

# U.S. Onshore Unconventional Exploration and Production Water Management Case Studies

Prepared for the Energy Water Initiative



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Prepared by  
**CH2MHILL**

### EWI participants in the case studies include:

- Anadarko Petroleum Corporation
- Apache Corporation
- BP America Production Company
- Chesapeake Energy Corporation
- ConocoPhillips
- Devon Energy
- Marathon Oil
- Newfield Exploration Company
- Pioneer Natural Resources USA, Inc.
- QEP Resources, Inc.
- Southwestern Energy
- Talisman Energy USA Inc.

## Energy Water Initiative

The Energy Water Initiative (EWI) is a collaborative effort among participating members of the U.S. oil and natural gas industry to study, describe, and improve lifecycle water use and management in upstream unconventional oil and natural gas exploration and production. EWI is not a formal non-profit organization or trade association. Individual companies are responsible for communicating any information relative to their respective operations and business practices.

In April 2014, EWI requested that CH2M HILL assist with describing case studies of recent oil and natural gas development lifecycle water management experiences among its members, with specific emphasis on production involving hydraulic fracturing. The objectives of the case studies were to:

1. Illustrate the diverse, regional water resource challenges the industry faces
2. Share innovative strategies and lessons learned that individual companies have developed to continually evolve stewardship practices with EWI's members and stakeholders



CH2M HILL and EWI do not advocate or endorse any specific technology or approach represented in this study. Appropriate water management strategies and solutions are best developed by producers in concert with local stakeholders based on inherently unique, site-specific water resources, regulatory, and operations considerations.

# The Evolving Link Between Water and Energy

EWI was organized in response to public and stakeholder interests to better understand and improve lifecycle water use, conservation, and management in U.S.-based upstream unconventional oil and natural gas exploration and production (E&P). Its members promote research, knowledge sharing, and tool development to evolve water management practices, at times with participation from academic institutions and non-government organizations (NGOs).

## Industry Responds to Improve Water Resources Stewardship

On a lifecycle basis, energy from unconventional formations remains one of the least water-intensive fuel sources for transportation and power generation (Mielke, Anadon, & Narayanmurti, 2010; Scanlon, 2013). However, the acute demand on local water resources during the early development phase, particularly in water-scarce regions, is a persistent challenge recognized by producers, local communities, regulators, and policymakers.

The industry has made significant advances in recent years to reduce its demand for freshwater and to improve the logistics around handling and disposal of water. As a result, EWI sponsored this project to document case studies of its participating members' approaches, successes, and challenges in water management.

### The case studies review had two objectives:

- Share lessons learned among participating companies to advance water resources management practices
- Educate stakeholders about the unique water management challenges in different producing regions of the country and share the advancements the industry is proactively achieving to address these challenges

The review was facilitated by CH2M HILL, a leading international consulting, engineering, construction, and operations firm, headquartered in Denver, Colorado. The review began with a two-day workshop in May 2014, where individual companies presented their operations selected for the case studies. The workshop was followed by fact-finding tours of the operations in June and July. This report documents the findings from these water management case studies. The 12 companies shared water management experiences and lessons learned from operations covering Arkansas, New Mexico, Ohio, Pennsylvania, Texas, Utah, and Wyoming (Figure 1).

The 12 case studies represent a snapshot of each company's operations at a specific location during the summer of 2014. Individual companies have different solutions as dictated by the different conditions in the range of areas where they operate. As demonstrated in this report, water management practices continue to evolve with advances in technology and approaches that are tailored on an ongoing basis to address unique issues associated with the locations where these companies operate.

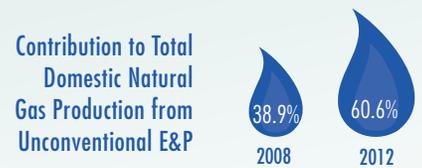


Figure 1 – Case study locations spanned operations from Utah to Texas to Pennsylvania.

The U.S. is experiencing a renaissance in domestic energy production in part from the momentum in oil and natural gas production from unconventional oil and gas E&P. The productivity of oil and natural gas wells is steadily increasing in many basins across the U.S., due in part to the increasing precision and efficiency of horizontal drilling and hydraulic fracturing (Krohn & Ford, 2014).



Shale and tight formations are forecasted to account for 50% of production by 2019. (U.S. Energy Information Administration [EIA], 2014).



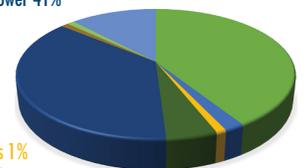
U.S. natural gas production rose more than 85% from 2008 to 2012 (EIA, 2012).



The industry, by some estimates, directly employs more than 1 million Americans and indirectly employs as many as 10 million in associated construction, manufacturing, and information technology (Mills, 2014).

### Percentages of Water Used Nationally per Industry

- Thermoelectric Power 41%
- Aquaculture 2%
- Domestic 1%
- Industrial 5%
- Irrigation 37%
- Livestock 1%
- Mining/Oil & Gas 1%
- Public Supply 12%



Hydraulic Fracturing Water Usage (FracFocus, 2014).

## Water in the Exploration and Production Lifecycle

The majority of water use and management occurs during the early exploration, drilling, and production phase of the E&P lifecycle, which was the focus of this study. Water is both a necessary input and a byproduct of oil and natural gas production from unconventional E&P operations, as shown on Figure 2. A small amount of water is needed for drilling. However, most of the water demand occurs during the completion stage when the wells are hydraulically fractured to create the pathways for oil and natural gas to flow to the production well. Makeup water can come from a variety of sources. It is transported to the drill site, called a pad, either by truck or, increasingly, by permanent or temporary pipelines. Water is stored in impoundments, modular tanks, or mobile containers (frac tanks).

Water used for hydraulic fracturing may stay in the target formation, though some will return to the surface as produced water along with oil, gas, or natural gas liquids (NGLs or condensate). During this flowback process, the produced water flow rate is comparatively higher than long-term produced water rates. (See Figure 3.)

Water production varies by region and play. It can range anywhere from 10% to more than 100% of the total volume of water used for the hydraulic fracturing operation and may include naturally occurring formation water that also returns to the surface. Produced water is collected and can be reused or disposed.

