

Successful Oilfield Water Management

Brent Halldorson, P.Eng. Fountain Quail Water Management

Copyright 2013, AADE

This paper was prepared for presentation at the 2013 AADE National Technical Conference and Exhibition held at the Cox Convention Center, Oklahoma City, OK, February 26-27, 2013. This conference was sponsored by the American Association of Drilling Engineers. The information presented in this paper does not reflect any position, claim or endorsement made or implied by the American Association of Drilling Engineers, their officers or members. Questions concerning the content of this paper should be directed to the individual(s) listed as author(s) of this work.

Abstract

Oilfield water management includes sourcing fresh water, recycling, disposal, water impoundment, conveyance (trucking or pipeline) while also taking into consideration environmental, public and regulatory issues. There are also potential reservoir and production impacts resulting from fracturing shale formations with different water compositions. Every shale play has unique water management issues.

Recycling wastewater associated with shale gas development is challenging due to the varying composition of the wastewater. The traditional solution has been to dispose of the wastewater via injection wells. While forming part of the solution, disposal alone is not sustainable and recycling is required to allow the industry to grow. Fountain Quail pioneered commercial oilfield water recycling in the Barnett (TX) and has since expanded into the Marcellus (PA) and Eagle Ford (TX). Results and challenges associated with recycling water from various shale plays will be discussed.

The ultimate water management plan for shale gas development will include variations of (1) on-site water re-use including TSS removal to allow re-fracturing of wells using saltwater; (2) desalination of brine using NOMAD or similar technology; and (3) disposal or beneficial re-use of residual wastes such as concentrated brine or salt. Success will require participation and cooperation between industry and regulators, common sense, and a range of technology solutions.

Introduction

Fountain Quail Water Management (“FQWM”) pioneered shale water recycling in the Barnett Shale and has worked continuously in this field to date. Additional experience has been gained through operations in the Marcellus (PA), Eagle Ford (TX) and Permian Basin (TX). Throughout this 10 year period water recycling has grown from an emerging new industry into a recognized component of developing unconventional oil and gas plays. Recycling has gone from a pilot project to an ever-more integral part of oilfield operations.

In this paper FQWM experience will be summarized and five very different case studies will be reviewed. For the sake of simplicity “unconventional oil and gas” development will simply be referred to as “shale” development, even though this is not strictly accurate. When “shale” is referred to in this paper it refers to any unconventional oil and/or gas play where large volume hydraulic fracturing is being utilized, regardless of whether it is a true shale or other formation (limestone, conglomerate, etc.) being developed.

Water Management – A Complicated Issue?

Water management can prove challenging in shale plays due to the variable nature of the water and the dynamic nature of shale development.

In early stage shale plays the drilling program is often chaotic as production companies are forced to “drill-to-hold” acreage in order to meet lease commitments. Water management is very difficult when there is no structured completion program. Once out of the early “drill-to-hold” pattern producers settle into a more structured development program and water management becomes easier.

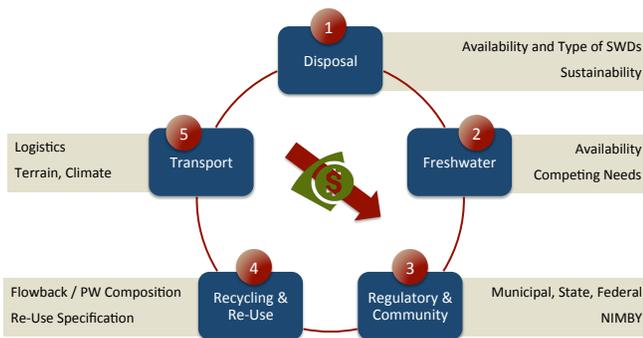
There are five main areas that dominate water management. These are far from all-encompassing, however they give the reader an idea of the “big picture” forces at work when considering water management in particular shales.

- (1) Disposal. What is the availability and cost of disposal in the region (typically saltwater disposal wells hereafter referred to as “SWD”s)? Is there a possibility of induced seismicity due to the depth and formation used for saltwater disposal?
- (2) Freshwater. What is the availability and cost of freshwater? Often there are competing needs from other industries (agriculture) or municipalities.
- (3) Regulatory and Community. Shale development is occurring in areas that are not used to oil and gas development (PA, OH and possibly NY). Media and public opinion has often impacted development in these areas, despite gross misinformation and fear-mongering. This is a very real issue that needs to be

dealt with and it impacts how water is managed in these regions.

