EAModel of the Use and Production of Water in the Gulf of San Jorge Basin*

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Abstract

In the non-conventional hydrocarbon exploitations, the water cycle goes through the stages of acquisition, conditioning, utilization, return flow, treatment, reuse and / or final disposal.

The purpose of this document is to present the general characteristics of water management in the extraction of unconventional hydrocarbons, highlighting the last stages of the cycle: treatment, reuse or final disposal.

Wastewater composition is the result of naturally occurring constituents originating in the formation, solids and fluids, as well as chemicals associated with the fracturing fluid.

Operators have several strategies for wastewater management, with the most widespread option being the final disposal in injection wells. Other practices include reuse in subsequent operations of hydraulic fracturing (after different levels of treatment), treatment in waste reconditioning plants (often followed by reuse), evaporation in sinks (mainly in arid regions), use for irrigation, and direct discharge for livestock or agricultural use.

Each of these strategies is developed under protocols that, if applied correctly, seek to minimize environmental damage.

From the analysis of the available information it is concluded that in the hydrocarbon industry there are work and operation protocols to minimize the damage to the environment, as well as wastewater management strategies that share this objective and, if applied correctly, seek

to reduce the maximum environmental impact. We also consider it of utmost importance that each jurisdiction carry out control and monitoring procedures for all extractive activities, analyzing and adapting the requirements for the preservation of its natural resources.

Introduction

In the non-conventional hydrocarbon exploitations, the water cycle goes through the stages of acquisition, conditioning, utilization, return flow, treatment, reuse and / or final disposal (Figure 2). The purpose of this document is to present the general characteristics of water management in the extraction of unconventional hydrocarbons, highlighting the last stages of the cycle: treatment, reuse or final disposal.

Wastewater (Fracture Fluid + Production Water)

Wastewater composition is the result of naturally occurring constituents originating in the formation, solids and fluids, as well as chemicals associated with the fracturing fluid. Hydraulic fracturing wastewaters are generally high in total dissolved solids (TDS), especially those from shales and tight formations, with TDS values ranging from less than 1,000 mg/L to hundreds of thousands of mg/L. The TDS in wastewaters from shale formations is typically dominated by sodium and chloride and may also include elevated concentrations of bromide, bicarbonate, sulfate, calcium, magnesium, barium, boron, strontium, radium, organics, and heavy metals. Wastewater from shales with high concentrations of uranium and thorium can contain radium, especially where TDS concentrations are also high.

The organic content in flowback waters can vary based on the chemical additives (e.g., biocides, antiscalants, gelling agents, breakers) used in hydraulic fracturing fluids and the chemistry of the formation, but the organics generally include polymers, oil and grease, volatile organic compounds (VOCs), and semi-volatile organic compounds (SVOCs). Examples of other constituents detected include alcohols, naphthalene, acetone, and carbon disulfide, compounds that may be remnants of hydraulic fracturing fluid chemicals.

Constituents in Residuals

Depending on the wastewater and the treatment processes used, treatment residuals can consist of sludges, spent media (used filter materials), or brines. Residuals may require further treatment (e.g., dewatering sludges) prior to disposal. Residuals can contain constituents such as total suspended solids (TSS), TDS, metals, radionuclides, and organics. These constituents will be concentrated in the residuals, with the degree of concentration depending on the type of treatment employed. Processes such as electrodialysis and mechanical vapor recompression have been found to yield residuals with TDS concentrations in excess of 150,000 mg/L after treating waters with influent TDS concentrations of approximately 50,000 – 70,000 mg/L.

Produced Water Handling

Water is a byproduct of oil and gas production. After the hydraulic fracturing of the formation is completed, the injection pressure is reduced, and a possible inactive period where the well is “shut in” is completed, water is allowed to flow back from the well to prepare for oil or gas production. This return-flow water may contain chemicals injected as part of the hydraulic fracturing fluid, chemicals naturally occurring in the formation, or the products of reactions that take place in the formation. Initially this water, sometimes called flowback, is mostly hydraulic fracturing fluid, but as time goes on, water chemistry becomes more similar to water associated with the formation. For formations containing saline water (brine), the salinity of the returned water increases as time passes as the result of increased contact time between the hydraulic fracturing fluid and the formation and inclusion of an increased portion of formation water. For this assessment, and consistent with industry practice, the term produced water is used to refer to any water flowing from the oil or gas well.