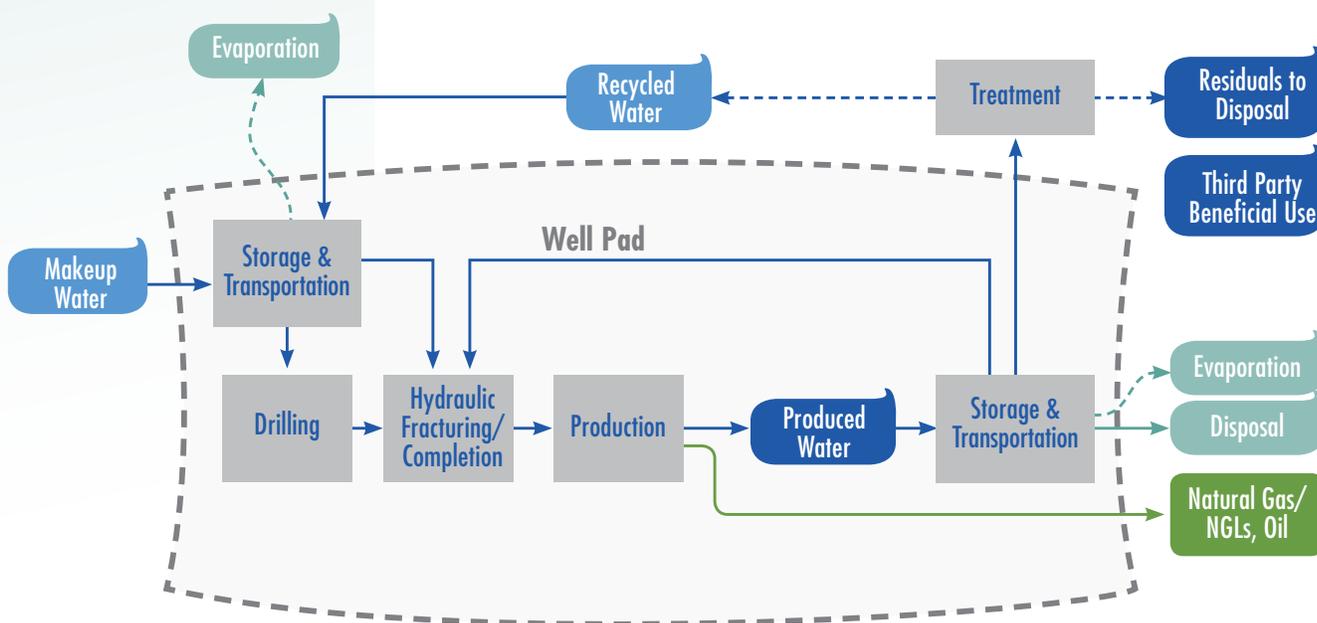


Figure 2 – Typical water use and management in exploration and production.

Eventually, produced water production from a well declines and stabilizes as shown on Figure 3. This comparatively low fraction of produced water is separated from the oil/gas/NGLs and disposed of in accordance with the relevant regulations. Because the volume of water needed at a given time may not match the volume produced, it is not operationally possible to determine a standard uniform reuse target at all times (e.g., 25% or 50% reuse). Nonetheless, water recycling and reuse, where feasible, continue to grow as a trend in the industry.

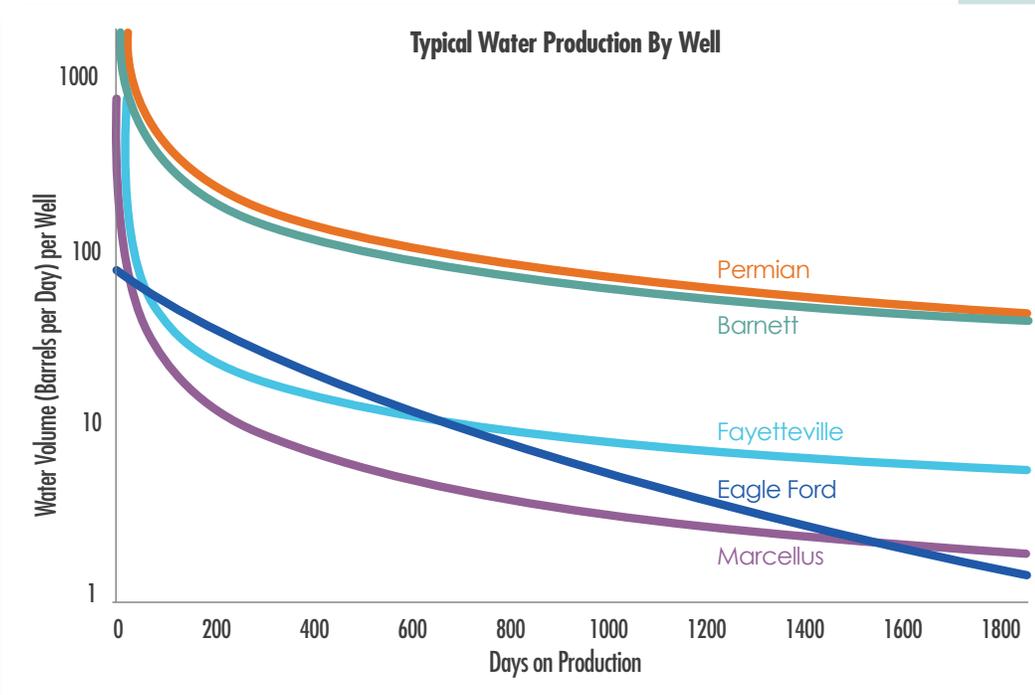


Figure 3 – Produced water flow from unconventional formations varies by location, play and basin, and total water used in hydraulic fracturing completion. The graph illustrates some representative examples.

## Water Management Trends Demonstrated in Case Studies

The case studies highlight six water management trends that the industry is employing to evolve water stewardship practices:

- 1 – Development and improvement in fracturing chemistry enables industry to use non-freshwater sources.
- 2 – Treatment technology innovation continues to make produced water reuse more feasible.
- 3 – Improvements in water conveyance for gathering and distribution reduce truck traffic.
- 4 – New water storage designs provide flexibility and reliability in alternate, non-freshwater sourcing.
- 5 – Transparency improves relationships with communities, industry, and regulators.
- 6 – Dedicated water staff within E&P organizations improve water management planning, technical support, and performance.

Detailed descriptions of these water management trends, including where they may be applied and example applications, follow the Case Study Overview in the next section.

## Case Study Overview

Twelve companies volunteered to participate in cases studies highlighting different exploration and production-phase water management practices from around the U.S. A comparative summary is shown in Table 1. Refer to the glossary for hydraulic fracturing method definitions.

Table 1 – Summary of case studies for 12 companies, highlighting different E&P phase water management practices around the U.S.

