-profit SkyTruth and Argonne National National Laboratory, built tools that compiled FracFocus data into a downloadable, searchable database (which greatly increased the ability for researchers to analyze data on hydraulic fracturing volumes), FracFocus modified their website in a manner that effectively blocked these tools.[13]

Earthworks has also encountered problems when trying to download large numbers of records from the FracFocus web site over a short period of time, and has had its access to the FracFocus data suspended with the message "Automated Bot Response Activity from this account has been flagged as possible Automated (non-human) activity".[14]

These examples exemplify the need to make FracFocus more user-friendly and accessible to the public whose interest it is supposed to serve.

and/or recycled water.[17] Operators using the FracFocus system are not required to provide details on how much fresh versus recycled or produced water are used.

Also, as shown in the Colorado example below, volume data reported in FracFocus sometimes conflict with data filed by operators with their home-state agency. Thus, researchers are confronted with the challenge of guessing which data more accurately reflect volumes used during hydraulic fracturing.

Colorado

COGCC requires operators to report "the total volume of water used in the hydraulic fracturing treatment of the well" or "the type and total volume of the base fluid used in the hydraulic fracturing treatment, if something other than water" for fracturing operations performed on or after April 1, 2012.[18]

In addition to reporting volumes to FracFocus, operators must submit Form 5A ("Completed Interval Report") to COGCC. This form was revised in June 2012, and the new version specifically asks operators to report volumes of fluids and gas used in the hydraulic fracturing or other well treatments, including: total fluid; total gas; total acid; recycled water; fresh water; and total proppant.[19]

While information on water volumes is available to the public, it is not provided in an easily accessible manner; nor do operators always include the information on Form 5A, even though it is asked of them.[20]

Differences between FracFocus and Colorado water data

Data filed with the COGCC do not always match the data found in FracFocus.

Earthworks reviewed Form 5As for a subset of wells completed in the Weld County, namely those located in the DJ Horizontal (Niobrara) field. Of the 111 DJ Horizontal wells in the county, 50 were completed after the new Form 5A took effect. Seven of the wells (14%) that should have filed Form 5As were missing the document.[21]

We compared FracFocus water volumes with those found in the Form 5As for the remaining 43 wells. The volume data matched for 27 (63%) of the wells. For 16 (37%) of the wells, volume data differed by at least 10,000 gallons and as much as 1 million gallons. (See Appendix B for more information)

Water volume data filed with the COGCC are more detailed than FracFocus.

FracFocus only requires operators to report the total volume of water, which may include fresh, produced and/or recycled water, but does not require a breakdown of the volumes of each type of water. The revised COGCC Form 5A requires operators to report the volumes of total fluid, fresh water and recycled water used during hydraulic fracturing. There were two cases out of 43 where COGCC data showed that the volume of water reported to FracFocus included recycled water. Eleven wells reported that they recycled water, but the recycled water volumes were not included in the water volume reported to FracFocus.

Anyone wanting to understand the volumes of fresh versus recycled water being used for hydraulic fracturing in Colorado will need to use the COGCC data. Researchers should be aware that it is a cumbersome process to gather data on a large number of wells; and that currently, it takes the COGCC an average of six months or more to review submitted Form 5As and post them online.[22] So analysis of

recently fractured wells may not be possible.

Texas

In addition to reporting volumes to FracFocus, the RRC requires operators to file well completion reports (G-1 for gas wells and W-2 for oil wells). These forms ask operators to report the amount and kind of material used to perform completion activities such as hydraulic fracturing, acid, shot, cement squeeze and others. But a review of filed completion forms shows that operators do not always report volumes of water used.[23] Therefore, FracFocus appears to be the only publically accessible source of data on hydraulic fracturing water use for wells in Texas.[24]

North Dakota

In addition to reporting volumes to FracFocus, operators must submit Form 6 "Well Completion or Recompletion Report" to NDIC.[25] Operators report volumes of fluids used to fracture or stimulate a well on Form 6, but the form does not specify what exactly is being reported (e.g., total volume of fluid used, volume of water, volume of recycled water, etc.) A copy of the Form 6 filed by an operator may be available in a well's Well File, which is downloadable from the NDIC web site (through a paid subscription service).[26]

Pennsylvania

In addition to reporting volumes to FracFocus, DEP requires operators to file a Well Completion Report (Form OOGM0004b, hereafter referred to as "Form 4b") after a well is completed, which requires operators to report the total volume of water used to stimulate unconventional oil and gas formations. Form 4b also requires operators to report the volume of recycled flowback or produced water used.[27] A well's Form 4b is not available online, but can be accessed through a Right-to-Know request or by conducting a file review in the appropriate DEP office.

West Virginia

As mentioned above, hydraulic fracturing chemical and water usage information is only required to be posted to the FracFocus website for natural gas horizontal wells, although operators of other wells may submit this information to FracFocus voluntarily.[28]

WV DEP has additional reporting requirements for water used during hydraulic fracturing. If an oil or gas well uses more than 300,000 gallons of water during a fracturing operation, operators must report the total volume used on DEP's Frac Water Reporting system.[29] Data from this system are not publicly available except through Freedom of Information Act (FOIA) requests.[30] Also, all wells, including those using fewer than 300,000 gallons of water for hydraulic fracturing, are required to report volumes of water used on Form WR-35 "Well Record Completion Report".[31] Copies of WR-35s filed with DEP are not available online. Presumably, these forms could be obtained through a FOIA request, and the total volume of water used for well stimulation of all oil and gas operations in the state could be calculated.

Water source types and locations

	CO	TX	ND	PA	WV
Hydraulic Fracturing Water Use – Sources					
Report sources of fresh water	F	F	F	C	C
Report sources of recycled water	F	F	F	F	C

Pennsylvania and West Virginia require operators to report sources of fresh water used for hydraulic fracturing, and WV also requires reporting sources of recycled water. But data are not available online in either state. Colorado, Texas, and North Dakota do not require reporting the source of water used in hydraulic fracturing.

Colorado, Texas, North Dakota

The reporting of sources of water (fresh or recycled) used for hydraulic fracturing is not required in Colorado, Texas or North Dakota. In these states, some data may be available on both groundwater and surface water extraction, but in most cases the ultimate use of that water is not known or not specific enough to tie it to a particular oil and gas well site.[32] Non-industry observers, therefore, have only been able to derive rough estimates of hydraulic fracturing water volumes from groundwater, surface water and recycled sources based on information obtained from water suppliers and/or oil and gas operators.

For example, Nicot et al. (2012) report that in 2011 approximately 80% of the water used to hydraulically fracture wells in the Eagle Ford Shale play of Texas was fresh water (90% sourced from groundwater, 10% from surface water), while approximately 20% was brackish groundwater, and almost no oil and gas wastewater was being recycled/reused by operators.[33] These estimates were based on private information provided by a select group of Eagle Ford operators.

In North Dakota, researchers estimate that a good portion of the fresh water used for hydraulic fracturing in the Bakken Shale oil play is currently sourced from public or private water distribution sites, which get their water from either groundwater reserves or surface water.[34] Researchers have tried and been unable to find records indicating which water depots were used for each hydraulic fracturing operation.[35]

It has been suggested that surface water sources, primarily the Missouri River system and Lake Sakakwea, can more than accommodate the future water needs for the Bakken Shale play; however, access issues, potential fees and high transportation costs are challenges that may limit the ability of the oil and gas industry to make use of this source of fresh water in the near term.[36]

Flowback and produced water are not currently being reused on a large scale in the Bakken – the high dissolved salt content of flowback and produced water makes recycling challenging and economically unattractive.[37]

Pennsylvania

As mentioned previously, the Pennsylvania DEP collects information on water sources proposed for use in Marcellus shale gas well development in a company's Water Management Plan. The name and location of water sources are included, but the plans do not list all of the oil and gas wells that will use water from these sources.

DEP's "Well Completion Report" (Form 4b), however, requires operators to list the source(s) of water used to stimulate wells in unconventional oil and gas formations, and reference the relevant Water Management Plan. Form 4b also requires operators to report the volume of recycled water used during well completion, but the source of the recycled water is not reported.[38] Water source data are not accessible electronically (online) by the public. Parties interested in such data can file a Right-to-Know request to obtain Form 4bs for wells of interest, or conduct well file reviews in DEP offices to view these forms and companies' Water Management Plans.

For Marcellus shale wells located in the Susquehanna River Basin (SRB), the Susquehanna River Basin Commission (SRBC) requires operators to obtain approval for consumptive water uses related to natural gas development, which includes water used for hydraulic fracturing. SRBC also requires operators to report post-hydraulic fracturing information including sources or origin of freshwater and/or wastewater used. Detailed data from SRBC are available for download, but it costs $250 to purchase 3 months of data. Using summary data available, Hansen et al. (2013) determined that between 2008 and 2013, 6 billion out of 8.3 billion gallons of water used at Marcellus wells in the SRB came from surface and groundwater sources.[39]

West Virginia

As mentioned above, the WV DEP collects information on water withdrawn for use in those hydraulic fracturing operations that use more than 750,000 gallons. Data such as water source (including the source of reused "frac water"), name, location and withdrawal volume is reported to DEP through the Frac Water Reporting Form.

One of the shortcomings of this system, as reported by Hansen et al. (2013), is that water withdrawal volumes are reported by extraction event and well site, so "it is therefore not possible to determine the volume of water withdrawn for use at any individual well."[40]

In addition, data on water sources are not available for wells that require less than 750,000 gallons of water for hydraulic fracturing.[41]

Water source/withdrawal data are not readily accessible in West Virginia. Hansen et al. (2013) had to submit a FOIA request to WV DEP to obtain water withdrawal data from the Frac Reporting System. From the data received, Hansen et al. were able to determine that between 2010 and mid-2012, hydraulic fracturing operations in West Virginia relied most heavily on surface water withdrawals (81%), followed by purchased water (10%), reused flowback fluid (8%) and groundwater (1%).

Hydraulic Fracturing Waste Production and Disposal

North Dakota and Texas do not require reporting of hydraulic fracturing flowback volumes or flowback disposal methods. Colorado requires some flowback-related reporting, and West Virginia and Pennsylvania collect detailed information on flowback volumes and disposal methods. Pennsylvania provides the greatest public accessibility to flowback data.

Hydraulic fracturing fluid wastes that return to the surface are referred to as *flowback*, which is generally defined as fluid that is geochemically similar to the hydraulic fracturing fluid.[42] Knowledge of the volume of flowback recovered is important because it can inform operators and others about how much fracturing fluid wastewater may be available for use at other wells, as opposed to having to rely on fresh water sources.[43]

One challenge that has surfaced in tracking flowback volumes is that there is no standard timeframe for measuring flowback. Fluids pumped underground during hydraulic fracturing flow out of the well over an indeterminate period of time, which varies from well to well.

The initial flowback period is followed by production of *produced water* (discussed in the following section), which bears the geochemical characteristics of the water naturally occurring in the fractured formation rather than the fracturing fluid. In contrast to flowback, which may be recovered over a few weeks to months after well stimulation, produced water often continues to be removed from a well over its entire lifetime. Produced water is often referred to as brine or saltwater, as water originating from oil and gas formations often contains high concentrations of salts.

States that require operators to report flowback generally use 30 days as the flowback reporting period. The U.S. Geological Survey characterization of flowback as "mainly occur[ring] during the first several weeks or months after hydraulic fracturing" captures the uncertainty surrounding the flowback period.[44]

Flowback recovery volumes

	CO	TX	ND	PA	WV
Hydraulic Fracturing Flowback Production and Disposal					
Report volume of flowback recovered	B	F	F	A	C

Colorado

The June 2012 revision of COGCC's Completed Interval Report (Form 5A) requires operators to report the volume of flowback, which it describes as the total combined volume of hydraulic fracturing treatment fluids and produced water recovered after well stimulation.