- (4) Recycling and Re-Use. Due to the varying subsurface geology, the composition of flowback and produced water is radically different from shale to shale. Certain plays exhibit very high TDS wastewater (Marcellus, Bakken) and others have relatively low TDS wastewater (Fayetteville). The different levels of TDS, hardness and other factors impact the relative cost and efficiency of different types of treatment.
- (5) Transport. This is a simple but often overlooked component of water management. Trucking is much more expensive than pipelines (on a per-bbl basis) for handling water. The local terrain and weather have a large impact on the transportation and storage options open to producers in that region.

Figure 1 – Dominant Water Issues



The above factors have different impacts depending on the shale. To demonstrate,

- The Marcellus Shale (PA) has very limited disposal, however it has abundant freshwater. In this shale the predominant water management strategy generally involves re-using saltwater in new frac stimulations in order to avoid costly disposal. This works well for early stage development where water is always in deficit (the volume to be disposed of can go into a new frac stimulation), however as more and more wells are drilled the volume of produced water (“PW”) will eventually become a very real issue due to the limited disposal availability in this region.
- The Barnett Shale in north Texas is the polar opposite of the Marcellus. The Barnett has abundant low cost disposal due to the Ellenburger formation (immediately below the Barnett Shale). The Barnett often struggles with freshwater availability, especially during times of prolonged drought as are inevitable in the region.

Coupled with the big picture water issues are the multitude of other water related issues. Certain producers may opt for

the lowest cost and simply re-use flowback and produced water with minimal, if any, treatment. Experience has shown that re-using water with no treatment will negatively impact the decline curve of the well due to downhole scale deposition and/or plugging of the formation. The question becomes whether the impact on the well decline curve justifies water treatment or not. This is a question being addressed by the individual producers and is not a topic for this paper.

Other issues include permits for storage and withdrawal of water, NORM management, liability for potential saltwater leaks or spills, road damage from trucking water, pit closure costs, odor issues, downhole scaling, microbial control, etc. Many more could be listed.

These questions and many more can lead to paralysis and producers become bogged down in evaluating the details. It sometimes feels like an “endless DO Loop” with no resolution. Another complicating factor is water treatment companies that bombard the energy producers with ridiculous unscientific claims, often that make no sense at all or involve “black boxes”.

The point of this paper is to try to simplify these issues and chart a logical water management path.

The Big Question: Saltwater or Freshwater?

The fundamental question in shale water management is whether the producer wants to deal with (1) saltwater, or (2) freshwater. Once this question is addressed the decisions going forward become much easier to deal with. Case studies involving both saltwater and freshwater will be discussed later in the paper.

Figure 2 – The Big Question: Saltwater or Freshwater?

Freshwater	Saltwater
• Higher cost (thermal distillation).	• Lower cost (minimal treatment).
• Lower risk – store and transport freshwater.	• Difficult logistics (storage + transport)

(1) Saltwater.

On the surface, the re-use of saltwater is a much lower cost alternative if it is practical. FQWM offers basic TSS removal utilizing its ROVER clarification system for the range of \$1/bbl of water treated. Other service providers offer technology such as electrocoagulation, dissolved air flotation (DAF) or filtration to meet customer needs for saltwater re-use. These are generally high capacity, low cost systems that give back a certain quality of saltwater. FQWM prefers the ROVER as it can easily adapt to varying water composition and also can provide targeted treatment objectives (i.e.: it can selectively precipitate certain species the producer wants to eliminate). Saltwater

can be re-used regardless of the TDS of the feed – the goal is generally to remove TSS and polymers so that the clean brine can be blended with make-up water for new fracture stimulations.

While the treatment options for saltwater are varied and generally low cost, the storage and handling of large volumes of saltwater can become very challenging. For example, in Texas the producer is required to have an H-11 approved pit to store large volumes of saltwater. The permitting and construction of such pits becomes significant for large volume fracs. Case studies ‘C’ and ‘D’ below show examples of saltwater re-use scenarios.

(2) Freshwater.

