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Water Management
The 2017 Techbook

A supplement to *E&P*

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Hart Energy's Techbook Series

The 2017 Water Management Techbook is the 11th in a series of techbooks in which Hart Energy will provide comprehensive coverage of effective and emerging technologies in the oil and gas industry. Each techbook includes a market overview, a sample of key technology providers, case studies of field applications and exclusive analysis of industry trends relative to specific technologies.

To learn more about E&P technology trends, ***visit EPmag.com.***

Table of Contents

Spring rains delivered much-needed water to a Permian Basin drillsite. *(Photo by Tom Fox, courtesy of Hart Energy's* Oil and Gas Investor*)*

Oil and Water Do Mix

Advanced water management techniques coupled with innovative thinking and new technologies are helping balance the needs of unconventional oil and gas E&P with the needs of the public.

By Jennifer Presley
Senior Editor, Production Technologies

For such a simple molecule of two hydrogen atoms to one oxygen atom, water carries with it significant complexities wherever it flows. In its simplicity is the versatility that has lead to the application of water in all facets of life. Take energy production, for example. Not only is water critical in the production of energy; it also is its own waste product. The relationship between the two is loosely defined as the water-energy nexus. From electrical power generation to the extraction, transportation and processing of oil and gas and more, maintaining balance within the nexus is a primary goal.

Water in all its forms is a key ingredient in the development of oil and gas resources. *(Photo by Tom Fox, courtesy of* Oil and Gas Investor*)*

One of the petroleum industry's great ironies is that it takes water to make oil recovery possible. Known for a dogged refusal to mix, water and oil manage to coexist in reservoir formations that, without using one to drill for the other, producing either or both would be impossible. Water is a primary ingredient in the drilling fluid pumped downhole to keep the drillbit cool before carrying cuttings back to the surface for the geologists to decipher like tea leaves, looking for insights into the formation.

Water is the hammer cracking open fractures in shale while simultaneously delivering proppant to hold open the escape route for oil and gas to find the fastest path to freedom. Water cleans the new well of excess solids once it is put on production during a flowback. Over the multi-decade life of the well, wastewater will be produced that will require disposal or recycling. The story of oil (and gas, too) is a water story.

Because of this duality, the business of an E&P company is more about safe and responsible water handling than it is about recovering oil and gas. As Global Water Intelligence reported in a March 2011 market profile, "The oil industry is effectively a water industry that delivers oil as a byproduct. In the North American onshore oil industry, eight barrels of water are brought to the surface for every barrel of oil."

However, the petroleum industry long ago found a way to make those eight barrels of produced water work for them in applications like EOR. In the development of shale resources, those barrels, for example, can become after treatment a supply source for reuse in hydraulic fracturing operations.

The onset of the shale gale more than a decade ago brought with it the need for significant quanti-

ties of water to fracture and free the trapped oil and gas, but not without a cost. In 2014 the unconventional oil and gas industry spent close to $6.4 billion on water supply chain management, according to a Bluefield Research report.

Like most everything in oil and gas E&P, adoption of recycle and reuse is shale-play dependent.

What works in one might not work in another due to a variety of criteria like access to water supplies, regulatory factors, proximity to population centers and suitable underground formations for wastewater disposal. However, just like no two reservoirs are alike, there is no "one-size-fits-all shale plays" water management solution when it comes to unconventional oil and gas development.

"While all operators seek to minimize costs, the economics of water supply chain management are largely driven by basin-specific water regulations and constraints," said the authors of a May 2016 report on water usage in U.S. unconventional oil and gas drilling published by the Columbia University School of International and Public Affairs (SIPA).

Those basin-specific differences have kept water management teams busy in the Permian Basin and Eagle Ford looking for suitable supplies while teams at work in the Bakken and Marcellus look for suitable disposal solutions.

According to the SIPA report, operators face no serious water constraints in the Bakken region due to its low population density and abundant freshwater supply. With surface water options like the Missouri River and Lake Sakakawea, Bakken producers have little need to use groundwater.

In the Marcellus, the Susquehanna and Ohio rivers provide ample surface water, but tight regulatory oversight has lead to increased water management costs. The high population density of the region is cited in the report as being a major regulatory driver.

Standing in stark contrast to the Bakken and Marcellus are the Permian Basin and Eagle Ford regions where operators face "more acute water constraints, including high groundwater stress and an ongoing threat of drought," the SIPA report stated, noting that water demand for hydraulic fracturing is met though the use of groundwater resources.

While recycling and reuse are becoming a larger part of standard operating procedures in the development of unconventional oil and gas resources, there are some regions where the cost to do so is greater than the cost to dispose. In the Bakken, for example, there is little incentive for operators to recycle as there are "plentiful wastewater disposal wells" and the wastewater has "a saline content higher than ocean water" and makes recycling a challenge, according to the SIPA report.

Recycling rates in the Bakken are about 2%, according to the Bluefield Research report. In contrast—due to a lack of disposal wells in Pennsylvania and large transportation costs of trucking wastewater to Ohio for disposal—the average recycling rates in the Marcellus are 80% to 90% of the total wastewater produced in the basin, according to the SIPA report.

For the Permian Basin, the average recycling rate for the Midland sub-basin is about 2%, with no recycling reported in the Delaware sub-basin. Brackish groundwater provides 80% and fresh groundwater provides 20% of the Delaware's water supplies, the report noted. In the Eagle Ford there is a large volume of flowback water available for recycling, but its oily and highly saline nature make recycling an "often prohibitively expensive" option, according to the SIPA report.

Advances in technology and the smart management that experience brings have allowed the industry to better balance meeting operators' needs with that of the public. For example, centralized onsite water storage and recycling facilities have reduced transportation demands, leading to fewer trucks on the road. Pipelines are replacing trucks as midstream infrastructure is being built out to move water from Point A to Points B, C or Z.

The Internet of Things and Big Data are gaining greater acceptance in the water management world, with hardware and software companies developing the robust kit needed to make real-time monitoring and remote operation of water systems possible. Wastewater can now be traded like a commodity through a system that marries the beauty of online booking systems like Airbnb with the efficiency of a Google search, turning a cost center into a potential profit center for operators.

Included in this first issue of Hart Energy's Water Management Techbook is an extensive listing of key players in the water management technology space. We also look at a few best practices when it comes to the safe and secure management of water resources. A discussion on the advancements in new and old technologies being used in water management to help operators reuse produced water in an environmentally friendly manner also is featured. Case study examples that demonstrate the evolution of water management, like online booking of water services, recycling rather than disposing of water in the Permian Basin and the effective treatment of water using biocides are included. ■

Expertise, Technologies Keep These Key Players Ahead of the Game

Operators offer a range of solutions to help minimize water-related costs.

By Ariana Benavidez
Associate Managing Editor

The development of water sources for EOR; recycling of fracturing water; and management, treatment and disposal of produced water can result in substantial costs for oil and gas project operators.

A 2016 Columbia University and Barclays report said unconventional drilling accounts for close to half of U.S. oil and gas production, and this production is dependent on reliable and sustainable access to water.

Additionally, "across all U.S. shale plays, an average of 12 barrels of water is produced for every barrel of oil. In 2015 approximately 66 million barrels per day flowed out of onshore U.S. oil and gas wells. By 2020 produced water volumes are expected to reach 92 million barrels per day," according to Fountain Quail's website.

The following is a sampling of the key players in water management and some of the offerings they provide in this space.

Key Players

The Alfa Laval LYNX decanter centrifuge is a key component in solids control systems of drilling rigs and other oil and gas processes such as barite recovery, oily water and slop oil treatment. *(Image courtesy of Alfa Laval)*

Alfa Laval

Alfa Laval provides technology, expertise and services for onshore and offshore.

The company supplies products and solutions for heat transfer, separation and fluid handling through its key products: heat exchangers, separators, pumps and valves.

Alfa Laval's compact heat exchangers have the capability to recycle heat, optimize customers' energy consumption, cut costs and reduce environmental impact, the company said on its website.

In addition to separators, the company's line includes decanter centrifuges, filters, strainers and membranes.

Alfa Laval also offers tank cleaning equipment and installation material.

The company's DOLPHIN freshwater generators convert seawater into freshwater using vacuum distillation, ensuring freshwater with salinity levels below 2 ppm, according to the company's website.

Aquatech International

Aquatech International provides water purification technology for industrial and infrastructure markets with a focus on desalination, water recycle and reuse, and zero liquid discharge. The company has successfully executed more than 1,000 water management projects in more than 60 countries worldwide, according to its website. Aquatech has offices throughout North America and subsidiaries in Europe, the Middle East, India and China.

Water management services include spare parts supply, build-own-operate and maintenance contracts, technical audits, leased water treatment systems, technical training and remote monitoring.

Water treatment and wastewater services for upstream oil and gas companies include recycle and reuse of produced water, industrial process water, deoiling, induced gas flotation, walnut shell filters/oil removal filters, warm line softening clarification, after filters, ion exchange softening, evaporation, crystallization for zero liquid discharge, brine neutralization, and high-temperature membrane. These services can be applied to coal seam gas/coalbed methane associated water treatments, produced water deoiling, produced water treatments for boiled feedwater makeup, and evaporator brine treatments for discharge/deep well injection.

With treatment processes based on technology from Aquatech International, Aquatech Energy Services (AES) provides services on a turnkey basis to the unconventional shale and conventional oil and natural gas industry to manage and treat for beneficial reuse and to dispose drilling, flowback and produced water. In addition, Fluid Recovery Services (FRS) operates within Appalachia providing turnkey water services to the unconventional and conventional oil and natural gas industry, providing the same management and treatment services as AES.

FRS and AES provide disinfection services using biocides and disinfectants to treat source water and produced water for sulfate reducing bacteria, reduction of hydrogen sulfide and prevention of biofilm formation within oil and water tank batteries.

Aquatech's SmartMOD is a modular water recycle system for produced water treatment in the steam-assisted gravity drainage process. *(Image courtesy of Aquatech International)*

The companies operate multiple merchant central water treatment facilities to treat and dispose of wastewater from E&P activities.

Baker Hughes

Baker Hughes provides well chemical products and services that are designed to help improve hydrocarbon production and reduce operating and water-related costs throughout the entire life cycle of the well.

The Baker Hughes H2prO surface water treatment program uses the industry's oldest problem—unwanted water production and flowback—to solve its newest challenge of getting enough water for oilfield operations. This technology allows operators to get the water needed in the right place, at the right time and with the right quality to perform hydraulic fracturing, waterflooding and other crucial downhole operations, the company said.

The H2prO SR water management service uses proven filtration technology in a highly mobile system to remove suspended solids from produced and flowback water. The H2prO HD well chemicals service uses chlorine dioxide, an environmentally preferred chemistry, to treat produced and flowback water in tanks, reserve pits, impoundments and ponds.

The H2prO SR water management service uses proven filtration technology in a highly mobile system to remove suspended solids from produced and flowback water. *(Photo courtesy of Baker Hughes)*

In addition, Baker Hughes' StimPlus flow assurance service provides a combination of hydraulic fracturing and production chemistry for years of ongoing active treatment to maximize post-fracture production and minimize post-fracture intervention costs.

As part of its efforts to make unconventional resources more sustainable, Baker Hughes developed the BrineCare family of fracturing fluid systems that transforms former waste streams into cost-saving alternatives to freshwater systems. BrineCare won a 2016 Special Meritorious Award for Engineering Innovation in the water management category.

CUDD Energy Services

Cudd Energy Services' Water Management Solutions (WMS) division provides custom-engineered systems to address water management challenges in oilfield operations. Designed for water treatment, water recycling, biocide services and well remediation, these systems provide a method for managing onsite fluid supply, treatment and pit circulation for a variety of oilfield operations. The technology behind the WMS systems provides flexibility in setup configurations. These systems are designed to allow easy mobilization, rapid rigup capabilities and seamless integration with a variety of remote control and automated features, according to the company's website.

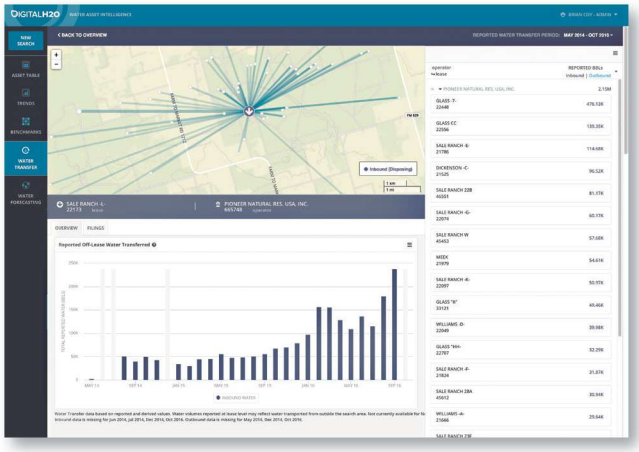
The WMS water treatment system is a contained, mobile unit that restores produced water for reuse in oilfield applications by eliminating bacteria from fresh, produced and recycled water sources. The water treatment system reduces solids content, removes hydrocarbons, breaks down emulsions, accelerates iron removal and destroys hydrogen sulfide in produced water. The system comprises compartmental units housed on individual trailers that can be rapidly mobilized to centralized pits, tank batteries and water collection/treatment facilities, the website stated. Produced water can be transported to the treatment area or extracted from tank batteries or existing pits.

In addition, the WMS biocide treatment system treats produced water, surface water, surface vessels and wells for bacterial control. The biocide treatment system also includes oxidizing treatments to control iron sulfide, eliminate hydrogen sulfide, remove biomass and biofilm, break emulsions, and control other oxidizable species. The system uses the company's Petro-Flo microbiocide, a fasting-acting biocide that effectively controls all types of bacteria including sulfate reducing, acid producing and biofilm-forming bacteria that contaminate water supplies, according to the company's website. WMS also can perform onsite water testing to determine the optimal dosage to treat the particular water source.

Digital H2O

Digital H2O is a digital oilfield technology company that delivers software-based insights and solutions for the end-to-end management of water in oil and gas production. The company deploys digital tools that use advanced data aggregation techniques, predictive decision analysis and connected sensors to help oil and gas producers and service companies reduce the life-cycle cost of managing water and identify new market opportunities.

The company's Water Asset Intelligence tool uses a proprietary data model and predictive algorithms to analyze tens of millions of publicly available oil and gas and water regulatory filings, completion and production observations. The platform's key datasets include disposal capacity and utilization, visibility into water logistics, and oil/gas/water production and consumption data. Water Asset Intelligence includes a water forecasting capability that leverages machine learning to provide a view of produced water volumes and saltwater disposal capacity to enable users to stay ahead of the oilfield water marketplace and reduce operating costs, the company said.



A produced water disposal landscape is shown using the Water Asset Intelligence platform. *(Image courtesy of Digital H2O)*

Digital H2O also is developing a water planning and inventory management platform that enables upstream E&P companies to manage, mine and perform predictive analytics on their own proprietary datasets as well as a fluid ticketing system that helps oil and gas producers and saltwater disposal well operators track water logistics in real time.

WATER RECYCLING

CUSTOMIZED WATER TREATMENT FOR THE OILFIELD

Cudd Energy Services (CES) provides custom-designed water treatment technologies to address water recycling requirements in oil and gas fields. This innovative technology, combined with a configurable, site-specific treatment process generates recycled water that is compatible with today's engineered fracturing fluid technologies. Our customized treatment features OxiFlo™ Oxidizer, a selective oxidant that efficiently destroys sulfidic compounds, including iron sulfide and hydrogen sulfide, as well as residual polymers in the water. CES' water recycling solutions optimize water reuse without jeopardizing the quality of your fracturing fluids and the productivity of your reservoir.

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DistributionNOW offers comprehensive engineering, design, fabrication and installation services for water management products and services. This includes custom-designed solutions for saltwater disposal packages, pumps, filtration systems, freshwater and produced water transfer skids, chemical injection skids and waterflood packages. These packages feature integration technology that allows a unit's operation to be completely automated in the harshest and most variable environments, the company's website stated.

DNOW Process Solutions also operates service centers for repair, fabrication and machining needs. The company employs factory-trained service technicians who are certified to diagnose and repair complex water management systems, offering both field and in-shop service.

