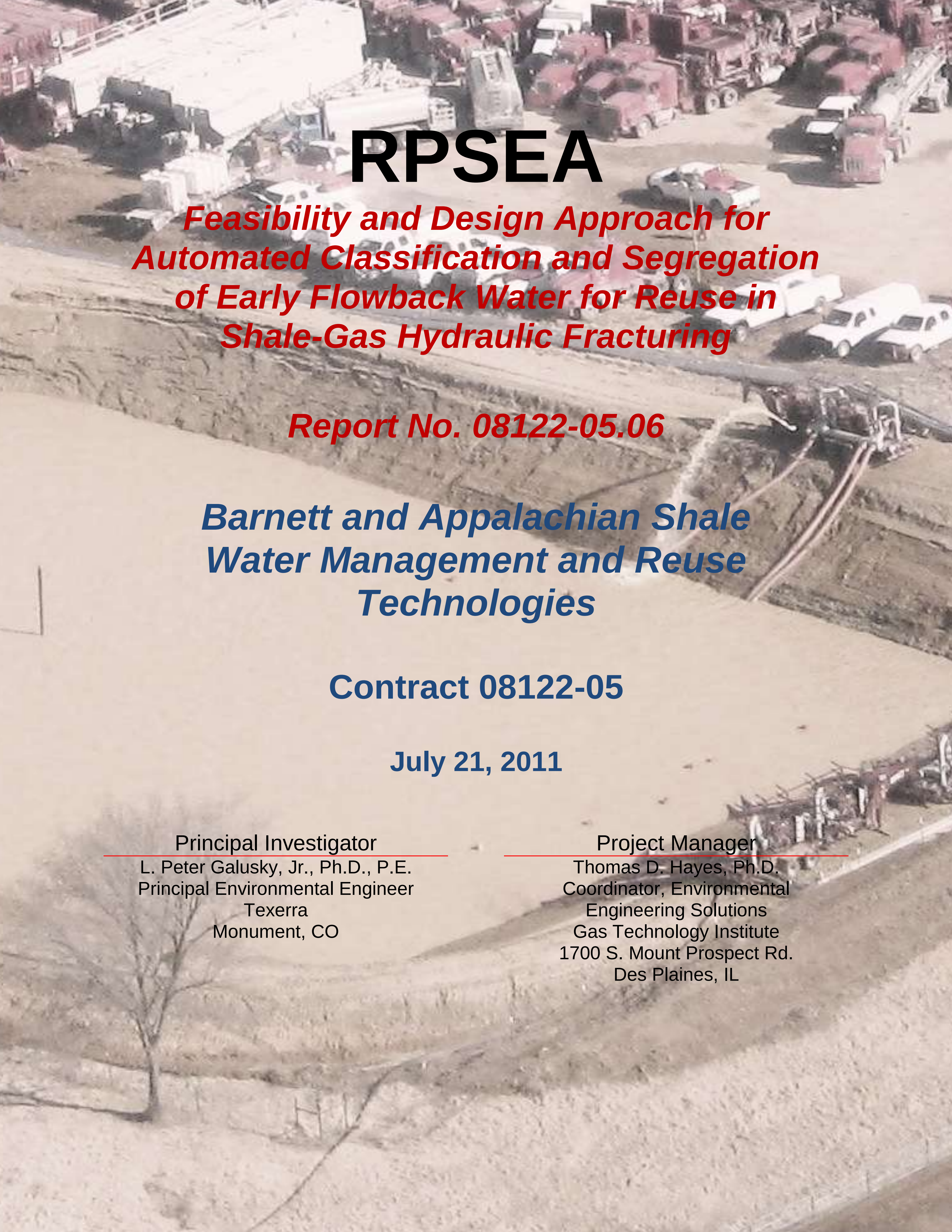

RPSEA

Feasibility and Design Approach for Automated Classification and Segregation of Early Flowback Water for Reuse in Shale-Gas Hydraulic Fracturing

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Abstract

Large volumes of water (1-6 million gallons containing chemical additives, friction reducer and sand propant) are required for the completion of a typical shale gas well. Approximately 10 to 50 percent of this “fracwater” is produced as “flowback” water during the initial weeks of fluid production. The rate of flowback water production is usually highest in the first day and rapidly decreases with time to a very low flow within a month to several weeks of a well completion. Shale gas flowback water contains various inorganic salts that increase in concentration over time from the onset of flowback production until flowback diminishes.

An effort was made to characterize flowback waters from a limited number of shale gas well completion locations in the Barnett Shale. This characterization included measurements of cumulative volume, electrical conductivity and selected constituents of interest (inorganic salts) in flowback water samples taken over time from each location. This report summarizes these data and examines the feasibility of using real-time electrical conductivity measurements to identify and segregate early flowback waters containing relatively low concentrations of total dissolved solids (TDS). Such low TDS early flowback water has potential for reuse in well drilling and completion with only relatively minor pre-treatment for its intended purposes. This could serve to significantly reduce the quantity of fresh water that is presently used to drill and complete shale gas wells and to reduce the total quantity flowback water that needs to be disposed. This could lead to significant logistical efficiencies and economic savings with respect to water acquisition, handling, trucking and disposal.