Produced water is piped directly to an injection well or stored and accumulated at the surface for eventual management by injection into disposal wells, transport to wastewater treatment plants, reuse, or in some cases, placement in evaporation pits or permitted direct discharge.

The term flowback has two major meanings. First is the process used to prepare the well for production by allowing excess liquids and proppant to return to the surface. The second use of the term is to refer fluids predominantly containing hydraulic fracturing fluid that return to the surface. Because formation water can contact and mix with injection fluids, the distinction between returning hydraulic fracturing fluid and formation water is not clear. Definitions of flowback are operational in the sense that they include some characteristic of the oil and gas operation (i.e., fluids returning within 30 days). These reflect that during the early phases of operation, a higher concentration of chemical additives is expected and later, water is characteristic of the formation.

Volume of Hydraulic Fracturing Flowback and Produced Water

The amount of produced water from a well varies and depends on several factors, including production, formation, and operational factors:

- *Production factors* include the amount of fluid injected, the type of hydrocarbon produced (gas or liquid), and the location within the formation.
- *Formation factors* include the formation pressure, the interaction between the formation and injected fluid (capillary forces), and reactions within the reservoir.
- *Operational factors* include the volume of the fractured production zone that includes the length of well segments and the height and width of the fractures.

Certain types of problems also influence water production, including possible loss of mechanical integrity and subsurface communication between wells, both of which can result in an unexpected increase in water production

The processes that allow gas and liquids to flow are related to the conditions along the faces of fractures. Conceptualized fluid flow across the fracture face as being composed of three phases, the first is characterized by forced imbibition of fluid into the reservoir and occurs during and immediately following fracture stimulation. Second is fluid redistribution within the reservoir rock, due to capillary forces. In the last phase, water flows out of the formation when the well is opened and pressure is reduced in the wellbore and fractures. The purpose of this phase is to recover as much of the injected fluid as possible to allow higher oil or gas flow rates. The length of the last phase and, consequently, the amount of water removed, depends on factors such as the amount of injected fluid, the permeability and relative permeability of the reservoir, capillary pressure properties of the reservoir rock, and the pressure near the fracture faces.

The well can be shut in for varying time periods depending on operator scheduling, surface facility construction and connection or other reasons.

Flowback of Injected Hydraulic Fracturing Fluid

The amount of water produced by wells within the first few days following fracturing varies from formation to formation. It is not possible to specify precisely the amount of injected fluids that return in the flowback, because there is not a clear distinction between flowback and produced water, and the indicators (e.g., salinity and radioactivity, to name two) are not routinely monitored. Rather, flowback estimates usually relate the amount of produced water measured at a given time after fracturing as a percentage of the total amount of injected fluid. Estimates of the fraction of injected hydraulic fracturing fluid that returns as flowback are highly variable. The maximum are less than 85% in all but, and most of the median values are less than 30%. In some cases, the amount of flowback is greater than the amount of injected hydraulic fracturing fluid, and the additional water comes from the formation or from a conductive pathway from an adjacent formation (Figure 1).

Produced Water Volumes

The amount of produced water over the long term as high, moderate, or low for several formations. Wells in conventional and unconventional reservoirs produce differing amounts of water. High rates of water production (flowback) typically occur in the first few months after hydraulic fracturing, followed by rates reduced by an order of magnitude. A general rule of thumb that, for unconventional reservoirs, the volume of flowback (which occurs over a short period of time) is roughly equal to the volume of long-term produced water. These trends in produced water volumes occur within the timeline of hydraulic fracturing activities, and show that the large, initial return volumes of flowback last for several weeks, whereas the lower rate produced water phase can last for years (Figure 1).

