Routledge
Taylor & Francis Group

Environmental Claims Journal

ISSN: 1040-6026 (Print) 1547-657X (Online) Journal homepage: http://www.tandfonline.com/loi/becj20

Produced Water—Emerging Challenges, Risks, and Opportunities

Earl L. Hagström, Christopher Lyles, Mala Pattanayek, Bridgette DeShields & Mark P. Berkman

To cite this article: Earl L. Hagström, Christopher Lyles, Mala Pattanayek, Bridgette DeShields & Mark P. Berkman (2016) Produced Water—Emerging Challenges, Risks, and Opportunities, Environmental Claims Journal, 28:2, 122-139, DOI: 10.1080/10406026.2016.1176471

To link to this article: http://dx.doi.org/10.1080/10406026.2016.1176471

Published online: 04 May 2016.

ENVIRONMENTAL CLAIMS JOURNAL
2016, VOL. 28, NO. 2, 122–139
http://dx.doi.org/10.1080/10406026.2016.1176471

Routledge
Taylor & Francis Group

Produced Water—Emerging Challenges, Risks, and Opportunities

Earl L. Hagström[a], Christopher Lyles[b], Mala Pattanayek[b], Bridgette DeShields[b], and Mark P. Berkman[c]

[a]Sedgwick LLP; [b]Integral Consulting Inc.; [c]Brattle Group

ABSTRACT
Produced water should be viewed as an environmental asset—part of the water resource solution—not as a waste that contributes to environmental problems; its treatment and reuse can reduce the stress on fresh water resources. Treatment cost is the most significant factor determining the volume of produced water that will be available for reuse. Water pricing, which is in large part a matter of public policy, must also be considered when reexamining how to maximize the use of this valuable resource. When deciding whether to treat and use produced water companies will need to weigh the risk of litigation and regulatory enforcement actions against the benefits of introducing treated water into the stream of commerce. Allaying the public's fear of chemicals in the water supply is also a significant factor in determining whether produced water is viewed as part of a water resource solution or as a waste by-product.

Introduction

As population increases and land uses change, in combination with changes in weather patterns and climate in the United States and worldwide, the demand for freshwater supply has increased. This problem is particularly evident across the arid western United States where water resources are particularly stressed given unprecedented drought and competing demands for ever scarcer water. The use of treated wastewater can help reduce stress on freshwater resources, allowing surface water and groundwater to be used for other purposes. As a result, treated wastewater, including produced water—a byproduct of oil and gas exploration and production—can represent a viable resource. The most significant constraint on the widespread use of produced water is the ability to treat the water to meet the water quality standards for its intended end use. After that hurdle has been met, the next step is to overcome public perception that treated water is tainted and unsafe to use.

CONTACT Earl L. Hagström earl.hagstrom@sedgwicklaw.com Sedgwick LLP, 333 Bush Street, 30th Floor, San Francisco, CA 94104-2834.
Color versions of one or more of the figures in the article can be found online at www.tandfonline.com/becj.

This article discusses the state of produced water generation, current handling practices and constituents of potential concern (COPCs) in produced water, and explores various reuse options and the environmental issues, risks, potential liabilities, and regulatory policies associated with reuse of produced water. Additionally, this article features a technical highlight section, which examines technical aspects of agricultural use of produced water, discusses costs, and provides insight on legal implications, public perception, and the future of water in the West.

Background

Produced water is water trapped in underground formations that is brought to the surface during oil and gas explorations (Guerra et al. 2011; National Energy and Technology Laboratory (NETL) 2014). This water has been in contact with the hydrocarbon-bearing formation for centuries, and as a result, contains some of the chemical characteristics of the formation and the hydrocarbon itself. Produced water may include water from the reservoir, water injected into the formation, and any chemicals added during the production and treatment processes. Produced water is sometimes referred to as *brine* or *formation water*. Constituents found in produced water may include:

- Salts (very old water left behind in the formation can be highly saline depending on the geologic formation)
- Oil (which can result from contact with the hydrocarbon bearing formation)
- Other natural inorganic and organic compounds
- Chemical additives from well drilling and operation
- Naturally occurring radioactive material (NORM)

Produced water is generated during conventional oil and gas production and production of unconventional sources such as oil shale, gas shale, tight sands gas, and coal bed methane (CBM). The volume of produced water and constituents present can vary significantly depending on the type of production and geological features present.

Unconventional oil and gas production operations often utilize techniques such as horizontal drilling and hydraulic fracturing to enhance recovery of the hydrocarbon, and generally produce much less water by volume than conventional oil and gas production. However, the enhancement process requires the use of large volumes of water. The largest waste stream associated with unconventional operations is "flow back" or "frac" water (Guerra et al. 2011), which differs in composition from produced water generated during conventional oil and gas production. In California, 38 percent of the substances used for fracking are not known because companies used nonspecific names or reported them as either trade secret, confidential, or proprietary (Pacific Institute 2016). For wells across the United States, information on chemicals that are not trade secret, confidential, or proprietary can be found on the Frac Focus Chemical Disclosure Registry Web site (www.Fracfocus.org) and additional information on chemicals can be found on state specific Web sites.