Introduction

Large volumes of water (typically 1-6 million gallons per well, along with friction reducers, chemicals and sand propant) must be injected into the producing formation of most shale gas plays in the United States to achieve effective hydraulic fracturing in order to stimulate and sustain natural gas production. Variable amounts (ranging from 10 to 50 percent) of this “fracwater” are returned as “flowback” during the first several weeks following well completion. Flowback waters are collected under pressure at the wellhead and must either reused or disposed.

The electrical conductivity (an indicator of salt content) of flowback water generally increases over time from the onset to the end of the flowback. Conversely, the daily rate of flowback typically declines rapidly from an initially high rate of perhaps thousands of barrels per day to less than a hundred barrels per day over this period. The largest fraction of total flowback is thus collected early on when salt concentrations are relatively low. The identification, segregation and collection of early flowback may therefore represent an opportunity to obtain moderately concentrated (with respect to total dissolved solids or salts) water requiring minimal processing prior to blending with other water streams for reuse in subsequent frac jobs.

The possibility of achieving significant water conservation through early flowback water capture and reuse was discussed by the Barnett Shale Water Conservation and Management Committee (BSWCMC), a group of shale gas developer companies within the Barnett Shale Play whose aim is to identify solutions and best practices in water management. Within the committee, the concept was thought to have merit as an approach for future assessment.

If, for example, it was important that chloride levels of 10,000 mg/l or 16,500 mg/l of total dissolved solids (TDS) were the desired specifications for the final blend of influent water used in future frac jobs (with the aim of avoiding adverse ionic strength effects to friction reducer performance), an early flowback water volume with an average concentration of over 60,000 could be blended with most types of surface waters at a 4:1 ratio (i.e. comprising a blend with 25% recycled flowback water content) and still meet the TDS spec for influent water quality. This, of course, is only an example reflecting industry thinking in 2007; over the past three years, a new class of friction reducers has been identified that perform well at twice the TDS concentrations.

The purpose of this project was to obtain flow and salt concentration data from representative fracturing operations in the Barnett Shale and to conduct an assessment of the feasibility and potential benefits of capturing early flowback water for reuse in future frac jobs. This report presents data from a limited number of locations and summarizes a general design approach for an automated system for classification and segregation of moderately concentrated flowback water streams from highly concentrated brines that are released following hydraulic fracturing performed for a shale gas well completion. A second report will be generated from this effort that will provide more detailed characterization of flowback water from locations in the Barnett Shale.

Scope and Objectives

Fracwater flowback volumes and field-measured parameters were obtained from multiple gas wells in the Barnett Shale of Texas over the period 2010 into 2011. These data were collected and analyzed with the following objectives:

1- To elucidate relationships between simple field-measured (or field measurable) inorganic parameters (chloride concentration, total dissolved solids, specific gravity and specific conductance) and flowback rates and cumulative volumes; and
2- To suggest a field measurement and monitoring protocol whereby flowback waters could be characterized for the purpose of classifying and segregating brines (i.e. early flowback water of low salt concentration from flowback and produced waters of higher salt concentrations), in real time, in order to facilitate the recycling and best management of these waters.

3- To describe a process flowsheet that could potentially be used to effectively segregate early flowback water of moderate TDS levels to improve reuse costs.

Methods

Flowback quantity data were measured in the field by gaging the daily accumulation of water in flowback tanks. Flowback quality parameters that were measured in the field included chloride concentration (using a field site glass refractometer) and specific gravity (using a field hydrometer). Waters were analyzed in the laboratory for specific conductance and total dissolved solids.

The graphs presented below present and summarize data for a single well that was selected among approximately a dozen sites as being most representative of them all. A subsequent report will present a wider analysis of inorganic and organic analytes among all of the sites considered together, focusing on their common, general attributes.

Results and Discussion

The daily course of flowback for the selected site is given in Figure 1. Despite the significant variation in flowback rate from day to day there is a clear pattern of exponential decline from the initial high rate. (Note that the days with zero flowback are indicative of operational vagaries, with the well being shut in for several days around day 60).