There is no specific time period set for measuring the flowback, but operators are instructed to "utilize the best measurement method available to determine a meaningful volume for the formation and briefly describe method," and report the total volume recovered as of the date the Form 5A is submitted.[45] Form 5A is supposed to be submitted within 30 days of completing a well.

Flowback data are available on a well-by-well basis, only,[46] which makes it a time-consuming endeavor to calculate flowback volumes, even for a subset of wells in Colorado.

Using data from the 43 Form 5As (06/12 version) for wells drilled in the Weld County portion of the DJ Horizontal Niobrara Field, we found that operators who submitted the forms did not always answer the questions related to flowback volume recovered (19% left the questions blank). (See Appendix B for data)

Of the 35 wells that reported flowback recovery volumes, the average volume recovered within approximately the first 30 days was 20% of the total fluid used to fracture the well. This is within the range found by Stepan et al. (2010) for wells in the Bakken Shale play (i.e., between 17% and 47% was recovered in 2 – 10 days); but it is a much higher percentage than the 6% and 8% of fluids recovered as flowback in Pennsylvania and West Virginia, respectively (discussed in more detail below). The median volume of flowback from the DJ Horizontal wells was 457,800 gallons, which is more than double the median volume that Nicot et al. (2013) estimated for Eagle Ford Shale wells. One DJ Horizontal well reported flowing back more than 100% of the volume used during hydraulic fracturing, which suggests that the well had already started to extract formation water from Niobrara shale.

Texas, North Dakota

Texas and North Dakota do not require operators to report flowback volumes. Available estimates, based on questionable data, indicate 17 to 47 percent of fracking fluid returns as flowback in North Dakota[47], and approximately 20 percent in Texas's Eagle Ford Shale. [48]

Pennsylvania

Pennsylvania DEP uses a 30-day flowback period.[49] According to Hansen et al. (2013), "statewide electronic data are not publicly available for . . . recovery volumes for Marcellus wells across Pennsylvania."[50] Operators are not required to report flowback recovery volumes in their well completion reports (Form OGM0004b).

Operators are, however, required to report the disposal volumes of flowback waste as part of their annual waste and production reporting responsibilities.[51] Data on the volume and waste disposal location of flowback are accessible electronically, free-of-charge, in the Waste Report Database available on the DEP's Oil and Gas Reporting Website.[52]

Assuming that the volume of flowback reported in an operator's waste report reflects the total flowback recovered, it should be possible to filter the DEP Waste Report Database to find all wells with reported volumes of flowback in a particular year. For each well with flowback, one could then look up the hydraulic fracturing water use information for each well on FracFocus. Using these two values, one could determine the flowback recovery rate for each well. Such an analysis, however, was not possible to carry out for this report.

For the subset of Pennsylvania Marcellus Shale wells located in the Susquehanna River Basin, flowback recovery data are available. The SRBC requires operators to report the volume and fate of flowback and fluids produced in the first 30 days after the release of pressure on the well following hydraulic fracturing.[53] SRBC charges $250, per quarter, to access post-hydraulic fracturing data. Hansen et al. (2013) report that between 2009 and 2012, Marcellus shale operators in the SRB recovered an average of 6% of the volume of fluid used during hydraulic fracturing during the 30-day flowback period.[54]

West Virginia

Operations that use more that 750,000 gallons to fracture a well in West Virginia are required to report either 50% of the original water used in the operation, or the volume of water recovered during the first 30 days of flowback, whichever occurs first.[55]

These data are reported through the DEP's Frac Water Reporting site. Flowback for other wells may be reported on form WR-34 "Discharge Monitoring Report", which asks operators to report total volume to be disposed from a facility and disposal method. According to DEP, this form is most relevant for wells that are not subject to the 22-6A Horizontal Well Act.[56] Neither the Frac Water Reporting data nor filed forms are available online. DEP will, however, provide this information in response to a FOIA request.

Hansen et al. (2013) obtained flowback data for WV horizontal Marcellus wells for the period 2010 through 2012, and found that wells reporting during that period recovered an average of 8% of the total volume of hydraulic fracturing fluid as flowback.[57]

Flowback disposal methods and locations

	CO	TX	ND	PA	WV
Hydraulic Fracturing Flowback Production and Disposal					
Report method(s) of flowback disposal	C	F	F	A	C
Report flowback waste disposal location	F	F	F	A	C

Colorado

COGCC's updated Form 5A requires operators to report if disposal or recycling of flowback occurred. Details on the method of disposal, however, are not reported on this form.

Earthworks looked at data for 43 wells drilled in the Weld County portion of the DJ Horizontal Niobrara field, and found that 12% of the well forms did not include any information for the question that asked about flowback disposition method. For the 37 wells that reported flowback disposition method, 54% recycled these fluids and 46% relied on some form of disposal. (See Appendix B for data)

COGCC does not require operators to report the actual disposal facility or location of reuse/recycling. So it is not possible to track how much flowback waste is being disposed of within state borders, or the distances being travelled to dispose of the waste.

Texas, North Dakota

Texas and North Dakota do not have reporting requirements for flowback disposal methods or locations. Information from operators suggests that recycling of flowback is not being done very frequently in the Texas Eagle Ford Shale play or in the Bakken Shale play of North Dakota.[58]

Pennsylvania, West Virginia

Both Pennsylvania and West Virginia require operators to report the method of flowback disposal in more detail than Colorado. For example, PA operators report the reuse, disposal at municipal sewage treatment or brine/industrial treatment plant, injection well disposal, or other method of flowback disposition, and the disposal location; WV operators report reuse, treatment, land application or injection well disposal, and also the disposal location.[59]

As with flowback volume data, the PADEP makes this information publicly available through its online Waste Reports, while the WVDEP does not provide data from its Frac Water Reporting Forms to the public except through FOIA requests.

According to Hansen et al. (2013), 74% of flowback fluid in Pennsylvania was reused in 2011, with the majority of the remainder going to brine or industrial treatment plants; while in West Virginia, 73% of flowback waste was reused, with most of the remaining waste going to injection wells. Reuse of flowback fluids in West Virginia, however, was showing a declining trend, while in Pennsylvania, it appeared to be increasing.[60]

Based on disposal location information, Hansen and his colleagues were able to determine that for the years 2010-2012, 43% of the flowback fluid recovered in West Virginia was transported out of state for disposal. They did not perform a similar calculation for flowback movement from Pennsylvania.[61]

Produced Water Generation and Disposal Methods

For the states examined for this report, Texas and West Virginia lag behind the others in terms of produced water data collection and reporting. Data on volumes of produced water are collected by Colorado and Pennsylvania agencies and are publicly available for free on their web sites; North Dakota collects the data, but charges a fee to access it.

Produced water may be *reused* or *recycled* for use at other wells, helping to reduce an operator's reliance on fresh water for subsequent drilling and hydraulic fracturing operations. Walter Dale, strategic business manager for water solutions at Halliburton, has stated that while the ability to recycle high volumes of water is the goal, "It's a function of how much available impaired water you have in proximity." Dale recommends that operators, "Look for the high volumes of impaired waters, such as flowback, produced water, and brackish water wells," in proximity to their unconventional completions that require high volumes of water.[62]

In order for operators to understand temporal or regional differences in produced water generation that may help them to maximize use of so-called impaired waters, they need access to good data on produced water.

As reported by Argonne National Laboratory, data quality varies significantly from state to state. In its 2009 report entitled *Produced Water Volumes and Management Practices in the United States*, Argonne researchers found that:

> *"Not all states had readily available precise produced water volume figures. In a few states, the agencies had very complete data records easily obtainable from online sources. Other states had summary-level volume data without much detail or had data available only in in-house data repositories. The most challenging states were those that had no produced water data at all."*

In states with no produced water data, the Argonne researchers resorted to estimating produced water volumes through extrapolation and correlations using hydrocarbon production and produced water volumes from neighboring states.[63]

The volume of produced water available for reuse or recycling will vary by oil and gas play, but also over time. For example, "When the Bakken first started, there were insufficient water volumes to consider recycling. But with the increased rig count, the flowback volumes are higher, and it makes a lot of produced water now that it's a few years old."[64] As oil and gas plays age, and the rate of hydraulic fracturing decreases, there will be an excess of produced water – much more than can be recycled and used to develop new wells – and waste disposal challenges are likely to intensify.[65]

Without adequate reporting of produced water volumes, it is difficult for agencies, the public, and operators, including those proposing waste disposal facilities, to understand future regional produced water disposal capacity needs.

For example, at a June 2014 hearing on a proposed produced water disposal well in the Eagle Ford Shale, a Texas Railroad Commission examiner wrote:

"There are many difficulties associated with attempts to forecast the demand for fluid disposal and the supply of fluid disposal capacity in a given area. First, operators are not required to report production of flow back and salt water from their wells, which is the source of most of the waste requiring disposal in commercial SWDs. This impairs any estimation of current or potential future demand for wastewater disposal [emphasis added]. . . thus there is no reasonably accurate means of quantifying the supply (available capacity) of fluid disposal in an area."[66]

Produced water volumes

	CO	TX	ND	PA	WV
Produced Water Generation and Disposal					
Report volume of produced water from oil or gas wells	A	F	B	A	F

Colorado

Colorado operators are required to report the volume of produced water generated at each well site. This occurs monthly, via the filing of Form 7.[67]

Colorado produced water data can be accessed on a well-by-well basis using the COGIS online database,[68] and produced water volumes for all wells can be found in the COGCC's statewide production data downloads, free of charge.[69] The downloadable data come in two formats: production summaries, which provide the total oil, gas and produced water volumes per well in a particular year; and production reports, which provide monthly volumes of oil, gas and water for each well per year.[70]

Anyone interested in annual produced water totals by county (or statewide) can use the COGCC Reports Portal. By conducting a simple query we produced a report showing that in 2013 Weld County wells generated 16,983,293 bbls of produced water, or 4.4% of the water produced in the state that year (386,514,770 bbls).[71] These volumes were up from 11,538,521 bbls in Weld County and 344,266,613 bbls statewide in 2011, and represented a 47% increase in Weld County and a 12% increase in statewide produced water volumes over that time period.

It is not possible to query the COGCC Reports Portal to determine volumes of water produced by operator or oil and gas field.

Texas

As with flowback volumes, the RRC does not require operators to report volumes of produced water generated for each oil and gas well.

As discussed below, the RRC does collect and track information on the portion of produced water that is disposed of through underground injection.

Researchers in Texas have had to find other means to estimate produced water generation. For example, Nicot and his colleagues utilized produced water data provided by IHS (a paid service) to estimate produced water volumes in the Barnett Shale and Eagle Ford Shale.[72] IHS provides estimates of produced water volumes for Texas oil leases and gas wells based on the oil/water ratio that well operators report to the RRC.[73] IHS told Earthworks that it "does not recommend trying to use the IHS estimated summary water production on a large area to draw any conclusions on the amount of

produced water."[74] [emphasis added by IHS] Nicot et al., therefore, did not rely solely on the IHS data. They compared the produced volumes for wells in the two shale plays to data on volumes of produced water injected in those regions of the state. Nicot and his colleagues found that the volumes of produce water estimated by IHS provided a decent "ballpark" figure when compared to the volumes of produced water injected.[75] Still, the Texas researchers were forced to rely on incomplete data that, according to IHS, may provide overestimates of water production in the early life of wells[76] – all because RRC does not track this information.