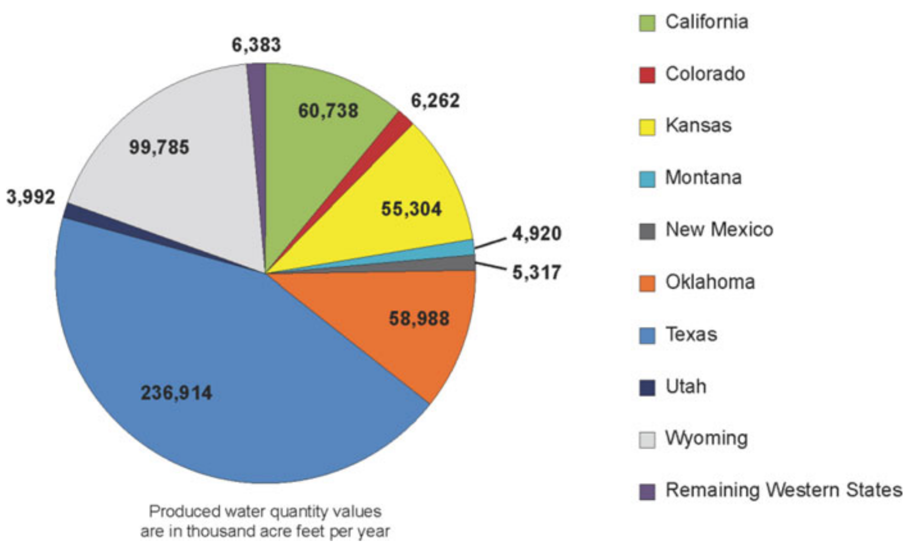

Figure 1. Produced water quantities by state in the western United States (adapted from Guerra et al. 2011).

Produced water is considered a byproduct of oil and gas production and is most commonly treated as waste for disposal, rather than reuse, and is the largest volume waste stream associated with oil and gas exploration and production. The National Energy Technology Laboratory (NETL) (2014) reports that approximately 21 billion barrels of produced waters are generated annually in the United States (this includes onshore and offshore production). On average, anywhere from seven to ten barrels of water are produced for every one barrel of crude oil (one barrel is approximately forty-two gallons). Figure 1 presents produced water quantities by state in the western United States.

There is significant overlap between areas of oil and gas production and areas with a potential for water conflict (Guerra et al. 2011; Ceres 2014). Competing demands on limited freshwater supplies for agricultural, municipal, recreational, industrial, and ecological use exist and are likely to continue to persist across the western United States in years to come.

Current handling practices

As produced water is largely considered a waste material and is the single largest waste stream associated with oil and gas production, its management and disposal are key factors that must be taken into account prior to undertaking exploration and production programs. Depending on a variety of factors, produced water may be disposed of by land application or discharge, evaporation ponds, percolation ponds, subsurface injection, and offsite trucking (Clark and Veil 2009). Figure 2 depicts a conceptual cross-sectional view of wells used for underground injection for enhanced production and wastewater disposal.

Figure 2. Injection wells for enhanced production and wastewater disposal.

Subsurface reinjection is the preferred disposal method, although it can be infeasible as the formation may not be able to receive the produced water. Injection wells are sometimes operated in concert with adjacent extraction wells to enhance recovery. A combination of produced water and other constituents is used to flood the reservoir to increase the recovery of oil and gas. This process is referred to as enhanced recovery, and is a common practice in the industry. Where these methods are unavailable or not feasible to producers, produced water can be trucked off-site to permitted disposal wells, which is costly, where they are injected far below potable water supplies into acceptable formations. These types of permitted wells are known as Class II injection wells.

Several Class II wells were recently closed in California after a USEPA (U.S. Environmental Protection Agency) review of the state oversight program revealed that some permitted wells have been injecting wastewater into potentially potable water supplies. The state is currently working toward compliance with the federal Safe Drinking Water Act and has recently extended emergency rulemaking necessary to do so. California is not the only state with oversight lapses. As discussed in a June 2014 Government Accountability Office (GAO) report to congressional requesters, "Drinking Water—EPA Program to Protect Underground Sources from Injection of Fluids Associated with Oil and Gas Production Needs Improvement," the GAO recommends that the underground injection control program (which administers oversight of state class II wells) task its working group with reviewing emerging risks and developing related program safeguards to protect underground sources of drinking water from becoming contaminated and that Congress approve additional rulemaking to both improve reporting/data transparency and better enforce violations.

Generally, potable water supplies are considered to be waters that have a salinity concentration less than 10,000 ppm (mg/L), which is largely a technologically driven consideration, and can be treated to meet water quality standards. The salinity benchmark is based on the feasibility (including cost-effectiveness) of reducing salinity concentrations down to acceptable levels for consumption by humans. Salinity is a major driver of consideration for any potential reuse or disposal scenario, as are the cost for treatment to meet water quality standards and public perception.

Constituents of potential concern

As discussed previously, produced water may contain salts, metals, and radionuclides characteristic of the formation from which the water was extracted. These properties will also vary throughout the lifetime of the well (Veil et al. 2004). Produced water can also contain polycyclic aromatic hydrocarbons (PAHs); benzene, ethylbenzene, toluene, and xylene (BTEX); phenols; trace elements (e.g., boron); and fossil fuel-related organic compounds from contact with petroleum, coal, or natural gas. Some of these constituents occur naturally within produced water, while others are related to chemicals that have been added to enhance oil and gas production and help with well maintenance. When present in high concentrations, these chemicals can present a threat to a variety of receptors that may be exposed to this water under the proposed reuse scenario.

Since no two produced waters are alike, region-specific studies should be conducted to address the potential environmental impacts from disposal and reuse. The underlying site-specific climate, geology, and physicochemical characteristics of the receiving discharge site will influence the fate and transport of COPCs that are typically in produced waters. However, considering the different chemical properties of these COPCs and the environment, primary potential environmental impacts associated with different produced water reuses are discussed below.

Regulatory policies

Currently, U.S. regulations and policies as well as specific state regulations place limits on the reuse of produced water. In most cases, produced waters are considered solid wastes that are not hazardous wastes (i.e., they are exempt from hazardous management requirements of Subtitle C of the Resource Conservation and Recovery Act).