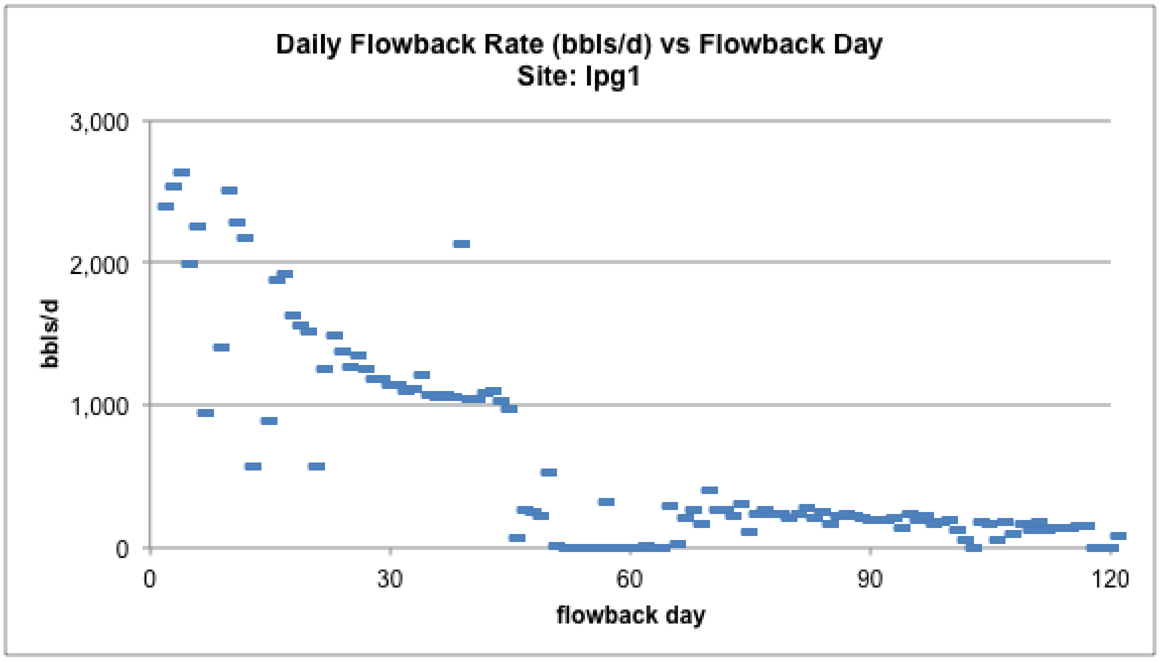

Figure 1 – Daily course of flowback water quantity over time.

The cumulative flowback over time and the fraction of fracwater recovered as flowback are given in Figures 2 and 3. The cumulative fraction of fracwater recovered (as flowback) in this well was approximately 33% of the total volume of fracwater used to frac the well. This is somewhat higher than the 20 to 25% fraction of fracwater that is normally recovered from most Barnett wells. However, the fact that fracwater production continues to decline after day 60 (Figure 1) indicates it is unlikely that an underlying water bearing formation has been penetrated during well fracturing.

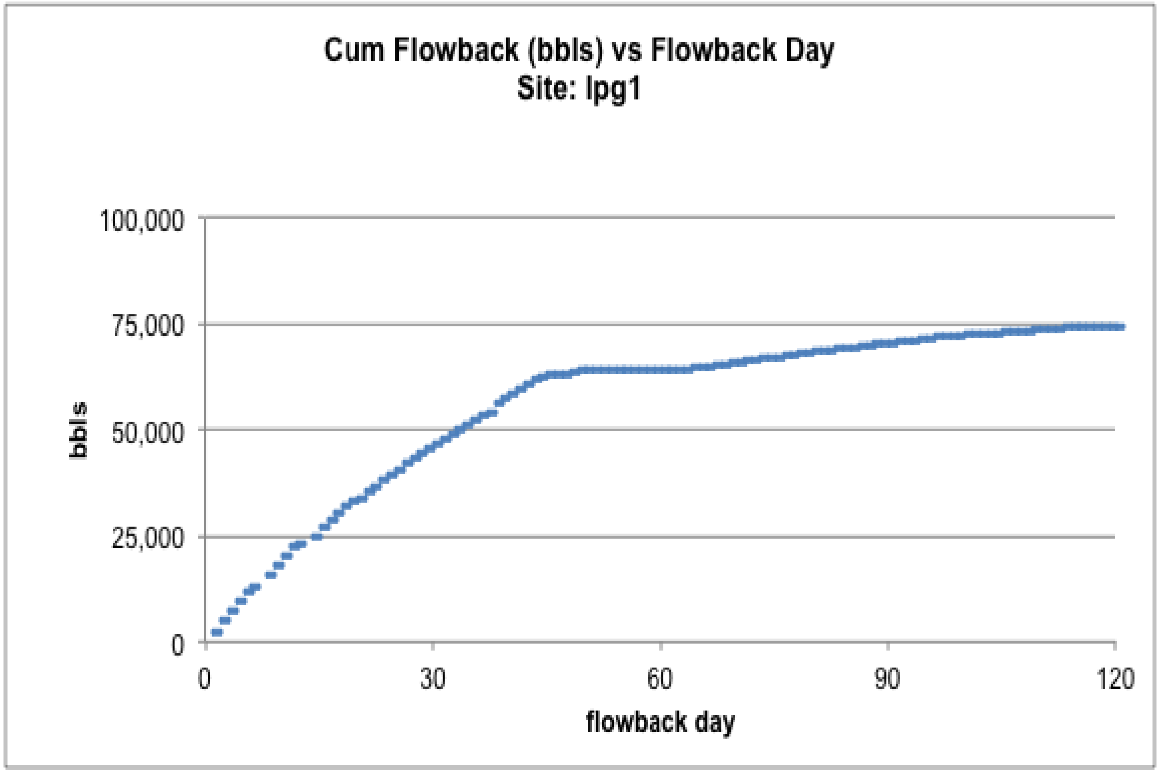

Figure 2 – Cumulative flowback volume recovered from the onset of flowback.