Case Study Location (Basin, County, State)	Company	Production Type	Hydraulic Fracturing Method	Case Study Highlights
Cotton Valley, Harrison County, East Texas	BP America Production Co.	Gas Condensate	Slickwater and Crosslink	<ul style="list-style-type: none"> <li>Evaluated complex pilot study for two separate treatment technologies to determine the effectiveness and viability of recycling produced water</li> <li>Significantly reduced truck traffic using centralized phase separation and water transport via pipelines</li> </ul>
Delaware Basin, Lea County, New Mexico	ConocoPhillips	Oil	Slickwater and Crosslink	<ul style="list-style-type: none"> <li>Transporting water via pipelines while addressing strict regulatory needs</li> <li>Implemented “fit-for-purpose” onsite treatment and recycling of produced water based on pilot study that demonstrated produced water reuse with minimal treatment and potential offset of 50% of current source water</li> </ul>
Eagle Ford Shale, Karnes County, South-Central Texas	Marathon Oil	Oil and Natural Gas	Borate Crosslink	<ul style="list-style-type: none"> <li>Conducted extensive field testing to advance reuse technology innovations</li> <li>Heavily using plentiful brackish water resource to supply the majority of needs</li> </ul>
Fayetteville Shale, Arkoma Basin, Arkansas	Southwestern Energy	Dry Natural Gas	Slickwater	<ul style="list-style-type: none"> <li>Using facilities to achieve zero disposal of produced fluids</li> <li>Identified water team focused on Fayetteville operation</li> </ul>
Marcellus Shale, Susquehanna River Basin, Pennsylvania	Anadarko Petroleum	Dry Natural Gas	Slickwater	<ul style="list-style-type: none"> <li>Using nearly all flowback/produced water during completion operations, utilizing a third-party treatment facility to process produced water when there is no available operation to use the water</li> <li>Employing comprehensive metering and supervisory control and data acquisition (SCADA) at truck loading and unloading station to track water use</li> </ul>
Marcellus Shale, Susquehanna River Basin, Pennsylvania	Talisman Energy	Dry Natural Gas	Slickwater	<ul style="list-style-type: none"> <li>Employing extensive real-time water withdrawal monitoring and automation</li> <li>Using technical assistance agreements with the U.S. Geological Survey (USGS) to fund new metering stations, as well as associated data collection</li> </ul>
Permian Basin, Barnhart, Irion County, West Texas	Apache	Oil	Slickwater	<ul style="list-style-type: none"> <li>Performing slickwater fracturing without using freshwater sources</li> <li>Handling produced water and brackish groundwater separately at Apache’s Central Water Treatment Facility</li> </ul>
Permian Basin; Crockett, Reagan, Irion Counties; West Texas	Devon Energy	Oil	Slickwater	<ul style="list-style-type: none"> <li>Performing slickwater fracturing with produced water and brackish groundwater</li> <li>Using instrumentation to monitor and record brackish well production volumes and storage volumes in covered impoundments</li> </ul>
Permian Basin, Midland County, West Texas	Pioneer Natural Resources	Oil	Hybrid and Crosslink	<ul style="list-style-type: none"> <li>Reduced truck use and traffic via centralized impoundment and pipeline network</li> <li>Developed water management organizations to mirror water utility operations</li> </ul>
Pinedale Anticline, Sublette County, Western Wyoming	QEP Resources	Natural Gas	Hybrid (Friction Reducer and Crosslink)	<ul style="list-style-type: none"> <li>Using recycled water for nearly 100% of needs</li> <li>Employed an extensive pipeline network to convey water throughout field and to centralized treatment facility</li> </ul>
Uinta Basin, Duchesne and Uintah Counties, Northeast Utah	Newfield Exploration	Oil	Slickwater and Borate Crosslink	<ul style="list-style-type: none"> <li>Achieved nearly 100% recycling of produced water</li> <li>Tested liner materials and leak detection systems for improved storage tank reliability</li> </ul>
Utica Shale, Carroll, Columbiana, Harrison, Jefferson, Mahoning, Stark, and Tuscarawas Counties, Ohio	Chesapeake Energy	Oil and Natural Gas	Hybrid	<ul style="list-style-type: none"> <li>Currently reusing two-thirds of produced water volumes in hydraulic fracturing operations</li> <li>Using belt press for rapid dehydration of sludges generated during treatment of produced water</li> <li>Reduced transportation costs associated with disposal of produced water</li> </ul>

Disclaimer: The case studies summarized in this table represent a snapshot of each company’s operations at a specific location during the summer of 2014. Individual companies have different solutions as required by the types of different conditions in the range of areas where they operate.

## Water Management Trend 1

# Development and improvement in fracturing chemistry enables industry to use non-freshwater sources

Slickwater vs. Crosslink: Different Processes with Different Water Requirements

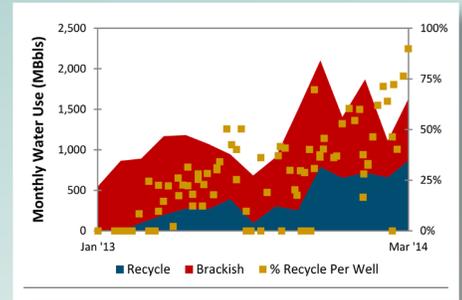
The largest water demand occurs during the completion phase for hydraulic fracturing. The two basic fracturing methods use either slickwater or crosslinked gels. Engineers choose fluid designs based on multiple variables. The total volume of water and water quality required to perform slickwater versus crosslinked gel hydraulic fracturing varies. In general, a crosslinked hydraulic fracture requires higher quality water but lower volumes than a slickwater hydraulic fracture for a given horizontal length.



Figure 4 – Chemistry is important for hydraulic fracturing. Photos source: Southwestern Energy

Because the chemical composition of commonly used crosslinked gels can interact with the chemistry of the source water used for hydraulic fracturing, crosslink requires better water quality to ensure proper performance. The higher viscosity of the gel allows greater sand concentrations while requiring less water overall. On the other hand, slickwater relies primarily on higher volumes of water and lower sand concentrations delivered at a high rate to maintain sand velocity. In slickwater hydraulic fracturing, the composition of the water is less critical and allows for use of more brackish or saline sources as well as other non-freshwater sources. The industry has made significant progress towards formulating gel systems using brackish and formation waters.

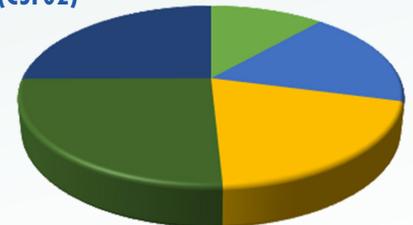
The technology and volumes used are generally driven by the reservoir characteristics and well design, and will vary by region and play. Depending on the variables described previously, the volume of water required in the case studies ranged from an estimated 20,000 to 400,000 barrels (bbls) per well, though the majority of unconventional wells require between approximately 95,000 and 160,000 bbls (3 and 5 million gallons) per well. (See FracFocus Chemical Disclosure Registry, <http://www.fracfocus.org>, for information on actual water use on a per well basis.)



### Case Study Focus – Slickwater Fracturing without Freshwater Sources, Apache (CSF01)

In the Barnhart area of Texas, Apache is recycling 100% of its produced water. In 2013, recycled water accounted for nearly 25% of total water used for hydraulic fracturing. In the first quarter of 2014, recycled water use increased to approximately 50% of total water used for hydraulic fracturing. Brackish water accounted for the remaining water used in both years.

### Case Study Focus – Increasing Use of Non-potable Water Sources, Marathon Oil (CSF02)



#### Water Consumption by Quality

- Class 1** 25.1% Unrestricted use for drinking, agriculture, or livestock
- Class 2a** 25.7% Not recommended for drinking, acceptable for all livestock and crops except sensitive plants (e.g., corn)
- Class 2b** 20.1% Not recommended for drinking, usable for livestock but not preferred, usable for crops with moderate tolerance (e.g., rye)
- Class 2c** 17.6% Not recommended except for very salt-tolerant plants, but expect yield reductions (e.g., barley)
- Class 3** 11.5% Not recommended for use (this is the permissible limit for a slickwater development [SWD] injection zone)

Source: Marathon Oil

Marathon Oil used 29.5 million barrels (bbls) of water in 2013 for its Eagle Ford hydraulic fracturing operations. Of that, 74.9% was brackish.

### Water Sources Vary by Region

Due to recent drought conditions in the Central and Western U.S., surface water has become more scarce than in the past, but groundwater (both fresh and brackish) is available and used by the oil and natural gas industry. In the Eastern U.S., the primary source is surface water, which is generally abundant.