Under the federal Clean Water Act (CWA), onshore exploration and production activities are subject to effluent limitations attainable through best practicable control technology (BPT) currently available. For onshore activities, BPT is considered "no discharge of wastewater pollutants into navigable waters from any source associated with production, field exploration, drilling, well completion or well treatment (i.e. produced water, drilling muds, drill cutting and produced sand)." Two exceptions are provided: Subpart E Agricultural and Wildlife Water Use Subcategory and Subpart F Stripper Subcategory. Subpart E further limits these reuse options to onshore facilities of the continental United States located west of the 98th meridian, which extends from near the eastern edge of the Dakotas through central Nebraska, Kansas, Oklahoma, and Texas.

Based on these regulations, the CWA does not recognize the variety of treatment technologies available for produced water and therefore limits reuse to agricultural or wildlife propagation when discharged to navigable waters. Under the current regulatory scheme, there is no recognition that treatment is a viable option making the treated water suitable for many other uses when discharged to land or surface waters.

Most states have no specific regulations. Reuse of produced water has been permitted in California at specific sites. Colorado has a general discharge permit for treated produced water from two types of facilities. Wyoming has developed regulations and guidelines specifically for produced water from oil and gas production facilities and for commercial oil field wastewater disposal facilities. West Virginia has developed a general permit for land application of treated or untreated water produced from CBM beds.

There are also federal regulations, briefly described in the "Current handling practices" section above, which detail construction, operation, permitting, and closure of injection wells that place fluids underground for storage or disposal.

Potential produced water reuse options

The majority of oil and gas production operations are located in the western United States. Figure 1 illustrates produced water quantities by state. In arid areas of the United States, where most of the production operations are located, water usage ranges from 600,000 acre-feet per year (AFY) in South Dakota to 43,000 AFY in California (Guerra et al. 2011).

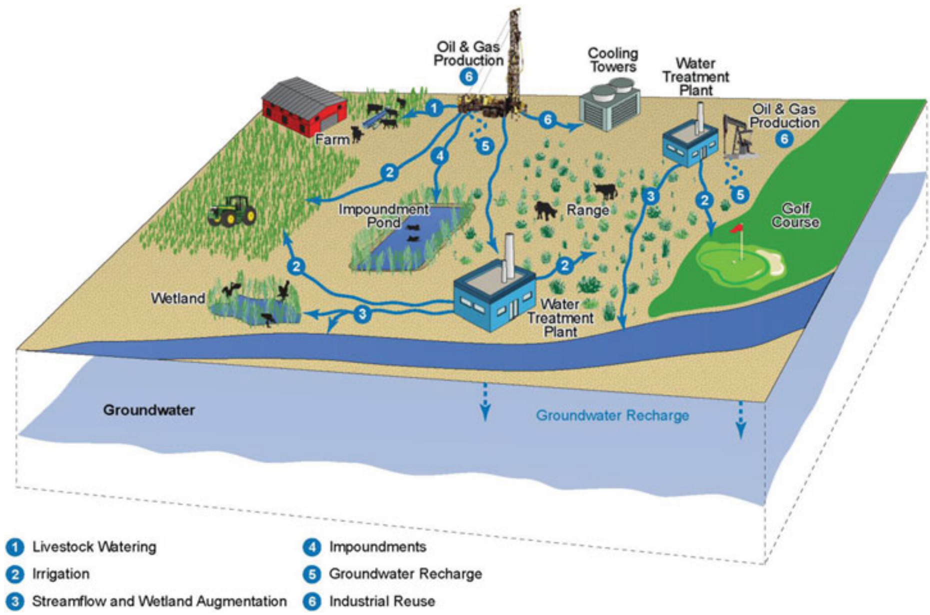

Figure 3. Beneficial reuse scenarios for onshore produced water.

Figure 3 provides an overview of potential reuse scenarios for produced waters. These reuses include irrigation of crops, rangeland and other vegetation; livestock watering; augmenting streamflow and natural wetlands; constructing artificial wetlands for treatment of produced water; impoundments; recharging groundwater for potable and nonpotable use; and various industrial uses. The distribution of applicable scenarios is a regional decision based on site- and region-specific characteristics and regulatory requirements. Understanding scenarios that are available for a specific situation is important in supporting a comprehensive decision framework. Regulatory requirements and constraints for reuse of produced waters are discussed in the "Regulatory policies" section above.

The following section discusses several potential produced water reuse options including irrigation, streamflow and wetland augmentation, groundwater recharge, and other reuses.

Irrigation

In most states, irrigation represents the majority of freshwater use. In estimates for the western United States in 2000, irrigation represented more than 70 percent of total state water usage (U.S. Geological Survey (USGS) 2005). Complementing irrigation needs with produced water therefore has huge potential, although due to their high salinity and sodacity, most produced waters will need to undergo some level of treatment or blending before being used for crop irrigation. The use of saline water for irrigation can hinder or prevent plant growth and also affect soil quality limiting crop yields. However, produced water from certain formations or from CBM operations can have salinity levels more amenable for irrigation.

Metals and other trace elements (e.g., boron, bromine, and fluorine) can also occur at elevated concentrations in some produced waters. These elements can be phytotoxic and are adsorbed by soil (Guerra et al. 2011), so their levels in produced waters should be evaluated before use. Salts and more mobile metals can be flushed from the root zone during precipitation events, which will favor plant health, but could impact shallow groundwater aquifers.

As well as having potential environmental impacts, certain COPCs can accumulate in crop tissues and have the potential to impact humans or livestock that ingest these plants, as discussed in further detail in the following sections. Produced waters can also contain volatile organic compounds (e.g., BTEX), and although less of a concern in an open air setting, potential exposure to farm workers or livestock should be considered.