Dow Water & Process Solutions

Dow Water & Process Solutions, a business unit of The Dow Chemical Co., specializes in sustainable liquid purification and separation technologies. The company's water treatment technologies include particle filtration, ultrafiltration, polymeric adsorbents, selective ion exchange resins, reverse osmosis and sulfate-removal nanofiltration membranes.

In September 2016 the company released its DOW FILMTEC FORTILIFE product line, an addition to its reverse osmosis and nanofiltration portfolio.

In November 2016 the company released its next-generation DOWEX MARATHON ion exchange resins for industrial water treatment to help users achieve as much as 10% greater productivity from their raw water (or more) with higher regenerability and operating capacity; longer resin life and lower replacement cost; less swelling for higher throughput and fewer regenerations; and flexibility to use in all system designs and to simplify inventory, a press release stated.

According to its website, the company's Water & Process Academies are a resource for building technical knowledge, learning new tactics for increasing efficiencies and discovering best practices for enhancing performance at a facility.

In April 2016 The Dow Chemical Co. was awarded the U.S. Water Prize by the U.S. Water Alliance for its work in promoting and enabling more sustainable use and management of water by companies across the water value chain, a press release stated. The company was recognized "for its leadership in developing new water management strategies, offering innovative products and technologies, and entering into effective collaboration models that make these solutions more attainable."

Fountain Quail Energy Services

Fountain Quail Energy Services offers integrated water management systems designed to reduce costs. The company operates in most major North American shale plays. The company's services include treating for reuse and surface discharge, disposal, storage, hauling, and water sourcing and transfer.

The company's three water treating and recycling systems are the MAVREX, ROVER and NOMAD. All are designed to help lower water-specific operating costs by 30% to 80%, depending on location.

ROVER technology removes suspended solids and polymers and is capable of recycling 10,000 bbl/d of clean brine. *(Photo courtesy of Fountain Quail Energy Services)*

MAVREX, for chlorine dioxide treating, is a water treatment plant housed inside a trailer. The system uses technology from International Dioxide that creates chlorine dioxide *in situ* with the water stream, thereby eliminating dangerous gas reaction chambers, the company said. The system monitors in real time pretreatment and post-treatment water and self-adjusts as water conditions change. "By automatically adjusting dose rates to changing conditions, chemical usage is optimized, overdosing is prevented, treated water will be bacteria-free and overall costs will be lowered," the company said.

ROVER technology removes suspended solids and polymers and can be easily configured for hardness reduction and the selective removal of specific elements. Each system is capable of recycling 10,000 bbl/d of clean brine.

NOMAD technology employs an energy-efficient thermal evaporator. The skid-mounted system is capable of generating 2,000 bbl/d of distilled, surface discharge quality freshwater.

In addition, Fountain Quail's MAG Tank is a modular, aboveground containment solution. The MAG Tank provides operators with a flexible, customizable footprint, multiple capacities and a solution that reduces truck traffic compared to individual frack tanks, the company said. MAG Tank's design features a modular approach with standardized panels. Containment capacities start at 10,000 bbl with designs that exceed 100,000 bbl. Multiple heating options are available.

H_2O Midstream LLC

H_2O Midstream LLC is a private-equity-funded midstream company focused exclusively on water. The company builds, owns and operates long-term water infrastructure that is designed to help producers improve the reliability, efficiency and safety of water operations while also lowering costs. The company is active in all major producing basins within North America.

Midstream services provided encompass the complete water life cycle including sourcing, transportation, storage, distribution and reuse of fresh, brackish and produced water as well as the gathering and disposal of hydraulic fracturing flowback and formation water over the life of the lease.

"H_2O Midstream focuses on creating value for all customers and stakeholders through a proven third-party midstream approach to operating assets, structuring long-term contracts and managing risk," the company said.

Halliburton

Halliburton provides technologies designed to minimize water costs and increase hydrocarbon production. The company addresses water management challenges from surface to subsurface with processes, tools and expertise.

Halliburton assists operators in capturing and treating complex fluids in agreement with local regulations. The company also helps operators repurpose produced waters for use in oil and gas operations and other applications.

Halliburton developed water-based polymer systems and sealants that have limited the flow of produced formation water into the wellbore. The company's relative permeability modifier technology provides water-oil separation in downhole conditions and has reduced water production, according to the company.

In addition, the simpler fluid chemistry and the nonrequirement for crosslinker make Halliburton's OmegaFrac fluid practical and economical for use in a wide variety of produced water.

Hydrasep

Hydrasep helps operators treat their fracture flowback water and produced water in-line and on site. This results in zero oil releases into ponds or storage, less loading on post-treatment processes like desalination, less work on the backend and less time on site.

A custom-designed Hydrasep handles both oils heavier than water and lighter than water. *(Photo courtesy of Hydrasep)*

HYDRASEP technology helps with water process treatment and is designed to lower operating cost. The company's separation units pretreat wastewater reducing downstream chemical consumption, filtering needs and system upsets. The technology also will treat recirculation cooling water, extending the life of pumps and spray nozzles, maintain product integrity and reduce downtime, according to the company's website. The technology also recovers groundwater contaminants.

Hydrozonix

Hydrozonix is a water management company that offers consulting, technology and services to reduce risk and operating cost by optimizing water quality and use throughout the fracturing water cycle. The company's crews, products and services are used by major and independent operators working in unconventional oil and gas throughout the U.S. Hydrozonix operates in North Dakota, Pennsylvania, Texas and Wyoming and has treated more than 100 MMbbl of water in five basins as of October 2015.

The company offers treatment and recycling of produced, brackish and fresh waters either on site or off site as well as pit/impoundment treatment and management. Services include optimization of chemical treatment programs in gathering systems,

Pit treatment by Hydrozonix takes place in the Permian Basin. *(Photo courtesy of Hydrozonix)*

gathering system troubleshooting and consulting, disinfection services, oxidation services for iron and sulfides, aeration services for pit water quality management and bacteria control, membrane treatment for sulfate removal as well as some new services that are scheduled to be released in early 2017, the company said. These new services include an evaporation system and coated media that control suspended solids, iron, sulfides and oil. These new technologies will supplement the company's patented oxidation systems that can operate up to 110 bbl/min and field chemistry that provides real-time chemical analysis and bacteria results within minutes.

ProSep

ProSep provides water treatment equipment, systems and services to assist operators in managing and treating their produced water streams and providing solutions that meet or exceed regulatory and/or other operational requirements, primarily focusing on effluent polishing technologies.

The company's CTour process removes dispersed oil and dissolved hydrocarbon contaminants in the produced water stream through injection of condensate. Not requiring any chemicals, the process is easy to install in existing systems and has a very low operating cost. The CTour process has been used in Norway, having treated as much as 70% of all Norwegian offshore produced water. This equates to more than 2 MMbbl/d of water.

In addition, ProSep's Osorb Media is a regenerable, organically modified silica adsorbent used to treat oilfield, refinery and petrochemical effluent waters and gas streams. It adsorbs free, dispersed and water soluble hydrocarbons as well as many nonpolar oilfield chemicals from produced water including BTEX (benzene, toluene, ethyl-benzene and xylene) components. Osorb also has successfully removed BTEX in a selective manner in natural gas dissolved water streams containing methanol with a 45% internal rate of return.

The TORR coalescing scalable technology addresses effluent excursions as well as increases in water cut for offshore operators. ProSep also offers mixers for water treatment applications demonstrating 25% to 60% reduction in chemical consumption as well as optimizing processes. TORR systems reduce oil-in-water content from 1,000 ppm down to discharge regulation, often less than 5 ppm to 10 ppm and remove/recover oil droplets larger than 2 microns.

Rockwater Energy Solutions

Rockwater Energy Solutions combines water management services with oilfield chemistry expertise to provide operators with an optimal approach to fluid quality and logistics issues. The company was formed in 2011 and has 1,500 employees located in every major shale basin across the U.S. and Western Canada.

Water management services offered include fluids conditioning, water transfer, flowback and well testing, fluid logistics, aboveground storage, and construction services. Rockwater provides fluids and proppant storage, transportation, transloading and disposal services through its fleet of trucks and tanks.

The company specializes in the development and distribution of chemical technologies including crosslinkers, friction reducers, surfactants and specialty chemicals used in completion, stimulation and production.

The company has treated more than 50 MMbbl of water for reuse with its fluids conditioning services, according to the website. The expandable modular

Rockwater fluids conditioning setup taps into a customer's produced water gathering system, centralizing water treatment for reuse on multiple fractures in the Rockies. *(Photo courtesy of Rockwater Energy Solutions)*

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design of the NeoHydro mobile treatment units combined with the company's line of water clarification chemicals enable customizable solutions capable of meeting performance standards of its customers, the company said.

In March 2017 Rockwater announced a merger with Crescent Companies, expanding the scale of its water management operations in key basins. The addition of technologies and services as a result of the transaction include EnviroEdge remote monitoring and control and Crescent Consulting wellsite and project management services.

Schlumberger

Schlumberger offers many products and services for water treatment including oil removal and polishing of produced water, seawater conditioning for primary injection, and controlled-salinity water injection for EOR.

The Schlumberger seawater injection module treats the seawater for reinjection in the secondary and tertiary oil recovery cycles. *(Image courtesy of Schlumberger)*

The company's water injection technologies are used in the treatment of seawater for biofoulant control, dissolved oxygen removal, and suspended and dissolved solids removal.

Schlumberger's METROL SEA-CELL electrochlorinator generates hypochlorite from seawater *in situ*, which is used to prevent the growth of living organisms. The company's BFCC copper chlorine system uses low levels of copper and hypochlorite to control biological activity in water systems. And the company's METROL SEA-SCREEN coarse strainer removes silt, plankton, algae and 98% of particles larger than 100 µm. It also can be used when space and weight are restricted.

The Polymem UF seawater ultrafiltration system removes suspended particles as small as 0.01 µm, which assists with reservoir injectivity. A company brochure stated that it offers significant reduction in operating weight and lower total life-cycle costs compared with traditional media and cartridge filters.

Schlumberger's separation technology also includes sulfate removal systems that are designed to remove divalent sulfate ions from seawater, reducing the potential for barium and strontium sulfate scaling and helping to prevent reservoir souring. It also offers reverse osmosis systems for low-salinity reservoir injection.

For oxygen removal, Schlumberger supplies its VDX vacuum-stripping deaeration system and its GDX gas-strip deaeration system. The company also has developed the CDX compact deoxygenation system for more compact and lightweight equipment.

Developed to mitigate water management challenges, the xWATER Integrated Water-Flexible Fracturing Fluid Delivery Service allows operators to reuse up to 100% of produced water, thereby reducing or eliminating costs associated with water acquisition, conveyance, treatment and disposal. This service won a 2016 Special Meritorious Award for Engineering Innovation in the water management category.

Select Energy Services

Select Energy Services provides water services, well testing, fluid handling, disposal, and wellsite completion and construction. Water-related services offered include water sourcing, water transfer, containment and water treatment.

The company has developed AquaView, a telemetry system with the ability to gain precise and accurate volumetric analyses of water assets and provide real-time data. The system provides users with hydrographic mapping, remote monitoring of the volume and quality of water assets, and reports and alerts. AquaView won a 2016 Special Meritorious Award for Engineering Innovation in the water management category.

In addition, AquaLogic, a suite of automated water transfer options, consists of automated equipment, including pumps and a proportioning system, that responds to operator specifications and changing conditions in real time. With AquaLogic, operators can automate the movement of water and conduct operations closer to their physical limits while maintaining strict safety standards, the company said on its website. The technology gives operators the ability to remotely set and maintain operational parameters. When the system detects

that a certain threshold has been crossed, it sends out an alert and then takes action to keep operations running safely and smoothly.

Sourcewater

Sourcewater.com is a free online search engine and marketplace for sourcing, recycling, transporting and disposing of water for the energy industry that launched in 2015 from the MIT Energy Initiative. Users include more than 500 energy operators, service companies, disposal wells, municipalities, water utilities, farmers, treatment facilities, and trucking and transfer companies.

Sourcewater's free search platform finds water, disposal and transport options in any region and can sort by best combination of price, transport cost, distance, dates, capacity and quality. The platform also allows users to list water, treatment, transport and disposal price and capacity.

In the Marcellus region most energy operators use the platform to efficiently recycle water between each other, replacing high-cost, long-haul disposal cost with low-cost, short-haul reuse, the company said. This increases total water supply available in the market and also allows operators to reduce their freshwater consumption while getting paid to reuse produced water in their completions.

In the Permian and other plays operators and service companies often use the platform to find discounted rates and shorter standby times on excess disposal, hauling and water capacity.

Water-related companies can promote their products, services and technology to users on the platform, similar to advertising in Google search results.

TekSolv

TekSolv provides integrated safety, equipment and automation services. The company's technologies and safety services are designed to improve oilfield automation, life-safety and water management systems for drilling, completions, flowback, production and midstream operations. The company has offices in Delaware, Pennsylvania, Ohio, Illinois and West Virginia.

HydroWatch is a water management technology system that allows quick deployment of critical water tracking hardware with integration into real-time management software, the company stated on its website. Using existing field hardware such as flowmeters, level sensors and other monitoring equipment permits for integration into existing infrastructures and provides a system that visualizes processes, analyzes system data, automates functionality and distributes real-time data to decision makers, operators and supervisors.

Water products and services include water tracking, pump/pipeline controls and transfer verification, production tank levels with leak detection, water treatment and storage, flow volumes and rate monitoring, multiple tank support, and more.

TETRA Technologies

With operations on six continents, TETRA Technologies provides water management, completion fluids and production well testing services to support land completion activity in all basins in the U.S. and Canada. The water management product line supports the upstream oil and gas industry, in particular hydraulic fracturing operations, where large volumes of water are required. The company's services support the transfer, storage and treatment of all types of water including fresh, brackish, produced and flowback water. Each project is custom-designed using the company's proprietary planning and engineering software.

The company's services include planning, testing, filtration, blending and treatment chemistries to deliver water at the required specifications. TETRA's BioRid and TETRAClean treatment additives are designed to be fast-acting, quick degrading, "green" biocides that kill bacteria as fracturing water moves through the tanks. The automated water blending controller and its patented blending manifold ensures that the water is consistent throughout the entire fracturing specification.

TETRA's frack water blending system includes a patented automated blending controller, coupled with a patented, on-the-fly blending manifold. The combination of these units provides accurate parameter-based blending and consistent blend quality, whether directly filling frack tanks or transferring water to another location. *(Photo courtesy of TETRA Technologies)*

TETRA's oil separator, the mobile ORAPT system, accelerates separation with the help of a chemical.

TETRA offers a variety of reusable aboveground storage options that are designed for easy assembly and relocation. The company's TETRA STEEL technology uses zero-discharge Storz Couplings and is mobilized using a patented rapid deployment system (TETRA STEEL RDV), which is designed to result in faster rigup and rigdown, shorter turnaround time between jobs and improved operational performance, the company stated on its website.

Veolia

Veolia designs and provides water, waste and energy management solutions that contribute to the sustainable development of communities and industries, according to the company. Through its three complementary business activities, Veolia helps to develop access to resources, preserve available resources and replenish them.

In 2015 the Veolia group supplied 100 million people with drinking water and 63 million people with wastewater service, produced 63 million megawatt hours of energy and converted 42.9 million metric tons of waste into new materials and energy.

The company has more than 350 water technologies for physical/chemical processes, biological treatment, anaerobic wastewater treatment, filtration and separation, extraction, evaporation and crystallization, mobile water treatment, treatment chemicals, and membrane-based solutions.

The company uses its technologies to design, build and operate water treatment systems, including solutions custom-tailored to meet the needs of the oil and gas industry in both the upstream and downstream sectors from standard products to full-scale design-build options for water reuse, surface discharge or zero liquid discharge. According to the company's website, it provides "a consistent quality of reclaimed water that meets regulatory requirements, protects the environment and ensures long life of facility and system assets."

