The role of water management in unlocking unconventional resources

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Introduction

Water Management for unconventional hydrocarbons requires several key decisions to be made in the early stage of field development to minimise overall water management costs. When decisions are not made early, or not implemented in a timely manner, the remaining water management options may be scarce and the cost of water management can escalate by an order of magnitude. This was the early experience of operators in Marcellus who delayed water management planning and were forced to pay more than US$500,000 per well to dispose of spent hydraulic fracturing (HF) fluids.

This extended abstract presents a water management strategy for HF operations. A decision framework is required to define variables that impact water management options and suggest the best strategy, for recycle, reuse, disposal, beneficial use, etc.

Early decisions are important to avoid the costly mistakes. Timing is critical for achieving low overall water management costs. Not all of the background data are available at a project's early stage. Background information must be developed to initially progress the water management decisions. Therefore the methodology and framework are discussed rather than a definitive set of recommendations.

Discussion

One of the factors that cause delays is a lack of knowledge of technical and economic options. Several options for water management are available at every stage of field development. Recognising options is a matter of experience. The most relevant experience originates from the US where many operators have learned the hard way. Wherever high costs have been incurred, service providers have stepped in. In time, competition between service providers has reduced the overall costs.

Water management for HF is straightforward. The water management decision framework is based on five key drivers:

1. Hydrology of the field (or region)—defines fresh water availability.

2. Regulatory Requirements and Community Concerns—defines disposal options.

3. Fracture Fluid Quality Required—defines the quality of water required.

4. Flow-Back Fluid Characteristics—defines the treatment options for recycling.

5. Stage of Field Development—defines the availability of technology.

These drivers are described in more detail in Table 1 below. Water management options are associated with each of these categories. By providing the required input information, the appropriate options can be refined. Once this is done, the next step is to populate a cost model from which the final water management strategy can be developed.

Each driver is accompanied by a simple question which helps to define the meaning of the driver.

Table 1. Key drivers and related simple questions.

Key drivers	Simple question
Hydrology/hydrogeology	Is fresh water available?
Regulatory and community	Is injection disposal an option?
Fracture fluid quality required	Can saline water be used for HF fluid make-up
Flow back fluid characteristics	In the flow back fluid saline?
Stage of field development	What kind of equipment packaging is required or appropriate?

Hydrology of the region

SOURCING OR THE ACQUISITION OF FRESH WATER

The hydrology/hydrogeology of the field define the availability of fresh water sources. In some regions where shale resources are found, there is plenty of fresh water available. In some cases (such as Marcellus), an operator can source fresh water directly from a municipal water supply for relatively low cost.

In the western US this is not the case. Fresh water is scarce and water is sourced from brackish or saline aquifers is the only option. Fresh water is then generated by reverse osmosis. The hydrology of the regional water system must be understood.

Is fresh water available yes or no?

Regulatory requirements and community concerns

DISPOSAL OF FLOW-BACK AND PRODUCED WATER

Regulations set strict constraints on the disposal of flow-back, produced water and any waste generated from flowback treatment. In the US and many other countries, regulations are developed by regional government bodies. Often regulations are based on past activity. If past activity has resulted in an adverse environmental impact, legislation will be prohibitive toward the disposal of waste, or toward resource development.

Community concerns are as important as regulations. Public pressure can delay, limit or prevent certain disposal options or even stop development. Community concerns start with environmental impact and expand to issues, such as traffic, transient workers, property value, fire, explosion hazard, etc.

Are disposal wells available yes or no?

FRACTURE FLUID QUALITY REQUIRED

The fluid quality to perform successful HF varies depending on shale type. Shales vary in quartz and clay content, in brittleness and ductility, in pressure required to propagate a fracture, in extent of pre-existing micro-fracturing, and in extent of the micro-fracturing after HF. All factors combine to dictate optimal fluid type for achieving required degree of enhanced production. The optimal HF fluid type may or might not require fresh water makeup (e.g.HF fluids based on non-ionic HPAM—partially hydrolysed polyacrylamide—are less sensitive to dissolved salts than the anionic form, which is typically referred to as a Slickwater fluid. Some of the polysaccharides are also less sensitive to ion content).