There are very limited technology options for converting shale wastewater into freshwater for re-use. It is often deemed to be impractical and many customers feel it is too costly to consider as an option.

The two established technologies for TDS removal include (1) membrane based systems, and (2) thermal based systems. Membrane systems have generally struggled to prove effective in oilfield wastewater due to poor recovery coupled with susceptibility to membrane damage from organics. New developments such as Forward Osmosis (“FO”) show promise for addressing some of these issues. The traditional alternative to membranes is thermal distillation, which has often been misrepresented as being too costly.

As an example, FQWM offers its patented NOMAD treatment, which is a compact and efficient thermal evaporator, for a cost range of \$3-\$4/bbl (including power, labor, chemical and equipment). This is 3-4X the cost of ROVER treatment, however it returns freshwater to the customer for re-use rather than saltwater. Despite the higher treatment cost, the customer has (1) a predictable frac water composition (freshwater), and (2) much less headache with water storage and transportation. Examples of areas where freshwater makes sense are shown below in case studies ‘A’, ‘B’ and ‘E’.

A by-product of NOMAD treatment is clean, heavy brine (the leftover solution after maximum water recovery has been achieved). This “concentrate” often has value to producers that need 10# brine for drilling and completions. In areas where re-using this heavy brine stream is advantageous it makes the freshwater scenario more cost effective.

Once the decision as to saltwater or freshwater re-use has been made, the remaining decisions on how to implement a water management strategy become easier.

Charting a Logical Path Towards a Water Management Strategy

On either path, freshwater or saltwater, simple and achievable goals must be set. It may be desirable to start with very basic goals and expand them over time depending on the level of success achieved. This should not be considered as “pilot” or “demonstration” treatment, but rather a phased in level of treatment starting with the very simple.

Regardless of the plan, both the producers and the treatment provider need to be adaptable and flexible. Solutions need to be capable of scaling up in size as the need increases.

Examples of water management goals include the following:

- Reuse as much flowback and PW as possible in new fracs (saltwater example).
- Eliminate the need for saltwater pits and allow the use of aluminum fastlines (freshwater example) without concern for environmental liability.

The overriding goals for each case study will be highlighted below.

Beware of Black Boxes

A complicating factor which has delayed the implementation of water recycling has been the entry of new technology solutions which are not based on real science. Often these gadgets make promises which cannot be delivered on or which contravene the laws of thermodynamics. For example, there are several companies today promoting that their solution is chemical free, uses no energy (some create energy!) and have no waste byproduct. In essence they are promoting dirty water in and clean water out without having any science behind it. Unfortunately many producers have tried these systems and it has left a bad taste for water recyclers in general. The old axiom holds true: “if it sounds too good to be true, it probably is.”

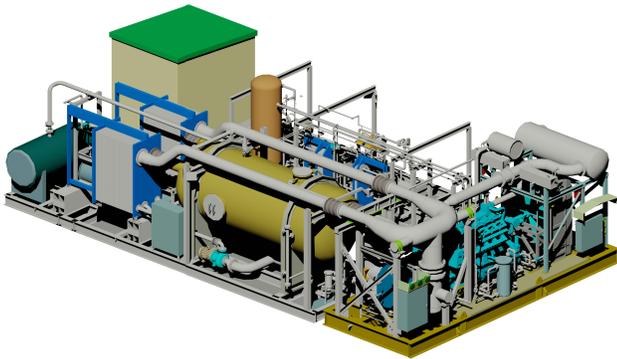
Experience trumps wild promises every time. Water recyclers need to invest the time and energy in learning to treat this highly variable wastewater and customers need to stop listening to vendors that cannot explain how their systems work.

Some producers are content to run an endless stream of pilot projects. This can gain some insight for the producer, however it makes more sense to work with a treatment company that has a real product based on real science and through work through the issues. Often the knowledge gained through a pilot leaves and has to be re-learned by the next vendor in line.

Case Study A – Freshwater, Devon Barnett Shale

In the early days of the Barnett Shale (north Texas), all the producers were fracing with freshwater and that was the goal for treatment – to get back to freshwater. Fountain Quail was fortunate to begin work with Devon Energy in 2004 with the NOMAD evaporator system which was developed specifically for shale wastewater. The NOMAD was designed to achieve the highest possible recovery of freshwater from shale flowback and PW, while still being easily transportable. Devon Energy were pioneers in shale development (formerly Mitchell Energy), and their input was valuable in developing the technology.