Veolia's OPUS technology treats produced water at a Chevron site in California. *(Photo courtesy of Veolia)*

Water Standard

Water Standard provides water treatment services and products to the upstream and downstream oil and gas industry and specializes in compact modular systems and mobile onshore and offshore facilities. The company's products include produced water, flowback and oily water treatment equipment; waterflooding/IOR/EOR seawater treatment systems; and units for filtration, desalination, softening, sulphate removal, deaeration (membrane), and ultrapure and service water production.

A Water Standard produced water filtration system is shown. *(Photo courtesy of Water Standard)*

Water Standard designs, engineers and manufactures various separation equipment using its Monarch Separators' facility for fabrication. "Monarch Separators has served the global energy industry for more than 40 years, and its produced water treatment equipment is a mainstay in the industry with more than 1,000 units installed around the world," the company said.

Water Standard's compact H Ocean Spectrum waterflood products are designed to offer flexible solutions, which can maximize oil recovery over the course of a field's life while its Membrane Deaeration (MDA) line of products is proven to reduce weight, footprint and costs for oxygen removal, the company said. It also offers the option of eliminating vacuum pumps through it MDA Torrnado products.

Water Standard offers consulting, engineering, trouble shooting and operations services including feasibility, concept select and FEED design services; troubleshooting and optimization of water treatment systems; membrane autopsies and related diagnostics; membrane cleaning testing and analysis; filtration/permeability reduction testing; cartridge filter deposit analysis; and onsite data collection. ■

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Leaving Produced Water Management to the Experts

Operators need guidance on water management to ensure compliance and to cut costs.

By Rick Von Flatern
Contributing Editor

Although it constitutes most of the total volume of liquids produced by the oil industry worldwide, operators have traditionally dedicated few resources to managing produced water. In the face of increased regulatory pressure and the extreme costs of produced water transportation, treatment and disposal, operators have been turning to water experts and full-service water management companies to fill voids in their engineering staffs. The increase in consultants and services within the upstream industry is testimony to the fact that efficient water management is a critical and complex operator function that is better left to the experts.

"Water treatment is as complicated as oil refining," said Schlumberger produced water product manager, Dan Shannon. "Most operators focus on the oil side and their expertise on the water side can be limited. The whole idea is to involve the water treatment experts who know the right questions to ask in order to determine the best solution."

Michael Dunkel, vice president, water for CH2M, an energy industry consulting firm, condenses recommended workflow and best practices for onshore water management into five essential steps:

- Assess the viability and risks to existing water sources and water disposal over the long term of five or more years, including the potential disruptions from drought, seismicity, regulations or other events;
- Evaluate all other sources and disposal options, including adding infrastructure for reuse for company or multi-company operations and develop a cost matrix for all options while considering risks and stakeholder issues;
- Develop an execution plan with options to lower source and disposal costs and risks. To increase operational flexibility, consider multiple water sourcing methods;
- Design water storage and pipelines for the anticipated life of the play, which may be decades; and
- To allow more efficient capacity use and to lower costs, consider sharing water infrastructure, sourcing and disposal infrastructure with other operators.

Cleaning waste

Formation liquids usually consist of hydrocarbons mixed with a significant fraction of water. The water fraction of this mixture usually increases over time and, without intervention, most formations will eventually deliver much more water per day than oil. The composition of produced water is as varied as the formations from which they flow but typically contain inorganic and organic compounds and some residue of chemicals introduced into the reservoir by stimulation and other EOR operations.

Regulatory-directed produced water purity requirements also vary widely around the world and depend on, among other things, final disposition of the water. Water intended for discharge overboard in the Gulf of Mexico, for example, has certain limitations on the contaminant levels of entrained oil found in the water that is to be discharged. In other areas of the world, no liquids at all may be discharged into the ocean. In the North Sea, regulators require operators to dispose of all produced water through injection into non-producing formations.

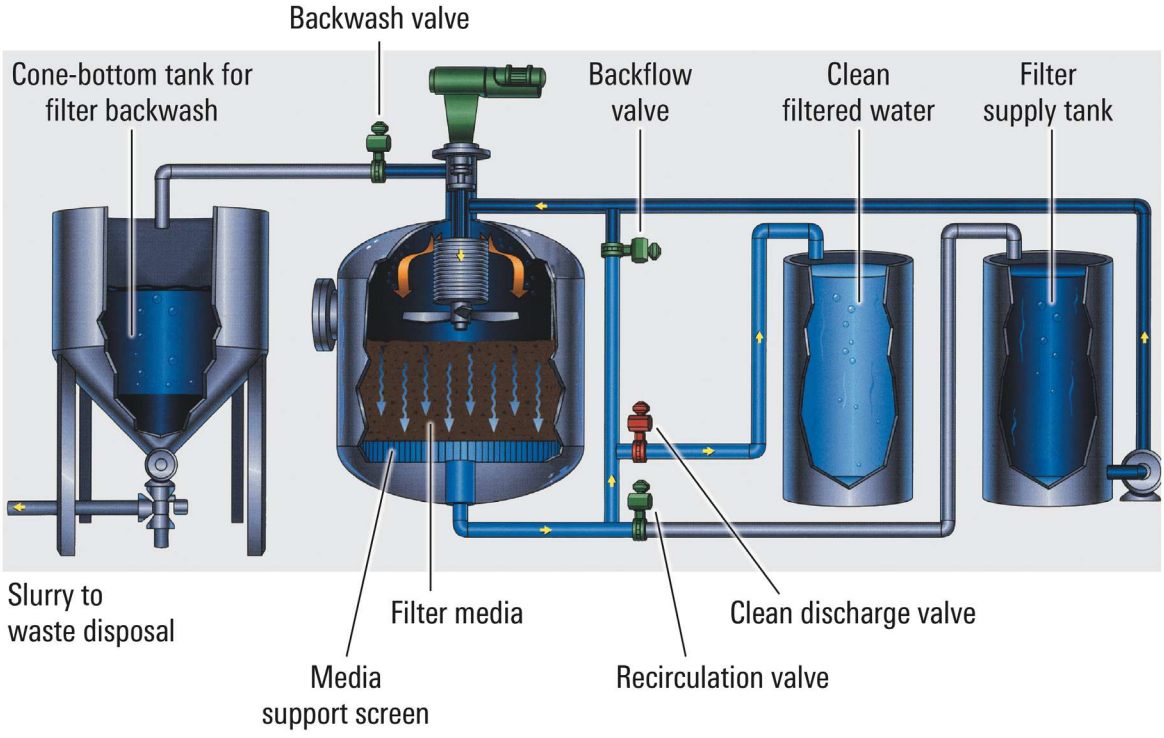
Permissible contaminant levels are dictated also in most parts of the world by how operators intend to use the produced water. Operators may choose to reuse produced water by injecting it downhole for pressure maintenance, water flooding or down injection wells used for disposal. In these cases, water quality standards are dictated by the need to remove contaminants that can damage the formation, surface equipment or well.

"Onshore, just getting your arms around flows, rates, volumes and true costs can get complex quickly, said Laura Capper, president of Houston-based Cap Resources. "Be prepared for a significant study to document these flows and costs–just to understand the starting landscape. Perhaps the biggest issues are that planning should be long term, 20 years if possible, supported by different economic scenarios.

"Systems may include mobile facilities and fixed facilities, along with all the conventional infrastructure needed to manage and move fluids," Capper said. "Production flows change very dramatically over the life of a given well, and the true life cycle of producing fields with many wells, and their fluid contributions, need to be rolled up for the big picture."

The equipment necessary to reach water quality goals in general comprise a series of filters and separators that reduce contaminants in the produced water that flows through them. The degree to which the water is treated in these systems, again dictated by final disposition of the water, ranges from nutshell filters that effectively remove solids and oil from produced water, to polishers that can remove miniscule oil and grease droplets to as small as a single micrometer across.

The makeup of produced water, according to the Baker Hughes website, is a function of reservoir rock characteristics, the wellbore and surface handling



Typical setup in which the Schlumberger PETRECO HYDROMATION nutshell filter is used. *(Image courtesy of Schlumberger)*

techniques. Water chemistry is also impacted by the target reservoir's temperature, pressure and naturally occurring elements.

To properly choose and size treatment equipment, experts use basic input that includes flow rates, influent water quality and desired effluent water quality. As the first two of these are easily known, best water management practices demand use of only quality assured produced water samples.

"What causes less than optimal performance is the water quality data not being identified correctly," Shannon said, referring to operator-taken water samples. "For instance, if crude oil gravity was taken on a sample with diesel in it allowing it to flow better, we need to know that. If the water quality is highly variant due to events in the formation, ongoing field development work or chemical additives–these variations need to be known as well."

After analyzing produced water samples, experts design water treatment solutions by establishing the quality window within which a treatment strategy is to perform. Because the quality of produced water changes as wells are produced, the solution must be able to accommodate a wide range of variables that might change over time. For this reason, optimal equipment is selected and then installed based on the quality requirements that evolve over the life of the field.

Depending on the operating environment, final water quality targets and budget, water management strategies might consist of a single treatment or of numerous increasingly refined treatments. The former solution, say some experts, is a prescription for less than optimal results and, because of its lack of flexibility, may not be able to deliver desired final water quality as the makeup of the produced water changes over time. In addition, when engineers specify a specific piece of water treating equipment, they may force experts into devising a best single-widget solution that is less effective than a solution that considers use of other options.

Integrated water service engineers possess expert knowledge of reservoirs and water treatment technology. They also understand the regulations that govern the industry and know what water quality must be achieved to accommodate operator plans. While large oil companies have regulatory staffs, because water use regulations vary significantly across relatively small geographical distances, most operators rely on water management experts to act as de facto regulatory advisors.

"Typically, customers reach out to us when facing challenges with the water they are producing. They basically say, 'we have water that needs to be treated for a particular use,'" Shannon said. "In other words, they are looking for a solution that treats the water from the current quality to the required effluent quality. During this discussion, our process design experts acquire the right information to ensure an optimal solution is modeled."

Use of experts is critical to water management best practices because staying abreast of technological improvements to existing equipment might have significant economic implications for end users. Dunkel advises operators to consider what they do not know about water management and to look to experts to fill the void.

"Consulting companies, service companies and other producers are potential sources of new ideas in the rapidly changing water management business for upstream oil and gas," he said. "Companies in different basins are doing things differently. Be sure not to overlook a method, process or idea that could cut your costs and improve your operations long term."

For example, Schlumberger's Shannon pointed out that traditional treatments for waterflood effluent containing polymers is to oxidize the water to destroy remaining polymers and then add polymers back to get the system to requisite viscosity levels before it is pumped back downhole. But, he said, Schlumberger's secondary treatment system can save the extra cost by treating the returned water without removing the polymer.

"When the water returns from subsurface, it still contains some valuable polymer," Shannon explained. "The traditional way to treat it is to use chemicals that completely destroy the remaining polymer. The inability to re-use this polymer later in operations can be a costly expense to the customer."

In the current oil price environment, trimming operating costs is a compelling driver of best water management practices, particularly in the booming shale plays. According to the Baker Hughes website, the estimated annual cost of water treatment and disposal of surface water in North America is more than $8 billion dollars. This estimate considers the full fracturing water cycle, which includes sourcing, storing, treating, transporting and hydraulic fracturing.

Shale, water and trucks

In 2014, according to the U.S. Geological Survey, the mining and oil and gas industries accounted for just 1% of all the water used in the U.S. per industry. It would seem a relatively small amount but for the fact that oil and gas exploration and production operations, particularly in shale plays, often take

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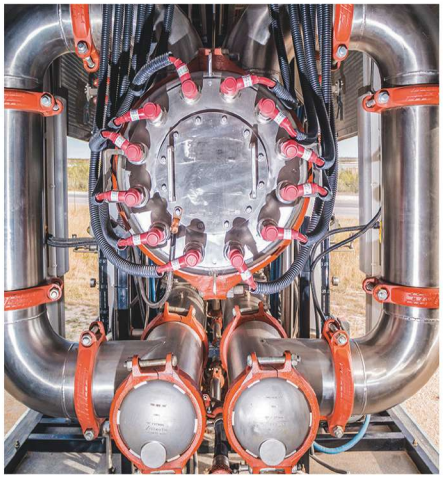

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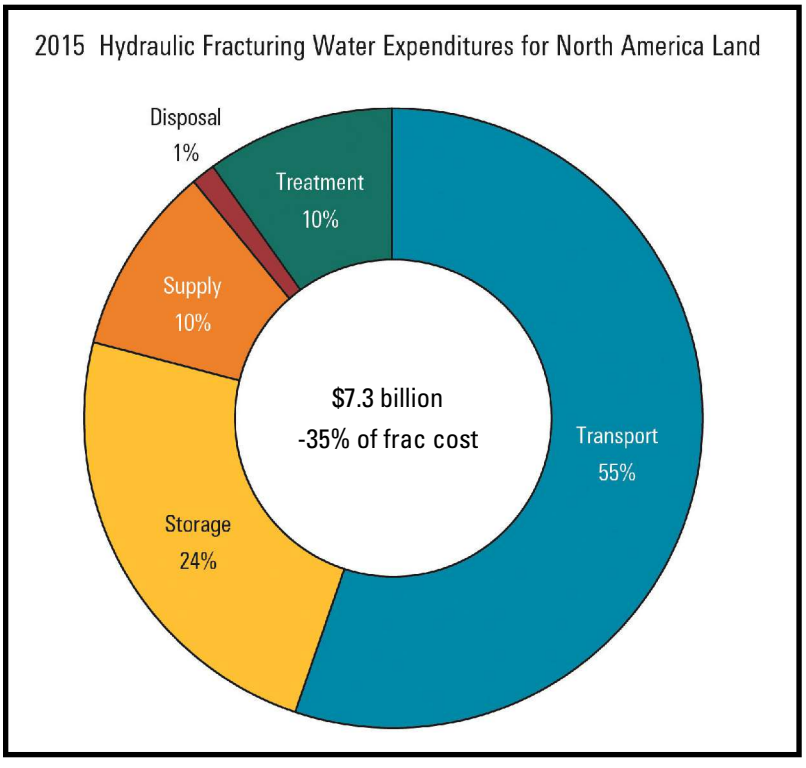

Based on 2015 IHS data, the hydraulic fracturing water expenditures for North America land were an estimated $7.3 billion—with transportation costs contributing 55%. *(Image courtesy of Schlumberger)*

place in water-strapped locales. Consequently, in the rush to exploit unconventional resources, the interests of business and corporate citizenship converge to drive operational efficiencies.

"The most important consideration in water disposal plans is to assure protection of public water sources, without question, Capper said. "This trumps all other considerations. Fortunately, disposal wells are very good at fulfilling this role. For operators, cost control will always be a close second. For disposal programs, this means getting your transportation costs under control—preferably piping water where you can, as opposed to trucking. This will also cut down on health, safety and environmental exposures like greenhouse gas emissions and the like."

According to Schlumberger's Jess Lee, well services chemistry portfolio manager, water accounts for about 35%, or about $7.3 billion, of total costs of hydraulic fracturing.

That figure arises from the cost to complete the full water cycle of transporting water to location, adding chemistry for fracturing fluid, performing the fracture, flowing the well back and transportation to a treatment or disposal site. Transportation in the form of trucks moving fresh and produced water between source, treatment and disposal sites accounts for more than half of the water costs. Large numbers of heavy water haulers also significantly impact nearby infrastructure and pose environmental risks associated with moving large volumes of contaminated water through public areas.

Traditionally, because the chemicals in water produced from fractured wells pose a threat to equipment, flowlines and the formation, operators have long had little practical choice but to pump it down disposal wells or recondition it for agricultural or industrial use. Seeking ways to minimize overall costs of hydraulic fracturing operations, operators have begun to turn to water recycling produced water, including water used to create fracturing fluids, which returns to the surface after all stages of a well have been fractured and the well opened to flow.

This so-called flowback water contains chemicals used in the fracturing fluid and hydrocarbons and other elements from the formation. To prepare produced water for recycling, technicians in mobile laboratories first determine its chemical makeup. Of special interest are elements that can cause corrosion or scale, bacteria that can impact fracture fluid performance and substances that can plug pore throats and restrict production.