North Dakota

In North Dakota, operators report the volume of produced water generated at each well site using Form 5.[77] For a fee, monthly produced water data can be accessed on the NDIC website by well, field, unit or for the state as a whole.[78] NDIC also has a downloadable Well Index database (also a paid service), but the water volume by well is reported as the cumulative volume produced over the life of the well, which does not enable users to determine monthly or annual produced water production.[79]

Using statewide production data accessed from the NDIC web site, Earthworks determined that in 2013 oil and gas wells in North Dakota generated 349,600,728 bbls of produced water. This is a 66% increase from the 2011 statewide produced water volume (210,468,717 bbls).

Pennsylvania

In Pennsylvania, operators report produced fluids annually (for conventional wells) and bi-annually (for unconventional wells) via DEP's Oil and Gas Reporting Website.[80] Produced fluids are differentiated from other fluid wastes, such as fracturing fluid and drilling fluid wastes, which are also reported to DEP. The public has free access to Waste Report data via the Oil and Gas Reporting Website, and can look up produced fluid and other waste volumes on a per well basis, or download datasets to view data for all wells in the state.

According to researchers who have used the DEP production data, the information, while easily accessible, has little data quality oversight by DEP, which creates challenges when attempting to analyze them.[81] Nevertheless, researchers like Lutz et al. (2013) have been able to "clean" and use the data to calculate produced water volumes for Marcellus shale and conventional wells in Pennsylvania. They determined that in 2011, Marcellus shale wells produced 3,144 million liters (830,556,933 gallons or 19,775,165 bbls) of wastewater, approximately 44.7% of which was brine.[82] We did not attempt to calculate 2013 produced water volumes for Pennsylvania wells due to the data quality issue raised by Lutz et al.

West Virginia

West Virginia DEP fails to track produced water volumes generated by wells.[83]

For West Virginia, Hansen et al. (2013) were not able to estimate produced water volumes. Through a comparison with Marcellus Shale wells in Pennsylvania, they surmised that "large quantities of waste – perhaps as much as 62% – remain unreported in West Virginia. . . This unreported waste is virtually entirely made up of brine [i.e. produced water] and drilling waste."[84]

Produced water disposal method and location

	CO	TX	ND	PA	WV
Produced Water Generation and Disposal					
Report method(s) of produced water disposal	A	F	F	A	C
Report produced water disposal location	F	F	F	A	C

Colorado

COGCC does not require operators to report the disposal facility name or locations where produced water is taken for disposal. The agency, however, does require operators to report the following methods of produced water disposal on Form 7:

- commercial disposal facility (operator pays for disposal)
- central disposal pit or well (operator-owned)
- onsite pit
- injected on lease
- surface discharge

The commercial disposal facility and central disposal pit/well are general categories that include a variety of methods of disposal (e.g., injection wells, pits, land treatment), and so, it is not possible to generate exact statistics on the volume of wastes disposed by a particular method.

In its 2013 report to the Colorado Water Quality Control Commission, COGCC estimated that:

> *"Approximately 50% of the water co-produced with oil and gas [statewide] is disposed of or used for enhanced recovery by underground injection. Most produced water that is not injected is disposed in evaporation and percolation pits or discharged under Colorado Discharge Permit System (CDPS) permit. A small amount of produced water is used for dust suppression on oil and gas lease roads. In addition, to minimize waste and the use of fresh water, many operators are reusing and recycling produced water and other fluids for drilling and well completion activities including hydraulic fracturing treatment operations."*[85]

Information on volumes of produced water disposed via the various methods was not included in the report.

Information on produced water disposal method is publicly accessible online through the COGIS Production Data query,[86] and also in downloadable database format via the COGCC Annual Production Reports.[87] We used Production Report data to generate a "rough" estimate for the methods used to dispose of produced water in Weld County.[88] We found that in 2013, 37% was disposed of at commercial disposal facilities; 35% of produced water from Weld County was injected on lease; 18% of disposal was via onsite pits; and 9% was disposed of via operator-owned central disposal pits or wells. We found no cases in 2013 where operators in Weld County reported surface discharge of produced water.

Texas, North Dakota, West Virginia

Not surprisingly, as Texas and North Dakota do not require operators to report volumes of produced water, they also do not require operators to report method or location of produced water disposal. West Virginia DEP requires operators to keep records on the method of disposal of produced water, and the collection and disposal locations of the water, but does not require operators to submit this information to the department.[89]

Pennsylvania

Pennsylvania operators report the disposal method for produced fluids (i.e., centralized treatment facility with discharge; centralized treatment for recycling; injection disposal well; landfill; onsite encapsulation; onsite pit; public sewage treatment plant; residual waste processing facility; residual waste transfer facility; reuse other than roadspreading; roadspreading; or storage pending disposal or reuse), as well as the name and location information for the waste disposal facility that receives the produced fluids.[90]

The data are available online in the Waste Reports found on the DEP Oil & Gas Reporting Website.[91] No recent analysis of produced water disposal methods was found for Pennsylvania.[92] Due to the time needed to address data quality issues raised by Lutz et al. (2013), performing an analysis of produced water disposal methods for Pennsylvania was beyond the scope of this report.

Fluid Waste Disposal Methods and Implications

Fluid wastes such as flowback, produced water and drilling wastes are disposed of through a variety of methods that include underground injection, treatment and discharge into surface waters, evaporation and percolation pits, and other means discussed below.

As reported elsewhere, a portion of the water used for hydraulic fracturing is not recovered during the flowback period. Some of the water will slowly return to the surface over the course of a well's life – mixed with produced water from the formation. But some hydraulic fracturing water will remain trapped underground, and therefore will be removed from the hydrologic cycle. Similarly, flowback wastes that are disposed of through injection into underground formations are removed from the hydrologic cycle as well.[93] Hansen et al. (2013) estimate that between 2009 and 2011, approximately 17.8 billion gallons of water were removed from the hydrologic cycle due to Marcellus Shale oil and gas operations in Pennsylvania; and between 2010 and October 2012, approximately 1.2 billion gallons of water were lost from the hydrologic cycle from Marcellus Shale operations in West Virginia.[94]

There is the potential for oil and gas operations to add new water into the hydrological cycle (e.g., by bringing water that had been trapped in underground formations to the surface).[95] For example, produced water can be released into groundwater (and the atmosphere) via percolation and evaporation pits/ponds, land application and roadspreading, beneficial reuse (e.g., agricultural or industrial applications), or to surface waters via treatment and discharge.[96] Due to the poor quality of most produced water, however, steps must be taken to ensure that it does not contaminate existing freshwater or soil resources.

Understanding the fate of produced fluids is a piece of the oil and gas water-waste picture that deserves more attention.

Only Pennsylvania actively tracks the volumes of different types of fluid wastes being disposed of via injection as well as through other "surface" disposal methods mentioned above. As mentioned previously, waste disposal data from the DEP's Waste Reports should be reviewed and corrections may need to be made to ensure that waste volumes are not double-counted.[97] After editing DEP Waste Report volume and location data, Lutz et al. (2013) were able to use the data to determine disposal methods for fluid wastes generated by Pennsylvania Marcellus wells from 2008 through 2011: 39% went to brine or industrial waste treatment plants; 15% went to municipal sewage treatment plants; 5% was disposed of through underground injection; 32% was reused; and 9% was disposed of in other ways. They also found that 88% of the total volume of produced wastes (excluding reuse and other) was disposed of in Pennsylvania, and 12% was shipped out of state.[98]

We took a cursory look at surface disposal information for Colorado, and found that the available data present a multitude of challenges to performing an in-depth analysis of the fate of all types of oil and gas waste fluids in that state.[99] For example, volumes of waste fluids being disposed of in pits, and the estimated evaporation and percolation volumes could be obtained by looking at Form 15s "Earthen Pit Report/Permit" for each individual pit, which would be a monumental task. For example, a search for pits in Weld County, alone, returned 1607 records.[100] Similarly, data on waste disposed at permitted land application sites could be slowly accumulated by reviewing online documents on a facility-by-facility basis.[101]

It became clear from the quick analysis of Colorado data that reviewing the surface-based disposal and beneficial reuse options and reporting requirements for oil and gas fluid wastes in CO, TX, ND and WV was beyond the scope of this report. We focused, instead, on the reporting requirements and data availability for wastes disposed of underground via injection wells.

Injection wells

Volumes of oil and gas wastes disposed of through underground injection can be determined for all states in this report. But only Texas and Pennsylvania collect enough information from operators to be able to track volumes of different types of waste disposed of through underground injection.

	CO	TX	ND	PA	WV
Underground Injection of Wastes					
Report volumes of fluid wastes disposed of through injection	A	A	B	A	C
Report source wells (i.e., wells sending wastes to disposal site)	B	F	C	F	C
Report transportation method of wastes to disposal site	B	F	C	F	F
Report volumes of different types of waste injected	F	A	F	F	F

There are two types of wells that inject oil and gas wastes underground: enhanced recovery wells and disposal wells.[102] In the United States, the federal Environmental Protection Agency's (EPA) Underground Injection Control (UIC) program oversees the regulation of waste injection; however, all of the states in this report except Pennsylvania have been granted "primacy" for Class II (oil and gas fluid injection) wells by EPA, enabling the states to control the implementation of UIC programs within their borders.[103] Thus, CO, TX, ND and WV bear the responsibility for regulating and collecting relevant data about underground injection of oil and gas wastes.

Colorado

COGCC collects data on the volume of oil and gas wastes injected underground at permitted UIC facilities in the state, but injection facilities are not required to report the volumes of specific types of waste injected.

Operators are required to report the sources of the wastes to be accepted at the injection facility on Form 26 "Source of Produced Water for Disposal". Details provided on sources include the name, API number, operator information, location, producing formation, transportation method (pipeline vs. truck) and total dissolved solids concentration of the produced water for each oil or gas well that may dispose of its waste at the site.

These forms, which must be filed whenever new source wells are added, are accessible online in the injection well's COGIS documents. There is no requirement, however, for operators to provide COGCC with data on the monthly volumes accepted from each source.

Total monthly waste injection volumes can be accessed on a facility-by-facility basis through the COGIS online data query system.[104] The COGCC Production Report dataset also provides monthly disposal volume data for injection wells, which are wells with the Well Status "IJ".[105] It should be noted, however, that the Production Reports for a particular year do not contain a complete set of data for that year. For example, the 2013 Production Reports are missing data for the last quarter of the year. Data for these months are contained in the 2014 Production Report.

We analyzed data from the 2013 and 2014 Production Reports and found injection volume data for 32 injection wells (disposal and enhanced recovery) in Weld County. According to our calculations, these wells injected a total of 28.3 millon bbls of fluid in 2013.[106] As mentioned above, the oil and gas wells in Weld County generated close to 17 million bbls of produced water in 2013.[107] So Weld County injection wells were disposing of more than 11 million bbls of wastes other than produced water generated by oil and gas wells in the county.

Also, it is certain that Weld County injection wells accepted produced water and other wastes from outside the county. We examined source data for one injection well in Weld County. We selected this well because it was the only one that we found with source data in a spreadsheet format, rather than as a scanned document (pdf or tiff file). The SWD C8A injection well operated by NGL Water Solutions DJ LLC listed more than 17,000 sources providing wastes for disposal.[108] Only 7,106 of these sources had well API data associated with them. Of these 7,106 wells, 88% were located in Weld County. The remaining 12% of wells were from 17 other Colorado counties, and one county in Wyoming.[109]

Texas

Injection facility operators in Texas report monthly volumes of injected waste on Form H-10, which is filed annually. In October 2011, operators were required to start providing additional information on the percentage of specific types of fluid and gases, such as fracture water flowback, fresh water, saltwater, naturally occurring radioactive materials, polymer, steam, air, carbon dioxide, hydrogen sulfide, natural gas, and nitrogen, that are injected per year.[110]

Data on total volumes injected and volumes of specific fluids injected are available online, using RRC's H-10 Filing System Query.[111] Users can query data for a specific injection well, county, RRC district or the entire state.