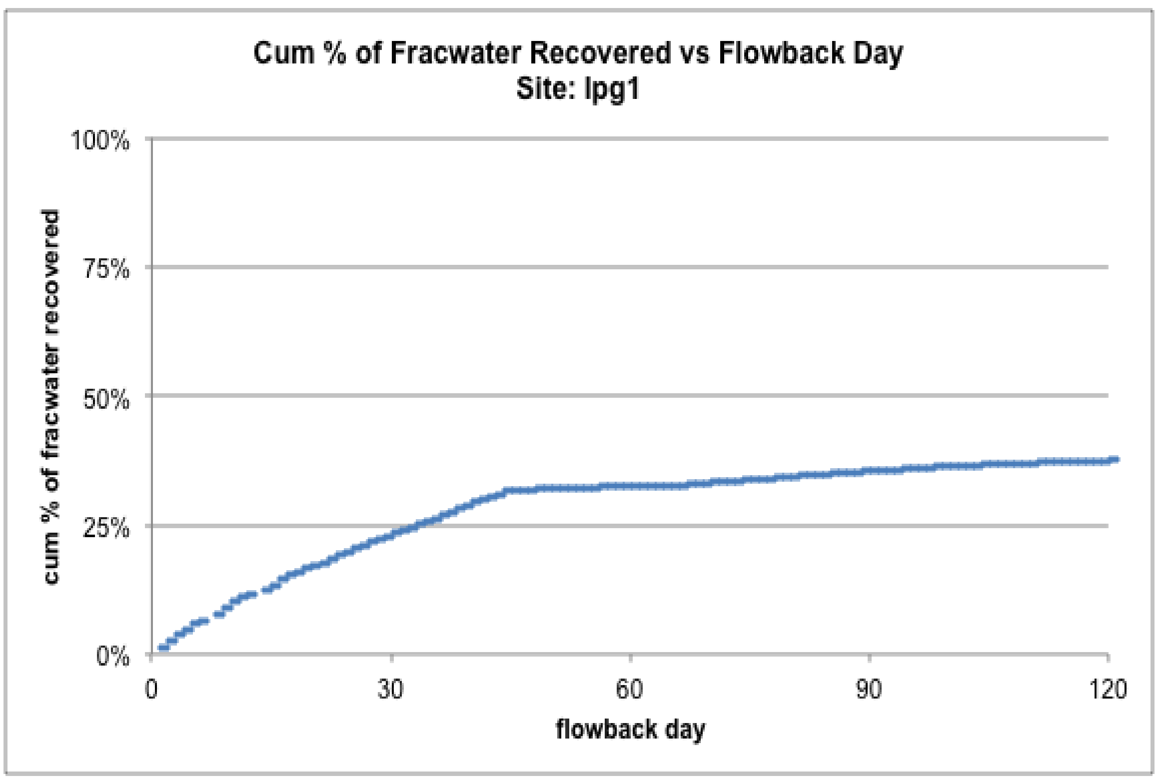

Figure 3 – Cumulative fraction of fracwater recovered as flowback over time.

The field-measured chloride concentration of fracwater over time indicates a rapidly rising initial trend that asymptotes according to a logarithmic decline curve (Figure 4). This indicates that fracwater that has penetrated further into the shale formation and has thus been resident there longer has entrained more soluble salts than the fracwater that was "last in and first out". The fact that the chloride concentration levels off over time suggests that the soluble constituents in the fracwater come into equilibrium with the formation over time, taking longer than approximately 45 days to do so. The converse is also presumably true, suggesting that equilibrium water quality models would not be accurate in characterizing early flowback. This is important because most of the flowback recovery happens before such equilibrium is approached (before day 45). Moreover, if the lion's share of flowback water does not come into equilibrium with the most soluble species (chloride) it certainly does not with species that are far less soluble.