Based on their analysis, they then design a system to condition the water to be compatible with the fracture fluid to be used on the next well and with the formation to be treated. Because multiple wells are drilled and stimulated from a single location or pad, this method not only reduces the need for a continuing source of freshwater but because the treatment systems are deployed on location, it eliminates much of the transportation and storage portion of the water cycle.

In the Permian Basin, an operator seeking to recycle water for multiple hydraulic fracturing operations used Baker Hughes H2prO water treatment service to design a system to neutralize hydrogen sulfide and bacteria. The operator used 3,400 bbl of treated water

in a polymer-based, cross-linked fracturing fluid. Two stages of the job were fractured using 100% treated water and because disposal and freshwater costs were reduced, the operation realized significant savings.

Taking flowback and produced water use to the next level, engineers and scientists at Schlumberger have expanded the concept by approaching water recycling from a different direction. Instead of conditioning available water to be compatible with the formation and fracture fluid, the company provides a service that allows produced water-based fracturing fluid formulas that use untreated produced water.

The new offering from Schlumberger is called the xWATER integrated water-flexible fracture fluid delivery service. The design of the fracture fluids, explained Max Nikolaev, stimulation technologies production champion, allows operators to use water that has gone through little or no treatment to build fracture fluids. "The ultimate goal," he said, "is to be able to build a fluid based on any available water source."

The theory behind the practice is reminiscent of the quality window concept, which accounts for water quality variance. In this case, however, the concept of flexibility in backflow water quality refers to ranges of salinity levels, temperatures, pH, sulfates and metals. Using the xWATER service, fracture fluids can be built that are compatible with water having a wide range of salt levels and other characteristics of the target formation.

"We know the composition of the formation water coming back, so our chemistry anticipates this," says Nikolaev. "This is what we are going to see and we make sure the chemistry is going to work with whatever water composition is coming back to surface."

The process begins with produced water analysis. Fracture fluid designs built on those analyses are then modeled and tested at every stage of the water cycle from pumping to flowback.

The service allows operators to build fracturing fluids using most types of available water sources such as brackish groundwater or seawater. The flexibility

A Gastar Exploration drilling and completion engineer checked the lines feeding into a freshwater frack-fluid pond in Kingfisher County. The pond stores about 300,000 bbl of water pumped from the Cimarron River, 10 miles away. *(Photo by Tom Fox, courtesy of Hart Energy's* Oil and Gas Investor*)*

to use multiple water source types with minimal or no treatment to provide a crosslinked gel system, significantly cuts costly steps from the full water cycle by reducing or eliminating the cost and pressure on area roads arising from transporting water over long distances.

In the Williston Basin of North Dakota, the xWATER service was used to hydraulically fracture a two-lateral well using filtered but otherwise untreated produced water. The operations used 7 million gallons of water, including 2.2. million gallons that were crosslinked, to place proppant in the Bakken and Three Forks formations.

The fluid used standard oilfield chemical practices and equipment and is based on an industry standard, widely available and inexpensive polysaccharide gelling agent. During the operation, engineers observed treating pressures that indicated better near wellbore proppant transport than is typically seen in the area.

The operation eliminated the need for freshwater and disposal of produced water, which Schlumberger calculates took 600 trucks off the road. Production from the treated formations is reported to equal or exceed of offset wells of similar design.

Conclusion

Within the traditional business model, water treatment companies acted essentially as manufacturers who built and installed equipment according to client specification. Their involvement after the equipment was online was confined to maintenance as needed. But with increasingly stringent regulations on contaminants and the growing economic importance of water supply and demand in the economics of North American unconventional resource production, operators are coming to view water treatment in a different light.

"Today, we merge responsibility for performance with inherent expertise," said Schlumberger's Shannon. "Clients often install various water treatment solutions but refrain from utilizing the solution experts when operating them. So, the approach now is to take ownership and utilize our water treatment expertise to not only communicate to the operator what these solutions do but also ensure they perform as expected." ■

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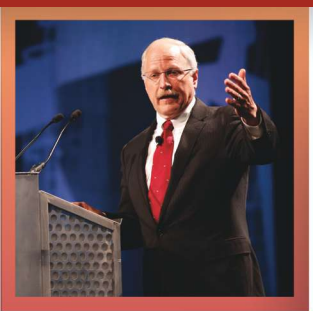

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Water Treatment Activity Increases as Operators Seek Injection Alternatives

Both old and new technologies are being used for water management as operators seek environmentally friendly ways to reuse produced water.

By Scott Weeden
Contributing Editor

In California's oil fields operators produce about 15 bbl of water for every barrel of oil. Disposing of that produced water became even tougher on Dec. 31, 2016, when state regulators shut down 30 active injection wells in the Central Valley.

The California Division of Oil, Gas and Geothermal Resources ordered the companies to stop injecting oily produced water into 10 aquifers in the valley. None of the aquifers are used for drinking water, but environmentalists said with new technology to clean up the brackish water those aquifers could provide drinking water in the future. There was no evidence that any freshwater aquifers in the Central Valley were contaminated.

After a 5.8 earthquake occurred in the Pawnee, Okla., area on Sept. 3, 2016, the Oklahoma Corporation Commission's Oil and Gas Division took action. The agency shut down 32 injection wells in the 1,116-sq-mile area of interest. There were 67 injection wells in the area of interest with 48 Arbuckle disposal wells under the Oil and Gas Division jurisdiction and 19 under the auspices of the Environmental Protection Agency (EPA).

Of the 32 wells that ceased operations, 27 were under state jurisdiction and five under EPA jurisdiction. Following another earthquake in the Cushing area in November 2016, another seven injection wells were shut in.

Oilfield water management is coming under stricter control. Those regulations are only likely to get more stringent as industrial, commercial, agricultural and residential users vie for limited resources.

Stressed water resources

When hydraulic fracturing was at its peak, recycling of produced water for fracturing fluid was a key water management option because freshwater resources started to become stressed by all the oil activity, said Mark Patton, vice president of sales and marketing for Hydrozonix.

"When oil prices dropped and completion activity declined, the water sources were no longer stressed. People had spent time and effort in developing brackish water sources so there would be less reliance or no reliance on freshwater," he said.

With brackish water resources becoming more plentiful, that moved produced water back into a traditional disposal mode in injection wells. In some areas like Oklahoma that stressed the resources and, when combined with reduced injection well capacity due to induced seismicity, caused spikes and increases in produced water and disposal costs, Patton said.

It is difficult to commit more injection capacity in areas with induced seismicity "because regulations are moving in the opposite direction trying to reduce the number of injection wells. That means they have

to come up with other options," he said. "But they can't commit to long-term programs because as activity increases somewhere down the road, they want to use that produced water again to recycle, because that is their lowest cost option."

One option Hydrozonix took on was to update a conventional evaporation systems. "This evaporation system will be rolling out in late February with some smaller installations already scheduled for first-quarter 2017. This is basically a portable system to move from well pad to well pad and use existing natural gas to evaporate the produced water," Patton said.

Since these are not permanent installations, an operator can have a long-term contract with the unit and move it from area to area as needed. This is especially useful in areas where it is economically or logistically not feasible to collect field gas and put it into a gathering system.

"Under current regulations you can use the stranded gas in an evaporation system. We think this new offering is a critical component to being able to have an overall produced water management program that is sustainable," he said.

Hydrozonix also is retrofitting flare systems that have scrubbing systems using produced water by basically converting the flare into an evaporator. "It is a lot cheaper than going out and buying an evaporator. We are in the process of implementing that design on nine flare systems in the Eagle Ford. Those were scheduled to be deployed in the first quarter," he said.

The company has another technology under development with a major multinational company. "It is a coated media that can be used to not only remove suspended solids but also iron and oil, including oil that is dispersed and emulsified. You can produce an iron-free, oil-free and solids-free product. We are still trying to finalize the exclusivity for the product with the company," Patton said.

Variable technologies for different plays

Even though the emphasis on water management in Oklahoma has been on reducing induced seismicity, the challenge Oklahoma operators are facing is that the water in different plays in the state varies from north to south.

"There is no one technological solution that will treat all these waters. We need variable technologies that can adapt to these kinds of shale formations because the salinity, characterized by total dissolved solids [TDS] in the produced water, change substantially from south to central to the northern part of the state. There is no silver bullet for these different applications," said Lnsp "Naggs" Nagghappan, senior director, business development, upstream oil and gas for Veolia Water Technologies.

This on-the-fly disinfection system is operating in the Permian Basin. *(Photo courtesy of Hydrozonix)*

In the Mississippi Lime play in northern Oklahoma, producers dispose of water primarily through deep-well injection. The disposal is really inexpensive in northern Oklahoma, but there are issues with induced seismicity associated with injection of produced water.

The central part of the state, where the STACK region is, is yet to have the seismic issues, although the producers are concerned about the future impacts.

"The challenge they are facing is high disposal cost. They're spending a lot of money because they don't have the network of piping that the northern part of the state does," he said. "In the southern part of Oklahoma in the Ardmore and Arkoma basins where they are facing a drought and high disposal costs, they don't have enough water for fracking."

Operators in northern Oklahoma are looking for a reliable disposal solution other than injection. "If they are actively fracking and if they have a way to get that water back as frack fluid, then reuse is the most economical way to get rid of the water. It makes sense where they have an active drilling program," Nagghappan said.

For reuse, only some of the contaminants must be removed from the water. For example, reuse technologies don't touch TDS. "We just remove the particulates, which are oil, solids and bacteria, along with scale formers like iron and manganese, and dissolved gases like H_2S," he said.

The company's ShaleFlow technology is used for removing these contaminants. The compact system is mounted on three mobile trailers. It has a system

capacity of up to 10,000 bbl/d. The system is designed to reduce operating costs, frack completion costs and water disposal costs, he said.

Conventional, unconventional water disposal

In 2010 operators were typically using about 50,000 bbl to 70,000 bbl of water for each U.S. shale well fracturing operation. Today many fracturing operations are using more than 500,000 bbl/well. At the same time, produced water volumes from existing wells are rising, creating many challenges for operators around total water management.

Oilfield water treatment can involve any number of technologies depending on the incoming water conditions—from filtration to electro-oxidation, which is used on this location in Pecos, Texas, by Rockwater. *(Photo courtesy of Rockwater Energy Solutions)*

Produced water from conventional and unconventional wells often is considered waste and sent to deep-well disposal, but large volumes of these waters also can be reused in EOR and fracturing operations.

"Water is clearly a central theme for operators, largely because of the changes in fracturing technology requiring increased frack fluid volumes to enhance well productivity," said Rockwater Energy Solutions CEO Holli Ladhani.

David Stuart, Rockwater vice president of operations, added, "Water treatment methods can vary depending on the basin, the quality of the produced water and the intended use of the treated water (i.e., frack reuse, EOR and disposal). We consider technologies that will allow us to adapt to those variations in water qualities and deliver conditioned water to meet the specifications required for its reuse.

"For example, our water treatment services for frack reuse are designed to remove contaminants that can be detrimental to not only the frack fluid but also may cause damage to the formation. In those cases, our treatment services might include removal of organics, suspended solids and metals."

It is most often not necessary to remove dissolved solids or salts from these produced waters because these components already are native to the formation.

"Simple filtration often is used to remove large to medium suspended solids. We also utilize an electro-oxidation technology called Neohydro, which helps destabilize and remove those fine suspended solids while oxidizing metals and hydrocarbons that can be problematic for reuse purposes. In addition, we have a selection of biocide treatment options for bacteria management," Stuart said.

Better types of water quality

One trend within oil and gas water management is to move toward alternative types of water to replace or minimize the use of potable water. These sources could be subsurface saline water, produced water or affluent water.

"The technologies that TETRA has developed are to help the customers use those types of water at a lower possible cost with no impact on the stimulation operations," said Barry Donaldson, global vice president of sales and marketing for TETRA Technologies Inc. "At TETRA we don't believe that one type of treatment fits all, and every water is a little bit different. We don't have a box-type approach. We look at the most economical applications to get that water fit-for-purpose."

The company does use some of the older technology such as filtration. "We are looking at more efficient and more economical types of filtration. We have multiple types of biocide. We have just introduced a new separation technology called ORAPT [oil recovery after production technology] to remove oil from produced water," he said.

Scott Richie, North American product line manager for water management for TETRA, explained that the transfer of water can result in unintended consequences when an operator is using alternative water sources.

"From the beginning of the job, we're engineering customized solutions for each transfer. We start with a site survey where we physically inspect the site and

route and take measurements of the distance, elevation and site specific things along the route that we have to be mindful of. We come back and plot that information into some software that we have developed to ensure that we get the right equipment for the right job in the right spot," he said.

"One of the other things the company is developing right now is getting automation and telemetry into our delivery system where we are moving water over greater distances. Being able to monitor that equipment in real time with centralized visibility and know what's going on with the pumps, line pressure and flow rates allow us to have better communication. If there is a problem along the line, early warning or notification means you can find it quicker and respond to it faster."

Donaldson added, "We can automatically shut down or idle down any part of or the whole transfer before the operator has time to react."

One of the challenges that TETRA addressed is balancing produced water with other sources of water to meet the specifications for the input water for the fracturing fluid system. The company designed a water blending controller and its patented blending manifold to ensure the water is consistent throughout the entire fracturing specification.

"Ultimately what our customers really require is consistency. They can dial in their frack chemistries and work on a very narrow range. They don't like variation, and that is where the blending controller hits the spot by making sure that the input waters will be in the proper proportion," said Yannick Harvey, TETRA's water management engineering manager.

With potential throughput ranging from 25,000 to 35,000 bbl/d, the TETRA ORAPT helps pull out as much oil as possible prior to filtering and blending produced water—down to 50 to 100 parts per million. *(Photo courtesy of TETRA Technologies Inc.)*

Treatment for discharge

The technology for producing low-cost potable water for drinking or agricultural purposes is the Holy Grail for water management companies. However it is not really an issue because it is too expensive at this point for everybody, Richie said.

"Every single black-box company out there is trying to develop technology to desalinate water. We're still a couple of years off. We're looking at different things, but eventually as regulations tighten around disposal or reinjection, I think there will be a market at efficient pricing," he continued.

When it comes to discharging water into the environment, TDS must be removed. Sodium chloride is the No. 1 contaminant and requires advanced technology to remove it, Veolia's Nagghappan said. Then there is boron. "Boron is not toxic to humans, but it is highly toxic to plants. Ammonia is the same way and it affects aquatic life. So we have to remove it from the water," he said.

Depending on the salinity of the feed water, Veolia offers multiple technologies (membranes and thermal processes) for treatment of produced water for surface discharge. Veolia's OPUS II technology, which is a membrane-based process, is an ideal fit to clean the produced water from the southern Oklahoma oil fields to a high-quality product suitable for discharge. In the northern part of the state where TDS concentrations in the produced water are higher, its CoLD crystallization technology can be applied on a brine solution after pretreatment. The CoLD crystallization

Veolia's OPUS II technology is a membrane-based process that generates effluent suitable for discharge to surface water or reuse for crop irrigation—a significant benefit in water-strapped regions. *(Photo courtesy of Veolia Water Technologies)*

Veolia's CoLD crystallization is applied to produced water with very high TDS to increase water recovery. *(Photo courtesy of Veolia Water Technologies)*

process has the lowest operating cost compared to a conventional approach.

Patton said Hydrozonix is using membranes for some sulfate removal work in the Permian Basin, which is one of the applications that is starting to grow. "We're experimenting right now with different coatings on membranes to decrease their fouling. We're also doing some studies with a vibrating membrane. We're also looking at some combinations of membranes with other pretreatment options to reduce the fouling, which is something we will be rolling out in the first quarter," he said. This will allow the use of membranes where they typically have not been used because of fouling concerns.

Rockwater aboveground storage tanks are approved to store produced water in six states. Pictured here is a nested tank configuration to provide secondary containment. *(Photo courtesy of Rockwater Energy Solutions)*

Produced water storage, oil separation

Operators are always looking for ways to be able to use produced water practically. They need to have a certain infrastructure to do that in a central location where they can store it so they have an adequate amount of water when it is needed, TETRA's Richie said.

"Produced water usually has a good portion of hydrocarbons in it. If the water is going to be reused for fracking, then hydrocarbons are not an issue because these are being sent back downhole. But when you're going to store millions of gallons of water at a time, typically your permits are for storing produced water and are not permits to store oil," he said. "The oil in the water is not a chemical issue. It is a storage issue."