Streamflow and wetland augmentation

Streamflow and wetland augmentation is the addition of waters to surface water bodies to supplement low flows, thereby sustaining the surface body ecosystem (Guerra et al. 2011). Augmentation, therefore, can minimize the effects of low-flow drought and provide benefits such as aesthetics or habitat conservation (USEPA 2012). Over-allocated water resources, where water taken from a surface body exceeds the flow or does not meet the needs of downstream users, can be ideal situations for produced water augmentation (Guerra et al. 2011).

The designated use of the water body is a critical consideration, as is the presence of native aquatic life (USEPA 2012). Salts, hydrocarbons, VOCs, trace elements, and chemical additives within the produced water can potentially cause toxic effects to aquatic organisms and wildlife. Some produced waters can also have high temperatures, high pH, and low dissolved oxygen, so their direct discharge to open waters can be detrimental to the health of aquatic organisms. Other important parameters to consider include impacts of elevated flows (e.g., erosion) and total quantity losses due to evaporation (Guerra et al. 2011).

Similar considerations need to be taken when using treated produced water to support natural wetlands. The benefits include helping systems gain beneficial wetland acreage, and supporting habitat diversity as well as biodiversity, healthy fisheries, and nursery grounds. Wetland creation can also mitigate flooding and provide recreational and educational benefits (USEPA 2012).

In addition to augmenting water flow in natural wetlands, artificial wetlands can be constructed for the treatment of produced water. Clemson University, in partnership with industry, developed and applied treatment using constructed wetland systems to decrease targeted constituents in produced waters. Pilot scale studies were conducted at the university and a demonstration project was performed within a producing coal bed methane field near Berry, Alabama. Treatment performance results indicated that these systems can be designed and built to promote specific environmental and geochemical conditions to reduce COPC concentrations (Castle et al. 2013). In another study, feasibility of treating produced water using constructed wetlands at the Rocky Mountain Oilfield Testing Center indicated improved water quality with wetland functions similar to those found in natural wetlands (Veil et al. 2004).

Groundwater recharge

Produced water can be used to recharge aquifers and subsequently recharge adjacent surface streams, or as seasonal storage below a site to allow for nonpotable use, such as irrigation. Although the groundwater recharge process will dilute and potentially filter some of the COPCs, the potential for environmental and human health impacts are significant.

If adequately treated, produced water could be of sufficiently high quality to support potable use. There are two major limitations to the reuse scenarios for potable applications: public perception and water quality regulations (see "Regulatory policies" section, above). From a public perspective, there is often concern from communities regarding use of treated effluent as drinking water, which requires water providers to invest in community outreach to ameliorate concerns (USEPA 2012). Another challenge is the federal and state regulations for human health, which are more stringent for potable than for nonpotable use. When initially proposed, the potable use of treated municipal wastewater (i.e., recycled water) was confronted with public opposition (i.e., "toilet-to-tap" concerns) but in the era of water scarcity, this barrier is diminishing and recycled water is in demand for some domestic uses, with the public beginning to consider the possibility of potable reuse. This trend if continued could translate into the public's acceptance of and an increased use of produced water for potable or other domestic uses of in the future.

Other reuses

Other reuses of produced water are:

- Industrial reuse: Produced water can become a significant replacement resource in many industrial processes if of satisfactory water quality (National Energy and Technology Laboratory (NETL) 2014) and can be reused in various oil and gas operations. Other uses can include dust suppression, firefighting, and cooling towers (Guerra et al. 2011; Murphree 2002).
- Livestock watering: Generally, livestock can tolerate water of a lesser quality than humans (Guerra et al. 2011) although produced water quality needs to be evaluated, as high levels of specific ions and salinity could harm animals.
- Impoundments: Produced water can also be collected in impoundments that can provide a source of drinking water for wildlife and offer habitat for fish and waterfowl in an otherwise arid environment. Impoundments can also provide recreational opportunities for hunting, fishing, boating, and bird watching (Veil et al. 2004), but it is important that the water quality is sufficiently protective of public health and wildlife.

Technical highlight—Human health and agriculture

With advancing technologies, virtually any water can be treated to achieve water quality standards for a particular use. The increased demand for freshwater is driving advances in treatment technologies as well as the cost-effectiveness of these technologies, although higher costs for freshwater are also more acceptable when water is scarce.

The use of treatment technologies to provide alternate water supply sources is already in place for municipal wastewater (i.e., recycled water) where reuse has evolved with treatment technology from disposal to indirect potable use. Similarly, desalination plants are being developed to utilize saline water. For reclaimed wastewater reuse, most states have regulations governing water quality criteria from centralized treatment facilities (USEPA 2012) and desalination regulations are also being put in place. In California, waste discharge requirements for recycled water use and for desalination are regulated by the State Water Resources Control Board (SWRCB)(2014, 2015).

For produced water reuse, although most states have no specific regulations, some state policies encourage recycling of wastewater to supplement water supply, provided it is suitable for its intended use. In California, the *Water Quality Control Plan for the Tulare Lake Basin*, 2nd ed., rev. January 2004 (Basin Plan) provides that "blending of wastewater with surface or groundwater to promote beneficial reuse of wastewater in water short areas may be allowed where the regional water board determines such reuse is consistent with other regulatory policies set forth or referenced herein."

Generally, water quality standards, in the form of effluent limits, are provided within waste discharge permits that could include numeric and narrative objectives such as constituent concentrations, toxicity, and taste and odor. These objectives are generally constituent concentrations below which adverse effects to human health and the environment are unlikely. The objectives also incorporate best available technology considerations.