We queried the H-10 Filing System and found that in 2013, operators reported that more than 6.95 billion barrels of fluid wastes were injected statewide; 97% of the wastes were reported to be saltwater (6.74 billion bbls), while less than 1% (68.35 million barrels) of injected wastes were reported as flowback.[112]

Other than Pennsylvania, Texas is the only state in this review that collects enough data to begin to get a picture of how much flowback is being injected, and therefore, potentially how much water is thereby removed from the hydrologic cycle. RRC data, however, may not be accurate enough to fully understand the losses – an analysis by Nicot et al. (2014) suggests that "the current RRC data clearly underestimate the volume of [hydraulic fracturing] fluids disposed in injection wells, most likely as a result of underreporting in the HF category and reporting to the salt-water general category instead."[113]

It is not clear whether or how RRC defines the flowback period. The H-10 instructions do not define a flowback period, but simply ask operators to report flowback as a percentage of total liquid injected during the cycle year.[114] Nor was a definition found in RRC rules. To ensure that operators and data users understand what is meant by "fracture water flowback," and enable operators to more consistently report these volumes, RRC should provide more guidance on how to differentiate flowback from saltwater.

North Dakota

For a fee, NDIC provides access to online data on the volumes of wastes (and water) disposed of at injection wells in the state.

Fluids permitted to be injected typically include Class II oil and gas wastes such as: produced water; drilling waste fluids; workover, completion and stimulation fluids; waste oil and fluids from oil field cleanup; and waste water from gas plants;[115] while enhanced recovery wells may be permitted to inject fresh water makeup and other waters.[116]

In North Dakota, injection disposal facility operators must include a list of source wells as part of the injection well application process.[117] NDIC also collects monthly information from operators on the sources of wastes on Form 16 "Saltwater Disposal Report" and/or Form 17 "Enhanced Recovery Report".[118] Copies of the filed forms may sometimes be found in the online Well File documents.[119]

Form 16 requires injection facility operators to list the waste source's operator, well name and number, location, whether the source is from a pit or a well, the monthly volume of waste transported from the source, and the form of transportation to the site (pipeline or truck).[120] Form 17 only requires the reporting of well name and number, location and monthly volume of injectate. Neither form requires operators to break down volumes by different types of waste (e.g., produced water, drilling fluids, used stimulation fluids, etc.), although the NDIC rules suggest that this is a requirement that the agency could impose on operators.[121]

NDIC-website users who have a paid subscription are able to obtain volume data for individual injection wells from NDIC.[122] However, we did not attempt to determine the volume of fluids injected in North Dakota – accessing and copying the online data for the 399 active saltwater disposal wells and 487 active enhanced recovery wells was beyond the scope of this report.[123]

Pennsylvania

The Underground Injection Control (UIC) program in Pennsylvania is administered by the federal Environmental Protection Agency (EPA), not the state.[124] According to the EPA website, in 2011 there were 1,857 Class II (oil and gas waste) injection wells in Pennsylvania,[125] but publicly available information on these wells is sparse.

For example, EPA's UIC web site does not include a list of the names of the injection wells overseen by EPA.[126] The agency does collect information on permitted UIC facilities, and maintain it in an internal electronic UIC database, but the public would be required to file a Freedom of Information Act request to access the data, and EPA may choose to redact data such as injection well location.[127]

Without access to EPA data, it is still possible to determine the volume of wastes originating from Pennsylvania oil and gas wells that is being injected in Pennsylvania. The PA DEP's publicly accessible Waste Report Database includes oil and gas waste volumes, method of disposal and name and location of the waste disposal facility (including permitted injection facilities located in Pennsylvania).[128] According to the Waste Database, in 2013 there were four injection wells located in Pennsylvania that accepted 198,371 bbls of waste (all produced water) from 451 Pennsylvania oil and gas wells.[129] It's not clear if the injection wells in Pennsylvania accept wastes from wells located outside of Pennsylvania, as this information is not reported to PA DEP.

West Virginia

Injection facility operators file Form WR-40 "Report for Waste Disposal Wells" each month. On the form, operators record the daily volumes of waste injected, as well as other operating parameters.

While not available online, information on the volume of wastes injected via disposal wells in West Virginia should be obtainable through filing a FOIA request.

Form WR-40 does not require operators to report the types of waste being accepted at the facility, but the UIC permit application asks for information on the physical and chemical characteristics of the injection fluid.[130] Similarly, source information is not reported on WR-40, but general information on sources of waste to be disposed at injection facilities is provided in the UIC permit application, as operators provide a list of all wells (by API number) that will be serviced by the injection facility.[131] DEP also has access to the manifest records for the facility, which document delivery of wastes, quantity, sources, transportation type and dates; however, these records are not actually submitted to DEP. Operators are simply required to furnish that information to the department if so requested.[132]

Conclusions

Oil and gas agencies in the five states reviewed here - CO, ND, TX, PA and WV - have differing, and in some cases, no reporting requirements for water use and waste production and disposal. Public access to data is also highly variable from state to state.

Information on water used for hydraulic fracturing is available for oil and gas wells in all of the states in this review, but because all of these states rely on FracFocus to some extent, they all suffer the same problem of enabling only moderate access to water-use data and uncertain data quality. Also, FracFocus reports do not provide any details on the volumes of different types of water used during hydraulic fracturing (e.g., fresh, brackish, reused/recycled).

One surprising finding is that eastern states require more stringent water reporting than western states, even though western states have more significant water scarcity concerns.

West Virginia and Pennsylvania require operators to submit Water Management Plans, and report details on fresh water sources used for hydraulic fracturing (including source location), and West Virginia also requires operators to report the source location of recycled water used during hydraulic fracturing. (Neither PA DEP nor WV DEP, however, provides easy access to the source data.) For the most part, Colorado, Texas and North Dakota do not have similar requirements.

Colorado

Colorado provides access to a significant portion of pertinent data on its web site, though often not in a format that allows for relatively easy analysis. Colorado is, however, among the better states when it comes to collection and presentation of data on produced water volumes, and waste injection volumes. Yet, Colorado does not track the sources of water used at each well site, nor require operators to report the disposal location for the wastes generated at a well site.

Texas

Of the states in this report, Texas has the least stringent reporting requirements for water and waste disposal. Oil and gas well operators are not required to report sources of fresh and/or recycled water used during hydraulic fracturing; nor to report volumes of waste generated at the well site.

Texas goes beyond other states, however, in one respect. The RRC requires operators of injection wells to report the volumes of different types of wastes being injected and the RRC has an easy-to-use online query system to access this information.

North Dakota

Sources of water used for hydraulic fracturing operations, the volume of hydraulic fracturing wastes (flowback), and disposal methods for flowback and other fluid wastes are not reported by operators of oil and gas wells in North Dakota.

The North Dakota Industrial Commission does a good job of collecting data on the volumes of produced water from each well, and total volume of produced water (but not other wastes) disposed of via underground injection. Injection well operators are also required to report the wells that are expected to send wastes to a disposal well. North Dakota limits public access by charging a fee to

access detailed online data. Water and waste data are not available in downloadable spreadsheets, but some data can be copied from tables generated through querying online databases.

Pennsylvania

Pennsylvania generally has more stringent reporting requirements for waste disposal volume and location data than other states in this report, except for West Virginia. Accessibility to waste data is also higher in PA than other states, although there is less data transparency in some respects.

For example, unlike Colorado (and North Dakota to some extent), Pennsylvania does not provide online access to the forms and documents filed by operators on a well-by-well basis. So some information, such as sources of fresh water and volumes of recycled water used for hydraulic fracturing, which is reported by operators on their Well Completion form, can only be obtained through a Right-to-Know request, or by conducting a well file review at a DEP office.

West Virginia

West Virginia, in many respects, has water and waste reporting requirements that equal and occasionally surpass those of Pennsylvania, such as requiring operators to report sources of recycled water used in hydraulic fracturing operations. But none of the West Virginia water and waste data are accessible online. To obtain the data, interested parties have to submit a Freedom of Information Act request to the DEP. Also, operators in West Virginia, like Texas, do not have to report the volumes of produced water generated by each oil or gas well.

Recommendations

All of the states reviewed in this report could improve reporting requirements and public accessibility to data on oil and gas water use and waste disposal.

The findings of this report lead to the following recommendations. By implementing these recommendations, states will both increase the availability of information regarding oil and gas development, and they will allow for a clearer understanding of water use and waste generation by this industry.

- **Recommendation #1: Reporting**
  - Reporting of water use and waste disposal should be required, not voluntary.
- **Recommendation #2: Transparency**
  - Reporting should be transparent to the public, and easily and freely accessible by the public online, whether on state websites or FracFocus.
- **Recommendation #3: Water Management Planning**
  - Operators should be required to submit water management plans for each well, including completion and stimulations through the life of the well.
- **Recommendation #4: Hydraulic Fracturing Water Use**
  - Operators should be required to report volumes of water used by type, and the sources of each type of water used.
- **Recommendation #5: Flowback & Produced Water Recovery and Disposal**
  - Operators should be required to report, separately for both flowback fluid and produced water, the volume recovered per well, how and where each well's flowback/ produced water is disposed, and how the waste is transported to the disposal site.
- **Recommendation #7: Disposal of Waste**
  - Disposal facilities should be required to report the source, type and volume of waste being disposed of at the facility.
- **Recommendation #8:Coordination of Oversight Across State Lines**
  - A mechanism for tracking the movement and volume of waste across state lines should be developed either by the states or EPA.
- **Recommendation #9: Penalties for Failure to Report**
  - Where reporting requirements are not met, states should penalize operators such that that the violating operator is deterred from future violations, and all operators cannot regard being caught and penalized as simply "the cost of doing business".

Where reporting gaps exist, states may be able to create new reporting requirements or revise existing forms to require more detailed information from operators. In some states, this may require a rulemaking to support the need for additional disclosures from operators.

Where data accessibility problems prevail, states may already have the data in internal databases, and may simply need to organize and publish the data in an accessible format. Other accessibility problems, however, may require the creation of a new online data management framework.

Improving reporting requirements and filling information accessibility gaps will require a commitment of resources to enable agency staff to review data and forms submitted by operators in a timely manner.

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Appendix B: Comparison of FracFocus and COGCC data.

The following two tables contain data from COGCC Form 5As for DJ Horizontal Wells in Weld County that underwent hydraulic fracturing treatments after April 1, 2012.[133] As of that date, Colorado operators have had to report fracturing water volume and chemical data to FracFocus.

Table B1. Comparison of fracturing fluid water volumes reported to FracFocus vs. COGCC for DJ Horizontal Wells in Weld County.