Produced Water Volumes at the Golfo San Jorge Basin (GSJB)

The produced water volumes at the GSJB (Figure 3) on July (2015) rates 522,000 m^3/d and oil production rates 41,725 m^3/d (92.6 % of water). This water production it is equivalent to almost four and a half times the fresh water that from the town of Sarmiento provides the coastal communities for human consumption. The main conclusion of this is that the oil industry has enough capacity to manage this water produced and reuse it Hirschfeldt (2015).

Chemical Composition of Produced Water

For hydraulically fractured wells, the chemical composition of produced water changes from being similar to the injected hydraulic fracturing fluid to reflecting a mixture of hydraulic fracturing fluids, naturally occurring hydrocarbons, transformation products, and formation water. Initial produced water data show continuous changes in chemical composition and reflect processes occurring in the formation.

Factors Influencing Produced Water Composition

Several interacting factors influence the chemical composition of produced water:

1. the composition of injected hydraulic fracturing fluids,
2. the targeted geological formation and associated hydrocarbon products,
3. the stratigraphic environment, and
4. subsurface processes and residence time

Produced Water Composition during the Flowback Period

The chemistry of produced water changes over time, especially during the first days or weeks after hydraulic fracturing. Generally, produced water concentrations of cations, anions, metals, naturally occurring radioactive material (NORM), and organics increase as time goes on. The causes include precipitation and dissolution of salts, carbonates, sulfates, and silicates; pyrite oxidation; leaching and biotransformation of organic compounds; and mobilization of NORM and trace elements. Concurrent precipitation of sulfates (e.g., $BaSO_4$) and carbonates (e.g., $CaCO_3$) alongside decreases in pH, alkalinity, dissolved carbon, and microbial abundance and diversity occur over time after hydraulic fracturing.

Produced Water Composition

The chemical composition of produced water continues to change after the initial flowback period. Produced water may contain a range of constituents, but in widely varying amounts. Generally, these can include:

- Salts, including those composed from chloride, bromide, sulfate, sodium, magnesium and calcium;
- Metals including barium, manganese, iron, and strontium;
- Radioactive materials including radium (radium-226 and radium-228);
- Oil and grease, and dissolved organics (including BTEX);
- Hydraulic fracturing chemicals, including tracers and their transformation products; and
- Produced water treatment chemicals

Wastewater Management Practices

Operators have several strategies for management of hydraulic fracturing wastewaters, with the most common choice being disposal via wells. Other practices include reuse in subsequent hydraulic fracturing operations (with varying levels of treatment), treatment at a centralized waste treatment facility (CWT) (often followed by reuse), evaporation (in arid regions), irrigation (with no discharge to waters of the United States), and direct discharge for livestock or agricultural use. The methods shown in Figure 4 represent wastewater management strategies, not all of which would be used at the same facility.

Management choices are affected by cost and a number of directly and indirectly related factors, including the chemical properties of the wastewater; the volume, duration, and flow rate of the wastewater generated; the feasibility of each option; the availability of necessary infrastructure; local, state, and federal regulations. The economics (such as transport, storage, and disposal costs) and availability of treatment and disposal methods are of primary importance. The availability and use of wastewater management strategies in a region can change over time as oil and gas production increases or decreases, regulations change, costs shift, and technologies evolve. Another factor influencing reuse is the pace of hydraulic fracturing in the area.

When hydraulic fracturing is active, demand for reuse is high. Researchers have developed optimization models to aid in the minimization of wastewater management costs as a part of comprehensive water management planning. For example, reusing flowback in scheduled hydraulic fracturing events to minimize the operational costs of transportation, treatment, storage, and wastewater disposal. Another modeling study proposes an approach to minimize the total cost of water usage and wastewater treatment and disposal by optimizing capital costs (such as the costs of treatment units and storage pits) and operating costs for flowback management, treatment, storage, reuse, and wastewater disposal.

Treatment

Overview of Hydraulic Fracturing Wastewater Management Methods

Centralized Waste Treatment (CWT) Facilities

A CWT facility is generally defined as one that accepts industrial materials (hazardous or non-hazardous, solid, or liquid) generated at another facility (off-site) for treatment or recovery (Wastewater may also be treated at on-site (Figure 5) mobile or semi-mobile facilities). The decision to treat hydraulic fracturing wastewater at a CWT and the level of treatment used depends upon several factors, such as a lack of proximity to Class II disposal wells; whether the wastewater might be reused for additional hydraulic fracturing jobs; the water quality needed if it will be reused.