Withdrawal of surface water in the Eastern regions is regulated by state or federal regulatory agencies. Water withdrawals are regulated seasonally and by the flow rate in the stream. E&P companies have designed innovative intake facilities, which use automated control systems to withdraw water from the stream only when the flow rate meets or exceeds the regulated minimum flow rate required in the stream.

Withdrawal of groundwater in the Central and Western regions is driven by water rights, and withdrawal rates are regulated based on the conditions of the well permit and the water rights.

### Case Studies Show Growing Use of Brackish and Other Non-Freshwater Sources

Through innovative progress, E&P companies are increasing the use of brackish water; municipal and industrial wastewater; and recycling and reuse of produced water as alternatives to freshwater sources (Figure 5).



Figure 5 – Innovations in hydraulic fracturing have enabled E&P companies to be less reliant on freshwater sources and expand options in water-stressed areas such as these brackish wells used by Devon Energy. Photos Source: Devon Energy

## Water Management Trend 2

# Treatment technology innovation continues to make produced water reuse more feasible

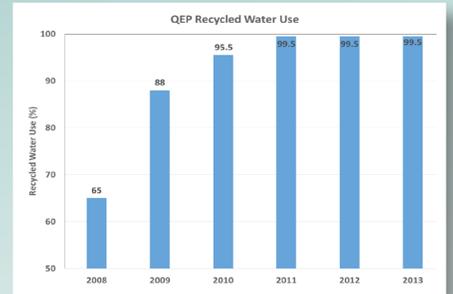
Produced water recycling is becoming more viable because fracturing technologies are becoming more tolerant of lower-quality water (Figure 6). Treating and recycling or reusing produced water is complex and may not be feasible for every field. The type of treatment required to recycle and reuse the produced water also varies by region and play.

Different treatment technologies can be used to treat produced water to varying water quality standards—from freshwater to clean brine. Treating produced water to freshwater standards can be complex, but it gives an operator more options for transportation and storage. Treating produced water to clean-brine standards is much often more manageable but may result in incompatibilities, higher expense related to the required fracturing fluid chemicals, and more challenges revolving around the handling, storage, and transportation of the water.

Complicated water compatibilities and/or small produced water volumes can limit the feasibility of some treatment technologies or inhibit recycling strategies altogether in some plays.



Figure 6 – Pioneer Natural Resources partnered with a startup company with a new carrier gas extraction (CGE) process that desalinates produced water with less energy and lower operating costs than comparable commercial technology. The first-of-its-kind plant was designed and installed in record time. The plant pretreats the water, and the CGE process reduces total dissolved solids (TDS) from about 120,000 parts per million (ppm) to about 500 ppm. Photo source: Pioneer Natural Resources USA



### Case Study Focus – Using Recycled Water for Nearly 100% of Needs, QEP Resources (CSF03)

QEP Resources is using recycled water for nearly 100% of its needs in Wyoming’s Green River Basin on the Pinedale Anticline—an area that represented 38% of QEP’s year-end 2013 proved reserves. QEP’s construction and operation of a liquids gathering system (LGS) has facilitated increased use of water recycling. The facilities in the system are operated by multiple operators and treat to different standards, depending on identified requirements. They use a permanent centralized treatment facility to treat produced water and onsite facilities to treat flowback water. This efficient and effective use of resources is environmentally responsible—it not only reduces the amount of freshwater needed for development, it has air quality benefits, and the reduced truck traffic benefits the abundant wildlife in the area.



### Case Study Focus – Advancing Reuse Technology Innovations, Marathon Oil (CSF04)

Marathon has conducted four field pilot tests in its Eagle Ford operations to identify effective methods to treat water to usable standards. Three of these were determined unsustainable for a 100% recycling solution. The fourth field pilot test is currently using reverse osmosis, a treatment system owned and operated by a third-party treatment provider. The current capacity of the treatment system is 2,500 barrels per day. Boron is successfully reduced from 90 to <10 ppm; however, the brine reject produced is high (60%). To mitigate this issue, Marathon recently began using the treated brine stream as a workover fluid, which improved overall operation of the system and is less expensive than purchasing brine.



### Case Study Focus – Achieving Nearly 100% Recycling of Produced Water, Newfield Exploration (CSF05)

Newfield has two active operations in Utah. First is the Green River play, which uses vertical wells, a hybrid fracturing design, and is produced with a waterflood operation. The second is in the Wasatch and Uteland Butte plays, with horizontal wells that also use hybrid fracturing designs. Both operations have recycling facilities, which together treat and recycle 98% of all produced water generated. This recycled produced water provided approximately 30% of the total used in Newfield's hydraulic fracturing operations in 2014.



### Case Study Focus – Unique Solution Uses Centralized Water Treatment Facility to Achieve Near-Zero Disposal of Produced Fluids, Southwestern Energy (CSF06)

Unique solutions employed by Southwestern in this case study include the establishment of CWT facilities to recycle its own produced water and potentially that of third parties. Southwestern has achieved near-zero disposal of produced fluids from their operations, in part because of these CWT facilities. During times when several rigs are active and fracturing is occurring in the area, no produced water is treated and discharged. During times when demand drops below the volumes produced, the water is treated and discharged, or other beneficial uses for the water are found. Long hauling distances to the nearest disposal wells are eliminated, and returning freshwater to the environment helps Southwestern meet their freshwater net neutral goals.

### Incubating New Saline/Brackish Water Treatment Technologies with Potential for Broader Benefits and Applications

The need to desalinate brackish groundwater to provide the necessary water quality for hydraulic fracturing in some plays has led the oil and natural gas industry to implement water treatment innovations for efficient and low cost desalination options. The accelerated research into desalination technologies (forward osmosis, mechanical vapor recompression, carrier gas extraction, etc.) will result in these technologies being available much sooner for the broad potable water market. This has the potential to benefit communities experiencing drought conditions, as well as coastal communities, by providing viable options to produce potable water from brackish groundwater or seawater sources.

### Addressing Limited Disposal Options in Some Plays through Reuse or Alternate Beneficial Use

Limits on injection capacity and access to surface water disposal, along with continuing successful experiences performing hydraulic fracturing with lower quality makeup water, is making reuse of produced water a more viable option.

The typical method for disposal of produced water is through the use of permitted injection wells. However, injection capacity can be limited due to geology and formation pressures. In some areas, injection-well operation has been temporarily stopped or curtailed due to concern that injection may be linked to inducing seismic activity. This increases the distances to wells that are allowed to accept water, increasing both cost and truck traffic.

Among the options to manage and generate benefit from the water produced by exploration and production is to treat and discharge produced water, so long as it meets certain technology based limits and there is beneficial reuse for agriculture or wildlife. This option is based on the Effluent Limitation Guidelines (ELGs) that were established by the U.S. Environmental Protection Agency (USEPA) under the Clean Water Act<sup>1</sup>. This option is typically limited to areas west of the 98th Meridian, in accordance with ELG requirements. For areas where this is not possible (east of the 98th Meridian or no beneficial reuse west of the 98th Meridian), the water can be transferred, treated, and discharged by a Centralized Waste Treatment (CWT) facility<sup>2</sup> as long as the CWT has an National Pollutant Discharge Elimination System (NPDES) permit with appropriate technology and water quality-based effluent limits. CWT facilities can be owned and operated by E&P companies or third-parties.