To establish water quality requirements for a specific reuse scenario, it is important to understand the potential exposure pathways from the source (in this case, produced water) to potential receptors (e.g., humans, plants, animals). This allows for assessment of the receptors that could potentially be impacted, which in turn allows for the selection of the most appropriate concentration-based thresholds protective of the identified receptors and exposure pathways. These thresholds are numerical values, often referred to as *benchmarks*, and are generally risk-based concentrations for the exposure medium (in this case, produced water) protective of the receptors likely to be exposed. Once these benchmarks are identified, the treatment requirements for the produced water can be identified, including the feasibility and cost associated with achieving the water quality standards.

For example, for an irrigation scenario, receptors that could be exposed to produced water include farmers/workers handing the irrigation water, crops, consumers of crops (humans), and livestock (Figure 4). Other receptors could include

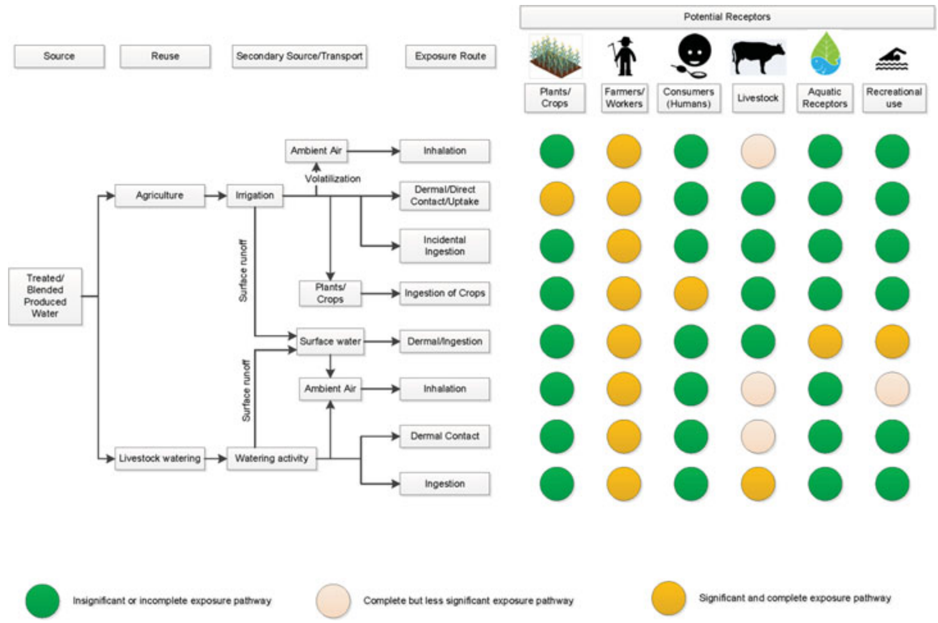

Figure 4. Conceptual site model for agriculture and livestock watering reuse.

receiving water bodies during irrigation via surface soil runoff to surface water and from soil leaching into groundwater. Benchmarks for determining safe reuse of water for irrigation are not readily available for all receptors and pathways/media. Of the potential receptors listed above, federal and state benchmarks are available for protection of surface water and groundwater, and limited benchmarks are available for protection of crops and livestock. In the United States, some states have adopted the water quality benchmarks from the Food and Agriculture Organization of the United Nations (Ayers and Westcot 1985) for protection of crops and livestock.

Benchmarks are not readily available for protection of farmers/workers handling reclaimed produced water, consumers of crops that are irrigated using reclaimed water, for livestock drinking reclaimed water, and for all the constituents that could be present in produced water. These limitations can be addressed by developing benchmarks, using regulatory agency-recommended exposure and toxicity data, protective of all potential receptors, and for all constituents in produced water including additives/treatment chemicals.

In agriculture-driven economies dependent on freshwater combined with conditions of water shortage, but with availability of produced water to meet those demands, such as in California, there has been growing interest among the agriculture sector and water managers in reusing produced water. The challenges and opportunities between these two industries are addressed in an independent study by the Pacific Institute, a nonprofit group (Pacific Institute 2015). The Pacific Institute recommends developing risk-based benchmarks protective of receptors by an independent science panel to help reduce uncertainties around the safety of this practice. Recently, a food safety group was assembled in California consisting of a panel of experts from regulatory agencies, oil and gas and food industries, academia, the nonprofit sector, and other scientists. The objective of this group is to provide information in the form of guidance and opinions that the SWRCB will consider when developing and implementing the regulatory program and orders that address the reuse of reclaimed produced water for irrigation of crops for human consumption.

Costs

The technology to treat produced water to achieve the water quality standards necessary for a designated use exists and continues to improve. However, as with any business operation, the issue of cost must be factored into the decision on whether to treat or dispose of the produced water. Unless the cost to treat produced water is equal to or less than the cost of disposal, the volume of produced water available for reuse will remain low relative to the volume of water disposed of by exploration and production companies.

What is the cost of managing produced water?

The cost of treatment and disposal varies considerably because the physical and chemical properties of produced water vary considerably depending on the geographic location of the field, the geological host formation, and the type of hydrocarbon product being produced. produced water properties and volume can even vary throughout the lifetime of a reservoir. Technology choices are complicated by the degree of treatment necessary to meet environmental requirements. Costs increase as the degree of contamination decreases, but highly concentrated water waste is likely to cost more to dispose of than less concentrated water. Thus, there is an important tradeoff between the degree of on-site treatment and disposal costs.