Figure 3 – NOMAD Mobile Evaporator



The objectives for this case study include the following:

- (1) Move the recycling to be near the drilling activity. This essentially cuts the transportation of both the saltwater and freshwater by placing both in the midst of the current drilling activity.
- (2) Frac with freshwater alone. This allows for predictable frac chemistry and reduced frac costs (using saltwater requires slightly more frac hp and additional chemical cost).
- (3) Avoids the transport and storage issues associated with saltwater. All frac fluid can be stored in freshwater pits (un-lined, non H-11) and can be transported via aluminum irrigation pipe.
- (4) Water leaks are not a concern and there is no liability from animals drinking the water (NOMAD distilled water far exceeds EPA secondary drinking water), water fowl landing in the pits or odor issues.
- (5) By placing the recycling in the midst of drilling activity, flowback and PW from nearby wells can be tied into the mobile recycling center via welded surface poly pipe (rather than trucking).



The operation continues today and the nearly 10 years of experience have been valuable to both Devon Energy and FQWM. There have been over a dozen different locations throughout this time. With low cost disposal available in the Barnett Shale, FQWM learned to become very efficient so that recycling could remain competitive with low cost disposal.

In March 2012 the Gas Technology Institute (“GTI”) completed a third party evaluation of the NOMAD technology at a Devon Barnett Facility utilizing a RPSEA grant.^[1] This report demonstrates the technical and cost effectiveness of the NOMAD treatment system on shale wastewater.

Case Study B – Turning PW into Freshwater in West Texas

West Texas contains some of the best oil-producing formations in North America. One of the challenges in this area is a lack of available freshwater resources. This client has taken the bold approach of using their existing PW as the feedstock for a NOMAD system to create freshwater.

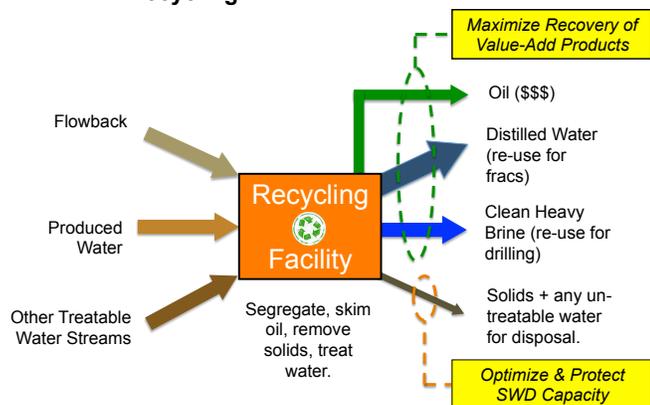
The objectives for this case study include the following:

- (1) Reduce and even eliminate the producer’s reliance on groundwater. Use existing PW as the source water for development in the region.
- (2) Reduce the SWD volume and extend the SWD life. This SWD is owned and operated by the producer. By recycling the majority of the PW back into freshwater, the existing SWD can now serve for disposal of the NOMAD concentrate alone (clean, nearly saturated brine without polymers or TSS).
- (3) Utilize a portion of the NOMAD concentrate as 10# brine for drilling and completions in the region.
- (4) Recover additional oil that is currently going down the SWD well.
- (5) Have the ability to recycle high solids flowback from

the local area that is currently being hauled long distance for disposal.

Disposal of brine and recycling are often viewed as two completely separate options. This case study demonstrates that recycling and disposal can be combined to (1) maximize the recovery of value-add products such as freshwater, heavy brine and oil, while simultaneously (2) protecting and extending the life of the disposal well.

Figure 5 Recycling “Hub” Combining Disposal and Recycling



Case Study C – Saltwater Re-Use, Eagle Ford Shale TX

New shale plays initially follow chaotic development as producers “drill-to-hold” their acreage positions. This requires a highly flexible and adaptable water management strategy. The Eagle Ford Shale in south Texas offers an example of this type of play.

FQWM developed the ROVER for this purpose – to allow customers to re-use their brine in a highly mobile package at a very low cost. In its more basic form it is removing TSS and polymer using a high pH clarification process. This is the same pre-treatment that FQWM has used ahead of its NOMAD systems for close to a decade. The system has proven capable of handling highly variable wastewater influent and delivering consistent, clean brine for re-use. Solids are de-watered on the system utilizing a built-in sludge thickener and filter press.