Depending on the initial quality of the water, as well as the treatment technology(ies) used, water can be treated for reuse or surface discharge, reducing or eliminating the volumes of waste requiring disposal.

These treatment requirements for produced water to meet discharge standards—depending on the location—offer flexibility to manage produced water in ways other than just via injection wells. Alternate beneficial uses may include irrigation and non-freshwater supply for internal use or use by other industries.

<sup>1</sup> 40 Code of Federal Regulations [CFR] 435, Oil and Gas Extraction Point Source Category

<sup>2</sup> CWT facilities are defined in 40 CFR 437.2(c) as "any facility that treats (for disposal, recycling or recovery of material) any hazardous or non-hazardous industrial wastes, hazardous or non-hazardous wastewater, and/or used material received from off-site."

### Water Management Trend 3

## Improvements in water conveyance for gathering and distribution reduce truck traffic

Historically, E&P companies have relied primarily on trucks to transfer water to and from well sites. These companies are increasingly using pipelines to reduce the number of trucks on the road to improve safety, decrease impacts to roads, and reduce associated vehicle emissions.

For example, a typical truck holds approximately 120 bbls of water. Approximately 1,250 truck trips are required to carry the 150,000 bbls of water for one typical hydraulic fracturing operation. Using a pipeline network to deliver the water eliminates these trucks from the road.

The majority of the E&P companies in the case study review have designed and constructed some level of pipeline network to transfer water throughout certain fields. Corrosion-resistant and leak-proof connections and monitoring methods are continually being evaluated and tested for use in the field. These include evaluations of the pipeline material design life and the most effective sizes for field use.

Temporary surface pipelines can be used for short-term needs for a small number of wells where the water source and well pad site are reasonably close. Permanent buried pipelines can be considered where long-term development and well density support them. Both temporary and permanent pipelines, above-grade and buried, are being used, depending on needs and landowner preferences.

Key characteristics necessary for effective field use include the flexibility of systems to meet a range of site conditions, durability, and reliability. Temporary pipeline systems are commonly comprised of layflat hoses or smaller diameter high density polyethylene (HDPE) pipe that can be efficiently set up and removed or relocated. More permanent pipeline networks may be established for operations that are expected to remain in a general area for several years. Regulations and landowner agreements may drive the use of pipelines and where and when they can be employed.

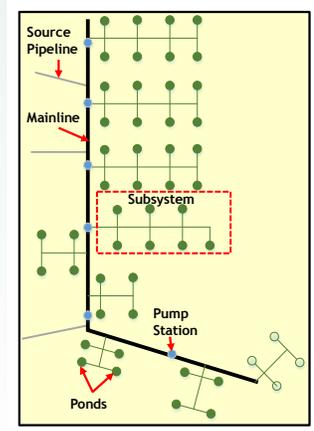
Layflat hose (Figure 7) provides a large capacity pipe that is very compact when being transported or stored compared to traditional stiff-walled pipe. Installation and setup times are much faster than for stiff-walled pipe. Technological advances in layflat hose include higher pressure ratings, better connections, and ultraviolet (UV) and abrasion resistance. Layflat hoses allow for a cost-effective, flexible, and safe way to move water. Such hoses reduce truck traffic and increase the feasibility of some water management options.



Figure 7 – Examples of layflat hoses. Photos sources: Newfield Exploration, Pioneer Natural Resources USA

### Case Study Focus – Relying on Pipelines for Water Transportation While Addressing Regulatory Needs, ConocoPhillips (CSF07)

ConocoPhillips in its Delaware Basin operations transports source water primarily via above-grade pipelines. While produced water is managed primarily by trucking at this point in time, ConocoPhillips recently received approval from the U.S. Bureau of Land Management (BLM) to transfer treated produced water in above-grade pipelines, and successfully transferred 40,000 bbls of treated produced water in layflat hose. There are additional requirements ConocoPhillips must meet in order for the BLM to allow above-grade pipelines to cross BLM land, including the total amount of time the pipeline can remain on the ground based on the pipeline type and material. Layflat hose can be used for 10 days from the time it is installed to the time it is removed. Polyline can be used for 45 days from the time it is installed to the time it is removed.



### Case Study Focus – Centralized Impoundment and Pipeline Network Reduces Truck Use and Traffic, Pioneer Natural Resources USA (CSF08)

Pioneer Water Management LLC (PWM) is a water company established by Pioneer Natural Resources in 2014 to address meeting the company's water needs in West Texas. (See CSF13 for more information on PWM.) In addition to its focus on reducing reliance on freshwater and mitigating produced water disposal needs, PWM seeks to reduce water acquisition and transportation costs. PWM is planning a significant pipeline network to move usable water to the well site with the objective of reducing truck traffic and water transfer costs. PWM also expects to have additional capacity to deliver water to other operators working in the same area.

**Case Study Focus – Pipeline Networks Deliver Flowback and Produced Waters to Completion Sites for Treatment and Reuse, Anadarko Petroleum Corporation (CSF09)**

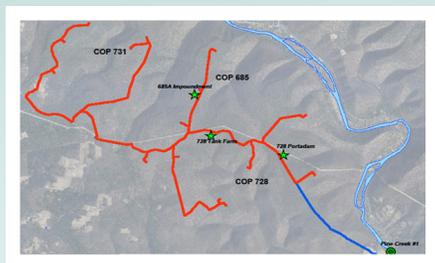


Figure 8 – Co-location production and disposal facilities reduced truck traffic by 14,810 truckloads in 2013 for BP’s Woodlawn field produced water. (One truck load equals 6,500 gallons for a 157-bbl tanker.) *Photo source: BP America Production Company*

In Marcellus, Anadarko constructed a pipeline network for delivering water to completion sites in order to more efficiently move water and reduce truck trips in the community. The company also uses new completion sites for the treatment of flowback and produced waters for reuse, thus eliminating an extra trip from a fixed treatment site. With the combination of these two approaches, in 2014 Anadarko eliminated more than 80,000 truck trips and transported more than 120,000 bbls of water per fracture. The photos above show the pipeline network in one of Anadarko’s operational areas and current flowback and produced water treatment practice. The company reuses nearly all flowback and produced water during completion operations and utilizes a third-party treatment facility when there is no available operation to use the water.

## Water Management Trend 4

### New water storage designs provide flexibility and reliability in alternate, non-freshwater sourcing

Steel frac tanks, in-ground impoundments, and modular above-grade impoundments are used for storage of fresh and produced water. Frac tanks are used to store small volumes of water (typically 500 bbls). These tanks are mobile and can easily be moved between locations. In-ground impoundments (Figure 9) are used to store large volumes of water (typically up to 400,000 bbls), and modular above-grade impoundments can hold a volume between frac tanks and in-ground impoundments (typically up to 40,000 bbls).