	Frac Focus (gallons)	COGCC Form 5A - (volumes converted from bbls to gallons)			Notes on COGCC and FracFocus (FF) data (≈ means approximately equal to)
API	Total water	Total fluid	Fresh water	Recycled	
05-123-35248	**2,596,968**	5,276,082	2,556,666	2,719,416	COGCC fresh water and FF differ by ≈ 40,000 gallons. Clearly, recycled water not included in FF.
05-123-33563	**2,615,004**	2,673,972	2,542,386	131,586	COGCC total fluid and fresh water differ from FF by ≈ 59,000 to 73,000 gallons, respectively.
05-123-33689	**2,131,287**	**2,131,290**			**Total fluids reported to COGCC ≈ FF.**
05-123-33688	**1,882,061**	**1,882,062**	**1,882,062**	0	**Total fluids = fresh water reported to COGCC ≈ FF.**
05-123-32424	**1,354,917**	1,342,950	1,342,950	0	COGCC and FF data differ by ≈ 12,000 gallons.
05-123-33080	**2,121,747**				No Form 5A found in COGCC well documents.
05-123-33493	**4,042,843**				No Form 5A found in COGCC well documents.
05-123-33166	**2,533,209**	2,670,024	2,502,738	167,286	COGCC total fluid and fresh water differ from FF by ≈ 137,000 to 30,000 gallons, respectively.
05-123-33330	**2,541,168**	2,686,236	**2,541,168**	145,068	**Fresh water reported to COGCC ≈ FF**. Clearly, recycled water not included in FF report.
05-123-33238	**2,250,080**	2,387,154	2,230,914	156,240	COGCC total fluid and fresh water differ from FF by ≈ 137,000 to 19,000 gallons, respectively.
05-123-33451	**2,485,465**				No Form 5A found in COGCC well documents.
05-123-33436	**2,431,468**	2,566,746	**2,431,254**	135,492	**Fresh water reported to COGCC ≈ FF**. Clearly, recycled water not included in FF report
05-123-35102	**2,192,442**	4,311,510	2,350,194	0	COGCC total fluid and fresh water differ from FF by ≈ 2,119,000 to 158,000 gal., respectively.
05-123-33958	**1,775,689**	**1,775,676**	505,890		**Total fluids reported to COGCC ≈ FF.**
05-123-33681	**2,230,246**	**2,230,242**	84,042		**Total fluids reported to COGCC ≈ FF.**
05-123-34404	**1,962,267**	**1,962,282**			**Total fluids reported to COGCC ≈ FF.**
05-123-36702	**6,898,942**	**6,898,962**	**6,898,962**	0	**Total fluids = fresh water reported to COGCC ≈ FF.**
05-123-35277	**2,235,748**	2,153,508	**2,235,744**	0	**Fresh water reported to COGCC ≈ FF.**
05-123-33800	**2,023,392**	2,193,366	2,046,030	147,336	COGCC total fluid and fresh water differ from FF by ≈ 170,000 to 23,000 gallons, respectively.
05-123-33822	**2,399,286**	2,275,266	0		COGCC total fluid and FF data differ by ≈ 124,000 gallons.
05-123-35804	**2,274,469**	2,290,680	0		COGCC total fluid and FF data differ by ≈ 16,000 gallons.
05-123-33956	**1,663,495**				No Form 5A found in COGCC well documents.
05-123-33475	**2,130,855**	2,285,850	**2,130,828**	155,022	**Fresh water reported to COGCC ≈ FF.** Clearly, recycled water not included in FF report.
05-123-33945	**2,514,414**	2,636,004			COGCC total fluid and FF data differ by ≈ 121,600 gallons.
05-123-33311	**1,762,899**	2,927,736	2,760,324	167,412	COGCC total fluid and fresh water differ from FF by ≈ 1,165,000 to 997,000 gal., respectively.
05-123-33231	**2,200,245**	2,338,938	2,181,858	157,080	COGCC total fluid and fresh water differ from FF by ≈ 139,000 to 18,000 gallons, respectively.
05-123-33267	**2,370,522**	2,511,684	**2,370,522**	141,162	**Fresh water reported to COGCC ≈ FF.** Clearly, recycled water not included in FF report.
05-123-36925	**3,234,127**	**3,234,126**	180,432	2,600,808	**Total fluids reported to COGCC ≈ FF.**
05-123-36926	**3,539,260**	**3,539,256**	0	0	**Total fluids reported to COGCC ≈ FF.**
05-123-36605	**3,831,215**	**3,831,198**	3,604,734	226,464	**Total fluids reported to COGCC ≈ FF.**
05-123-36052	**3,918,628**	**3,918,642**			**Total fluids reported to COGCC ≈ FF.**
05-123-38130	**4,371,681**	4,384,254	**4,371,738**	0	**Fresh water reported to COGCC ≈ FF.** (FF report says that water included "mix water supplied by client," but no recycled water was reported to COGCC. Unclear what is meant by mix water.)
05-123-37744	**6,581,502**	6,591,900	6,591,900	0	COGCC total fluid and FF data differ by ≈ 10,000 gallons.
05-123-33413	**3,322,228**	6,837,054	**3,322,200**	3,514,854	**Fresh water reported to COGCC ≈ FF.** Clearly, recycled water not included in FF report.
05-123-34750	**1,781,356**	2,781,366	0	2,781,366	Total fluid = recycled water reported to COGCC, differ from FF by ≈ 1,000,000 gallons.
05-123-36639	**2,176,734**	2,331,546	**2,176,734**	154,812	**Fresh water reported to COGCC ≈ FF.** Clearly, recycled water not included in FF report.
05-123-36034	**2,120,908**	**2,120,916**	**2,120,916**		**Total fluids = fresh water reported to COGCC ≈ FF.**
05-123-36854	**3,441,006**	3,450,510			COGCC total fluid and FF data differ by ≈ 10,000 gallons.
05-123-33086	**2,569,147**	5,242,398	2,555,280	2,687,076	COGCC total fluid and fresh water differ from FF by ≈ 2,673,000 to 14,000 gallons, respectively.
05-123-33097	**2,898,219**	5,975,802	**2,898,210**	3,077,592	**Fresh water reported to COGCC ≈ FF.** Clearly, recycled water not included in FF report.
05-123-36660	**2,089,016**	2,219,364	**2,088,996**	130,368	**Fresh water reported to COGCC ≈ FF.** Clearly, recycled water not included in FF report.
05-123-33067	**1,678,556**	3,460,590	**1,677,858**	1,782,690	**Fresh water reported to COGCC ≈ FF.** Clearly, recycled water not included in FF report.
05-123-33087	**2,046,641**				No Form 5A found in COGCC well documents.
05-123-33082	**1,997,623**				No Form 5A found in COGCC well documents.
05-123-33801	**2,050,259**				No Form 5A found in COGCC well documents.
05-123-34877	**3,867,440**	**3,867,444**			**Total fluids = fresh water reported to COGCC ≈ FF.**
05-123-35060	**2,445,408**	2,605,554	**2,445,408**	160,146	**Fresh water reported to COGCC ≈ FF.** Clearly, recycled water not included in FF report.
05-123-36123	**3,839,735**	**3,839,724**	**3,839,724**	0	**Total fluids = fresh water reported to COGCC ≈ FF.**
05-123-35958	**2,156,994**	**2,156,994**			**Total fluids reported to COGCC ≈ FF.**
05-123-33796	**2,175,684**	**2,175,684**	**2,175,684**		**Total fluids = fresh water reported to COGCC ≈ FF.**

Blank cells mean no value was reported in Form 5A.

Table B2. Flowback data reported on COGCC Form 5A (6/12 version) for DJ Horizontal Wells in Weld County.

API	Total fluid used during hydraulic fracturing (gallons)	Total fluid used during hydraulic fracturing (barrels)	Flowback recovered (barrels)	% of hydraulic fracturing fluid recovered	Flowback disposal method
05-123-35248	5,276,082	125,621	11,570	9.2	recycle
05-123-33563	2,673,972	63,666	6,983	11.0	recycle
05-123-33689	2,131,290	50,745			
05-123-33688	1,882,062	44,811			
05-123-32424	1,342,950	31,975	13,668	42.7	disposal
05-123-33080					
05-123-33493					
05-123-33166	2,670,024	63,572	15,149	23.8	recycle
05-123-33330	2,686,236	63,958	9,126	14.3	recycle
05-123-33238	2,387,154	56,837	10,668	18.8	recycle
05-123-33451					
05-123-33436	2,566,746	61,113	10,407	17.0	recycle
05-123-35102	4,311,510	102,655	11,048	10.8	recycle
05-123-33958	1,775,676	42,278			
05-123-33681	2,230,242	53,101			disposal
05-123-34404	1,962,282	46,721			
05-123-36702	6,898,962	164,261	39,065	23.8	disposal
05-123-35277	2,153,508	51,274	7,800	15.2	disposal
05-123-33800	2,193,366	52,223	6,995	13.4	recycle
05-123-33822	2,275,266	54,173			
05-123-35804	2,290,680	54,540			
05-123-33956					
05-123-33475	2,285,850	54,425	8,721	16.0	recycle
05-123-33945	2,636,004	62,762			recycle
05-123-33311	2,927,736	69,708	11,341	16.3	recycle
05-123-33231	2,338,938	55,689	9,450	17.0	recycle
05-123-33267	2,511,684	59,802	9,382	15.7	recycle
05-123-36925	3,234,126	77,003	8,005	10.4	disposal
05-123-36926	3,539,256	84,268	9,085	10.8	disposal
05-123-36605	3,831,198	91,219	10,900	11.9	disposal
05-123-36052	3,918,642	93,301	24,879	26.7	disposal
05-123-38130	4,384,254	105,387	32,848	31.2	disposal
05-123-37744	6,591,900	156,950	26,531	16.9	disposal
05-123-33413	6,837,054	162,787	2,980	1.8	recycle
05-123-34750	2,781,366	66,223	2,105	3.2	disposal
05-123-36639	2,331,546	55,513	11,424	20.6	recycle
05-123-36034	2,120,916	50,498	12,045	23.9	disposal
05-123-36854	3,450,510	82,155	2,570	3.1	disposal
05-123-33086	5,242,398	124,819	15,403	12.3	recycle
05-123-33097	5,975,802	142,281	12,233	8.6	recycle
05-123-36660	2,219,364	52,842	208	0.4	recycle
05-123-33067	3,460,590	82,395	9,555	11.6	recycle
05-123-33087					
05-123-33082					
05-123-33801					
05-123-34877	3,867,444	92,082	64,330	69.9	disposal
05-123-35060	2,605,554	62,037	7,616	12.3	recycle
05-123-36123	3,839,724	91,422	35,559	38.9	disposal
05-123-35958	2,156,994	51,357	18,757	36.5	disposal
05-123-33796	2,175,684	51,802	52,014	100.4	disposal

Blank cells mean no value was reported in Form 5A.

Endnotes

[1] Hansen et al. 2013 provide information on the data challenges, including data quality issues for PA and WV. See Sections 7.1.2 and 7.2.2 Data Collection and Reporting for WV and PA, respectively, and Appendices C and D..

[2] Hansen et al. 2013.

[3] For PA and WV data, we draw on our own research as well as information provided by the Hansen study.

[4] Freyman, M. 2014. Hydraulic Fracturing & Water Stress: Water Demand by the Numbers. (Ceres) Available at: http://www.ceres.org/resources/reports/hydraulic-fracturing-water-stress-water-demand-by-the-numbers/view

[5] Horner et al. 2014, p. 11.

[6] PA DEP. Marcellus Shale Development Fact Sheet. p. 3. http://www.portal.state.pa.us/portal/server.pt/document/1376566/marcellus_shale_development_pdf

[7] SRBC web site: Frequently Asked Question #5: "In addition to the requirement for mitigation, what other kinds of conditions are included in SRBC's consumptive use approvals?" http://www.srbc.net/programs/natural_gas_development_faq.htm

[8] SRBC Presentation: "An Overview of the Project Review Process and Docket Content." http://www.srbc.net/programs/docs/SRBC_Regulatory_Introduction.pdf

[9] SRBC web site: Approved Source List for Natural Gas Development. http://www.srbc.net/wrp/ApprovedSourceList.aspx Approval documents are for docketed approvals only.

[10] Hansen et al. 2013, Table 11.

[11] WV DEP. Water Management Plan/Water Addendum Instructions. http://www.dep.wv.gov/oil-and-gas/Water%20Management/Documents/Water%20Management%20Plan%20Revised%20Instructions.pdf

[12] Hansen et al. 2013, p. 12.