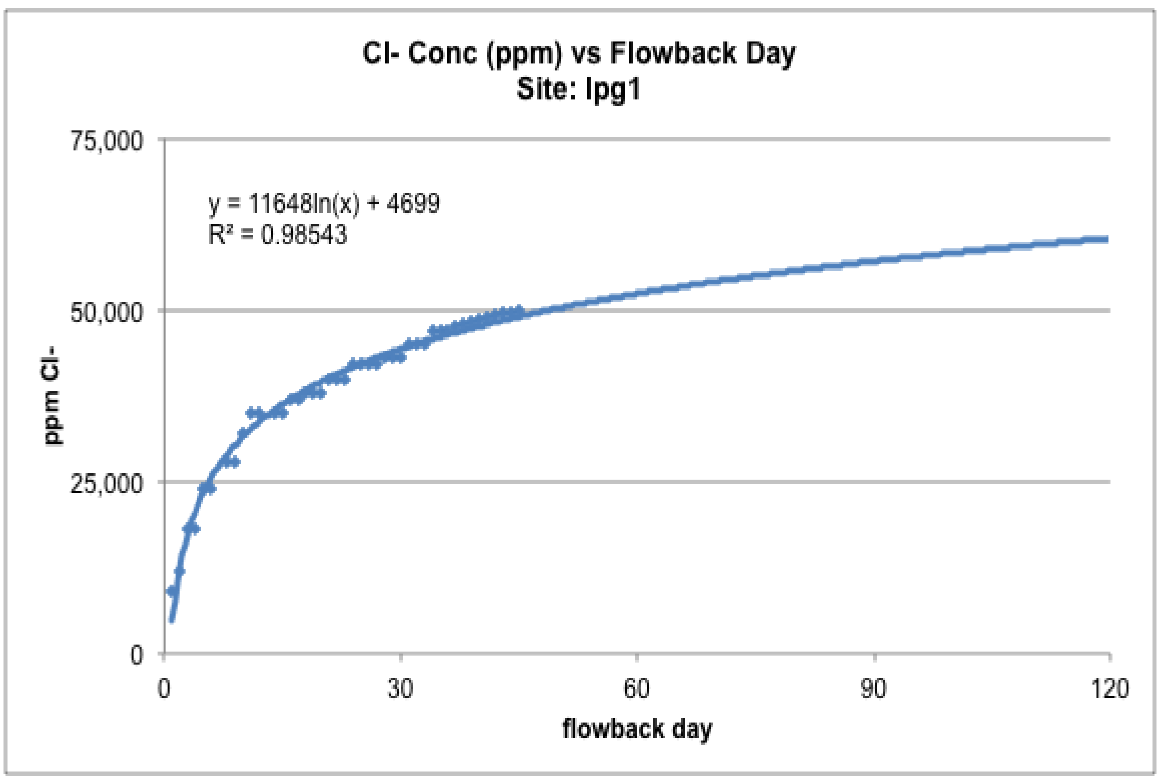

Figure 4 – Field-measured chloride concentration of recovered flowback water over time.

The cumulative mass of chloride recovered (Figure 5) in flowback water is a function of both the total flowback volume (Figure 2) recovered as well as the flowback water chloride concentration (Figure 4). The total mass of recovered dissolved solids (TDS) is a parallel, linear function of recovered chlorides (Figures 6 and 7). Figure 7 thus indicates that approximately 2.5 million pounds (1,250 U.S. tons) of total dissolved solids have been recovered from this well over the course of three months. Given that the initial chloride concentration of the fracwater used to complete the well was less than 200 mg/kg it is clear that virtually all of this TDS mass is from the shale gas formation.

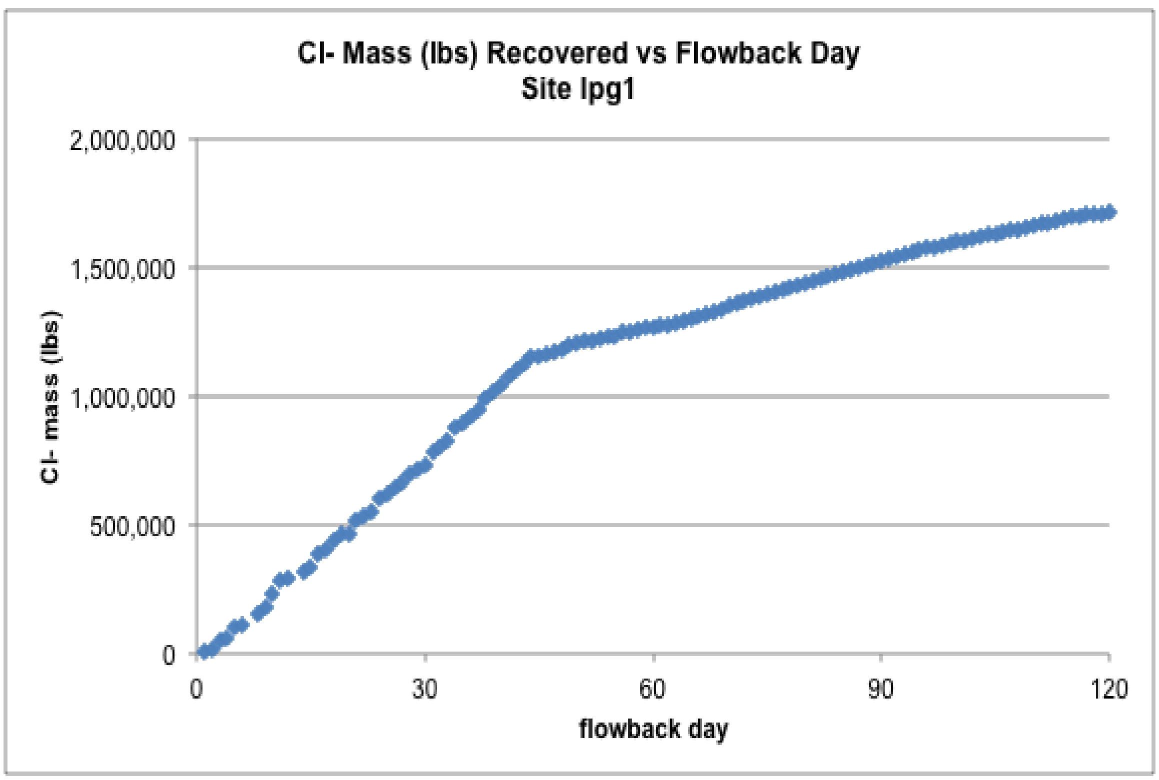

Figure 5 – Cumulative chloride mass recovered in flowback water over time.