Storage and Disposal Pits and Impoundments

The use of pits and impoundments as part of a wastewater management strategy is a historic as well as current practice in the oil and gas industry. These structures are either used for temporary storage (on-site at oil and gas production wells or off-site at CWTs or disposal wells) or they are intended for permanent disposal (evaporation or percolation).

Storage

Throughout the production phase at oil and certain wet gas production facilities, produced water is stored in containers and pits that can contain free phase, dissolved phase, and emulsified crude oil. Since the crude oil is not efficiently separated out by the flow-through process vessels (such as three-phase separators, heater treaters, or gun barrels), this crude oil can remain present in the produced water container or pit.

Produced water that is to be treated or disposed of off-site is typically stored in storage tanks or pits until it can be loaded into transport trucks for removal. Tank storage systems are typically closed loop systems in which produced water is transported from the wellhead to above ground storage tanks through interconnecting pipelines.

Unlined Storage Pits and Percolation Pits

Whether an unlined pit is designed and intended to percolate wastewater into the ground for disposal or if it is built for storage, it provides a pathway for wastewater to infiltrate into the subsurface and potentially reach groundwater. Such pits have been used historically for conventional oil and gas wastewater. More recently, they have received wastewater in areas where hydraulic fracturing takes place.

Evaporation Ponds

Evaporation ponds, referred to as Commercial Oil Field Waste Disposal Facilities (COWDFs), are a waste management strategy commonly used. Evaporation is a simple water management strategy involving transporting wastewater to a pond or pit with a large surface area and allowing passive evaporation of the water from the surface. As the water component of the wastewater is subject to evaporation, the fluid remaining in the pond becomes concentrated, and a sludge layer is formed. Remaining residual brines in the pond can be collected and disposed of an underground injection well, and the solids can be taken to a landfill. In cold, dry climates, a freeze-thaw evaporation method has also been used to purify water from oil and gas wastewater

Underground Injection

Oil and gas related wastewater might be disposed at injection wells that can receive a large percentage of wastewater from the oil and gas industry, including wastewater associated with hydraulic fracturing. The location and number of wells is determined by geology (including depth and permeability of geologic formations appropriate for injection), permitting, and historical demand for disposal of oil and gas wastewater. The decision to inject hydraulic fracturing wastewater into wells depends on cost, including transportation costs. Therefore, the distance between the production well and a disposal well is an important consideration. For oil and gas producers, underground injection is a low-cost management strategy unless significant trucking is needed to transport the wastewater to a disposal well.

In the GSJB there are about 3,000 injection wells that distribute all the water produced (522,000 m^3/ d), which is used as an energy source for the displacement of oil from reservoir rocks to increase oil production (oil projects) secondary recovery due to water flooding or "flood flooding"). Another important aspect to note that 45% of the oil production of the basin comes from this method, and in some fields, it exceeds 80%. It is also important to remember that fresh water is not used in the GSJB to be injected into these production improvement processes (Hirschfeldt, 2015).

Wastewater Reuse for Hydraulic Fracturing

The reuse of hydraulic fracturing wastewater for subsequent hydraulic fracturing operations has increased in recent years. This practice is driven by factors that include cost (including treatment costs), the lack of availability of other management options (e.g. disposal wells), and changes to state regulations. Depending on its characteristics, produced water can be recycled and reused on-site. It can be directly reused without treatment (after blending with freshwater), or it can be treated on-site prior to reuse. Wastewater may necessitate treatment. For example, high concentrations of barium and sulfate can lead to scaling, and the presence of some constituents in wastewater can hinder crosslinking.