Not surprisingly, reviews of various capture, treatment, and disposal methods indicate a wide range of costs between $0.01 and $100 per barrel of water (Fakhru'l-Razi et.al. 2009), the technologies associated with this range are shown in Table 1. Even at the lower end of this range costs to manage produced water can be substantial. On average, about seven to ten barrels, or 280 to 400 gallons, of water are produced for every barrel of crude oil (Guerra et al. 2011). The production rates of produced water from gas wells are typically lower. Based on the seven barrels of produced water per barrel of crude and a disposal cost of $0.01 per barrel of water, the cost per barrel of oil is only $0.07. However, at a cost of $4 per barrel of water, the cost per barrel of oil grows to $28. Even when oil prices were approximately $100 this is a significant cost. At early 2016 prices (approximately $40/bbl) this is a prohibitive cost. Further, the ratio of water to oil and gas grows as wells age, increasing the cost further. A potential offset to these costs in some circumstances is the sale of treated water.

Table 1. Produced water disposal methods and costs.

Method	Estimated cost ($/bbl)
Surface discharge	0.01–0.08
Secondary recovery	0.05–1.25
Shallow reinjection	0.10–1.33
Evaporation pits	0.01–0.80
Commercial water hauling	0.01–5.50
Disposal wells	0.05–2.65
Freeze-thaw evaporation	2.65–5.00
Evaporation pits and flowlines	1.00–1.75
Constructed wetland	0.001–2.00
Electrodialysis	0.02–0.64
Induced air flotation for de-oiling	0.05
Anoxic/aerobic granular activated carbon	0.083

Legal implications

As with costs, when deciding whether to treat produced water so that it can be put to a productive use, exploration and production companies will need to weigh the risk of litigation and regulatory enforcement actions against the benefits of introducing treated water into the stream of commerce.

The productive use of produced water, even after treatment, presents various risks to the producer. All states have adopted water quality policies designed to maintain existing water quality wherever possible. In California, that policy is commonly known as the *antidegradation* policy. Adopted by the SWRCB in 1968, the *antidegradation* policy (Resolution 68–16) sought to limit water pollution to no more than the ambient levels found in water as of 1968. At the federal level, the ambient baseline level year is considered by most to be 1975. In 1983 USEPA amended federal regulations to require the states adopt formal antidegradation policy (see 40 CR 131.12). Each state was required to adopt an antidegradation policy to protect existing beneficial uses. Unlike the federal regulations, Resolution 68–16 makes no distinction between surface water and groundwater. The surface water/groundwater distinction differs among the states. This distinction can have a significant impact on the types and potential uses for treated water.

In pertinent part Resolution 68–16 states:

> Whereas the California Legislature has declared that it is the policy of the State that the granting of permits and licenses for unappropriated water and the disposal of wastes into the waters of the State shall be so regulated as to achieve highest water quality consistent with maximum benefit to the people of the State …and …
>
> Whereas the quality of some waters of the State is higher than that established by the [water quality control policies] and it is the intent and purpose of this Board that such higher quality shall be maintained to the maximum extent possible …
>
> Whenever the existing quality of water is better than the quality established in policies as of the date on which such policies become effective, such existing high quality will be maintained until it has been demonstrated to the State that any change will be consistent with the maximum benefit to the people of the State, will not unreasonably affect present and anticipated beneficial use of such water and will not result in water quality less than that prescribed in the policies.

Broadly read and applied antidegradation policies prohibit the introduction of constituents of any type into water, surface, or subsurface, that would negatively affect the current and foreseeable beneficial use of that water. There are exceptions. However, exceptions put the burden on the company that wants to use the treated water to demonstrate that the exception applies, which can be a challenging task. The exceptions, where allowed, have mostly been confined to those situations where the receiving water quality would continue to meet basin plan objectives despite the introduction of lower quality effluent. As with most policies, the ability to use treated water either directly, as in the case of agriculture and livestock, or indirectly, as a means of recharging a basin, requires the balancing of competing interests within each basin. In undertaking this balancing the demands, including economic, social, and intangible factors, on the effected waters, must be considered and may include both qualitative and quantitative measurements. The costs associated with establishing the basis upon which to demonstrate that an exception should apply could outweigh the cost of disposing of the produced water through conventional methods.

California's antidegradation policy has been applied to both surface water and groundwater. In addition to the regulatory requirements and associated risks, the specter of private party and public interest litigation exists. In its simplest form, private party litigation would arise as a tort, which may include claims for negligence, nuisance, or in some states, trespass. The range of potential damage claims would include diminution in land value, crop damage cleanup costs, water supply well treatment, stigma where recognized, and bodily injury.

State and federal statues provide nongovernmental organizations (NGOs) with the ability to file similar litigation under the guise of protecting the public health and welfare or public trust. In these suits, often referred to as *citizen suits*, the NGO "stands in the shoes" of the public or the regulatory agency and seeks to enforce the antidegradation polices under state and federal laws. If judged to be a prevailing party, the NGOs may recover their attorneys' fees and costs associated with protecting the public.