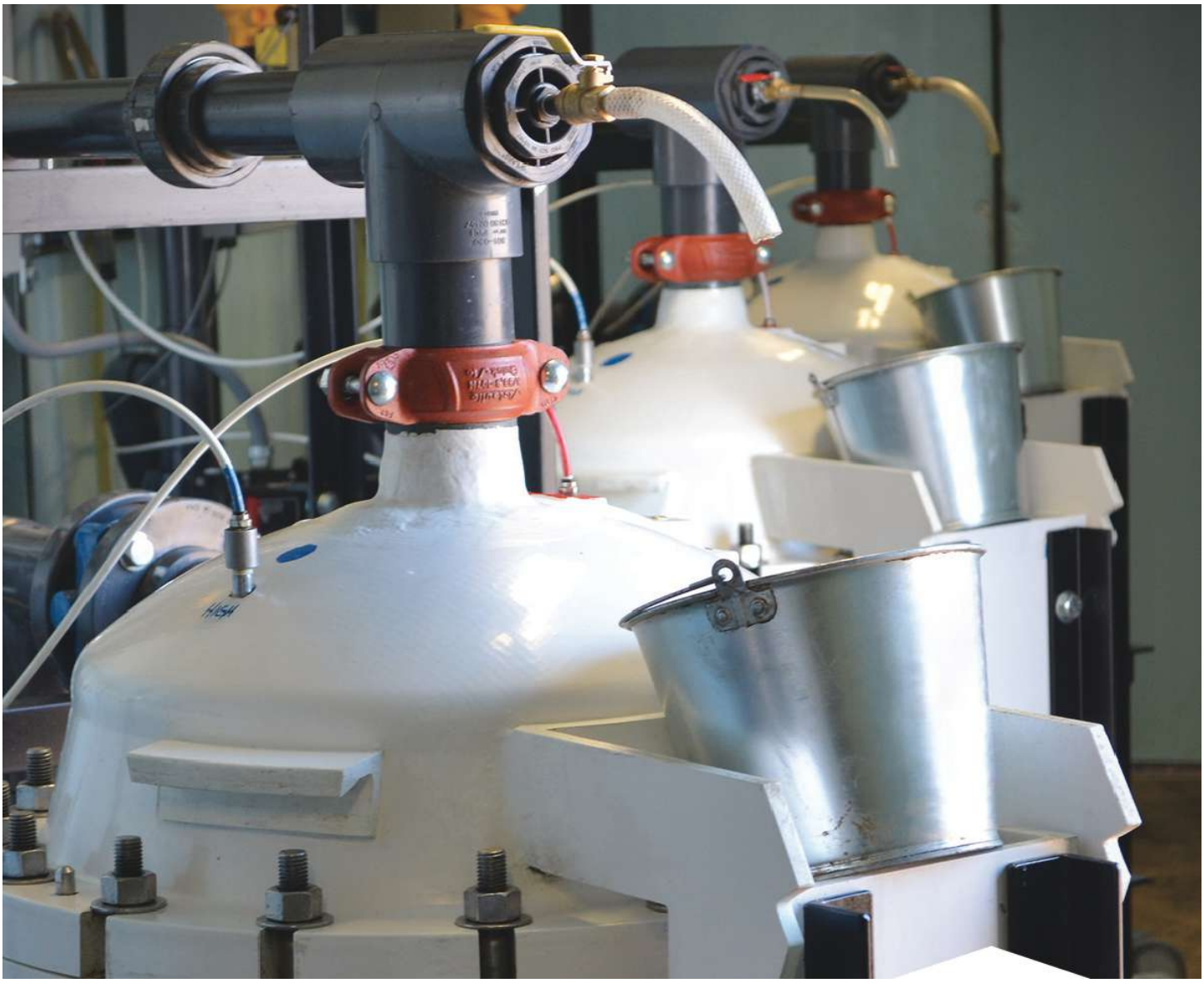
Harvey developed the oil separator that is called the ORAPT system. It is a mobile, standalone system that basically accelerates the separation with the help of a chemical. The system is so effective that the customer can resell that oil, the company said. The customer is saving money on both sides, because the oil does not need to be disposed of, and the oil can be recaptured and sold. The amount of hydrocarbons being stripped is almost paying for the service.

"Our customers have been happy that we've been able to catch that oil and then resell it. They don't have to use secondary means to remove it from storage volumes," Harvey said.

Water storage is also an important part of Rockwater's water management solutions. The company offers aboveground storage tanks (ASTs) from 4,500 bbl to 60,000 bbl in capacity. A 60,000-bbl tank can be delivered on five trucks loads and erected in a single day.

"That replaces 120 conventional frack tanks and associated trucking in and out of a location. This reduction in environmental footprint is extremely important to our customers. ASTs are not only a cost-effective solution compared to conventional storage but also eliminate a large number of potential leak points associated with large manifolds used to connect multiple frack tanks. The AST is a single structure so the elimination of these multiple connections is a significant HSE benefit," Rockwater's Ladhani said. "ASTs are now commonly used for produced water storage as well. We were the first AST provider to receive permits to hold produced water in six different states."

Stuart said Rockwater also has "nested" tank configurations that provide full secondary containment in the event there is ever any leakage from the primary tank. The nested tanks have become widely used for storing produced water. ■



WANT TO SIGNIFICANTLY INCREASE RECYCLING OF PRODUCED WATER?

Customers wanting to recycle produced water in their oilfield operations need to clean it first, removing as many particles as possible. Traditional bag filters can't deliver the finer levels of particle filtration without facing clogging and maintenance issues. **TEQUATIC™ PLUS Filters**, however, can reliably filter down to 15 microns with minimal maintenance and maximum efficiency — and with remote control capabilities.

Learn how one oilfield water infrastructure provider helped a customer recycle 100% of its produced water and save around $2/barrel of water, reducing operating costs by about 60%. **See cleanfiltration.com.**

Dow Water & Process Solutions

Technologies, Services and Solutions for Water Management

Innovative processes and technologies help operators minimize water management costs.

Compiled by Ariana Benavidez
Associate Managing Editor

Cost-effective practices for managing oilfield water require a thorough understanding of reservoir characteristics, production volumes, design and environmental factors, among other factors. Reducing and recycling produced water and minimizing freshwater use help improve profits and contributes to water conservation.

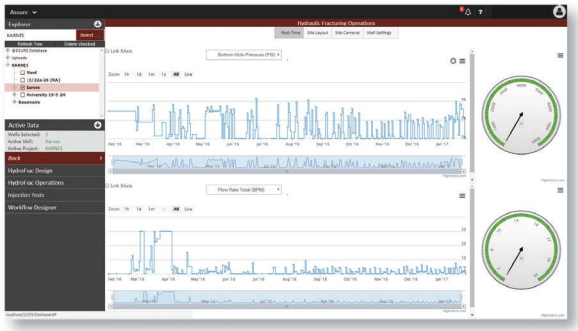
Oil wells worldwide produce about 220 MMbbl/d of water, which is about 3 bbl of water for every barrel of oil, Halliburton explained on its website. "In older fields the water 'cut,' or ratio of water to oil, can be 95% or higher. Managing this produced water is a great challenge for operators."

The following is a sampling of some of the latest products and services available for water management.

Editor's note: The copy herein is contributed from service companies and does not reflect the opinions of Hart Energy.

Well monitoring and surveillance platform for understanding trends

Advantek Waste Management Services recently released a comprehensive, real-time, web-based well monitoring and surveillance platform called @SSURE. The platform enables real-time assessment of the health and performance of a single or network of injection wells, including a full assessment of the subsurface formation response. By using best-in-class well testing techniques applied to real-time data, @SSURE enables the operator to understand trends in injectivity, near well damage, seismicity and other variables that are key to assuring the long-term health of the well. *advantekwms.com*



The @SSURE platform enables operators to understand trends in injectivity, near well damage, seismicity and other variables. *(Image courtesy of Advantek Waste Management Services)*

Vacuum drum dewatering filter replaces filter press

A total disposal recovery operation on a Watford, N.D., oil field took in and processed oilfield tank bottoms, cutting fluids, dissolved air flotation sludge and drilling mud. A plate-and-frame filter press was used for oil recovery and mud dewatering. The cuttings and large slugs of solids were removed with a centrifuge, and the centrate was sent to the press system. Despite the centrifuge doing the heavy lifting,

The Auto-Vac rotary vacuum drum dewatering filter is shown. *(Photo courtesy of ALAR Engineering)*

the mud blinded the filter plates and the solids coming off the press needed excessive amounts of fly ash to absorb the moisture. Mud samples were shipped for bench simulation testing to ALAR Engineering, which has released the Auto-Vac rotary vacuum drum dewatering filter. Satisfied with the results, the company shipped a tote of its wastewater to ALAR for a test bay demonstration. Grab samples of the dry solids and clear effluent were taken and sent out for laboratory analysis. The company rented a pilot test unit and later purchased a trailer-mounted Auto-Vac Model AV660. Once installed, the Auto-Vac produced water with less than 50 ppm total suspended solids (TSS) and solids that were many times drier than from the filter press. The need for fly ash was eliminated. The Auto-Vac solids were used to absorb the moisture from the centrifuge solids. On some occasions it would extract valuable condensate from the process, which was recovered in the clean water tanks. The low TSS enhanced post desalinization or other ultrafiltration methods. *alarcorp.com*

Mobile or semi-permanent onsite water treatment

Proper water treatment is critical to oilfield operations to ensure operators perform safely, efficiently and in compliance with governmental regulations. Baker Hughes H2prO HD water treatment services offer a cost-effective method to efficiently treat fresh, produced, flowback and brackish water for reuse, recycle or disposal. Based on chlorine dioxide, the system offers a highly effective mobile or semi-permanent onsite treatment that kills bacteria and oxidizes hydrogen sulfide, iron sulfide and polymers in the water. Additionally, the Gen III system is the newest addition to the H2prO HD fleet. The next-generation systems are fully compatible with existing equipment to allow seamless integration. This is specifically beneficial for on-the-fly treatments during hydraulic fracturing operations and surface water treatment in pits, tanks and vessels where system flexibility and mobility are key. *bakerhughes.com*

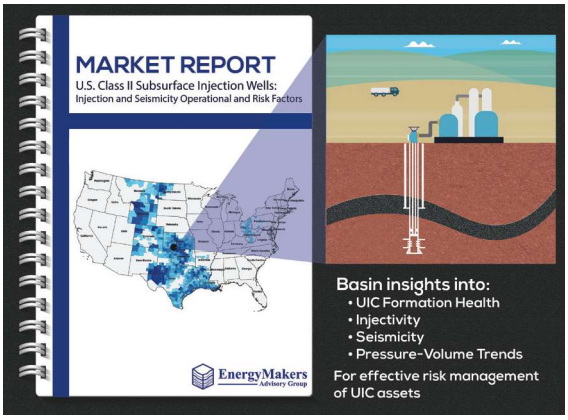
Treatment reduces contaminants by up to 99%

The rapid increase in hydraulic fracturing in unconventional completions has put great stress on freshwater sources. As a result, many producers are tapping the deeper supplies of brackish (moderately saline) water. The problem that arises is that brackish water contains more than just salt. Depending on the location, it might host one or more of the following in levels high enough to reduce performance or damage wellbores: sulfates, manganese, iron, bicarbonate, calcium and other dissolved solids. Bosque Systems' AnCat treatment reduces these and other contaminants by up to 99%. It accomplishes this using a specifically designed ion exchange resin. Installed onsite, the AnCat unit is scalable, can be remotely monitored and operates 24/7 as needed. One case study showed that AnCat reduced the sulfate content of brackish water from 400 ppm to 2 ppm to 6 ppm. *bosquesystems.com*

Bosque Systems removes the sulfate during the treatment process with its safe AnCat technology. *(Photo courtesy of Bosque Systems)*

New report on US class II subsurface injection wells

The EnergyMakers Advisory Group is publishing a comprehensive 200-page meta-study. The report identifies and qualifies the complex risk factors and recent trends associated with the oil and gas industry's operational reliance on class II saltwater



A 200-page meta-study addresses and attempts to quantify key questions on a basin and formation level for SWD stakeholders. *(Image courtesy of The EnergyMakers Advisory Group)*

disposal (SWD) wells for the safe and effective disposal of produced water, frack water and approved oilfield liquid wastes as well as the protection of U.S. drinking water sources. There is an array of conflicting information surrounding use and regulation of underground disposal wells, often with politically driven undertones. In an even-handed, fact-based manner, this report specifically addresses and attempts to quantify key questions on a basin and formation level for SWD stakeholders, including oil and gas operators, investment professionals and private-equity firms, oilfield service companies, water management companies, and midstream businesses. The study provides in-depth coverage of the leading onshore U.S. basins and includes topics such as understanding basin and region-specific injection; seismicity risks and formation health indicators; scientific underpinnings; regulatory and litigation landscapes; operations continuity and best practice considerations; region-specific opportunities for risk reduction; and new investment frontiers. *energymakersAG.com*

Chemical-free bacteria and scale treatment device

In 2016 ENSERVCO Corp. released its HydroFLOW bacteria and scale treatment device for use in treating fresh and recycled water in fracturing and injection well applications. Traditionally, E&P companies have used chemicals to prevent downhole scaling and corrosion caused by bacteria in water. HydroFLOW, which uses electrical induction technology to achieve up to a 95% bacterial kill rate, is a lower-cost, chemical-free, environmentally friendly alternative to traditional methodologies. ENSERVCO is conducting field trials with a major E&P operator to prove the effectiveness of HyrdroFLOW. These trials include use of a mobile laboratory to conduct infield testing using Rapid-B flow cytometry, whereby a quantitative assessment of live bacteria rates is made to determine whether additional treatment is necessary. *enservco.com*

HydroFLOW offers E&P companies an environmentally friendly alternative to chemical treatments. *(Image courtesy of ENSERVCO Corp.)*

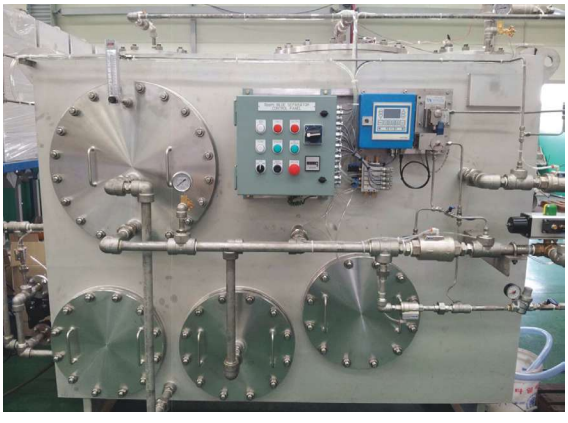
Mobile automated filtration system operates without manpower

Fountain Quail recently released SCOUT, a mobile automated filtration system. The backbone of the SCOUT system is a completely automated back-washable media filtration system that removes 95% to 98% solids greater than 2 microns while simultaneously removing 90% to 95% of hydrocarbons. This performance is achieved in a small footprint. In fact, a system with capacity of more than 10,000 bbl/d of water can be pulled by a pickup truck and set up by a single operator, thereby decreasing costs and footprint. The system operates without manpower, chemical or the need for disposal of filter media. There is a far higher flux rate than traditional filters, which means less size, weight and cost. The SCOUT platform allows quick setup time, and the product is synergistic with the Fountain Quail's MAVREX and ROVER platforms. The product will be used for oilfield applications including infield produced water treatment (including short duration wellsite-specific projects), pit remediation and saltwater disposal pretreatment. *fountainquail.com*

Oily water separators exceed environmental regulations

Efficiently and effectively removing oil from water, along with contaminants, has long been a struggle for the oil, gas and marine industry. GenOil's Crystal oily water separators exceed industry environmen-

tal regulations. Crystal has been certified by the U.S. Coast Guard and the American Bureau of Shipping. During vigorous testing, Crystal has purified oily water down to below 1 ppm. The separators have a filter-less operation with no internal moving parts, which enables continuous operation for many years requiring no downtime for maintenance and/or cleanings. The separators also were designed to run 24 hours a day in the harshest environments. With an ultracompact footprint, Crystal is customizable and can be used in a wide range of applications such as oil fields, oil platforms, ship bilges, sand washing plants, wastewater treatment plants and salt mines. *genoil.ca*



