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Optimization models for impaired water management in active shale gas development areas

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ABSTRACT

In this work we present a mixed-integer linear programming model to support upstream operators in identifying optimal strategies for impaired water management in active shale gas development areas. The proposed model is designed to coordinate three key development decisions such that the net present value is maximized: a) the fracturing schedule, b) the water supply sourcing and distribution strategy, and c) the selection of appropriate water storage solutions. We specifically allow return-to-pad operations in the fracturing schedule and we assume that water blending ratios for fracturing jobs are unrestricted, i.e., companies may use only impaired water to meet the completions water demand. Moreover, we explicitly consider the sizing and timing of water storage solutions. By applying the optimization model to a real-world case study, we find that impaired water disposal volumes can be reduced drastically if operators manage to coordinate their fracturing schedule with impaired water availability.

1. Introduction

It is well-known that shale gas development – which involves hydraulic fracturing – requires significant quantities of water; often several million gallons of water for a single well. However, it is fairly common that a portion of the injected water is recovered after the respective well is turned in-line. The shale industry distinguishes between so-called *flowback water* during the early phase of a well's production life cycle (typically 10–30% of the injected water) and *produced water* further into the lifetime of a well. Both, flowback water and produced water are referred to as *impaired water*, since the water is contaminated. Minerals and organic constituents present in the formation dissolve into the water, creating a brine solution that includes high concentrations of salts, metals, oils, greases, and soluble organic compounds (Gregory et al., 2011). Initially, the shale gas industry disposed of impaired water in class-II injection wells. However, this practice is both costly and may also have resulted in undesirable, injection-induced seismic activity in certain areas of the U.S. (Folger and Tiemann, 2014).

Rather than disposing of the impaired water, operators nowadays are increasingly reusing the recovered water to reduce the freshwater demand for fracturing new shale gas wells (Mauter et al., 2013). Companies are proactively blending freshwater and impaired water, thereby reducing the water volumes that have to be sent to disposal wells (Mauter et al., 2014). The objective of this work is to explore whether and how impaired water disposal expenses can be lowered, while simultaneously taking advantage of any available flexibility in fracturing operations. One option that appears intriguing are so-called *return-to-pad operations* (Drouven and Grossmann, 2016), i.e., to intentionally delay individual fracturing jobs on a multi-well pad until an increasing amount of impaired water can be reused, rather than sent to disposal. In essence, our goal is to evaluate whether water operations should have a bigger impact on the fracturing schedule, i.e., whether water operations should possibly even “drive” the fracturing schedule.

Fig. 1 highlights the scope of this work and demonstrates selected degrees of freedom within water management operations in active shale gas development areas. At the center of the illustration lies a candidate well pad, which is a location where an upstream operator intends to drill, fracture and complete a set of shale gas wells in the foreseeable future. We assume that the timing of individual fracturing jobs is flexible and has not been determined yet. Hence, the fracturing schedule is an important degree of freedom. In order to fracture any of the selected wells on a particular candidate pad, significant volumes of water need to be acquired.

Clearly, one possible option is to use freshwater for fracturing purposes. For this reason producers will typically scout out active development areas, and locate as many freshwater sources within the vicinity of a candidate pad as possible. Water availability forecasts, maximum withdrawal rates and acquisition expenses are all pre-determined for these

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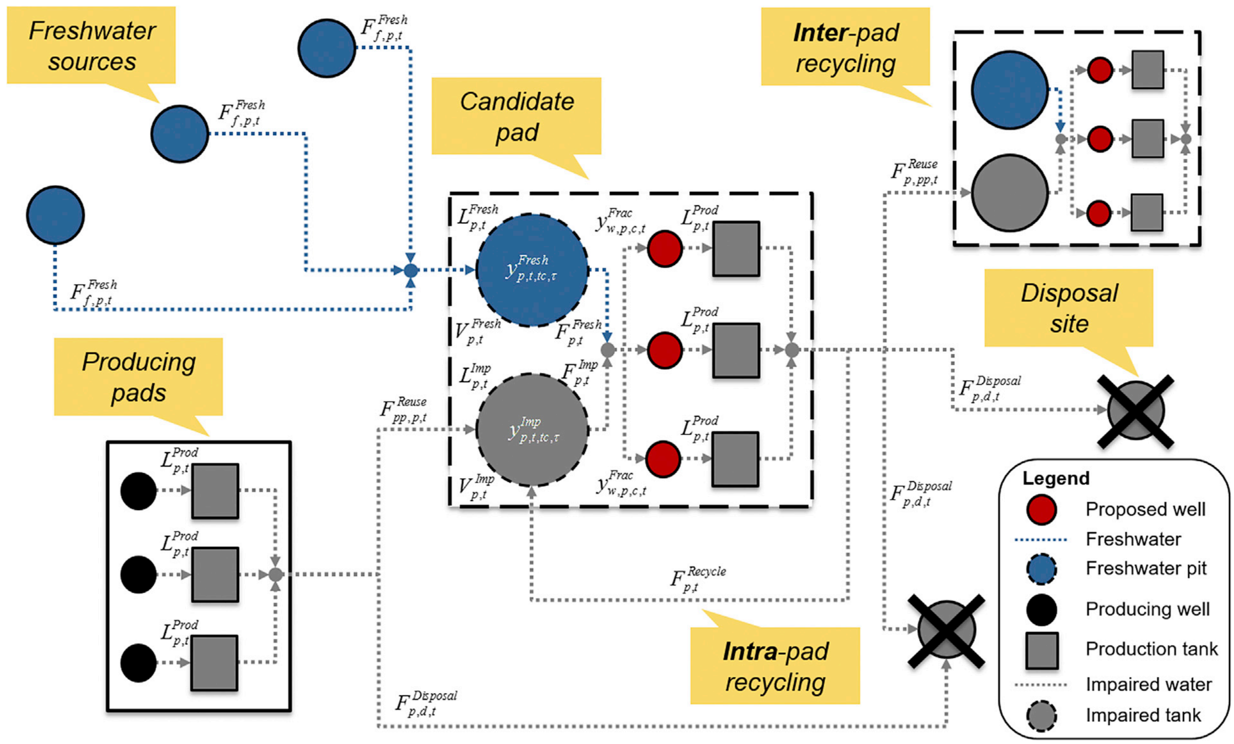