Public perception

Public perception is a crucial consideration when examining options for the reuse of produced water. The public is increasingly wary of the efficacy of regulatory oversight and associated systems meant to protect public health and the environment. The recent failings of these systems have been thrust into public view, as evidenced by the lead crisis in Flint, Michigan, and in other cities (http://mobile.nytimes.com/2016/02/09/us/regulatory-gaps-leave-unsafe-lead-levels-in-water-nationwide.html?_r=1&referer=). Recently, fears over the use of produced water for agricultural use have also emerged in the media (http://www.nytimes.com/2014/07/08/us/california-drought-chevron-oil-field-water-irrigation.html). In an effort to increase public acceptance, increase stakeholder awareness, and foster increased collaboration and trust between industry, regulators, and the public, working groups have been established in several states where produced water can provide a potentially significant buffer during times of drought and augment dwindling surface water supplies. Additionally, the successful conveyance of accurate and defensible scientific data to the public is important to combat misconceptions about produced water and potential reuse. Well-informed citizens will often perceive lower risk. A critical component to this is transparency. Transparent treatment processes, and publicly available water quality and analytical chemistry data, may help to dispel negative perceptions and instill public confidence. The oil and gas industry recently faced similar criticisms from the public regarding transparency in its hydraulic fracturing operations. Specifically, industry was hesitant to disclose the composition of hydraulic fracturing fluids, and subsequent public and regulatory pressure led the establishment of the national Frac Focus Chemical Disclosure Registry Web site (www.fracfocus.org). Note that some chemicals are still listed as either trade secret, confidential, or proprietary.

Parallels to produced water reuse can be drawn with increased efforts in extremely arid regions to augment water portfolios with recycled water, by utilizing highly treated grey and black water— also sometimes called "toilet to tap programs" by the media. Focus groups have been set up to increase public awareness and decrease the *yuck* factor associated with using recycled water for potable supply. Recycled waters are already widely used for nonpotable uses, including irrigation of golf courses, parks, and public spaces, and act as salt water barriers in southern California. The public is beginning to consider recycled water for potable use, especially as demand on freshwater supplies increases. Treatment technologies are improving, and water, whether it is municipal wastewater or produced water, can often be feasibly treated to constituent levels safely below drinking water standards. Nevertheless, the public's willingness to accept treated water as a resource, as opposed to viewing it as a waste, presents challenges for the use of produced water.

As discussed in the "Technical highlight—Human health and agriculture" section (above), California's Central Valley Regional Water Board has established a food safety panel to seek expert advice in the use of produced water for agricultural use and associated potential human health risks. Written recommendations from the panel will eventually inform policymaking and may spur additional research into toxicological effects and human health risk from crop consumption (http://www.waterboards.ca.gov/centralvalley/water_issues/oil_fields/food_safety/meetings/2016_0112_fs_of_water_proj_charter.pdf). Additionally, the Oklahoma Oil & Gas Association, under the direction of the governor, has formed a fact-finding work group to look at ways that produced water can be reused in that state (http://www.orwp.net/2015/12/governor-mary-fallin-forms-fact-finding-group-to-look-at-ways-produced-water-can-be-reused/).

Future of water in the West

Governors across the West have understood the importance of water to their respective economies and have worked to provide resiliency to volatile supply. This volatility in water supply poses not only an economic threat but an environmental threat. From ephemeral streams, headwaters, rivers and estuaries, and the flora and fauna inextricably tied to water for their livelihood, there is much at stake. Exploring options for water reuse, specifically waters that might otherwise be disposed of, reduces stress on surface water and groundwater resources. The Western Governors Association in its recent Drought Forum Webinar Series has presented on various reuse and recycled water topics; notably one of the seven key themes is "Produced, Reused and Brackish Water" (http://westgov.org/initiatives/drought-forum). Additionally, water research, conservation, and reuse are increasingly being looked at as a priority at the federal level. The Obama administration has called for an aggressive two-part water innovation strategy: (1) by increasing efficiency, reuse, and conservation; and (2) investing in research to reduce the cost of desalination and recycling with the goal of reaching pipe parity with water withdrawn from rivers. Additionally, the administration has planned a water summit at the White House, which will have occurred by the time this article has been published (http://m.sfgate.com/nation/article/Obama-proposes-new-approaches-to-Western-water-6818673.php).

Water and its importance to vibrant communities and economies has been thrust to the forefront after the Intergovernmental Panel on Climate Change presented data indicating that annual average mean precipitation is likely to decrease in the southwestern United States and that snow season length and snow depth are very likely to decrease across most of North America (https://www.ipcc.ch/publications_and_data/ar4/wg1/en/ch11s11-5.html). Currently, drought conditions persist across the West according to the drought monitor published by the National Drought Mitigation Center (http://droughtmonitor.unl.edu/home/regionaldroughtmonitor.aspx?west) and benchmark- April snowpack levels have continued to decline in many portions of the mountainous West (http://www3.epa.gov/climatechange/science/indicators/snow-ice/snowpack.html).

Between western state governors and increased interest at the federal level, combined with increased funding for advancement of desalination technology and recycled water options, water reuse will provide the foundation upon which water policy will be developed.

Conclusions

Produced water must be viewed as an environmental asset—part of the water resource solution—not as a waste that contributes to environmental problems.

The use of produced water can help reduce stress on freshwater resources, allowing surface water and groundwater to be used for other higher value purposes. Produced water can be reused in a wide range of applications, including irrigation, livestock watering, streamflow and wetland augmentation; can be placed in surface impoundments; and can be used for numerous industrial processes. Additionally, produced water can be placed into aquifer storage for later use, providing a savings account for withdrawal in low precipitation years. The large volume of produced water generated annually, combined with the prevalence of persistent droughts becoming more commonplace across the western United States, calls for the reexamination of this water as a potential resource instead of a waste. Water pricing, which is in large part a matter of public policy, must also be considered when reexamining how to best use this resource. A significant challenge is gaining an understanding of the best reuse for produced water while using the best available science and technology to be protective of public health and the environment.

In order for produced water to be viewed as an asset and not a waste, the costs and risks associated with its use must be properly managed by industry, monitored and regulated by the appropriate environmental agencies, and presented to the public in a manner such that the public does not reject its use because of a lack of health and safety information.