Figure 9 – Examples of typical in-ground impoundment facilities, one empty (top) and the other filled (bottom). Photos sources: Marathon Oil (top), Pioneer Natural Resources USA (bottom)

The use of and decision of where and when to use in-ground and modular impoundments to store treated produced water is driven by regulations and landowner agreements. In certain states, in-ground impoundments are not allowed for the storage of treated produced water. The impoundments are designed and constructed with liners. Typically, single liners are installed in impoundments that store freshwater and double liners are installed in impoundments that store treated produced water. In addition to double liners, impoundments used to store treated produced water are constructed with impoundment leak detection and water-level monitoring devices. E&P companies are also making progress toward using covers on the impoundments to reduce evaporation.

#### Case Study Focus – Pairing Tested Storage Tank Materials to Meet Local Conditions with Leak Detection for Storage Reliability and Safety, Newfield Exploration (CSF10)

Storage at Newfield’s recycling facility includes 15 frac tanks for a total incoming storage capacity of 7,500 bbls of produced water. After treatment, the produced water is stored in two aboveground storage tanks (ASTs), for a total storage capacity of 58,000 bbls. These two ASTs are double lined with 36-mil polypropylene liners and equipped with leak detection. Newfield studied and tested various liner types and determined that HDPE and low density polyethylene (LDPE) liners were not the best for handling temperature fluctuations and the resulting expansion of the steel ASTs. Polypropylene liners have provided a better combination of elasticity and tensile strength.

#### Case Study Focus – Covers on Brackish Groundwater Impoundments to Reduce Evaporation Losses, Devon Energy (CSF11)



Brackish groundwater is stored in 30 to 40 in-ground impoundments (frac impoundments) throughout Devon Energy’s operating area. Each impoundment is approximately 400,000 bbls (total of 12 million to 16 million bbls storage capacity). The impoundments are constructed with 3-to-1 side slopes and single-lined with felt and 40-mil HDPE liner or with a single 40-mil HDPE liner. The bottoms of the impoundments are generally 375 feet by 375 feet, and water depth is generally 14 to 16 feet. The impoundments are equipped with water level transducers, which are connected to a SCADA system. In addition, water levels are monitored manually. Most of the frac impoundments are covered with 40-mil liners constructed and installed to control evaporation.

Advances in the design of large storage systems have been made in recent years, addressing variables such as slopes, soil composition, moisture control, dual liners, sump, thickness of liners, covers, and monitoring wells. Figure 10 illustrates a typical in-ground impoundment design with many of these components.

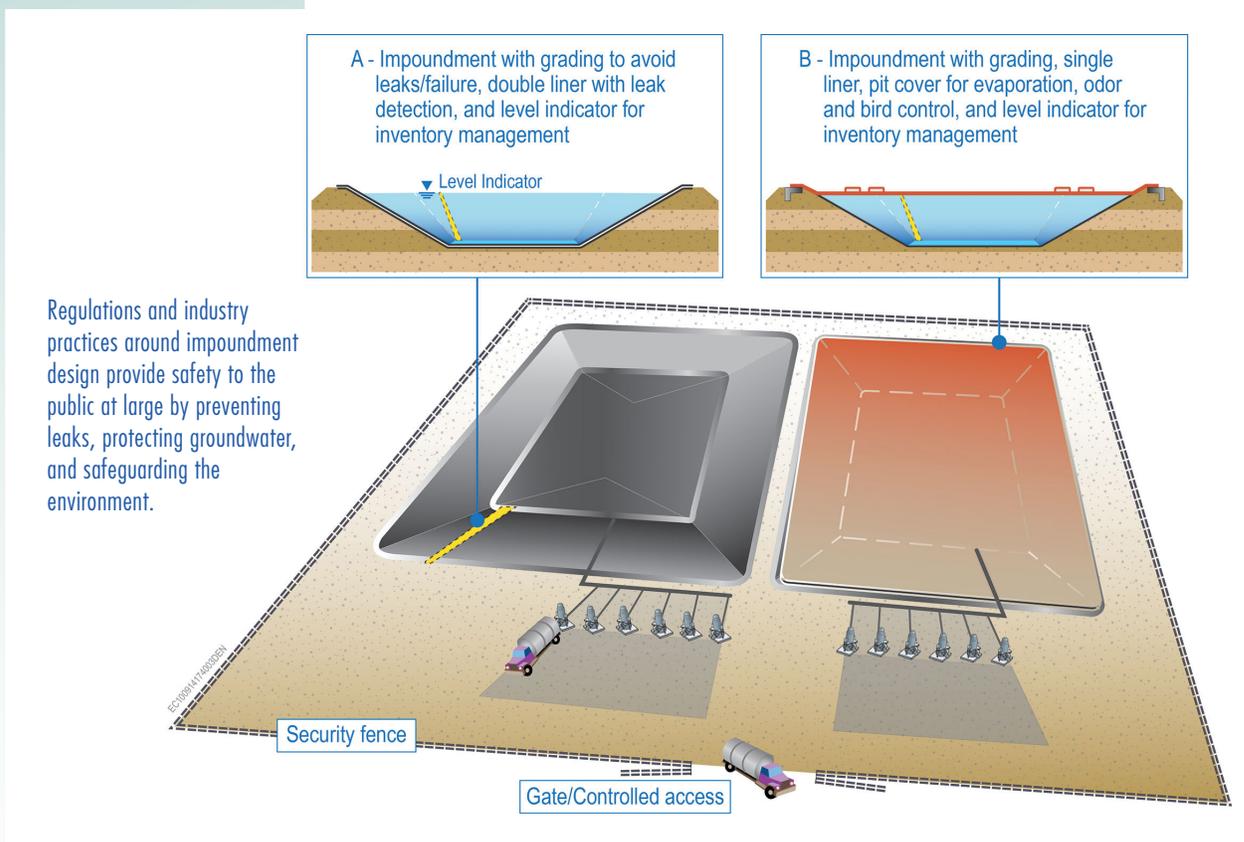


Figure 10 – Design components of a typical in-ground impoundment facility.

### Using Cover Systems to Enhance Water Conservation

Due to high temperatures and associated evaporation in west Texas, several companies, including Pioneer Natural Resources, Devon Energy, Apache, and others, have instituted construction of evaporation control covers (ECCs) at blending impoundments (Figure 11). These 40-mil-thick covers prevent evaporation and save an estimated 6 feet of evaporation per year in this area (Texas Water Development Board, 2013). Covers are viable if the impoundment is needed for several years; however, high winds can destroy ECCs that are not built and installed correctly.



Figure 11 – Evaporation control covers are used to prevent evaporation losses at Pioneer Natural Resources USA site. Photo source: Pioneer Natural Resources USA

## Water Management Trend 5

# Transparency improves relationships with communities, industry, and regulators

### Corporate Responsibility Reflected in Chemical Disclosure

E&P companies have responded to public concerns around chemicals used in hydraulic fracturing by providing over 85,000 disclosures to FracFocus.org since its inception in April 2011 through October 2014. FracFocus.org is a national chemical registry that was developed by the Groundwater Protection Council (GWPC) and the Interstate Oil and Gas Compact Commission (IOGCC) to provide the public with factual information concerning hydraulic fracturing water volumes pumped and chemicals added. The missions of both the GWPC and IOGCC revolve around conservation and environmental protection. EWI member companies currently account for over 37,000 of these 85,000 FracFocus disclosures, or 43% of the total disclosures.