Hydraulic fracturing fluid formulations that can use high TDS waters (e.g., as high as 150,000 mg/L to over 300,000 mg/L) facilitate reuse with minimal treatment. Reuse can be accomplished by blending either untreated or minimally treated hydraulic fracturing wastewater with fresh water to lower the TDS content. Wastewater may be reused at a site with multiple wells, eliminating the need for transport to a CWT. Alternatively, wastewater can be treated at a CWT and then taken by operators for mixing with other water sources for reuse. Flowback may be preferable to later-stage produced water for reuse because of its lower TDS concentration. Also, it is typically generated in larger quantities from a single location as opposed to water produced later on, which is generated in smaller volumes over time from many different locations.

Reuse can reduce the costs associated with water acquisition and produced water management. Such economic and logistical benefits can be expected to inform ongoing wastewater management decisions. Costs can be the most significant driver for reuse. For example, the costs of transporting wastewater from the generating well to the treatment facility and then to the new well can be weighed against the costs for transport to alternative locations. Reuse rates may also be driven by wastewater production rates compared to the demand for reuse, with both production and demand increasing in a region if more wells go into production or decreasing as plays mature. Other logistics to consider include proximity of the water sources for aggregation and sequencing of completion schedules.

Conclusion

From the analysis of the available information it is concluded that in the hydrocarbon industry there are work and operation protocols to minimize the damage to the environment, as well as wastewater management strategies that share this objective and, if applied correctly, seek to reduce the maximum environmental impact. We also consider it of utmost importance that each jurisdiction carry out control and monitoring procedures for all extractive activities, analyzing and adapting the requirements for the preservation of its natural resources.

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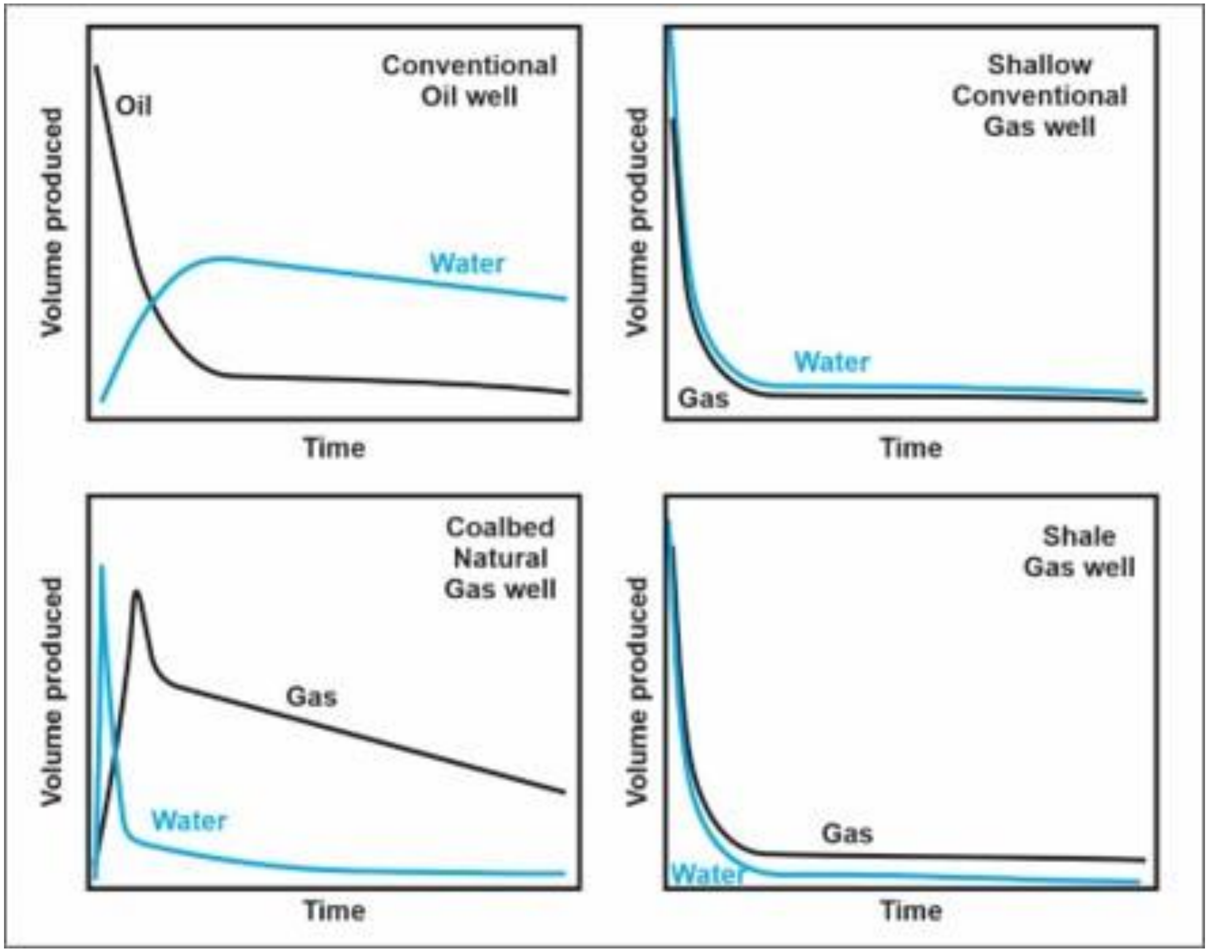