Fig. 1. Superstructure illustration of water management operations in shale gas development.

freshwater sources. Hence, the producer only needs to decide how much water to transport from each of these available sources to a given candidate pad at any given point in time. Companies may choose to either truck freshwater on-site (typically from rivers or lakes), or use temporary water lines to pipe water to the pad (typically from nearby creeks). Generally, it is preferable to pipe water since it is much more cost-effective than trucking as shown by Yang et al. (2014). If freshwater is used to stimulate selected wells, then sufficient on-site freshwater storage capacity needs to be provided. This storage capacity is typically realized by either constructing a freshwater pit or installing temporary above-ground storage tanks (so-called *ASTs* for short). Generally, the operator can decide which storage option to select and how much storage capacity to provide for development operations.

As an alternative to freshwater, the producer may choose to use impaired water to fracture wells on a candidate pad. Impaired water can be obtained from so-called *producing pads* surrounding the active development area. A producing pad is a location where completed shale wells are actively producing natural gas, and impaired water. The impaired water is typically fed into limited capacity production tanks. The water stored in these tanks can either be sent to disposal or hauled to a candidate pad for reuse. How much water is sent to disposal, and how much is recycled at any point in time, is an additional degree of freedom. If a company decides to haul impaired water onto a candidate pad, then sufficient impaired water storage capacity needs to be provided. Impaired water may not be stored in freshwater pits or freshwater ASTs, but only in dedicated, temporarily installed impaired water ASTs. Assuming that both freshwater and impaired water are available at a candidate pad, the operator needs to determine how much of each to use for every individual fracturing job. This so-called *blending ratio* is one of the key degrees of freedom in impaired water management.

Once the prospective wells on a candidate well pad have been fractured, completed and turned in-line, they too will produce flowback water, and eventually, produced water. As on producing pads, these wells will feed their impaired water into production tanks, which – due to their limited capacity – need to be emptied regularly. Any producer has three alternative options for processing these volumes: (a) the water can be reused for an upcoming fracturing job on a neighboring candidate pad (*inter-pad recycling*), (b) the water can be sent to attainable disposal sites, or (c) the recovered water can be recycled on-site by feeding it back into an available impaired water storage tank (*intra-pad recycling*). Since all three options are generally feasible and not exclusive to each other, the operator needs to evaluate carefully how to schedule impaired water deliveries over time. Hence, given the operational setup described above, the goal is to identify the most cost-effective fracturing schedule and water management strategy simultaneously.

2. General problem statement

The problem addressed in this paper can be stated as follows. Within an active shale gas development area as shown in Fig. 1, an upstream operator wishes to fracture and complete a set of previously drilled shale gas wells. Such assets are also referred to as drilled but uncompleted wells or "DUCs" (EIA 2016). Type curve production forecasts, individual well lateral lengths, the water demand for fracturing, estimated completions durations and costs are pre-determined for every well. In addition, a set of attainable water sources can be used to service all considered candidate pads. For every water source the water availability as well as water transfer costs – accounting for trucking and piping options if available – are known.

Given the information described above, the problem is to determine: (a) the optimal fracturing schedule, (b) the optimal water supply sourcing and distribution strategy, and (c) optimal on-site water storage solutions including their capacities. The fracturing schedule specifies when each targeted well is fractured. The water management strategy determines the optimal water blending ratio for each well, i.e., how much freshwater is used to fracture a well compared to how much impaired water is used for the fracturing job. Moreover, the water management strategy specifies how much of the recovered impaired water is reused on-site, off-site or sent to disposal, and when. A crucial component of the selected water management strategy involves the selection of necessary freshwater and impaired water storage equipment. This selection includes the determination of preferred freshwater pit impoundment