Figure 6 – ROVER Mobile Clarifier



One of the key benefits to a system like this is the flexibility. If the producer wants to remove a certain scale forming species, then FQWM can usually precipitate it by varying the chemical addition or softening. The cost may go up slightly, however it is still targeting the specific treatment needs of the customer at the lowest possible cost.

In this case study the customer wanted to treat flowback and produced water. The goal was to effectively remove polymer, TSS and iron. The ROVER system was delivered to site and was completely rigged up and operational within 12 hours of arrival. The system treated all of the flowback and PW available. Results from the recycling are shown in the figures below.

Figure 7 – Case Study C, ROVER Flowback Results

Eagle Ford Flowback

Parameter	Metric	Influent to ROVER (Feed)	Effluent from ROVER	Removal
Alkalinity (CaCO ₃)	mg/L CaCO ₃	406	206	49%
Iron (Fe)	mg/L	83	Trace	100%
Manganese (Mn)	mg/L	1.2	Trace	100%
Total Hardness (Ca+Mg)	mg/L	1025	602	41%
Silica (SiO ₂)	mg/L	148	27	82%
Total Suspended Solids (TSS)	mg/L	180	19	89%
Turbidity	NTU	>100	3.0	N/A
pH	pH	6.8	6.8	N/A
Conductivity	uS/cm	37,000	39,000	-5%
Total Dissolved Solids (TDS)	mg/L	32,835	34,610	N/A

Figure 8 – Case Study C, ROVER PW Results

Eagle Ford Produced Water

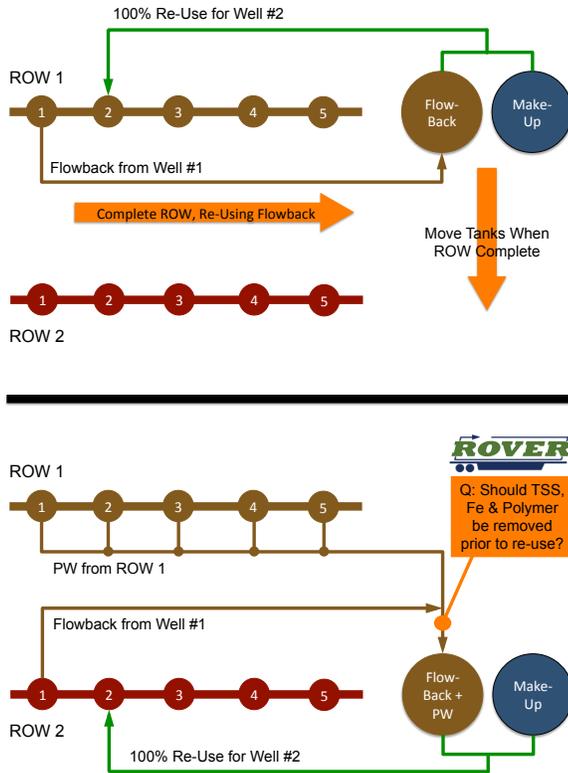
Parameter	Metric	Influent to ROVER (Feed)	Effluent from ROVER	Removal
Alkalinity (CaCO ₃)	mg/L CaCO ₃	340	101	70%
Iron (Fe)	mg/L	26.2	Trace	100%
Manganese (Mn)	mg/L	1.5	Trace	99%
Total Hardness (Ca+Mg)	mg/L	2,027	1,563	23%
Silica (SiO ₂)	mg/L	169	18	89%
Total Suspended Solids (TSS)	mg/L	277	32	88%
Turbidity	NTU	44	3.0	N/A
pH	pH	7.1	7.1	N/A
Conductivity	uS/cm	52,400	54,500	-4%
Total Dissolved Solids (TDS)	mg/L	46,501	48,365	N/A

Case Study D – Saltwater Re-Use, Woodford/Cana OK

This case study shows how inventive producers have become at managing flowback and PW. In this case the producer drills all their wells in linear “rows”. As the wells are drilled and fraced, the flowback is hard-piped along the

row back to a tank. This flowback is blended with make-up water (fresh) and used to frac the next well (without treatment).