The Crystal separators have a filter-less operation with no internal moving parts. *(Photo courtesy of GenOil)*

Sulfate remover improves oil recovery

GE's Water & Process Technologies recently released the new SeaWater Sulfate Reducing (SWSR) membrane to remove sulfate from injection water for offshore oil production. The SWSR membrane removes sulfate to reduce scale and corrosion in the injection well, which can reduce oil recovery and plug the well. The product also has fouling resistance due to its three-layer membrane design and smooth surface. The SWSR membrane series is an advancement of GE's DK series nanofiltration membrane and provides a high transmission of sodium chloride into the permeate water to minimize operating pressures. The membrane offers a physical barrier for any suspended particles including bacteria, pyrogens and colloids. Additionally, the new membrane will help prevent strontium and barium sulfate scale in injection wells and will better mitigate well souring by reducing sulfate. *gewater.com*

The SWSR membrane removes sulfate from injection water for offshore oil production. *(Image courtesy of GE Water)*

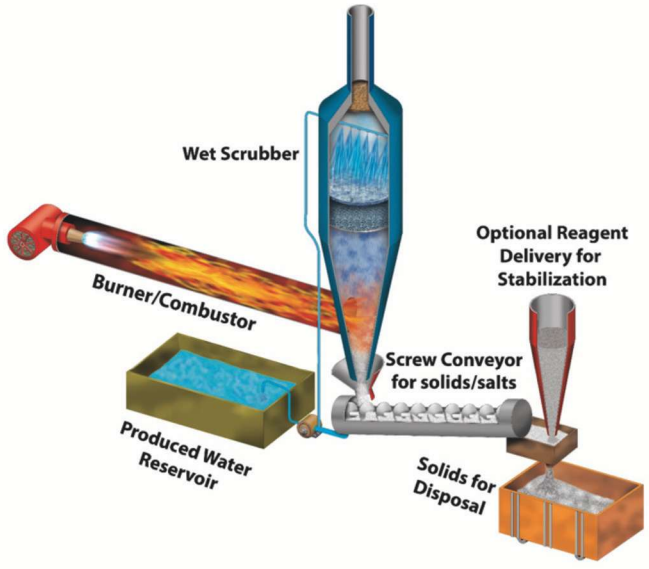
Treatment for oily water process needs

When a coastal LNG project required oil/water separators to meet the harsh environment and stringent requirements of the end user, Hydrasep delivered its water treatment services despite seismic, hurricane force winds, freezing temperatures, high sediment content and customization. Hydrasep offers services for all oily water process treatment needs. The company will help operators treat their fracture flowback and produced water onsite and in-line. Hydrasep also will help lower operating cost, lower downstream process upsets, filtering needs and chemicals consumption. The company will work to lower water reuse and recycling cost, and the oil recovered with a Hydrasep is pipeline quality. *hydrasep.com*

HYDRASEP manufactures custom-designed oil/water separators. *(Photo courtesy of Hydrasep)*

Water evaporator runs on field gas

HydroFlare by Hydrozonix is a new produced water evaporator that runs on field gas. The patent-pending HydroFlare helps resolve produced water disposal capacity concerns either due to increasing produced water volumes, capacity restrictions due to induced seismicity or increasing disposal cost for remote wells. The evaporator can be a permanent installation or a portable device that can be relocated from area to area. Besides produced water evaporation, HydroFlare can be used as an alternative to collecting field gas under Quad O(a). In areas where



The HydroFlare evaporator can help resolve water disposal issues. *(Image courtesy of Hydrozonix)*

collecting field gas is uneconomical, the evaporator becomes a flare alternative that also evaporates produced water, solving two concerns in one device. The HydroFlare provides the flexibility the produced water management program needs. *hydrozonix.com*

Better mixing at a lower pressure drop

Inyo Process has developed a series of integrated injection systems designed specifically to work with the Storm Mixer series of static mixers. These integrated products are designed to provide better mixing at a lower pressure drop than traditional static mixers. These mixers are nonfouling and can handle sludge and dirty waste streams that would clog other types of mixing equipment. These injection systems include retractable injectors, fixed injectors and gas/liquid injectors for CO_2. They can be used to meet difficult environmental challenges including treating produced water, emulsion breaking and dewatering of oil sand mature fine tailing. These integrated products can be used with polymers, acid and caustic injection for pH control, and sludge/dewatering activities. *inyoprocess.com*

Inyo Process mixers are nonfouling and can handle sludge and dirty waste streams that would clog other types of mixing equipment. *(Photo courtesy of Inyo Process)*

Rig-based, modular system treats, recycles slop water

The ENVIROUNIT offshore slop water treatment system from M-I SWACO, a Schlumberger company, provides a rig-based, modular process for treating and recycling slop water, which is especially advantageous in offshore and remote environments. The technology enables the extraction of expensive oil- and synthetic-based drilling fluid from slop water to make it reusable in drilling practices, saving considerable costs. Leftover water receives further cleaning to reach a level permissible for overboard discharge either onshore or offshore. Overall waste volume is reduced by more than 90%, and the previously contaminated water is treated so thoroughly that it can be discharged in compliance with the most stringent environmental regulations. The system also reduces the overall environmental footprint of drilling operations. It minimizes the fluid waste sent to shore for disposal and reduces carbon emissions by decreasing transport with supply vessels to shore and road transport from harbor to disposal facility. *slb.com*

The ENVIROUNIT offshore slop water treatment system employs a four-step treatment process that enables the reuse of valuable drill-in fluid. *(Image courtesy of M-I SWACO, a Schlumberger company)*

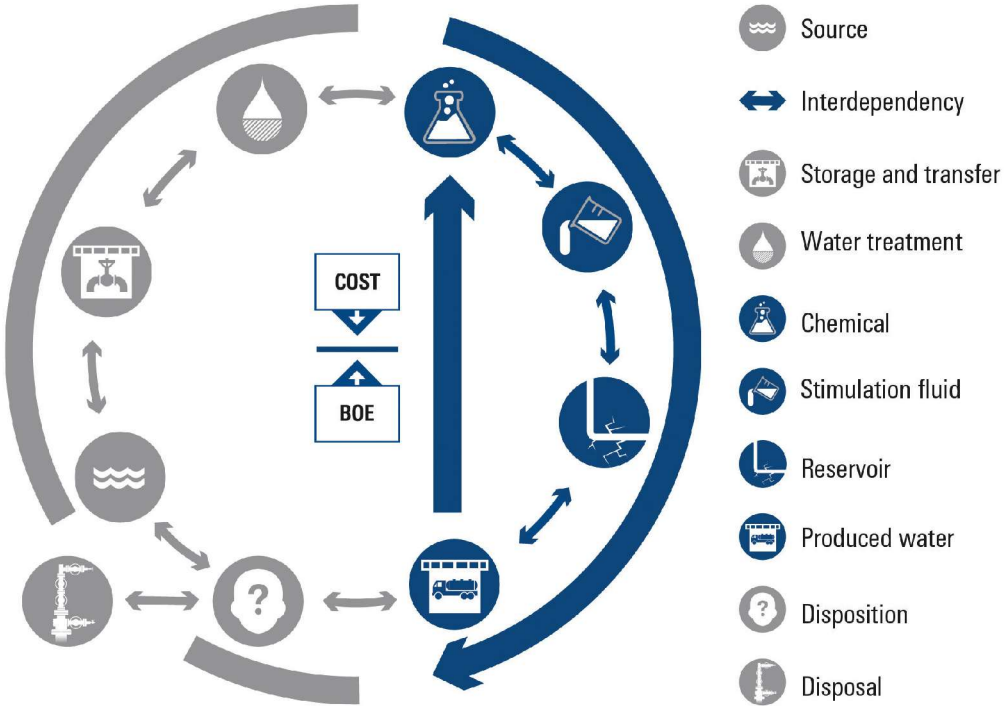
System recovers oil, suspended solids in single stage treatment

NOV has released a higher-capacity model of the WaterWolf dynamic oil recovery (DOR) system. Able to handle up to 50,000 bbl/d of water, the WaterWolf DOR 500 recovers oil and suspended solids from produced water in a single stage of treatment without the use of chemicals or filters, reducing waste and enabling significant cost savings. Ideal for use in centralized production sites or high-volume saltwater disposal facilities, the WaterWolf DOR 500 combines the nonshearing action of progressing cavity pumps with de-oiling and de-sanding hydrocyclones. This creates highly efficient oil recovery that recovers as much as 20 additional barrels of oil for every 10,000 bbl of water produced. The system builds on the heritage of proven hydrocyclone technology, long used in offshore oilfields, to simplify produced-water handling and improve well injectivity. It also allows an optional de-sanding skid to prevent solids accumulation in tanks, which can be a major source of air-polluting emissions. *nov.com*

The WaterWolf DOR 500 can handle up to 50,000 bbl/d of water. *(Photo courtesy of NOV)*

Water-flexible fracturing fluid system optimized for each well

Schlumberger developed the xWATER integrated water-flexible fracturing fluid delivery service to mitigate the economic and environmental burden of freshwater sourcing, transportation, treatment and disposal in hydraulic fracturing operations. The service enables operators to use engineered fracturing fluids customized for the available alternative water source, well conditions and reservoir properties. This reduces water-related costs, which can account for up to 40% of the total fracturing operation cost. The fracturing fluid system is optimized for each well, carefully designed to ensure compatibility with the most difficult water sources while minimizing or

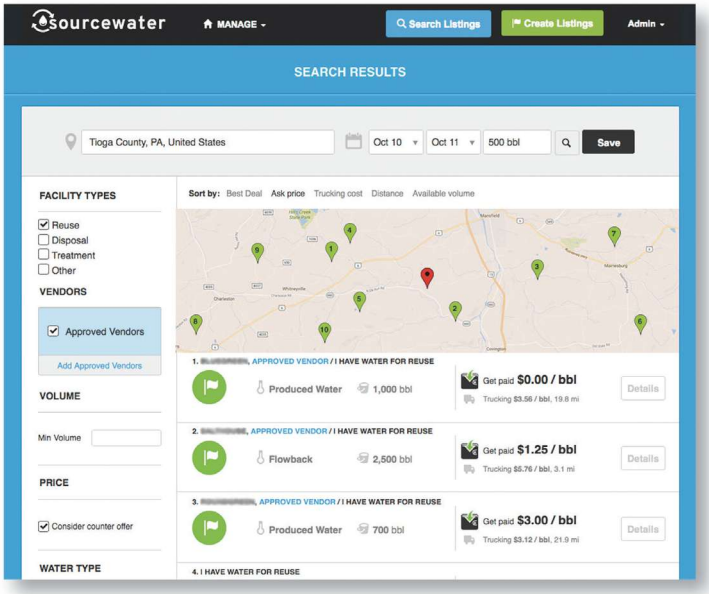


The Schlumberger xWATER service (shown in blue) cuts the traditional water management cycle in half. *(Image courtesy of Schlumberger)*

eliminating water treatment. Following a comprehensive assessment (water analysis, scale modeling and review of local regulations) of the water management cycle, the xWATER service uses the custom-engineered fracturing fluid that provides a cost-effective solution. As the well enters the production phase, the produced water is collected in a centralized, onsite storage facility and transported to new fracturing sites. *slb.com*

Platform finds water, disposal and transport options in any region

Sourcewater.com is a free online search engine and marketplace for sourcing, recycling, transporting and disposing of water for the energy industry. Sourcewater's free search platform finds water, disposal and transport options in any region and can sort results by best combination of price, transport cost, distance, dates, capacity and quality. The platform also allows users to list water, treatment, transport and disposal price and capacity. The shale boom made water management a major cost of upstream production and also made water the primary critical input and output of the upstream supply chain. Operators need real-time water market data to minimize operating cost, ensure the supply chain and reduce environmental and community impact on water resources. Service companies need a platform to communicate real-time price, capacity and standby times to operators to maximize utilization. In the Northeast, operators use Sourcewater to save on high-disposal costs and minimize community impact on water resources. In the Permian, operators use the platform to find better deals on hauling and disposal and plan completions with better water source research. *Sourcewater.com*



This *Sourcewater.com* screenshot shows water search results. *(Image courtesy of Sourcewater.com)*

H_2S removal system treats about 900 million gallons of sour water per day

Hydrogen sulfide (H_2S) is among the most dangerous and costly contaminants in oil and gas. Oxidation chemistries often are used to remove H_2S from water. The Talon Reagent System by Streamline Chemical is a patented H_2S removal tool that is effective and affordable. Talon Reagent has a 10-year record of success in other industries and treats about 900 million gallons of sour water per day worldwide. Streamline Chemical obtained exclusive rights to this system for oil and gas and is working with several upstream operators to increase removal efficiency and reduce treatment costs. The company recently completed a very successful field trial on a large Capitan Reef Aquifer water well in the Delaware Basin. Influent H_2S levels were more than 120 ppm aqueous before treatment. Streamline's system reduced H_2S to 0 ppm effluent. The customer benefitted from a significant reduction in treatment costs. *streamlinechemical.com* ■

The Talon Reagent System is shown being applied in the field. *(Photo courtesy of Streamline Chemical LLC)*

WATER TECHNOLOGIES

Veolia's Produced Water Treatment Solutions eliminate the risk and liability associated with produced water management and disposal.

Added benefits are:

- Enhanced oil recovery
- Reduced lease operating expenses
- Fresh water recovered for reuse in operations, irrigation or surface discharge

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Optimizing Biocide Selection for Stimulation Applications

Multiple factors should be considered when selecting a biocide for use in fracturing fluids.

By Jeffrey F. Kramer
BWA Water Additives

Advanced stimulation techniques, such as hydraulic fracturing of horizontal wells, have made the exploitation of low permeability oil and gas formations possible in recent years. Water, sand and various chemical additives are injected into the ground to fracture open a formation and unlock the oil and gas. While the various chemical additives typically make up less than 1% of the injected fluid (water and sand make up about 99%), they play an important role in the fracturing process. Some of the additives like acid, friction reducers (FR) and corrosion inhibitors only play a role during the fracturing process. Others, like biocides, play a role both during and after the fracturing process to protect the integrity of the fracturing fluid and to prevent souring of the well, respectively.

Although biocides play a critical role in the overall effectiveness of a fracturing job, the traditional selection process is usually limited to laboratory tests to evaluate their biocidal activity and effect on the performance of the fracturing fluid, which doesn't tell the whole story. Biocides that are typically selected using this traditional process include dibromonitrilopropionamide (DBNPA), glutaraldehyde and glutaraldehyde/quaternary ammonium blends.

Enhanced selection process

The enhanced selection process takes biocide evaluation a step farther by considering additional factors that affect biocide stability and performance in the presence of a wide range of fracturing additives, environmental conditions and secondary properties of the biocide. The enhanced biocide selection process includes an evaluation of:

- Compatibility with a full range of fracturing fluid additives;
- Ability of biocide to withstand a wide range of environmental conditions (pH, temperature and time);
- Synergy with other fracturing fluid biocides; and
- Other nonbiocidal properties (corrosion inhibition, clay control and emulsion control).

A different picture appears when the enhanced selection process is used to evaluate biocides for fracturing applications as performance limitations of the commonly used fluid biocides appear (Table 1). The result is that biocides such as DBNPA, glutaraldehyde and glutaraldehyde/quaternary ammonium blends no longer appear to be the best choice.

A biocide offering compatibility in fracturing applications when using the enhanced selection process is Bellacide 300 from BWA Water Additives. This nonoxidizing biocide not only has the fast kill and compatibility with FR that are essential features for a fracturing fluid biocide but also has excellent compatibility with oxidizing biocides, such as bleach and chlorine dioxide (ClO_2), that the other commonly used fracturing fluid biocides lack. This is important since the popularity of bleach and ClO_2 as fracturing fluid biocides is increasing as operators look for cost savings.