About the authors

Earl L. Hagström is an environmental partner residing in Sedgwick LLP's San Francisco, California, office. Prior to becoming an attorney he was an exploration geologist and development supervisor at two multinational exploration and production companies. Christopher Lyles is a professional geologist registered in the State of California with Integral Consulting Inc. in their San Francisco, California, office, where he focuses on supporting clients in water resources, emerging contaminants, and redevelopment markets. Mala Pattanayek is a senior managing scientist with Integral Consulting Inc.; her expertise includes ecological and human health risk assessment and environmental toxicology. She has worked on evaluating impacts from several contaminated sites across the United States and developing risk-based cleanup goals protective of human health, livestock, and ecological receptors. Bridgette DeShields is a principal scientist with Integral Consulting Inc.; she specializes in regulatory strategy, site remediation, sediment and water quality management, environmental toxicology, and supports litigation matters. Her work has been focused on sediment assessments and waterfront projects with natural resource components and complex regulatory frameworks. Mark P. Berkman is principal in the Brattle Group's San Francisco, California, office. Dr. Berkman is an expert in applied microeconomics. His experience spans the areas of the environment, energy, and natural resources; environmental health and safety; discrimination; and intellectual property. He has assisted both public and private clients and provided testimony before state and federal courts, arbitration panels, regulatory bodies, and legislatures.

References

Ayers, R. S., and D. W. Wescot. 1985. Water quality for agriculture. FAO irrigation and drainage paper. http://www.fao.org/DOCReP/003/T0234e/T0234e00.htm (accessed March 15, 2016).

Castle, J. W., J. H. Rodgers Jr., B. Alley, A. Beebe, R. Coffey, K. Jurinko, M. Pardue, T. Ritter, and M. M. Spacil. 2013. Innovative Water Management Technology to Reduce Environmental Impacts of Produced Water, final report. Clemson, South Carolina: Clemson University.

Ceres. 2014. Hydraulic Fracturing and Water Stress: Water Demand by the Numbers, Shareholder, Lender and Operator Guide to Water Sourcing. http://www.ceres.org/issues/resources/reports/hydraulic-fracturing-water-stress-water-demand-by-the-numbers/view (accessed March 15, 2016).

Clark, C. E., and J. A. Veil. 2009. Produced Water Volumes and Management Practices in the United States. Prepared for the U.S. Department of Energy, Office of Fossil Energy, National

Energy Technology Laboratory. http://www.ipd.anl.gov/anlpubs/2009/07/64622.pdf (accessed March 15, 2016).

Fakhru'l-Razi, A., A. Pendashteh, L. C. Abdullah, D. R. A. Biak, S. S. Madaeni, and Z. Z. Abidin. 2009. Review of technologies for oil and gas produced water treatment. *Journal of Hazardous Materials* 170 (2–3): 530–551.

Government Accountability Office (GAO). 2014. *Drinking Water—EPA Program to Protect Underground Sources from Injection of Fluids Associated with Oil and Gas Production Needs Improvement*. http://www.gao.gov/products/GAO-14-555 (accessed March 15, 2016).

Guerra, K., K. Dahm, and S. Dundorf. 2011. *Oil and Gas Produced Water Management and Beneficial Use in the Western United States*. Denver, Colorado: U.S. Department of the Interior, Bureau of Reclamation, prepared under agreement no. A10-1541-8053-381-01-0-1.

Murphree, P. A. 2002. Utilization of water produced from coal bed methane operations at the North Antelope/Rochelle Complex, Campbell County, Wyoming. Paper presented at Ground Water Protection Council Produced Water Conference, Colorado Springs, Colorado. http://www.gwpc.org/Meetings/PW2002/Papers-Abstracts.htm (accessed March 15, 2016).

National Energy and Technology Laboratory (NETL). 2014. Produced water information system. http://www.alrc.doe.gov/technologies/pwmis/intropw/index.html (accessed December 2014).

Pacific Institute. 2015. Oil, food, and water: Challenges and opportunities for California agriculture. http://pacinst.org/publication/oil-food-and-water-challenges-and-opportunities-for-california-agriculture/ (accessed March 15, 2016).

Pacific Institute. 2016. Issue brief: Fracking in California, wastewater handling and disposal. http://pacinst.org/news/california-fracking-report-evaluates-risks-and-provides-reccomendations/ (accessed March 15, 2016).

State Water Resources Control Board (SWRCB). 2014. General waste discharge requirements for recycled water use. http://www.waterboards.ca.gov/board_decisions/adopted_orders/water_quality/2014/wqo2014_0090_dwq_revised.pdf (accessed March 15, 2016).

State Water Resources Control Board (SWRCB). 2015. http://www.waterboards.ca.gov/board_decisions/adopted_orders/resolutions/2015/rs2015_0033_sr_apx.pdf (accessed March 15, 2016).

USEPA. 2005. Class II Oil and Gas Related Injection Wells. http://www.epa.gov/uic/class-ii-oil-and-gas-related-injection-wells. (accessed March 15, 2016).

USEPA. 2012. *Guidelines for Water Reuse*. EPA/600/R-12/618. Wsashington, DC: EPA, Office of Wastewater Management, Office of Water. http://nepis.epa.gov/Adobe/PDF/P100FS7K.pdf (accessed March 15, 2016).

U.S. Geological Survey (USGS). 2005. Estimated use of water in the United States county-level data for 2005. http://water.usgs.gov/watuse/data/2005/(accessed March 15, 2016).

Veil, J. A., M. G. Puder, D. Elcock, and R. J. Redweik Jr. 2004. White paper describing produced water from production of crude oil, natural gas, and coal bed methane. Prepared for the U.S. Department of Energy. Argonne National Laboratory. http://www.ipd.anl.gov/anlpubs/2004/02/49109.pdf (accessed March 15, 2016).