Is fresh water required for make-up of the HF fluid yes or no? If yes, desalination required.

FLOW-BACK FLUID CHARACTERISTICS

If flow-back fluid recycling is to be undertaken, the characteristics of the fluid are critical in determining the type of technology that will be successful. Generally, fluids pumped into the ground do not necessarily determine fluids that flowback. In some cases yes, in others, no. In Marcellus, even fresh water HF fluids typically become saline through shale contact.

STAGE OF FIELD DEVELOPMENT

In the early stages of development, a number of individual wells are drilled and completed. There are various reasons for this. In the US, mineral rights are owned by the land lease holders. In the early stage of field development, several wells will be drilled to either secure acreage or determine the extent of the hydrocarbon bearing zone. Intensive in-field drilling and completion of isolated wells requires mobile water treating equipment. Such equipment is compact and can be placed on a flatbed truck.

As field development progresses, the leases become secure and the drilling campaign becomes more structured. It is then possible for several adjacent wells to be developed in sequence or simultaneously. This facilitates the use of a modular water treating system. In this study a daisy-chain or hub-and-spoke type of water piping arrangement is constructed to feed the water treatment unit and to convey treated water to the wells.

Later in field life, many wells are in relatively close proximity. The construction of a water conveyance network, together with a centralised facility becomes justified with time.

THE COST MODEL

Final selection of the most appropriate water management options and development of the water management strategy is completed by using a cost model. The most expedient way to make the required decisions is to develop a detailed cost model and systematically run through the options. The cost of water management options for any given field is region-specific and location-specific. Availability of staff, materials, remoteness and regulatory practice factors influence the cost of water treatment.

The cost model must be developed before field development starts and is initially based on data from other regions, and is tailored to the regional regulations and local hydrogeology. Once field development commences, the model can be updated with actual field data. The model must be updated periodically as additional wells are drilled and the field matures from remote wells to clustered wells, to a full producing field with a relatively well connected gas and oil gathering system. During field development, the number and type of water treatment options changes and there is increasing potential for reducing cost.

Slutz et al (2012) have developed a model for several shale fields in the USA. The advantage of these models is that they are based on actual field experience, a logical starting point.

Output for two fields is shown in tables below.

Table 2. Water management cost model for the Marcellus Field.

Description	Source FW and dis-pose (bbl)	Re-use volume (bbl)	Recycle volume (bbl)	Disposal volume (bbl)
Total HF fluid	120,000	120,000	120,000	120,000
Flowback fluid	30,000	30,000	30,000	30,000
Re-use available		30,000		
Recycle available			18,600	
Disposal			11,400	30,000
Fresh water make-up required	120,000	90,000	101,400	
Description	**Source FW and dis-pose (USD)**	**Re-use cost (USD)**	**Recycle cost (USD)**	**Disposal cost (USD)**
Fresh water supply	18,000	13,500	15,210	
Freshwater transportation	24,000	18,000	20,280	
Disposal transportation	600,000		228,000	600,000
Disposal injection			11,400	30,000
Water treatment transport		30,000	18,600	
Water Treatment	30,000	30,000	105,000	30,000
Total cost per job	672,000	91,500	389,490	660,000

In the New York (NY) and Pennsylvania (PA) portions of the Marcellus field disposal by well injection is not a viable option. Disposal wells are available in Ohio which is roughly 650 to 1,000 km from most of the NY and PA Marcellus wells. If waste is trucked, water management is expensive. The option to reuse the HF fluid is significantly less expensive and is the option being used by operators in Marcellus.

Table 3. Water management cost model for the Barnett Field.