[13] According to Horner, et al. 2014, "Using an automated program, the pertinent well data for the North Dakota portion of the Bakken play was downloaded from FracFocus.org." The automated program used to extract data from FracFocus was utilized in 2013, apparently prior to the changes to the FracFocus web site. (Pers. Comm. with Argonne report author Corrie Clark). http://www.ipd.anl.gov/anlpubs/2014/05/104645.pdf. Skytruth web site: Fracking Chemical Database. http://frack.skytruth.org/fracking-chemical-database.

[14] Pers. Comm. From Mike Nickolaus, Groundwater Projection Agency (which administers the FracFocus web site) to Bruce Baizel, Earthworks. August 20, 2013. "One way to avoid this kind of problem in the future is to slow down a little. If you wait until one search completes or one pdf loads before requesting another, the system will not think you are a bot."

[15] "Pursuant to West Virginia's Legislative Rule Title 35, Series 8, Section 10.1.a., certain hydraulic fracturing chemical information is required to be disclosed for wells permitted under West Virginia Code §22-6A [Natural Gas Horizontal Well Act]. The information is required to be provided to both the Office of Oil and Gas and the FracFocus Chemical Disclosure Registry. (From: Instructions for Completing Well Record (Form WR-35), p. 3. http://www.dep.wv.gov/oil-and-gas/GI/Forms/Documents/WR-35%20Instructions%20For%20Completing%20Well%20Record.pdf) Conceivably this definition would omit shale oil wells and vertically fracked natural gas wells, were any to be developed in WV.

[16] FracFocus: http://fracfocus.org/ We searched the FracFocus database by State = Colorado and County=Weld, and used the date filter option to include jobs that occurred in 2013. The data in FracFocus show that some wells performed more than one treatment, e.g., fractured different formations, and reported them separately. We removed what appeared to be duplicate data for twelve wells 1) because it appeared that the company had posted the data twice (well name, fracture dates and volumes were exactly the same), and there was no indication in COGCC documents that the company performed more than one fracturing treatment on the particular date; 2) fracture dates were different on two dates but COGCC data showed that only one treatment occurred, and the data matched one of the set of dates; 3) Duplicate data had all of the same information except the depth and volume were different – so we assumed the company filed updated information with FracFocus to correct a reporting error.

[17] FracFocus web site: "How to read a fracturing record."http://www.fracfocus.org/welcome/how-read-fracturing-record Also, see the caveat added for Total Water Volume" found on the bottom of FracFocus reports.

[18] See COGCC Rule 205A "Hydraulic Fracturing Chemical Disclosure". COGCC Rules are available at: http://cogcc.state.co.us/RR_Docs_new/Rules_new2.html

[19] The old version of the form simply asked operators to report a brief summary of the formation treatment.

[20] To obtain data, one must download the Completed Interval Report for each and every well of interest. This is done through a COGIS Facility Search (http://cogcc.state.co.us/cogis/FacilitySearch.asp) to find a well's Scout Card (can search for a well by name, API, county, operator, etc.). Sometimes the data from Form 5As are listed in the Scout Card data under "Completed information for formation XXX"). Otherwise, from the Scout Card, Form 5A can be accessed by clicking on the "Doc" heading at the top of the screen. In the documents, the COGCC-approved form is listed as "Completed Interval Report." (The document entitled Form 5A is the version submitted by the operator prior to approval.)

Only wells that filed Form 5A after June 2012 are supposed to report the volume of fresh water and recycled water used. Not all operators include the information on fresh and recycled water. As seen in Table B1 (Appendix B), out of 50 Form 5As submitted after June 2012, there were six instances where operators did not include any volume information for fresh or recycled water – just total volume of water used for hydraulic fracturing. In other cases, fresh water was reported as 0, and the recycled water space was left blank, so it is unclear what type of water was used.

[21] According to COGCC, currently, it takes the agency six months or more to review the submitted forms and post them online. (Pers. Comm. Between Lisa Sumi and Jane Stanczyk, COGCC. August 27, 2014). The wells that we looked at were completed between 13 and 24 months prior to when we searched the COGCC online records (data accessed September 7 – 14, 2014). So completion information should have been in the online well files.

[22] Pers. Comm. Between Lisa Sumi and Jane Stanczyk, COGCC. August 27, 2014.

[23] We examined G-1 and W-2 forms for 50 wells completed in Karnes County, TX. Many of the wells did not have any data on the amount and kind of material used during "acid, shot, fracture, cement squeeze, etc.". This may be because the wells were not yet completed. Of the 23 wells that had information on materials used, only one provided information on "water" used. Others referred to "total fluid", "slickwater", and two provided information on "brine" used in the treatments. Several W-2/G-1s simply listed the number of frac stages, but not information on materials used.

A copy of the filed G-1 or W-2 can be found online via the RRC Oil and Gas Completions query. Pdf versions of the forms are downloadable. http://webapps.rrc.state.tx.us/CMPL/publicHomeAction.do

[24] Some researchers have used data from IHS, a consulting firm. But this is a paid service and not publically accessible, as noted by Nicot et al. 2014.

[25] NDIC Form 6 Well Completion Or Recompletion Report. Available at: https://www.dmr.nd.gov/oilgas/rules/fillinforms.asp

[26] The Well Files contains scanned images of the forms filed by the operator in one large pdf file, and these pdfs can be searched to find Form 6 or other forms of interest. Well Files can be accessed by web site users who have a basic or premium subscription. For more information see: https://www.dmr.nd.gov/oilgas/webhelpfaq.asp#subs1. Checking data quality by comparing data in Form 6s to that reported in FracFocus reports could have provided information on data quality; however, the process of looking through large numbers of Well Files hoping to locate Form 6s was too time consuming for this report.

[27] See DEP Form 8000-FM-OOGM0004b Instructions: http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-87038/8000-FM-OOGM0004b%20Instructions.pdf Also, Earthworks reviewed more than a dozen OOGM0004b forms accessed through a previous project, and the source of recycled water was not reported on any of them.

[28] FracFocus web site: "While FracFocus is not intended to replace or supplant any state governmental information systems it is being used by a number of states as a means of official state chemical disclosure. Currently, ten states: Colorado, Oklahoma, Louisiana, Texas, North Dakota, Montana, Mississippi, Utah, Ohio and Pennsylvania use Fracfocus in this manner." Although not required by WV operators, a search of the FracFocus database returned information on 770 West Virginia wells as of Sept. 8, 2014.

[29] WV DEP web site: Frac Water Reporting Form. http://www.dep.wv.gov/WWE/wateruse/Pages/FracWaterReportingForm.aspx

[30] Pers. Comm. Brian Carr, WV DEP and Lisa Sumi. Sept. 3, 2014.

[31] Pers. Comm. Justin Nottingham, WV DEP and Lisa Sumi. Sept. 22, 2014. WV DEP Form 35 "Well Operator's Report of Well Work" is accessible at: http://www.dep.wv.gov/oil-and-gas/gi/forms/Pages/default.aspx

[32] E.g., Nicot et al. (2014, p. 6) write that in Texas "volumes of surface water withdrawn are well-known but their ultimate use is not, because several uses are bundled into larger categories, e.g., in the case of HF, "mining"". Horner et al. write that in North Dakota, "there is no easy way to link hydraulic fracturing activities to their specific water sources… much of the water used for hydraulic fracturing in North Dakota comes from public or private water depots. Records indicating which water depots were used for each hydraulic fracturing occurrence could not be found." (p. 3) In Colorado, the Colorado Division of Water Resources tracks permits for water supply wells, and it is possible to identify some that belong to oil and gas companies; but the actual volumes used and the specific use of the water is not provided. The COGCC lists "potential sources of water for hydraulic fracturing" such as water transported from outside the state, irrigation water leased or purchased from a landowner, ground water diverted from various basin, etc. But no specific details or even estimates of volumes from the different types of sources are provided. http://www.ipd.anl.gov/anlpubs/2014/05/104645.pdf

[33] See p. 8, "Notes on Collected Information" and tables on page 56.

[34] E.g., see Kurz et al. 2011. and Horner et al. 2014. pp. 11, 13.

[35] Horner et al. 2014, p. 3.

[36] Kurz et al. 2011. p. 3, 4.

[37] See Kurz et al. 2011 p. 2, and Horner et al. 2014. p. 15.

[38] See DEP Form 8000-FM-OOGM0004b Instructions: http://www.elibrary.dep.state.pa.us/dsweb/Get/Document-87038/8000-FM-OOGM0004b%20Instructions.pdf Also, Earthworks reviewed more than a dozen OOGM0004b forms, and the source of recycled water was not reported on any of them.

[39] Hansen et al. 2013, p. 28.

[40] Hansen et al. 2013, p. 16.

[41] WR-35 forms do not require operators to report sources of water used to stimulate oil and gas wells; just volumes of water used.

[42] Nicot, J-P, Scanlon, B.R., Reedy, R.C. and Costley, R.A. 2014. Source and Fate of Hydraulic Fracturing Water in the Barnett Shale: A Historical Perspective." Journal of Environmental Science and Technology. 2014:48(4), pp. 2464-2471. Copy of Just Accepted Manuscript available at: http://www.beg.utexas.edu/water-energy/docs/Nicot-et-al_Barnett%20Shale%20Water%20Use_ES&T-2014+SI.pdf.

[43] Nicot et al. 2014.

[44] US Geological Survey (USGS). March 2014. A Framework for Assessing Water and Proppant Use and Flowback Water Extraction Associated with Development of Continuous Petroleum Resources. Fact Sheet 2014-3010. p. 2.

[45] COGCC. Form 5A Example Definitions. http://cogcc.state.co.us/forms/instructions/5A_Instruction20120705.pdf

[46] For some wells found through searching the COGIS database, the well's online Scout Card lists "Completed information" for the various formations. In that section, data from the Form 5As, such as flowback volume recovered and disposition method for flowback can be found. (E.g., cogcc.state.co.us/cogis/FacilityDetail.asp?facid=12337744&type=WELL). In other cases, the data can only be found by going into the documents for the well, and downloaded Form 5A, also sometimes referred to as Completed Interval Report (e.g., cogcc.state.co.us/cogis/FacilityDetail.asp?facid=12332505&type=WELL).

[47] ibid.

[48] Nicot et al. 2013, p. 156.

[49] PA DEP web site: Act 13 Frequently Asked Questions. "When does the hydraulic fracturing operation officially end for the purposes of this section?"http://www.portal.state.pa.us/portal/server.pt/community/act_13/20789/act_13_faq/1127392

[50] Hansen et al. 2013: p. 31.

[51] State Review of Oil and Natural Gas Environmental Regulations Inc. (STRONGER) 2013. Pennsylvania Follow-up State Review. p. 163. http://strongerinc.org/sites/all/themes/stronger02/downloads/Final%20Report%20of%20Pennsylvania%20State%20Review%20Approved%20for%20Publication.pdf

[52] PA DEP web site: PA DEP Oil & Gas Reporting Website – Waste Reports.

[53] SRBC web site: Frequently Asked Question #5: "In addition to the requirement for mitigation, what other kinds of conditions are included in SRBC's consumptive use approvals?" http://www.srbc.net/programs/natural_gas_development_faq.htm

[54] Hansen et al. 2013, p. 31.

[55] WV Department of Environmental Protection. "Hydrofracturing Water Use Reporting Instructions." http://www.dep.wv.gov/WWE/wateruse/Documents/HydrofracturingWaterUseReportingInstructions.pdf

[56] WV DEP. Form WR-34. "Discharge Monitoring Report." http://www.dep.wv.gov/WWE/permit/npdes/Pages/default.aspx Also, Pers. Comm. Justin Nottingham, WV DEP and Lisa Sumi. Sept. 12, 2014.

[57] Hansen et al. 2013, p. 20.