Figure 9 – Case Study D, “Row” Development



The objective of this case study was to evaluate whether or not to remove the TSS and polymer from the flowback prior to re-use. After studying the water, it was determined that the water was easily treatable with a ROVER mobile clarification system. The turbidity could be dropped from 600 to 5 NTU. The ROVER treatment could achieve this goal for a budget price of \$0.79/bbl. The customer struggled to quantify whether the removal of the TSS and polymer (and reduced scaling index) would have a significant impact on their oil production.

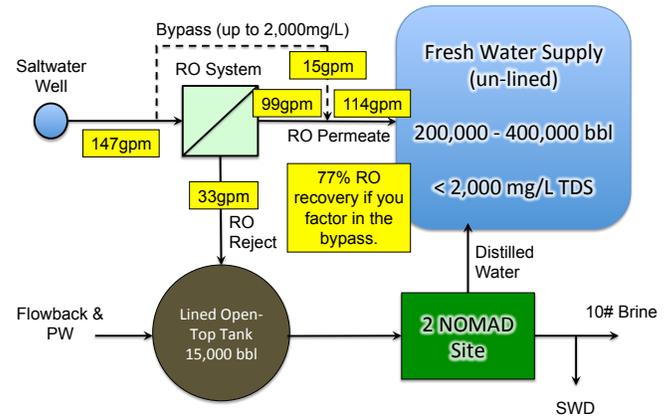
In this case the customer opted to do nothing and continue without treatment. Sometimes this is the answer and recyclers need to understand and accept that “no treatment” might be part of a successful water management strategy.

Case Study E – Brackish Water Study, Wise County TX

This case study demonstrates a unique challenge and creative solution. The customer has limited freshwater in this Barnett Shale county (Wise county), however they do have “brackish” saltwater wells. Despite this, the customer still prefers to frac wells with freshwater.

In this case it makes sense to look at membrane technology to desalinate the brackish saltwater (consistent composition, no hydrocarbon). FQWM came up with the following “hybrid” solution utilizing an RO system to treat the brackish water and also using a NOMAD evaporator to treat the RO reject combined with flowback and PW in the region.

Figure 10 – Case Study E, Brackish RO + NOMAD



The customer continues to study this idea and may set up a small scale system initially. This demonstrates how different technologies can be combined to arrive at a solution. Texas has ample brackish water and there are many ways that it can be incorporated into a water management plan, either by using it directly or treating it to freshwater as demonstrated in this case study.

Conclusions

These case studies demonstrate how both freshwater and saltwater re-use can be successfully incorporated into an energy producer’s water management strategy. To arrive at a solution the customer must be prepared to answer the initial question: freshwater or saltwater? After this it is a matter of laying out simple and achievable goals and selecting a treatment partner or technology that is based on real science and has actual oilfield experience.

Both the producer and the treatment company must be committed to working jointly through the issues as they arise, and success will inevitably follow.

Acknowledgments

Devon Energy has been invaluable as a resource and partner for FQWM. Not only has Devon helped launch FQWM as a recycling service provider, it has tested dozens of other technologies and continues to be an example of pioneering new and better ways of developing oil and gas ^[2.1].

Nomenclature

DAF	<i>Dissolved Air Flotation.</i>
FQWM	<i>Fountain Quail Water Management, LLC.</i>
GTI	<i>Gas Technology Institute</i>
NORM	<i>Naturally Occurring Radioactive Material.</i>
NTU	<i>Nephelometric Turbidity Unit, Turbidity Measurement</i>
RRC	<i>Texas Railroad Commission</i>
TSS	<i>Total Suspended Solids (stated in mg/L or ppm).</i>
TDS	<i>Total Dissolved Solids (stated in mg/L or ppm).</i>

References

1. Hayes, Tom, Ph.D., Severin, Blaine F., Ph.D., PE.: "Evaluation of the Aqua-Pure Mechanical Vapor Recompression System in the Treatment of Shale Gas Flowback Water – Report #08122-05.11." RPSEA Contract 08122-05. March 12, 2012.
2. Ewing, Jay R. PE, Werline, Rusty, PE: Devon "Culture of Achievement – Pioneering Water Recycling" video regarding water recycling projects, www.dvn.com.