Description	Source FW and dispose (bbl)	Re-use volume (bbl)	Recycle volume (bbl)	Disposal volume (bbl)
Total HF fluid	100,000	100,000	100,000	100,000
Flowback fluid	40,000	40,000	40,000	40,000
Re-use available		40,000		
Recycle available			30,680	
Disposal	40,000		9,320	40,000
Fresh water make-up required	100,000	60,000	69,320	
Description	**Source FW and dispose (USD)**	**Re-use cost (USD)**	**Recycle cost (USD)**	**Disposal cost (USD)**
Fresh water supply	25,000	15,000	17,330	
Freshwater transportation	30,000	18,000	20,796	
Disposal transportation	40,000		9,320	40,000
Disposal injection			6,990	30,000
Water treatment transport		4,000	3,068	
Water Treatment	30,000	50,000	160,000	30,000
Total cost per job	125,000	87,000	217,490	100,000

As shown, for the Barnett field, disposal cost is not prohibitive due to the permitting of disposal wells. Reuse is less attractive and recycling is prohibitive due to water treatment cost. Reasons for this are explained below.

Each cost model starts with an understanding of the regional regulations and the location's hydrogeology. Hydrogeology defines water availability for use in drilling and completion. Regulations define the constraints for disposal. Within these two constraints, more precise options are developed by considering the fluid types, and the stage of field development.

The next constraints required are related to the fluid properties to be treated. Four fluid type options are used for HF:

1. Slickwater frac (non-ionic, cationic, or anionic HPAM).
2. Linear polymer (guar or other non-cross-linked polysaccharide).
3. X-linked gel (guar or other cross-linked polysaccharide).
4. Hybrid (typically slickwater to start and a finish using x-linked guar).

In addition to fluid types pumped into the well, characteristics of flow-back fluid must be considered. Salinity (TDS), the composition of dissolved components and the presence of particular contaminants such as iron, boron, and scaling components must be known.

These fluid types (pumped and flow back) have important effects on two key aspects of water management: (1) the type of water treatment technology that will be required, and (2) the likelihood that the D&C specialists will be encouraged to reuse or recycle the fluids.

Once regulatory, hydrogeological and fluid type constraints are known, early water management options can be evaluated. Early options will be different from later options. Water treatment at the beginning of development must deliver water, using appropriate technology, to the well site without the benefit of a water pipeline or gathering system afforded to a centralised treatment system.

The framework for building the cost model is given in the table below.

Table 4. Decision framework for water management.

Key Drivers	Areas affected	Options
Hydrogeology	Determines the availability of fresh water	Aquifer, reuse, or recycle
Regulations	Determines the possible disposal options	Disposal well, CWT, POTW, irrigation, reuse, recycle
Fluids injected	Determines the difficulty of treatment, whether high concentration of organic suspended solids will be present	Primary treatment: flocculation, sedimentation, and filtration, sludge handling. Secondary treatment: activated sludge, MBR, MBBR.
Flow back fluids	Determines volume (load recovery) and whether de-salination is required to recycle or dispose of the fluids	Desalination using RO or evaporation. RO requires extensive pre-treatment.
Stage of development	Determines water conveyance options	Type of treatment facility required: mobile, modular, or centralised treatment facility

As an example of how this framework can be used, this extended abstract refers to the Marcellus plays in the mid-development stage (2010–12). During this time, successful operators were beginning to lay hose networks, build water pipelines, and establish truck loading and unloading stations between pipeline networks. Networks allowed Centralised Water Treatment (CWT) works to discharge into the public owned treatment works (POTW). In this case, the CWT would remove suspended organics and reduce the total dissolved solids. Discharge to existing POTW ensured the final water quality for discharge to the environment.

Operators have begun to reuse HF flow-back fluid. This requires onsite holding ponds toblend and equilibrate the flow-back water. Also, it requires on-site chemical treatment (biological control, scale and corrosion control), onsite testing, and basic water treatment (settling, filtration). It also requires that the injected HF fluid be compatible with the HF flow back fluid. This generally requires the use of salt tolerant polymers (e.g. non-ionic partially hydrolysed polyacrylamide).

The authors believe that the direct reuse of HF fluid is occurring at the Perth Basin exploration wells. Here minimal storage and disposal is required. In the coal seam gas (CSG) industry in Queensland, flow-back water is stored in regional holding ponds and aggregation dams and treated.