Figure 1. Decline curves: water volume vs. hydrocarbons volume Healy et al., (2015).

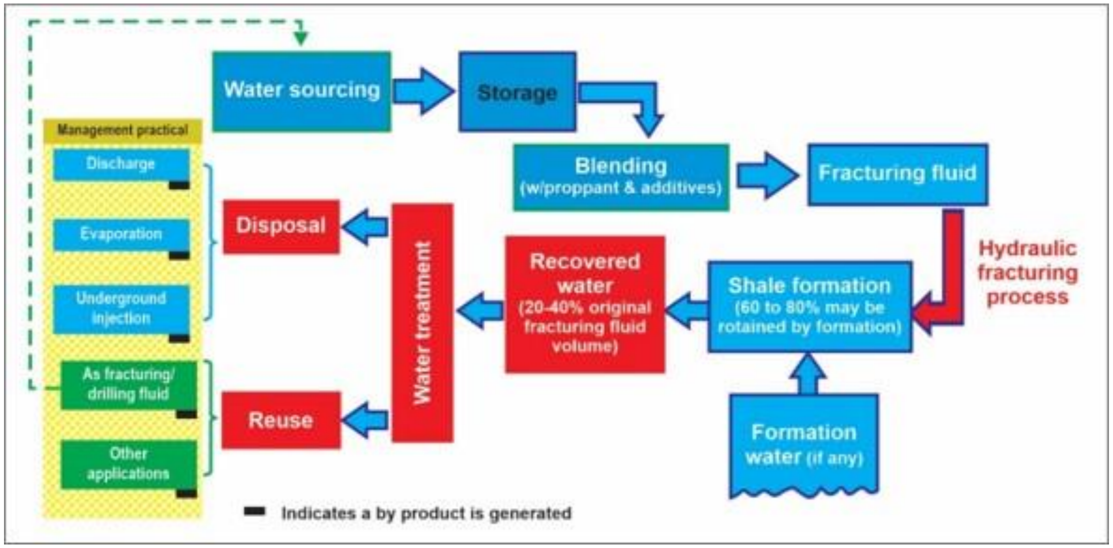

Figure 2. Water cycle overview with identified management practices.