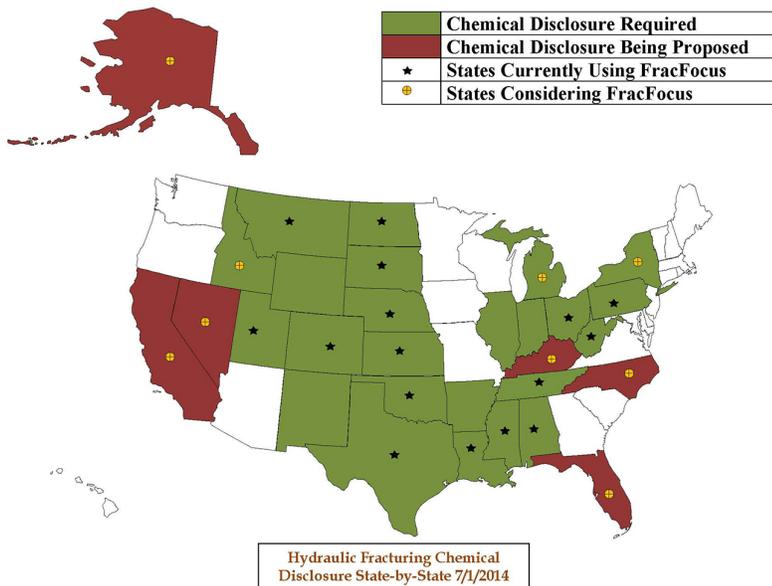


Figure 12 – Hydraulic Fracturing Chemical Disclosure Status  
Photo source: FracFocus.org

## Case Study Focus – Extensive Water Use Monitoring Provides Transparency, Talisman and Anadarko (CSF12)



All of Talisman’s current operations in the Marcellus Shale are located within the Susquehanna River Basin. Water withdrawals, diversions, and consumptive uses within the basin are regulated by the Susquehanna River Basin Commission (SRBC). Surface withdrawals are gauged based on flows recorded by USGS meters, which Talisman partially funds through technical assistance agreements. These collaborative arrangements have enabled the USGS to gather and publish more stream data from areas where previously there had not been monitoring. In 2013, approximately 2 million bbls of fresh surface water were used in Talisman’s Marcellus operations in the basin (77% of water used). At some locations, surface water withdrawals are taken from an intake box in the stream, and they flow via gravity to a wet well where they are pumped to storage impoundments. The withdrawal system is monitored via SCADA (pictured above) and is programmed to automatically shut down when the stream flow does not meet the USGS metered passby conditions set by the SRBC.



Anadarko has developed a standard truck filling station at impoundments, which consists of hydrants and filling stations. All hydrant stations are metered and connected to SCADA to provide detailed and accurate data that identify each truck, its filling activities and capacity, and its current settings. River intake parameters are also automatically monitored via SCADA, and red indicator lights at the hydrants indicate when passby conditions are not being met. The hydrant truck drivers manually open one valve, and the system automatically fills the truck based on a pre-programmed truck volume for that specific truck.

### Corporate Responsibility Reflected in Self-Imposed Measurement and Tracking of Water Use

E&P companies have responded to public concerns about water used during hydraulic fracturing by increased data gathering and disclosure to the public. From initial source water intake systems, through transportation via both truck and pipeline, and at the storage and disposal levels, increasingly sophisticated systems have been deployed to track water use and management. This data collection enables E&P companies to make more informed decisions about their water management practices, as well as to drive continuous improvement. Public disclosure is typically provided via sustainability and social responsibility reporting (Figure 13) and company websites.

### Collaboration in Lease Agreements

Water management strategies are influenced by landowner agreements and requirements, which may limit or even dictate water management activities in some cases. For example, the location of pipelines and storage facilities may be affected by landowner agreements. On private lands, individual landowner requirements may also prescribe the source water used. For example, the E&P company may agree to buy groundwater from the landowner for use on-location.



*Figure 13 – EWI members' commitments to transparency and corporate responsibility in the area of water management are reflected in a variety of public reports and public involvement activities. Photos sources: Wetland photo- ConocoPhillips*

### Evolving Regulations

State regulations for oil and natural gas operations are evolving to reflect regional water resources conditions and to better balance the interests and needs of communities, the industry, and the environment. Local conditions, such as water resources, geology, and environmental matters, can influence state requirements for well construction, water sourcing, transport, storage, and disposal. Agencies can draft regulations to allow for innovative water management strategies to be developed and implemented. For example, Texas encourages greater water reuse with Texas Administrative Code Title 16, Part 1, Chapter 3, Rule §3.8 Water Protection, established in 2013.

### Industry Cooperation to Improve Water Management Practices

While the industry remains competitive, groups like EWI bring water experts with varying backgrounds from all over the country together to work with top consultants to find solutions to the industry's most challenging issues. The group provides a forum to share experiences and look at options to share infrastructure, enabling efficient recycling programs. In addition to EWI, there are many other federal, state, and local agencies working cooperatively to improve water management practices.

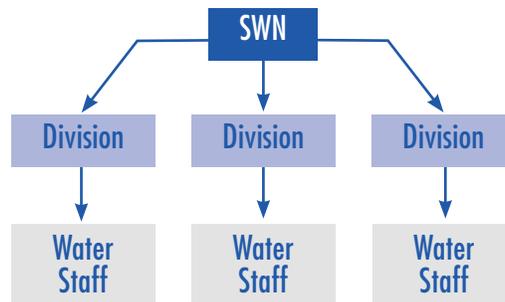
## Water Management Trend 6

# Dedicated water staff within E&P organizations improve water management planning, technical support, and performance

The EWI companies, representing some of the most progressive in the industry, have created dedicated internal resources to help facilitate water management improvements and advancements. Approaches range from developing a separate entity that functions much like a water utility to centers of excellence within the company. These teams take lessons learned and best practices from the industry and their own operations and look at how they can be implemented on the ground in their operations. For those firms that have dedicated water management staff at the corporate level (for examples, see Figures 14 and 15), their focus is primarily on planning, standardization, and research—working at the strategic level to support advancement of effective water management practices. In many cases, local supervisors are managing day-to-day operations, including water management at the local level; providing feedback to the central organization; and implementing advancements.

While each EWI company in the case studies had identified approaches to improve water management planning, technical support, and performance, in virtually all cases, companies were adding dedicated staff in this area. Practices include centralizing lessons learned, establishing standards, and identifying internal subject matter experts to provide advisory support. Across the board, the EWI companies have evolved their water management practices to take a lifecycle approach that builds on successes and helps push technological innovation.