Water management in future Canning Basin operations is likely to follow the Barnett field water management protocol as similar conditions prevail. Evaporation ponds however, would likely be used as opposed to deep well injection.

For water management in shale and tight gas in the Cooper Basin, alternative water sources are used. These include recycling of recovered fracture stimulation fluids where practicable, recycling produced formation water or extraction (under licence) of water from the Great Artesian Basin. Cooper Basin water management follows the reuse and recycle scenario, similar to Barnett field, but utilising holding and evaporation ponds.

Table 5. Decision framework applied to Marcellus Field.

Key Drivers	Result
Hydrogeology	Plentiful source water
Regulations	Disposal wells not permitted. Direct discharge from wells to POTW not permitted. Discharge to CWT which discharges to POTW permitted.
Fluids injected	Slickwater. No extensive pre-treatment required. Reuse feasible, particularly with non-ionic slickwater.
Flow back fluids	High TDS, high NORM. Ion exchange, precipitation softening effective.
Stage of development	Water network beginning to establish

Stage of development

Water network beginning to establish

The input parameters and results given in the above table suggests that reuse of HF flow back fluid would be the preferred option.

Whether this is indeed the low cost option is tested by running the cost model. As shown in Table 1, reuse costs US$91,500 for a typical well versus US$672,000 for disposal injection in a neighbouring state.

The water treatment costs used in the model are calculated in detail for each treatment type. There are four treatment categories: Minimal, Mobile, Modular, and Centralised. Factors that determine cost (cost drivers), for each of these types are significantly different. They are outlined as follows. Rough estimates are given which are derived from various project specific assumptions.

Minimal: this includes coarse filtration and chemical treatment for biological control and scale inhibition. Used for disposal well injection.	
Coarse filtration	30%
Chemicals	70%
Labour (usually included in chemical costs)	0%
Average costs	1.00USD/bbl 6.30 USD/kL
Mobiles: this covers a range of treatment technologies. The capital cost of the equipment is rarely a factor in determining the overall of cost of treatment. Instead, the cost depends on the number of staff required to operate the equipment, water processing rate. This rate determines man-hours.	
Transportation and establishment	20%
Labour, fuel, and treating cost	70%
Miscellaneous	10%
Average costs	7.00 USD/bbl 44.30 USD/kL
Modular: this involves skid mounted equipment loaded on one or more trucks which is delivered to site and constructed in a timely manner. Cost for water treating using a mobile treating system depends on the cost mobilisation and demobilisation.	
Gathering system	25%
Transportation and establishment	3%
Fuel and chemicals	30%
Labour cost	40%
Miscellaneous	2%
Average costs	4.00 USD/bbl 25.00 USD/kL
Centralised: this involves traditional industrial water treatment technologies (primary, secondary, tertiary) and results in brackish or potable water quality. An extensive gathering network is required to transport the water to the CWT and dispense the treated water to environment or further treatment systems. The model used does not include the cost of the gathering network.	
Fuel and chemicals	30%
Labour cost	40%
Miscellaneous	20%
Average costs	0.16 USD/bbl 1.00 USD/kL

Conclusions

The starting point for developing a water management strategy involves answering five questions defined by the key drivers.

The first two questions define whether the reuse or recycling of flow back fluids is needed at all.

The next two questions define whether desalination is required. If low salinity water is required for fracture fluid makeup and if the flow back water is high salinity, then desalination is required. Also, the type of fluid that is used will dictate the level of pre-treatment required.

If the flow back fluids are to be recycled, the stage of the development will define whether mobile, modular, or centralised facilities are to be used:

- Mobile technologies are required at an early stage of development when limited infrastructure is available for transporting water.
- Modular technologies can be used when clusters of wells are developed. Water from one well can be treated and used on the next well in the cluster.
- Centralised facilities offer the greatest number of treatment options and the lowest per barrel costs.

The final technology selection will depend on application of a cost model.

Acknowledgements

The authors wish to acknowledge with thanks receiving a copy of reference [1] and having a discussion with the author of that paper, B. Halldorson, this source defines five key aspects of a water management strategy. The authors greatly appreciate the input and guidance of Mr. Halldorson.

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