[58] Horner et al. 2014 (pp. 8 – 10, 13) report that flowback water is not currently being reused on a large scale in the Bakken shale play. In Texas, based on information from operators, Nicot et al. 2012, (pp. 54 and 70) reported that in 2011, close to 0% of flowback was being reused/recycled.

[59] For wells using more than 750,000 gallons to fracture a well, this information is reported through DEP's Frac Water Reporting Form. http://www.dep.wv.gov/WWE/wateruse/Pages/FracWaterReportingForm.aspx Other wells may report the information on Form WR-34 "Discharge Monitoring Report" http://www.dep.wv.gov/oil-and-gas/GI/Forms/Documents/WR-34%20-%20Discharge%20Monitoring%20Report.pdf

[60] Hansen et al. 2013, pp. 21, 22 and 35.

[61] Hansen et al. 2013, pp. 25 and 37.

[62] Boschee, P. Feb. 2014. "Produced and Flowback Water Recycling and Reuse – Economics, Limitations and Technology." Oil and Gas Facilities. p. 20. http://www.halliburton.com/public/multichem/contents/Papers_and_Articles/web/Feb-2014-Oil-Gas-Facilities-Article.pdf

[63] Clark, C.E. and Veil, J.A. 2009. Produced Water Volumes and Management Practices in the United States. Argonne National Laboratory. Prepared for U.S. Department of Energy. p. 7. Report is available at: http://www.ipd.anl.gov/anlpubs/2009/07/64622.pdf

[64] Boschee, P. Feb. 2014. "Produced and Flowback Water Recycling and Reuse – Economics, Limitations and Technology."Oil and Gas Facilities. p. 20. http://www.halliburton.com/public/multichem/contents/Papers_and_Articles/web/Feb-2014-Oil-Gas-Facilities-Article.pdf

[65] Vidic, R.D., Brantley, S.L., Vandenbossche, M., Yoxtheimer, D. and Abad, J.D. 2013. Impact of Shale Gas Development on Regional Water Quality. Science. Vol. 340. pp. 1235009-5 and -6.

[66] RRC of Texas. Oil and Gas Docket No. 01-0285309. June 2, 2014. Examiners Report and Proposal for Decision. The Application of District Disposal, LLC, Pursuant to Statewide Rule 8 for a Commercial Permit to Dispose of Oil and Gas Waste by Injection into a Porous Formation not Productive of Oil or Gas, District Shiner SWD Lease, Well No. 1, Eagleville (Eagle Ford-1) Field, Gonzales County, Texas. http://www.rrc.state.tx.us/media/21707/01-85309-r9-pfdplusattachmt.pdf

[67] COGCC Form 5 "Monthly Report of Operations"(http://cogcc.state.co.us/Forms/forms.html)

[68] COGCC COGIS Production Data Inquiry. http://cogcc.state.co.us/cogis/ProductionSearch.asp

[69] COGCC web site: Production Data Downloads. http://cogcc.state.co.us/Library/statistics.asp

[70] It should be noted that the COGCC Production Reports for a particular year do not contain a complete set of data for that year. For example, the 2013 Production Reports are missing data for the last quarter of the year. Data for these months are contained in the 2014 Production Report.

[71] COGCC Reports Portal. http://cogcc.state.co.us/COGCCReports/production.aspx?id=MonthlyWaterProdByCounty The Reports Portal provided a different state total of produced water (386,514,770 bbls), which is more than we calculated from the COGCC 2013 Annual Production Summary (386,259,508 bbls). It may be that the Reports Portal contains the most up-to-date information, while the spreadsheet databases are not re-posted after revisions are made (or are infrequently revised and reposted to the web site). COGCC states that it measures oil and gas production in barrels, which is equivalent to 42 U.S. gallons (http://cogcc.state.co.us/COGIS_Help/FAQ.htm). There are 3.78541 liters in one U.S. gallon.

[72] Nicot et al. 2014, p. 7 and 14.

[73] According to IHS, "Texas water production is not required to be filed by the RRC so IHS calculates the water by using a Water Oil Ratio (Net Water, Net Oil) from the W-10 (Oil Capacity Test) and the G-10(Gas Capacity Tests). The percentage of Water to Oil is then applied to the reported lease/well level oil and gas production volumes." (Pers. Comm. Dick Catto, IHS, and Lisa Sumi. August 12, 2014).

[74] Pers. Comm. Justin Hirsch (IHS) and Lisa Sumi. August 12, 2014.

[75] Pers. Comm. J-P Nicot (University of Texas) and Lisa Sumi. August 12, 2014.

[76] For example, Nicot et al. (2014, p. 7) write that "Production water volumes were compiled from the IHS database. About 10% of the wells do not have production water data, most likely because of lack of reporting. . ."

Also, IHS provides these words of caution: "Our advice to users of the Texas water data is as follows: 1. Understand that it is an estimate; 2. The estimates are entirely predicated on good well tests – either initial potential or annual well capacity tests; 3. Estimates in the early life of the well are often too high; 4. Some wells do not have tests for many months (or more), during that time IHS will estimate 0 water do to the lack of test information; 5. The IHS estimates provide some useful information the water-cut from one well to other nearby wells. It can help users to determine if a specific reservoir in a specific area is water prone, and 6. IHS does NOT recommend trying to use the IHS estimated summary water production on a large area to draw ANY conclusions on the amount of produced water." Pers. Comm. Justin Hirsch (IHS) and Lisa Sumi. August 12, 2014.

[77] North Dakota Industrial Commission Form 5 "Oil Production Report" (https://www.dmr.nd.gov/oilgas/rules/fillinforms.asp).

[78] Both the Basic and Premium Subscription Services provide data on Production and Injection Volumes by field, unit, and well. The Premium Service also includes state production volumes. Information about these services can be found on the NDIC web site under Basic Services: https://www.dmr.nd.gov/oilgas/basicservice.asp and Premium Services: https://www.dmr.nd.gov/oilgas/subscriptionservice.asp

[79] The Well Index download is found under the Basic and Premium Service tabs of the NDIC web site: https://www.dmr.nd.gov/oilgas/

[80] According to the PA DEP Oil and Gas Reporting Website (https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Welcome/Agreement.aspx): "Pennsylvania's Oil and Gas Act requires unconventional well operators to submit production reports to the Department of Environmental Protection (DEP) biannually—on Aug. 15 for the period of Jan. 1 through June 30 for the same calendar year and on Feb. 15 for the period of July 1 through Dec. 31 of the previous calendar year. All other oil and gas operators are required to submit production reports on an annual basis on Feb. 15 for the previous calendar year."

[81] See Lutz et al. (2013). "Wastewater and gas production data are reported by oil and gas well operators in accordance with PA law with no attempt by PA DEP to control data quality."(p. 11) ". . . identical volumes of a given wastewater type for a single well were often repeatedly listed within a given year with each record indicating a different disposal facility. In these cases the volume listed was for the total amount of the wastewater type generated by the well that year, not for the amount taken to each facility . . . The true volume accepted by each facility is unknown, but for the sake of our analyses, we assumed each facility received equal volumes, thus dividing the wastewater amount reported for each well within a given year by the number of entries listing identical values. Approximately 23% of all Marcellus wastewater by volume had to be divided across facilities using this method. Importantly, without this correction, wastewater volumes are overestimated (by up to 45%) as well as systemically biased towards artificial inflation of Marcellus well wastewater." (pp. 8, 9 of Ahead-of-Print version.)

[82] Lutz et al. 2013. p. 16 of the Ahead-of-Print version.

[83] In West Virginia, operators do not report volumes. They are required, however, to retain records of produced water production, and furnish them to WV DEP upon request. (West Virginia CSR. Title 35, Series 8. Section 35-8-9.1.b.3.A. and 9.1.b.3.C. http://apps.sos.wv.gov/adlaw/csr/readfile.aspx?DocId=25702&Format=PDF)

[84] Hansen et. al. 2013, p. 72.

[85] COGCC. 2014. 2013 Annual Report to the Water Quality Control Commission and Water Quality Control Division. p. 7. https://www.colorado.gov/pacific/sites/default/files/T1_WQCC_181AR_COGCC-2013.pdf

[86] COGCC web site: COGIS Production Search (http://cogcc.state.co.us/cogis/ProductionSearch.asp). Users may search for individual well (or for all wells in a county, etc.). Click on the year to get the production report, which includes oil, gas and water production, and water disposal. Alternatively, the COGIS Facility Search (http://cogcc.state.co.us/cogis/FacilitySearch.asp) produces the online Scout Card for a well. If users click on the well name, all of the production data for the well are provided.

[87] COGCC web site. Production Reports by year. http://cogcc.state.co.us/Library/statistics.asp (Note: the Production Summaries do not include the produced water disposal code information).

[88] We used the 2013 and 2014 Production Report spreadsheets (downloaded from: http://cogcc.state.co.us/Library/statistics.asp). We filtered both spreadsheets by County = 123 (i.e., Weld County); then by year = 2013 (to remove non-2013 data). We then calculated the total volume of produced water disposed of by the various methods: I – Injected on lease; M – Commercial disposal facility; P – onsite pit; C – central disposal pit or well. We added the totals for each category for the two spreadsheets.

Why this is a rough estimate: there may have been data in the 2014 spreadsheets that duplicated or updated data from the 2013 spreadsheet. We did not look for duplicate monthly entries. Therefore, this should be considered a rough estimate. Also, there were some produced water volumes that did not have a disposal method associated with them – but all of these were determined to be injection wells reporting the volumes being injected (i.e., well status was IJ) except for four entries, which were producing wells. We looked up the API of that particular well (05-123-26493) in the COGIS online database, and found that the injection method was M. We also found, however, that the water volumes in the Production Report did not match what was found when we searched the online COGIS Production Data Query (http://cogcc.state.co.us/cogis/ProductionSearch.asp) for the well. The downloaded Production Report showed 18 barrels of water produced each month, for nine out of the first 10 months of the year (no report for September), whereas the online data show no water production in January, July, August, September and October. We did not perform a similar comparison for other wells, so it's not clear how many wells may have data discrepancies of this sort.

[89] Operators are required to maintain these records for three years, and furnish them to WV DEP upon request. (West Virginia CSR. Title 35, Series 8. Section 35-8-9.1.b.3.B. and 9.1.b.3.C. http://apps.sos.wv.gov/adlaw/csr/readfile.aspx?DocId=25702&Format=PDF)

[90] According to the 2013 report for Pennsylvania, "Records pertaining to waste volumes and the location of disposal or recycling facilities are submitted annually to OOGM as part of an operator's annual waste and production reporting responsibilities." (State Review of Oil and Natural Gas Environmental Regulations Inc. (STRONGER) 2013. Pennsylvania Follow-up State Review. p. 164. http://strongerinc.org/sites/all/themes/stronger02/downloads/Final%20Report%20of%20Pennsylvania%20State%20Review%20Approved%20for%20Publication.pdf)

[91] https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/Waste/WasteHome.aspx

[92] Hansen et al. (2013) conducted an analysis of flowback waste disposal methods, and Lutz et al. (2013) looked at disposal methods and disposal location for all types of fluid wastes (produced water, drilling wastes, flowback, etc.), but did not separate out produced water, per se.

[93] Hansen et al. 2013, p. 37.

[94] Hansen et al. 2013, pp. 25-26 and 37-38.

[95] To begin to understand the volume of water that might be introduced into the hydrologic cycle, researchers would need to know the volume of fresh water injected (or lost from the hydrologic system) during hydraulic fracturing, and account for that water by tracking flowback and produced water volumes. Only after a volume equivalent to the volume of fresh water injected has been removed from the well would subsequent produced water be considered a potential new source to the hydrologic system. Researchers would also have to know the fate of the produced water, to determine if it has, indeed, stayed at the surface where it could be incorporated into the global hydrologic cycle, rather than being disposed of underground (and again lost to the hydrologic system).