While oxidizing biocides are fast-acting bactericides at low concentrations, their high reactivity means they are not very persistent in the fracturing

Biocide	Fast kill	Compatible with FR	Compatible with pH buffers 10.5 (Borate)	Compatible with gel and FR breakers	Compatible with reducing agents	Compatible with oxidizing biocides	Long-lasting activity	Corrosion inhibition
Bellacide 300	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦♦	♦♦♦
DBNPA	♦♦♦♦	♦♦♦♦	♦	♦♦♦♦	♦	♦	♦	♦
Glutaraldehyde	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦	♦♦	♦	♦	♦♦
Glutaraldehyde/ Quaternary ammonium	♦♦♦♦	♦♦♦♦	♦♦♦	♦♦♦	♦♦	♦	♦♦♦	♦♦♦
Thione	♦	♦♦♦♦	♦♦♦	♦	♦♦♦♦	♦	♦♦	♦♦♦
Dimethyl-oxazolidine	♦	♦♦♦♦	♦♦♦	♦♦♦♦	♦♦	♦	♦♦♦	♦♦

♦♦♦♦ Superior ♦♦♦ Very Good ♦♦ Average ♦ Poor

TABLE 1. A ranking of biocides used during the enhanced selection process shows Bellacide 300 to be a superior choice as compared to other options. *(Data courtesy of BWA Water Additives)*

fluid, so they do not provide long-term biocidal protection during a typical multistage fracturing job. To address this issue, many operators supplement an oxidizing biocide treatment with a second, usually nonoxidizing, biocide. The following case study compares the effectiveness of an oxidizing biocide treatment to a dual oxidizing/nonoxidizing biocide treatment for stimulation.

Case study

An operator in Oklahoma was looking to improve the performance of a standard ClO_2 treatment used for stimulation by incorporating a second biocide at the blender. Table 2 gives details of the stimulation application.

Basin	Woodford
Well type	Horizontal
Well size	45 stages, 7,500 bbl/stage
Fluid type	Hybrid
Water source	Mixture of fresh and produced

TABLE 2. Stimulation application parameters for the Oklahoma case study are shown. *(Data courtesy of BWA Water Additives)*

Baseline results for ClO_2 were collected from 102 wells over a period of several years. Flowback samples were frequently collected from each well and analyzed for sulfate-reducing and acid-producing bacteria using standard bug bottles during a 90-day period. Positive bottles for both sulfate-reducing and acid-producing bacteria averaged 1.5 during the 90-day period with ClO_2, but some individual results were as high as eight positive bottles for both types of bacteria.

The first supplemental biocide evaluated was a thione-based product dosed at 0.25 gallons per thousand. While this dual treatment showed an improvement over ClO_2 alone against sulfate-reducing bacteria, performance declined against acid-producing bacteria (Figure 1). The reduced performance of this dual program is not surprising since thione biocides are not compatible with oxidizing agents like ClO_2.

The next supplemental biocide evaluated was Bellacide 300 dosed at 0.2 gallon per thousand. Compared to ClO_2 alone, the ClO_2 plus Bellacide 300 treatment reduced the average number of positive bottles from 1.5 to 1.2 for both sulfate-reducing and acid-producing bacteria. Bellacide 300 also was more effective against acid-producing bacteria than the thione biocide. In addition to the improved performance comparison to thione, Bellacide 300 was more cost-effective, resulting in a 25% cost savings for the operator.

Summary

The traditional fracturing fluid biocide selection process overlooks some critical aspects of biocide compatibility and performance, which

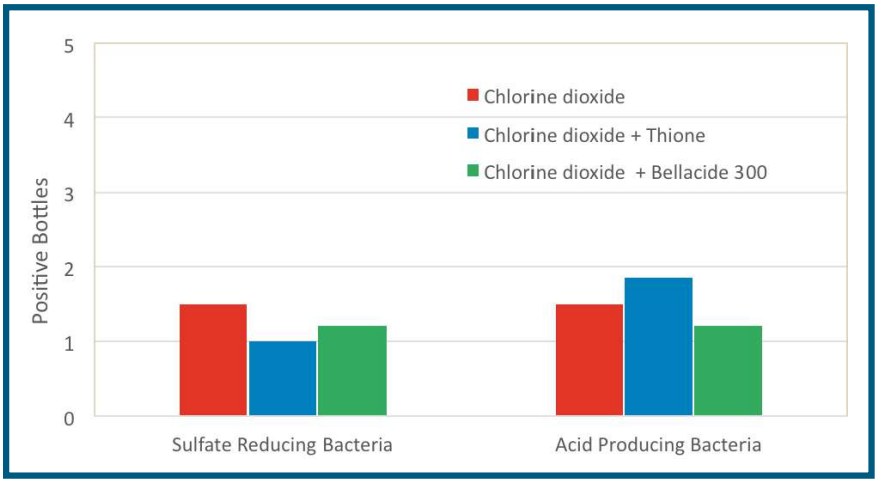

FIGURE 1. Dual treatment showed an improvement over ClO_2 alone against sulfate-reducing bacteria. Performance declined against acid-producing bacteria as thione biocides are not compatible with oxidizing agents like ClO_2. *(Data courtesy of BWA Water Additives)*

can have a negative impact on the overall effectiveness of a fracturing fluid biocide program. The enhanced fracturing fluid biocide selection process takes these interactions into account, which results in improved biocide decisions. Feedback from field applications with Bellacide 300 confirms the usefulness and benefit of the enhanced fracturing fluid biocide selection process. ■

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Water Recycling, Reuse in the Delaware Basin

SCE technology delivers a customized water treatment option for a Permian Basin operator.

By Kushal Seth, Kaarthic Madhavan and Julie Villalobos
Gradiant Energy Services

Water plays a pivotal role in the development of shale oil and gas wells as it is involved across the life cycle of the well and impacts drilling, completions, production and facilities operations. The management and proper handling of water is crucial to the long-term sustainable success of unconventional oil and gas development. Water can significantly impact the economics of a wellbore, in some instances 20% of the well cost.

Developing a sustainable water-handling strategy with successful reuse will significantly reduce costs for operators. Effective water management will include several associated services such as sourcing, transfer, storage and treatment. Water recycling not only decreases the economic issues of water disposal but also reduces the stress on freshwater sourcing and will remain a focus of environmental stewardship for the industry.

In certain active shale plays, the demand for water has increased significantly while freshwater sources have become more limited. Current well designs have longer lateral lengths, and volume of water demand per stage has increased in current completion designs. As the industry recovers from depressed oil prices, the inventory of drilled but uncompleted wells will demand a focus on water management, making recycling an attractive option.

Gradiant Energy Services (GES) is focused on developing, deploying and operating technical products and services in the industry by assisting operators in reducing their operating cost in a safe and reliable manner. The goal for these technologies and associated services is to be able to treat and recycle different sources of oilfield waste fluids that can reduce freshwater demand and disposal cost. With a broad portfolio of treatment solutions, GES can help

A GES produced and flowback water treatment plant deployed in Delaware Basin has been in operation since 2015.
(Photo courtesy of Gradiant Energy Service)

Carrier Gas Concentration or CGC	High Cost Disposal Locations Volume Reduction by Evaporation Produced Water Flowback Water Drilling Wastewater Rainwater Runoff	Safe, cost-effective and environmentally friendly solution Convert wastewaster into vapor Low energy, mobile and deployable Separates heating from the physical evaporation Meet stringent particulate matter emissions requirements
Selective Chemical Extraction or SCE	Reusable Clean Brine Reuse in Fracturing Produced Water Flowback Water Drilling Wastewater	Custom-engineered, multistep water treatment process Treatment of all types of wastewater Patented clarifier design for high-rate clarification Patented chemical addition algorithm Minimize waste generation
Free Radical Disinfection or FRD	Bacteria Disinfection Freshwater Produced Water Flowback Water Batch or On-the-fly Treatment	Safe, environmentally friendly bacteria treatment Uses only salt, freshwater and electrical energy Generates mixed oxidant with multiple free radicals No hazardous chemical storage onsite
Carrier Gas Extraction or CGE	Water Recovery - Dischargable High-cost Disposal Locations Produced Water Flowback Water Drilling Wastewater Rainwater Runoff	Low-cost desalination technology using air as a carrier gas Extract water vapor from wastewater Water recovered through dehumidification process 50% less energy usage compared to mechanical vapor recompression

FIGURE 1. Current oilfield water treatment technologies provide a variety of options for cost-effective and safe reuse of wastewater. *(Image courtesy of Gradiant Energy Services)*

operators solve complex water issues, outperforming conventional methods (Figure 1).

GES deployed a recycling plant for an operator in the Permian's Delaware Basin focused on treating produced and flowback water to reduce total water management costs for the field development. The treatment plant, operating since 2015, recycles produced water to a reusable clean brine that can then be used for the drilling and completions program. The client's requirement was to recycle volumes up to 12,000 bbl/d and about 3.6 MMbbl/year for servicing multiple hydraulic fracturing jobs in the area.

The application uses selective chemical extraction (SCE) technology, developed out of the Massachusetts Institute of Technology, incorporating a proprietary algorithm that can take the varying water quality of produced water and selectively dose chemicals in proper sequence and quantities to produce a consistent, higher quality effluent supply.

The selective chemical dosing and sequence minimizes the operating cost of the plant. Additionally, the treatment facility uses a patented clarifier design aimed at effective solid-liquid separation, sustainable at high rates of operation. This is an important technological breakthrough, as it minimizes the solids carry to the downstream processes, such as fracturing operations and water storage, specifically tanks and pits. The performance of the clarifier eliminates the need for an expensive polishing step such as filtration, which is a significant cost for a conventional water treatment process. The effluent water quality, defined by the operator for specific end use in the drilling and completion program included potential fracture designs of slickwater, zirconate and borate crosslinked systems. The liquid sludge was further processed to recover additional water and turn the sludge into a disposable solid cake to further reduce the disposal cost.

One of the most important key performance indicators achieved during plant operations was the treated water recovery ratio, which was greater than 99.7%. This was a result of the innovative process flow design, which maximized the produced and flowback water reuse while minimizing the waste product.

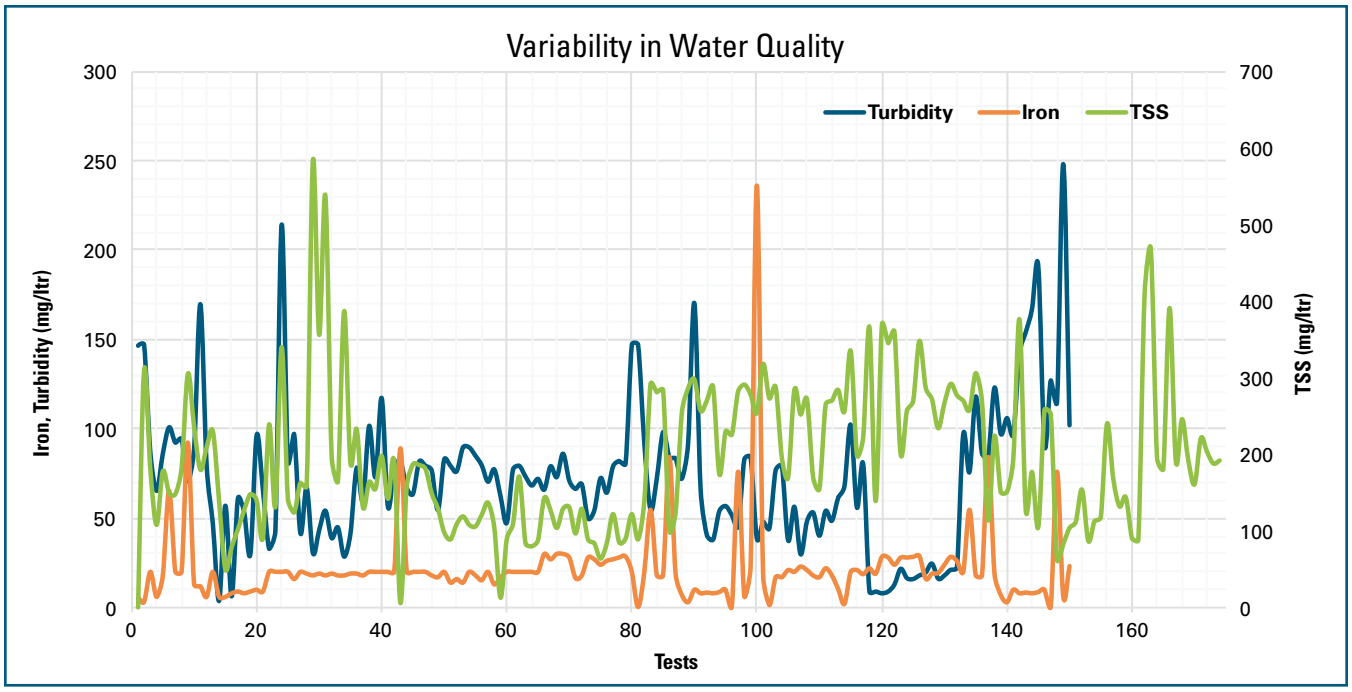


FIGURE 2. Variability in water quality presents a significant challenge in water treatment. *(Data courtesy of Gradiant Energy Service)*

Further cost reduction for the operator was achieved by producing non-hazardous solid waste, which was fit for landfill disposal.

Figure 2 depicts the challenge in treating produced and flowback water for any specific requirement. Unlike other water sources, oilfield waste streams are characterized by a significant variation in water quality day to day and at times hourly. It is critical to monitor the incoming water and adjust the chemical requirements to have a consistent effluent water quality that will meet operator's specifications. During operation of this plant, the algorithm for chemical addition was completely functional and could predict the chemical demand as per changing water quality, leading to a significant reduction in operating expense and waste generated. The treated water quality met the operator's requirement 100% of the time (Figure 3).

The data presented are an average of multiple daily measurements performed throughout the operating schedule. GES' SCE technology can reduce bivalent ions, primarily hardness and sulfates. In this particular case the operator's major concerns for the effluent water included iron, oil and grease, total suspended solids (TSS), turbidity, pH and bacteria control. Iron concentration in treated water was on an average below 5 ppm. Iron present in higher concentrations can cause premature crosslinking of guar-based fracturing fluids. The presence of higher concentration of TSS can impede the permeability of the proppant pack. This blockade can lead to lower production and in the worst case, formation damage. The SCE treatment has proven very effective in reducing TSS from the raw water (Figure 3).

Treatment plant setup

The SCE technology at its core is a proprietary chemical co-precipitation mechanism. It includes a patented inclined plate clarifier with an opposing pitch blade thickener that helps in effective separation. As mentioned previously, the key objective of the process setup was to remove or reduce iron, oil and grease, TSS and turbidity combined with efficient solids separation, pH balancing, solids dewatering and disinfection.

The produced water is continuously monitored in real time and fed into an enhanced gravity API oil water separator to recover residual hydrocarbons. The hydrocarbons are returned to the operator for further processing. With the addition of either a coagulant/flocculant and/or a polymer, GES is able to alter the pH to affect precipitation while minimizing the amount of slurry generated. The treated water is then readjusted for pH and disinfected before it is stored in a downstream buffer storage. The water quality in the downstream storage also is sampled and monitored to ensure the final water quality meets the fracturing operation requirement. The leftover slurry is pressed to form solid cakes that can be classified and disposed

in appropriate waste disposal sites. In this plant, the treated water was successfully reused for hydraulic fracturing applications.