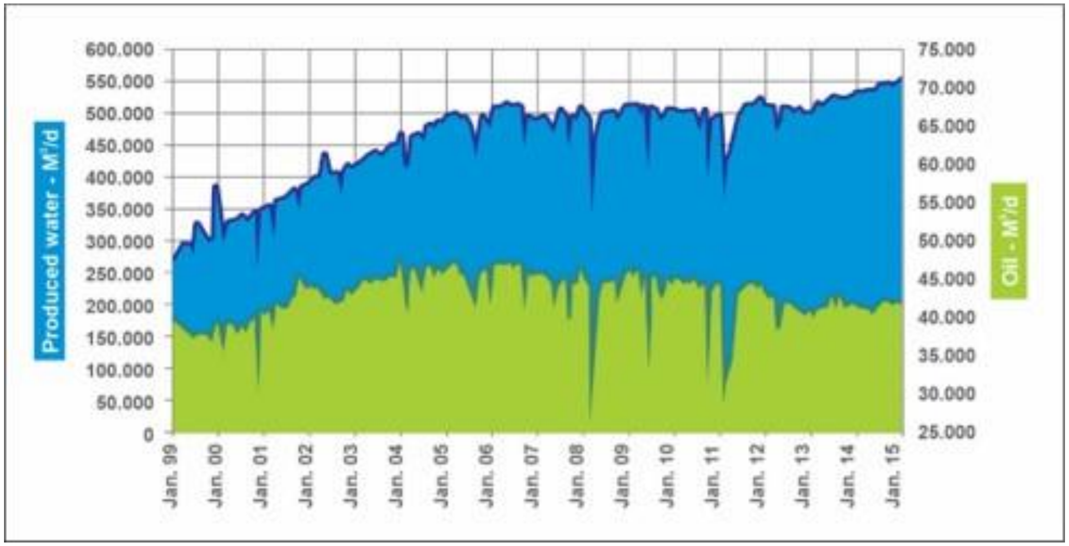

Figure 3. Oil vs Water production GSJB.

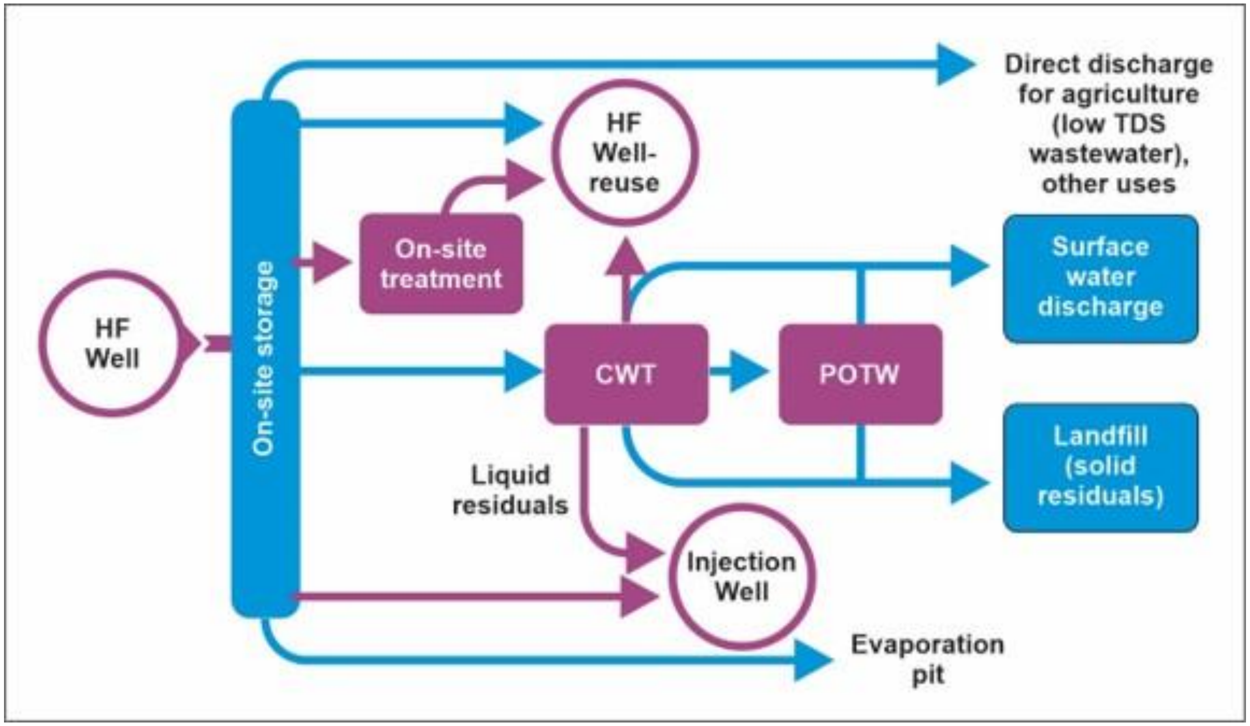

Figure 4. Schematic of wastewater management strategies. Purple lines indicate management strategies that involve injection, either for reuse or disposal, and blue lines indicate management strategies that lead to other end points such as discharge, evaporation, landfills, or other uses.