Figure 14 – Southwestern Energy (SWN) has developed within its organizational structure staff who are solely focused on water and water management. Each division (or play) has its own functional water team with responsibilities for planning, sourcing, and transportation of water. Southwestern also has a corporate group working with all divisions to implement programs such as the freshwater net neutral imperative. *Source: Southwestern Energy*



## Case Study Focus – Development of a Water Company for Focused Water Management, Pioneer Natural Resources (CSF13)

In early 2014, Pioneer Natural Resources established a water company to focus on meeting the company’s water needs in West Texas. Pioneer Water Management LLC (PWM) is focused on reducing reliance on fresh water used in drilling and fracture stimulation operations, mitigating the need for disposal of produced water through recycling, and reducing water acquisition and transportation costs. PWM has already substantially increased sourcing from Pioneer’s drilled brackish water wells, as well as from other non-freshwater sources, including the planned purchase of the City of Odessa’s wastewater. In parallel, PWM has plans for increased water recycling to build on the early successes of recycling programs established in the last two years. It also plans to enhance its pipeline network. (See CSF08.) Pioneer expects to have additional capacity to deliver water to other operators working in the same area. “Without a dedicated and empowered team focusing on water management, these major improvements in operations would be difficult to achieve,” said Stephen McNair, President of PWM.

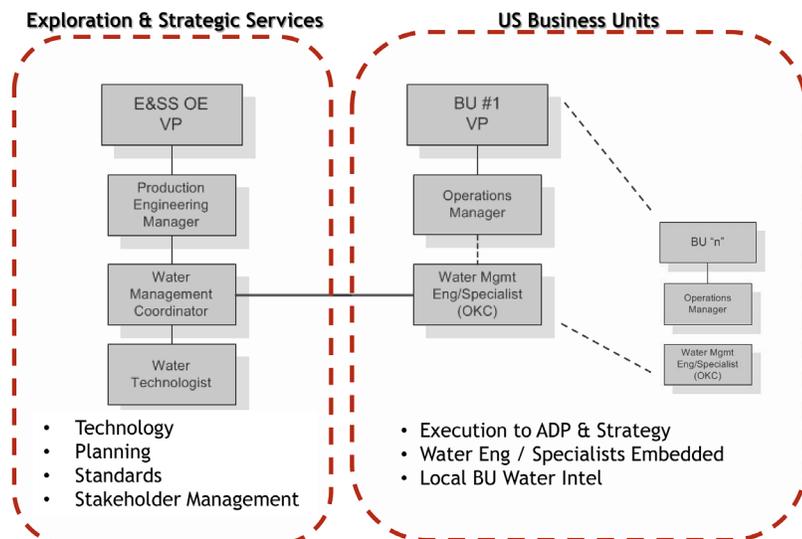


Figure 15 – Devon Energy’s Corporate Water Management Team utilizes engineers and specialists embedded in each of the Business Units to advance the group’s objectives around Technology, Planning, Standards, and Stakeholder Management. *Source: Devon Energy*

## Commitment to Continued Water Management Learning

While water demand for oil and natural gas operations generally makes up a small percentage of regional water demand and water intensity, the EWI companies in these case studies recognize the importance of progressive water management practices focused on reducing freshwater use and other practices to reduce overall environmental and community impacts.

Water management is operationally complex, involving treatment, storage, transportation, waste disposal, and recycling. Water management solutions vary by region and play due to geology, reservoir fluid differences, and fracturing design requirements. The case studies in this report represent an example of each company's operations at a specific location during the summer of 2014. Based on a review of the case studies, the following conclusions were developed:

1. Advances in fracturing chemistry have enabled the industry to move away from using strictly freshwater sources to using increasingly non-freshwater sources—brackish groundwater, produced water, and other non-potable sources.
2. Treatment technology innovations, together with advances in fracturing chemistry, continue to make reuse of produced water more feasible. These innovations also foster potential benefits for broader applications by other industries such as more efficient and lower cost desalination of brackish groundwater or seawater to potable standards. This has the potential to benefit communities experiencing drought conditions as well as coastal communities in need to additional potable water supplies.
3. Improvements in water conveyance for gathering and distribution reduce truck traffic and associated impacts to roadway safety, congestion, wear and tear, and emissions.
4. New water storage designs provide flexibility and reliability in water storage, focusing on providing leak and evaporation prevention through effective materials selection, monitoring, and innovative cover designs. These designs allow companies to use lower quality water and/or they eliminate evaporation losses.
5. Transparency improves relationships with communities, industry, and regulators. EWI companies have embraced water monitoring innovations both to track use and to responsibly meet regulatory requirements. At the same time, informing local government allows for unique solutions that take into account differences among regions and plays. In many regions, the industry is moving forward with water management activities that decrease overall environmental impacts.
6. Company organizational structures are evolving in many cases to include water management teams that focus on managing the full water cycle from sourcing to use, recycling, and disposal. They seek to improve water management planning, technical support, and performance through research and the identification of lessons learned and best practices.

## GLOSSARY

**Beneficial Use** – Any use other than oil and gas.

**Flowback** – The process of bringing initial production from a well online, often through temporary equipment, following hydraulic fracturing.

**Hydraulic Fracturing Fluids** – Primarily **slickwater**, **crosslink** or **crosslinked gel**, and a combination of the two (**hybrid system**). These fluids consist of primarily water (greater than 98%), friction reducer, **proppant**, and no or very low concentrations of additives. The fluid systems are designed based on the characteristics of target formation and fluids, makeup water source, and other considerations. Each fluid system has its advantages and disadvantages. The final decision is usually made based on multiple parameters.

**Crosslink or Crosslinked Gel** – A **hydraulic fracturing fluid** that uses gel systems (linear and crosslinked) designed to mitigate the **proppant** settling and placement concerns. Primary products include polymers, cross linkers, pH adjustment, and bacteria-control chemicals and gel breakers. Target formation characteristics determine the need for other additives. Compared to **slickwater**, it utilizes less water, carries more **proppant**, and provides better conductivity. It requires better quality water and is more sensitive to changes in the products and conditions. However, excellent progress has been made to formulate gel systems using brackish and formation waters.

**Hybrid System** – A **hydraulic fracturing fluid** that uses a combination of **slickwater** and **crosslinked gel** systems. The goal is to combine the advantages of **slickwater** and **crosslinked gel** systems. The volume of each fluid system varies depending on the design goals. Generally, the **slickwater** portion is larger, up to 80%.

**Proppants** – Sized inert particles (typically sand) mixed with fracturing fluids to keep fractures open after fracturing, allowing fluids to flow more freely to the wellbore. Proppants include naturally occurring sand as well as specially engineered resin-coated sand, ceramic beads, sintered bauxite, and other high-strength materials.

**Slickwater** – A type of hydraulic fracturing fluid that relies on a high volume of water because it is delivered at a higher rate than **crosslinked gels**. (See above.) Water and sand make up over 98% of the fluid used for slickwater hydraulic fracturing. Because the chemical composition is less complex, it is less sensitive to water quality compared to **crosslink** fluids and is more tolerant of poor water quality.

**Impoundment** – Water storage facilities at well pads or central areas. These can be either in-ground or modular above-grade. In-ground impoundments are used for large volumes of water. Modular above-grade impoundments are typically smaller volume containment structures than in-ground impoundment.

**Play** – A geographic region or geologic zone for exploration and production.

**Produced Water** – Water coming from the oil and gas well.

**Unconventional** – Oil and natural gas production from shale and tight (low permeability) formations—a relatively new method of production—as compared to traditional oil and gas well drilling and production that tapped underground reserves with greater permeability.

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