The water management process and technology must be economically sustainable to be adopted and used for long term. The GES technology for treating produced and flowback water has been projected to save about $450,000 for the operational timeline (Figure 4). Scenario 1 depicts the total cost to the operator if they would have chosen to dispose the water and source freshwater for hydraulic fracturing. Scenario 2 shows the projected cost and savings for treatment (including all associated costs such as energy, manpower, chemicals, etc.) and waste disposal. It is expected that the savings will continue and even increase with enhanced volume of water treatment as projected by the operator. ■

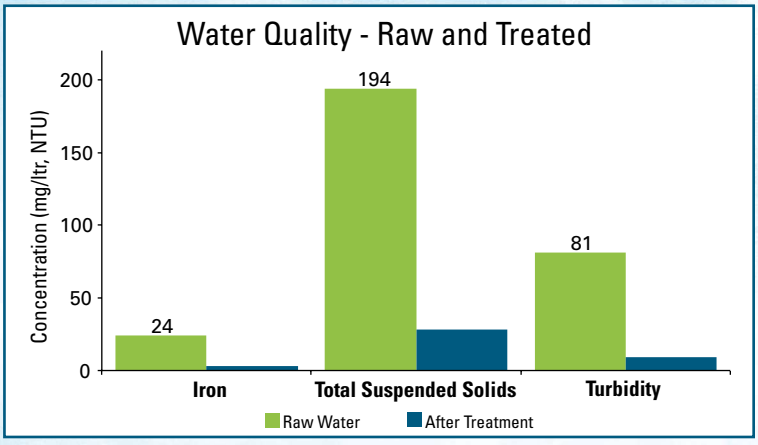
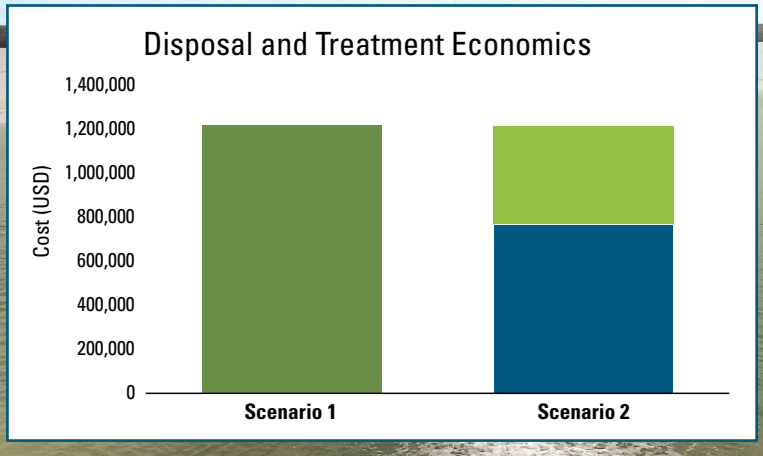


FIGURE 3. A significant reduction in the concentration of TSS in raw water is the result of SCE treatment. *(Data courtesy of Gradiant Energy Service)*

FIGURE 4. The economics of disposal are compared against treatment for cost savings. *(Data courtesy of Gradiant Energy Service)*



A freshwater frack pond is regenerated on Cimarex Energy's Leonatus 11-1H frack site in Culberson County, Texas. *(Photo by Tom Fox, courtesy of Hart Energy's* Oil and Gas Investor*)*

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Exploration: potential fields, geochemistry, seismic acquisition (land and marine), processing algorithms and software, reservoir characterization, interpretation software, and hardware

Formation Evaluation: wireline logging, core analysis, cuttings analysis and well testing hardware and software

HSE: hardware, software, and methodologies related to health, safety and the environment

Drillbits: natural diamond, impregnated, PDC, bi-center, milled tooth, hybrid, insert and hammer

Drilling Fluids/Stimulation: chemicals, drilling mud, additives, flow enhancers and green systems

Drilling Systems: LWD/MWD, motors, coring, tool joints, fishing tools, drillpipe, whipstocks, subs, packers and rotary steerable systems

Hydraulic Fracturing/pressure pumping: matrix acidizing, proppants and chemicals

Non-fracturing completions: modeling/simulation software, completion hardware and completion effectiveness monitoring (microseismic, tracers, etc.)

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E&P

Online Search Platform Optimizes Oilfield Water Management Decisions

Website offers real-time visibility into all available water sourcing, recycling, hauling, transfer, treatment and disposal options.

By Joshua Adler
Sourcewater

In U.S.-based unconventional wells the challenges of water management are predominantly centered on flowback logistics, produced water disposal and, in some regions, sourcing water for completions. The amount of water injected per fracture over the past five years has increased from 100,000 bbl up to 800,000 bbl for many operators, with more than 500,000 bbl not unusual.

Oilfield water management will be more challenging as the market rebounds. Although in recent years the total number of completions dropped off steeply, the amount of water used per fracturing job has risen even more. As the market rebounds, the number of completions will grow and operators will be short of both water supply and flowback disposal capacity, especially in regions where disposal capacity is constrained by new regulatory restrictions around seismicity. There will be fierce competition for available water resources.

Water management professionals at operating companies and service providers often rely on personal contacts and word-of-mouth about county-level micro-markets to obtain best pricing and capacity for sourcing, recycling and disposing of fluids. To coordinate a project's water management needs, a typical operator spends at least four hours on the phone reaching out to four to eight suppliers to find options for each new fracturing job, and retained landmen spend far more time and money identifying and signing potential water sources.

Searching for the same data through *Sourcewater.com* takes on average 10 minutes to 20 minutes at no cost. The free online search platform provides real-time visibility into all available water sourcing, recycling, hauling, transfer, treatment and disposal options, eliminating errors and missed opportunities and ensuring that transparent data-based economics drive management decisions without bias.

Data on the available water sources, produced water, disposal and treatment options in a region enable better, more informed decisions. Access to regional water management options prevents wasted effort and ensures users do not miss out on short-term opportunities to obtain discounted excess capacity or recycle.

Frank Nickens, COO of Clearwater Technologies, used Sourcewater in the transfer and processing of fluid between two leading operators in Tioga County, Pa. Nickens leveraged the platform to identify options that he didn't find through his personal network.

"We feel like we're ingrained in the activity in our region," Nickens said. "Today I was at a skeet-shooting event with one operator, a grill-out with another and a meeting with a third. It's a lot of effort. Finding trades is like hunting for a needle in a haystack."

Online water data are essential to mission-critical supply chain resilience

The inability to source sufficient water or dispose of produced fluid can be catastrophic to oil and gas operations. In response to risk in the water man-

agement supply chain, operators might consider investing in water management infrastructure. However, during the higher-intensity completions and slower development period of the past few years, investment in water logistics infrastructure has been limited.

The volatility of the energy market and unpredictability of water flows make proper economic and financial analysis for infrastructure projects challenging. Produced water chemistries and the inefficiencies of building infrastructure to accommodate peak flows adds environmental liability and low returns on equity that impair company value. Thus, as the energy market recovers, many operators will rely on third-party midstream operators to source water and build out flowback pipeline and disposal capacity. In the meantime, finding and maintaining continuous and sufficient water, disposal, transfer and hauling capacity will become the biggest challenge to avoiding critical supply chain breakdowns and massive cost overruns.

The free search platform is the key to ensuring operational resilience, enabling:

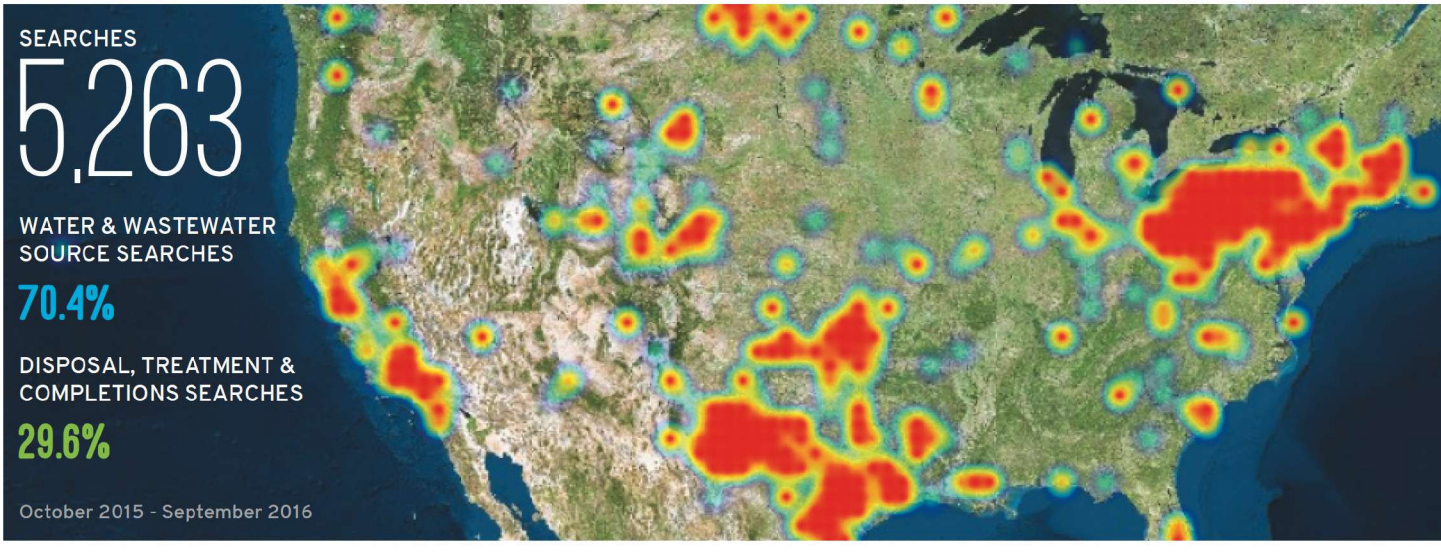
- Identification of new, previously unknown, water management options;
- Strengthening of the supply-chain with higher quantity of options;
- Increased efficiency in water management logistics;
- Improved community relations from fewer truck miles on roads, reduced freshwater consumption and disposal seismicity; and
- Better margins through reduced operating and completion costs.

Operators using Sourcewater's search tool obtain real cost savings. The labor cost to find and secure water and disposal is reduced by more than 90% online. Hauling costs are substantially reduced when fluids are not transported long distances. Disposal and sourcing costs are reduced when operators trade fluids directly. Both operators end up saving and, in some cases, reuse of water in completions can become a profit center. More importantly, reuse options and other nonfreshwater sources and uses add to the effective supply of both water and disposal in convenient oilfield locations. Production managers, logistics managers and even truck drivers on the Sourcewater smartphone app can optimize real-time disposal decisions trading off distance, dynamic prices that reflect available capacity, and standby times.

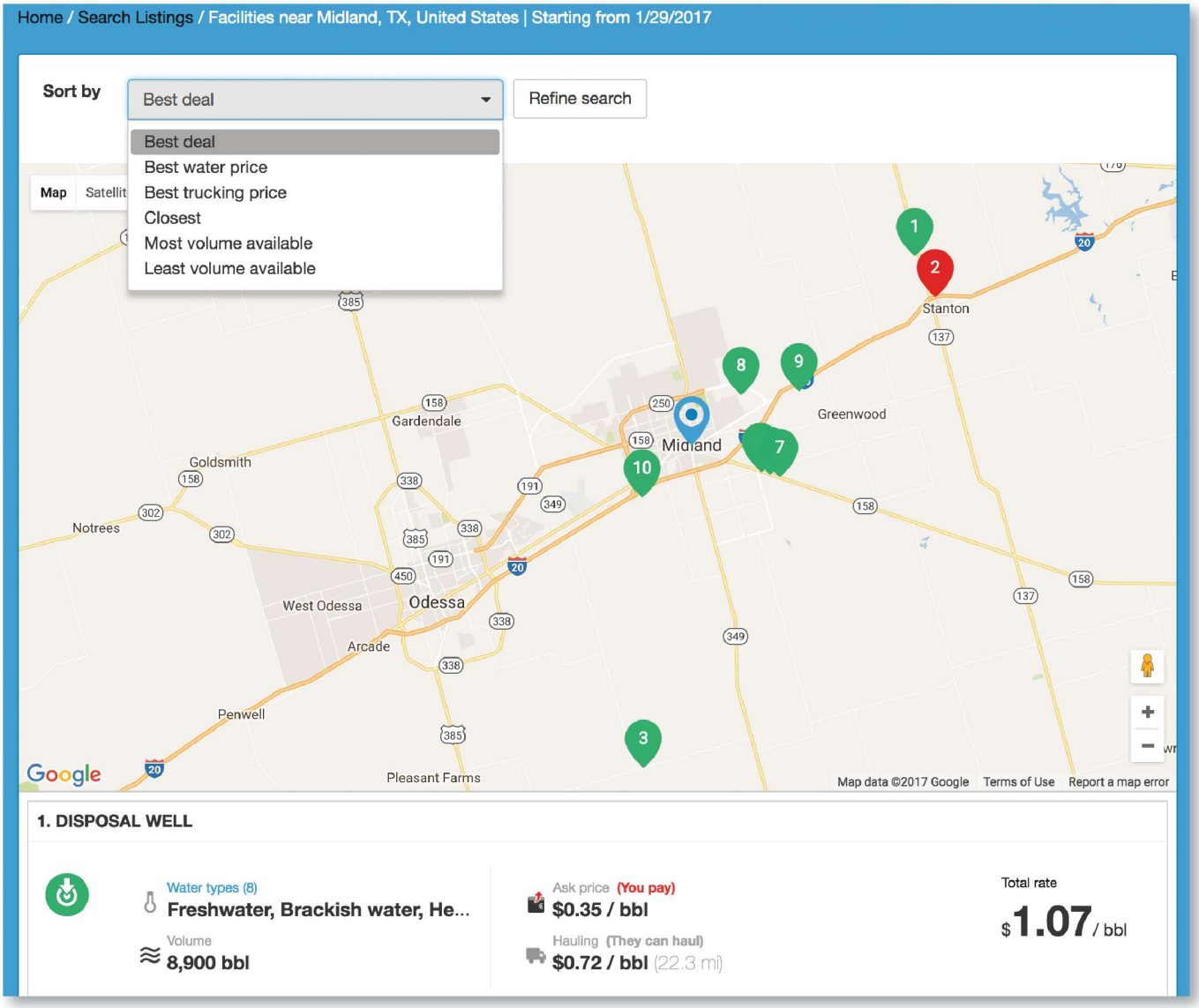
Learnings from the Cana Woodford

The value of a robust water management supply chain is often overlooked. A good case study to understand the true value of a robust supply chain was presented by IHS Energy Insight in the 2013 report "The Future of Unconventionals—Water Management Strategies"; a brief outline is presented here.

The story opens with the third-quarter 2012 earnings call transcript in which Devon Energy Corp. reported that wells drilled during second-half 2011 underperformed their expectations. In response to severe drought and increased competition for limited water resources, Devon had reduced the average volume of water used in completions. Wells completed during this time reported significant losses in both IP and mean monthly gas flow. The



This heat map shows the areas of highest search intensities using Sourcewater's online platform. *(Images courtesy of Sourcewater)*

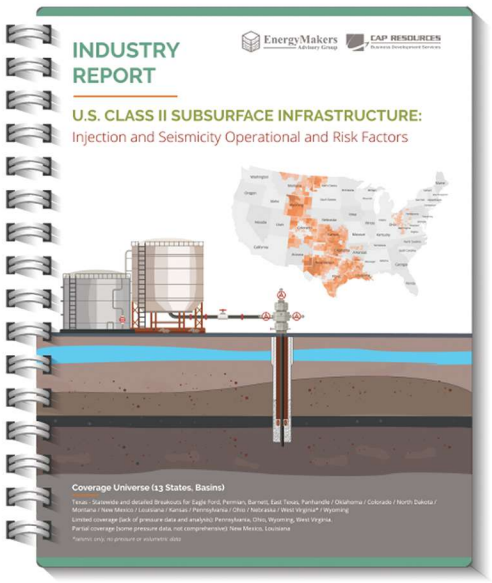


Search results for a disposal well in Midland, Texas, can be sorted to show the best deal, the closest location or by volumes.

analysis conducted by IHS quantifies the economic value of water for oil and gas operations. In this specific case, Devon experienced a $12 million loss of revenue per well and regression analysis linked 30% to 40% of the lost revenue to the supply chain challenges associated with water sourcing during completion. Thus, for Devon, during a high-growth phase of drilling and completion, supply-chain risk placed the value of water at between $80 and $95 per bbl of water.

Faced with this situation, operators have historically had to choose to either continue activity as normal until the supply-chain fails—causing a complete interruption to drilling and completion programs—or hope that they have sufficient access to infrastructure and service providers to ride out the period of risk.

Today, operators recognize that options for water management are no longer constrained to contacts they happen to know personally. The 21st century offers a digital economy in which operators can search, discover and optimize water management options that they did not know existed or excess capacity from known suppliers that would have otherwise gone to waste. ■



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