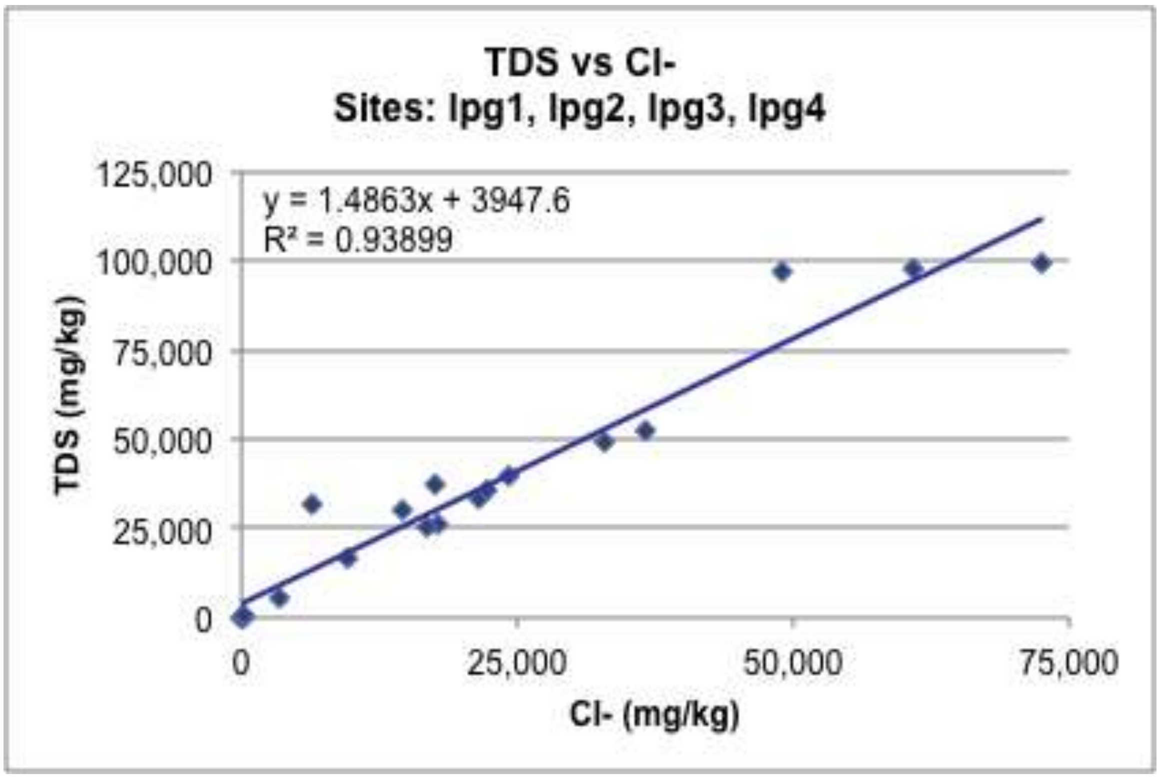

Figure 6 – Relationship between laboratory measured total dissolved solids and chloride concentrations for four producing shale gas wells.

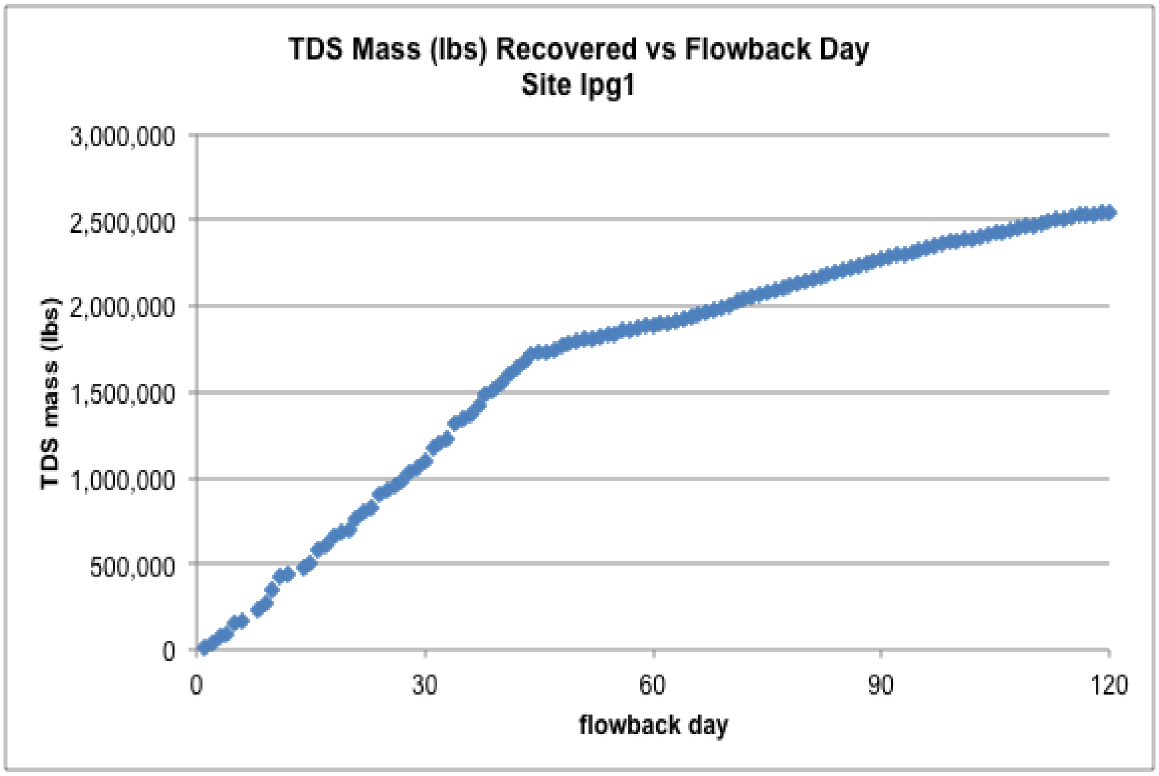

Figure 7 – Estimated mass of total dissolved solids (TDS) recovered in flowback over time, calculated according to the linear, regression relationship given in Figure 6.