[96] Clark, C.E. and Veil, J.A. 2009. Produced Water Volumes and Management Practices in the United States. Argonne National Laboratory. Prepared for U.S. Department of Energy. (See section 2.4 on Produced Water Management.) Report is available at: http://www.ipd.anl.gov/anlpubs/2009/07/64622.pdf

[97] See footnote 82 Lutz et al. (2013). "Wastewater and gas production data are reported by oil and gas well operators in accordance with PA law with no attempt by PA DEP to control data quality."

[98] Lutz et al. (2013) data appear in Hansen et al. (2013), p. 37; and Appendix D outlines steps taken by Lutz et al. to edit the DEP data. See also, Lutz et al. (2013, p.12) who report that only 13.6% of the data in the Waste Database had geographic coordinates for the disposal facilities; they used various alternative sources to find location data for these facilities, and in the end managed to find data such that the had location data for 60% of the wells.

[99] Produced water disposition data are included in the online data, accessible on a well-by-well basis, and in the annual Production Reports, which report monthly production of oil, gas and/or water, as well as the water disposition code, for each well, and ostensibly for each month of the year. Furthermore, if production is occurring from more than one geological formation, there is a separate entry in the database. So, for example, the well with API 5-123-5002 has 24 separate entries in the 2013 Production Report. And the water disposition method was not the same for all months (most months the water went to a central disposal pit or well, but in one month it was sent to a commercial facility. Depending on how many wells are being examined, and over what time period, it could be a very time-consuming process to summarize water disposition data for each well. Furthermore, one of the categories is "centralized pit or well". A centralized well, presumably involves the injection of wastes underground, while a centralized pit would be a surface disposal activity. More detail on the actual disposal method would be necessary to understand the volume of wastes lost or introduced to the hydrologic system, or even simply to better understand waste management practices on the whole. And finally, Colorado does not require operators to report the methods of disposal for flowback in detail (operators only report if these wastes are recycled or disposed, but not the method of disposal). The proposed method of drilling fluid waste disposal is reported on Form 2, but operators are not required to provide a volume of drilling fluid. (See Form 2, 8/13 revision, at: http://cogcc.state.co.us/Forms/forms.html)

[100] By conducting a COGIS Facility search for Pits (http://cogcc.state.co.us/cogis/FacilitySearch.asp), it is possible to get a list of all permitted pits in the state, or in a particular county or field.

[101] By conducting a COGIS Facility search for Land Application (http://cogcc.state.co.us/cogis/FacilitySearch.asp), it is possible to get a list of all permitted land application sites in the state, or in a particular county or field. But COGIS facility data, even for active sites, does not always contain the documents that would provide the information on types of wastes, and volumes (e.g., Waste Manifest reports).

[102] U.S. Environmental Protection Agency web site: "Class II Wells – Oil and Gas Related Injection Wells." http://water.epa.gov/type/groundwater/uic/class2/index.cfm

[103] Colorado does not have primacy for all classes of UIC wells; just Class II (oil and gas fluid injection) wells. (See: U.S. Environmental Protection Agency. No date."States' and Territories' Responsibility for the UIC Program." http://www.epa.gov/ogwdw/uic/pdfs/Delegation%20status.pdf)

[104] COGIS Facility Inquiry (http://cogcc.state.co.us/cogis/FacilitySearch.asp). Users can narrow their search by: UIC disposal, UIC enhanced recovery, and UIC simultaneous disposal facilities; and look for all wells in the state, or narrow the search by county, field, operator, etc. The COGIS disposal facility information includes a list of individual injection wells, and by clicking on the API number of an injection well and then the well name one can access monthly injection volume data.

[105] Production Reports are available at: http://cogcc.state.co.us/Library/statistics.asp

[106] We also found one additional injection well through a search of the COGIS Facility query = UIC Disposal. The Suckla Farms Injection Well 1 (API: 05-123-14291) was not in the Production Report dataset. It appears from the well documents that this well is administered by EPA and the Colorado Department of Public Health and Environment, not COGCC, so the data on injection volumes do not appear in the COGCC's Production Report for the well (click on the well name to get production data http://cogcc.state.co.us/cogis/FacilityDetail.asp?facid=12314291&type=WELL). Volume data for the entire year 2013 were not found in the COGCC documents; only volumes from source leases for October 2013. So we did not include any volume data for this well.

[107] Wells in Weld County include a mix of conventional and unconventional oil and gas wells.

[108] COGIS facility information for SWD C8A can be found at: http://cogcc.state.co.us/cogis/FacilityDetail.asp?facid=12332858&type=WELL The Excel spreadsheet with sources can be found at: http://ogccweblink.state.co.us/DownloadDocument.aspx?DocumentId=2851509

[109] API numbers include the state and county code (the first two digits represent the state, e.g., 05 is Colorado) and the next three digits represent the county. There were 18 Colorado counties found when looking at source well API data: 001, 005, 013, 014, 031, 039, 041, 045, 057, 059, 069, 073, 075, 087, 113, 121, 123 and 125), and on Wyoming county (49-021).

[110] RRC. H-10 "Annual Disposal/Injection Well Monitoring Report" Instructions. http://www.rrc.state.tx.us/media/7960/h-10ins.pdf

[111] A list of Injection Permits by county, field, district or operator can be found using RRC's "Injection & Disposal Query" http://webapps2.rrc.state.tx.us/EWA/uicQueryAction.do Data on volumes injected by district, county or facility can be found through the H10 Filing System Query" http://webapps.rrc.state.tx.us/H10/h10PublicMain.do This system also enables users to conduct queries by fluid type, and search for violations related to injection wells.

[112] We used the RRC H-10 Filing System's (http://webapps.rrc.state.tx.us/H10/h10PublicMain.do)"Injection Volume Query" to determine the total volume of fluids (in bbls) injected in 2013. We selected District = All, County = All, From 2013 to 2013, and Commercial Injection Type we did not select anything. We added up the monthly volumes that were returned by the query, to get a total of 6,956,335,042 barrels of fluid injected. To determine the volume of saltwater injected we used the "Fluid Type Query. We Selected District = All, County = All, From year 2013 to 2013, and Fluids = Saltwater; and repeated the query for flowback but instead of Saltwater we selected Fluid = Fracture Water Flow Back. Query was conducted September 15, 2014.

[113] Nicot et al. 2014. p. 17.

[114] RRC. 2011. H-10 Annual Disposal/Injection Well Monitoring Report – Electronic Filing Requirements. V.2. http://www.rrc.state.tx.us/media/18800/h-10_edi_filing_specs.pdf

[115] We examined a number of injection well permits in downloaded well files, and the language about Class II wastes being authorized fluids was found in all of the permits.

[116] For example, in Hess Bakken Investments' application for enhanced recovery well BLDU G-314 (API 33-105-01578, Well File 16318), Hess states that "The injection fluid will be Dakota waters from Hess water supply wells BLDU B-308-SI and C-313-SI." See p. 29 of downloaded well file.

[117] See NDIC Form 14 "Application for Injection" Instruction 10. https://www.dmr.nd.gov/oilgas/rules/forms/form14.PDF

[118] Pers. Comm. Sept. 11, 2014. Alison Ritter, NDIC Public Information Officer, and Lisa Sumi. Blank forms can be accessed at: https://www.dmr.nd.gov/oilgas/rules/fillinforms.asp

[119] According to NDIC, copies of Form 16s will not be found in the Well File if there are submitted by the operator electronically. Paper copies of the filed forms can be found in the NDIC office. (Pers. Comm. Sept. 11, 2014. Alison Ritter, NDIC Public Information Officer, and Lisa Sumi.)

[120] NDIC Form 16a "Saltwater Disposal Report." https://www.dmr.nd.gov/oilgas/rules/fillinforms.asp

[121] According to NDIC Rules, Chapter IV (Section 43-02-05-12): "The operator of an injection well shall meter or use an approved method to keep records and shall report monthly to the industrial commission, oil and gas division, the volume and nature, i.e., produced water, makeup water, etc., of the fluid injected, the injection pressure, and such other information as the commission may require."(Rules are available on the NDIC web site: https://www.dmr.nd.gov/oilgas/)

[122] NDIC web site: https://www.dmr.nd.gov/oilgas/feeservices/getwellinj.asp Users must know the File Number of the injection well to access the data. These file numbers can be obtained from the NDIC Well Index Database, by filtering for Well Type = SWD for saltwater disposal wells and WI for enhanced recovery (water injection) wells.

[123] These numbers were generated by filtering the NDIC Well Index Database by Well Type = SWD and Well Status = A (Active); and doing the same for enhanced recovery (i.e., water injection) wells. There are many other categories of well status than active. Depending on how many years of data are being sought, an analysis of injection volumes may want to expand beyond active wells to include inactive, and temporarily abandoned, abandoned, and even plugged and abandoned. This, however, would add more than 1,300 injection wells to the analysis.

[124] DEP. 2011. Oil and Gas Wastewater Permitting Manual. p. 4. http://www.portal.state.pa.us/portal/server.pt/document/810213/oil_and_gas_wastewater_permitting_manual_pdf

[125] EPA. 2011. UIC Inventory by State. http://water.epa.gov/type/groundwater/uic/upload/uicinventorybystate2011.pdf

[126] EPA web site: Underground Injection Control Program. http://water.epa.gov/type/groundwater/uic/

[127] Pers. Comm. Sept. 4, 2014. Karen Johnson, UIC Program Manager, EPA Region 3 and Lisa Sumi.

[128] In addition to requiring approval from EPA, oil and gas waste injection wells require a permit (or registration) from DEP prior to well construction (DEP. 2011. Oil and Gas Wastewater Permitting Manual. p. 35. http://www.portal.state.pa.us/portal/server.pt/document/810213/oil_and_gas_wastewater_permitting_manual_pdf)

[129] The injection wells were: Spencer Land Co #2 Disp Well (033-22059); Irvin A-19 Fmly Fee A 19 Disp Well (033-00053); Morris H Critchfield F76 Disp Well (111-20006); And Curtis Oil - Underground Injection Control. Data on volumes were found by downloading Statewide Waste Reports for 2013 (Jan-Dec Conventional Wells; Jan-Jun Unconventional Wells; and Jul-Dec Unconventional wells), and filtering each spreadsheet by Disposal Method = Injection Disposal Well and then Waste Facility State = PA. Volumes of waste disposed from the resultant 451 wells were added to come up with the total volume figure. (Data Source: PA DEP Oil and Gas Reporting Web site. Statewide Data Downloads. https://www.paoilandgasreporting.state.pa.us/publicreports/Modules/DataExports/DataExports.aspx)

[130] WV Underground Injection Control – Class 2 and 3 UIC Wells. Permit Application Package Instructions and Guidance. Section 9 "Operating Requirements/Data".

[131] WV Underground Injection Control – Class 2 and 3 UIC Wells. Permit Application Package Instructions and Guidance. Section 9 "Operating Requirements/Data", and Appendix G.

[132] WV Underground Injection Control – Class 2 and 3 UIC Wells. Permit Application Package Instructions and Guidance. Section 10 "Monitoring".

[133] We searched COGIS for wells in the DJ Horizontal field, using County Code 123 (Weld County). We then removed wells with a completion date prior to April 1, 2012. For those wells that did not have completion data information, we used Frac Focus hydraulic fracturing job end date. We assumed these wells should have filed Completed Interval forms (5A) because obviously those wells had undergone completion treatments, and operators are required to file Form 5A whether the well completion was successful or not. (See COGCC Rule 205A "Hydraulic Fracturing Chemical Disclosure." COGCC Rules are available at: http://cogcc.state.co.us/RR_Docs_new/Rules_new2.html)