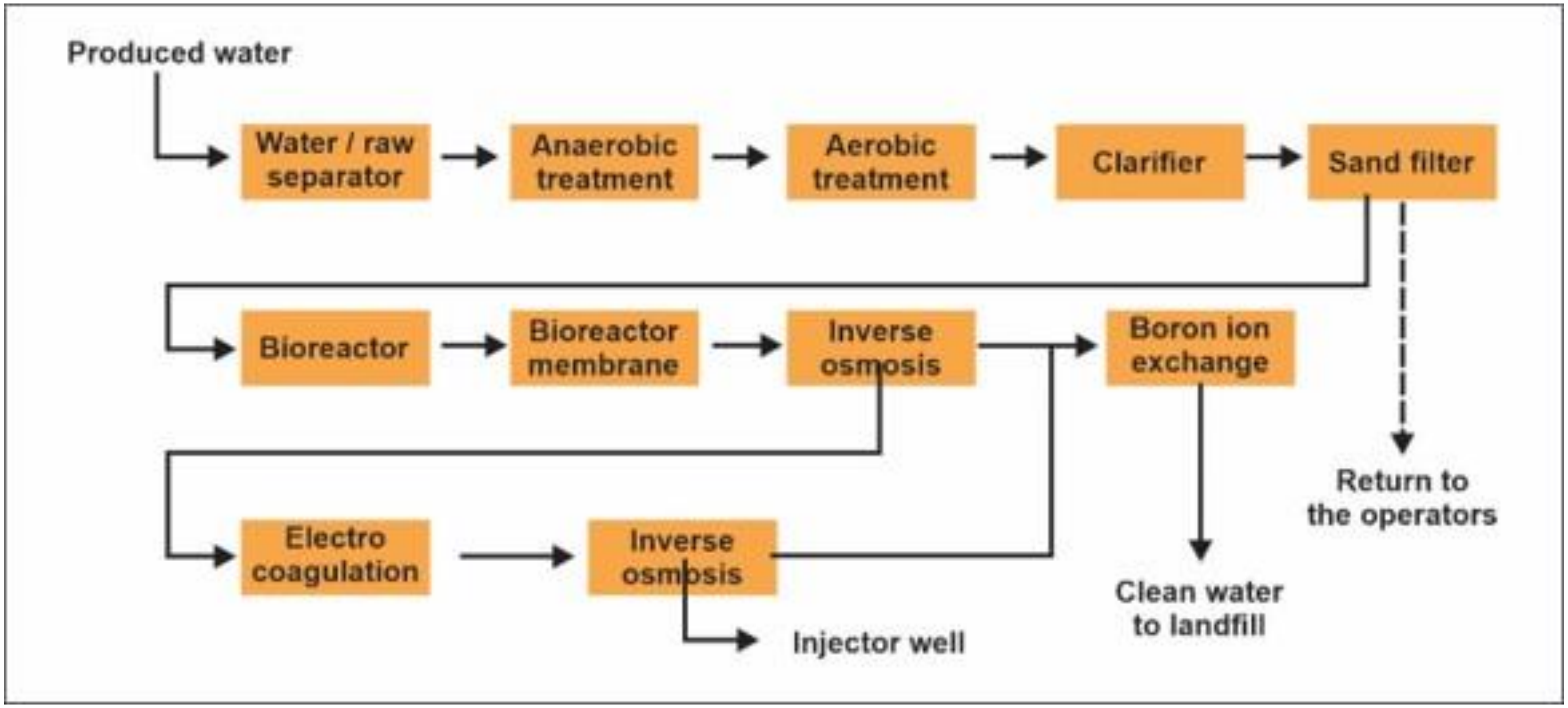

Figure 5. Example of water management on-site.