Summary

These data, taken together, indicate that Barnett shale gas flowback waters exhibit the following general trends and attributes:

1. Flowback begins at an initially high rate (greater than 2,000 bbls/d for the well presented here) and rapidly declines toward zero after about two months.
2. Most of the fracwater that is recovered is captured within the first thirty to forty-five days of the onset of flowback.
3. Dissolved inorganic constituents (as Cl- and TDS) increase logarithmically and asymptotically over time, indicating that early flowback waters (which represent most of the fracwater that is recovered) are not in chemical equilibrium with the shale formation.

4. The total cumulative mass of total dissolved solids (TDS) recovered are reflective of both the flowback water volume and its TDS concentration. Thus, although most flowback water is recovered early on, the relatively higher TDS concentration of later flowback causes the cumulative TDS recovery to continue to rise disproportionately to flowback water recovery; (compare Figure 7 to Figure 1).

Potential Application

As expected, a high correlation was observed between TDS and specific conductance. Using measurements on actual flowback waters from four well completion locations, a plot of this relationship is shown in Figure 8, where the correlation coefficient (as R^2) is greater than 0.97

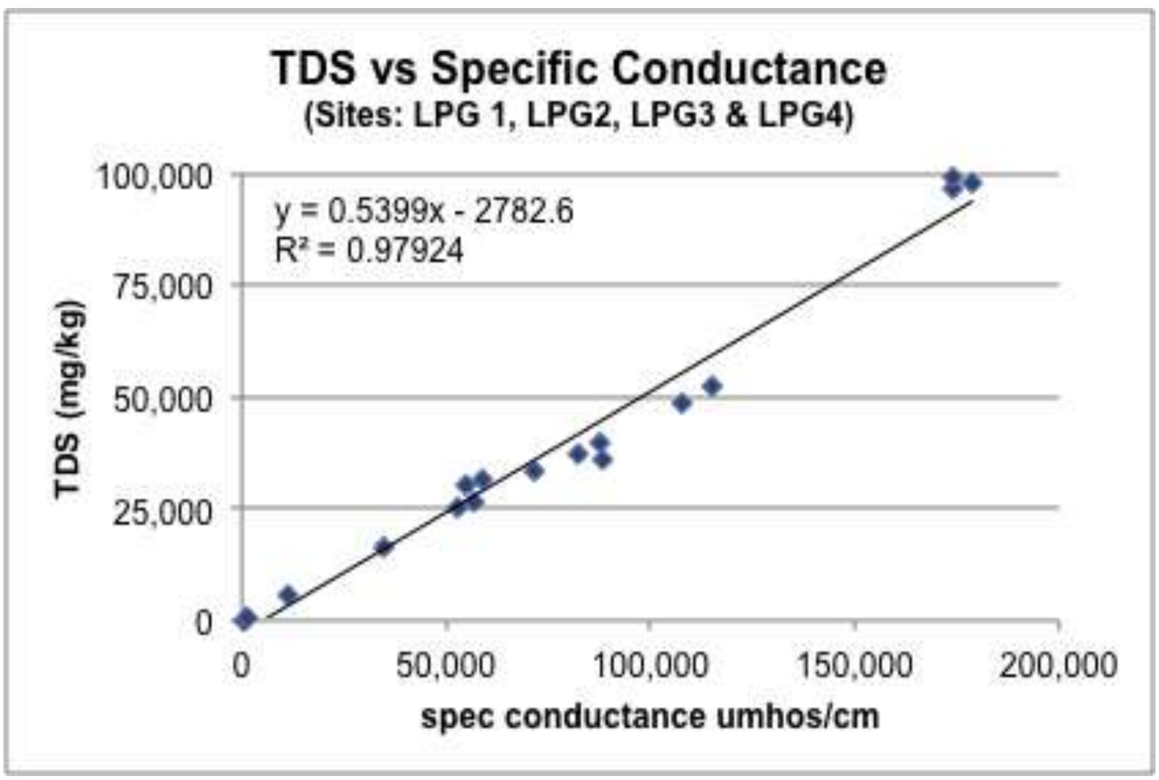

Figure 8 – Relationship between total dissolved solids (TDS) and specific conductance.

Specific conductance can be readily measured, calibrated and automated. The close correlation between TDS and conductance indicates that operators should be able to measure, separate and segregate flowback waters in real time using in-line conductivity transducers more or less according to the scheme presented below in Figure 9. In simple terms, flowback water would be analyzed in real time using an electronic, recording electrical conductivity sensor. This would be coupled to an electronically operated valve that would shunt water to different storage facilities according to programmed levels of measured conductivity. The numeric criteria for determining number and levels of measured conductivity would be determined based upon operational needs and logistical constraints.

In the example shown in Figure 9, the lowest TDS waters would presumably be the most valuable to recover and recycle since these pose the least restraints and requirements with respect to handling, treatment and re-use. Yet, given the rapid rise in TDS (shown as chlorides in Figure 4) it may not be realistic to capture nearly fresh (less than 3,000 TDS mg/kg) from Barnett shale gas flowback waters. However, if more realistic thresholds are set (say 10,000 mg/kg for low TDS waters and 25,000 mg/kg for high TDS waters) then such a system may afford realistic potential to recover and recycle early flowback waters and thus significantly reduce the total quantity of “new” water used to fracture subsequent wells.

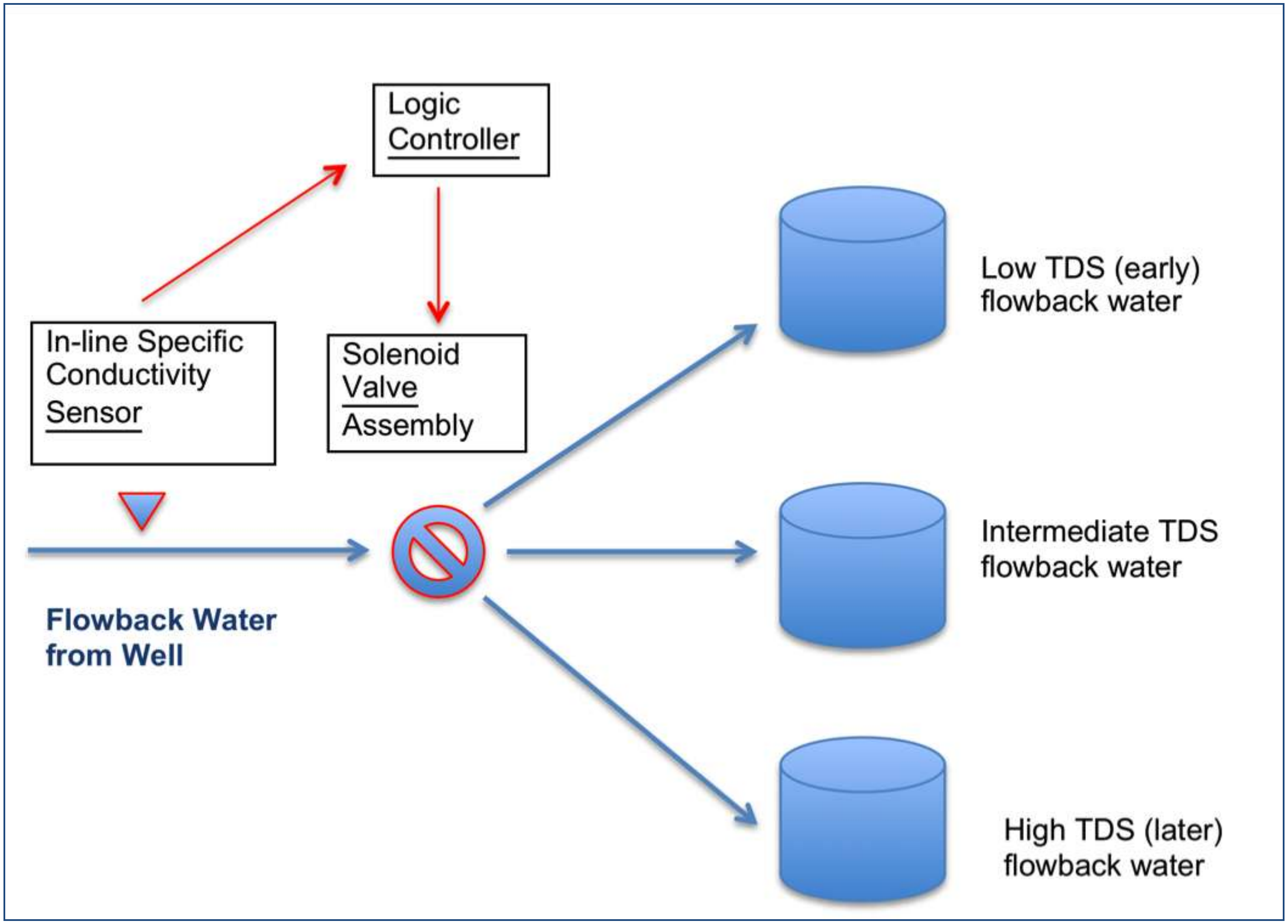

Figure 9 – Simple, schematic layout of a hypothetical flowback measurement, separation and segregation system.

Conclusions

Barnett Shale flowback waters generally exhibit an exponential decline in flowback quantity over time (Figure 1) and a logarithmic increase in chloride (and by correlation, total dissolved solids, or TDS) as flowback diminishes (Figure 4). Approximately twenty to thirty per cent of the fracwater used to fracture the gas-bearing shale is recovered as "flowback" during the first thirty to ninety days of fluids production (Figure 3). The recovered mass of total dissolved solids (TDS) is reflective of both the flowback rate and the TDS concentration. Although the rate of flowback declines rapidly over time the TDS concentration continues to rise. TDS recovery therefore continues to rise even as flowback tapers off; (compare Figure 7 to Figure 1). A high correlation (R^2 = 0.97) was observed between TDS and specific conductance (Figure 8). Specific conductance can be readily measured, calibrated and automated.

The close correlation between TDS and specific conductance indicates that operators should be able to measure, separate and segregate flowback waters in real time using an automated, electronically mediated system. In simple terms, and in-line conductivity transducer (sensor) would measure the specific conductance of flowback water from the well. The electronic signal from this sensor would be interpreted by a logic controller (computer). The controller would operate solenoid valves to direct and segregate water into separate tankage based on its electrical conductivity. The cut points for the segregation of flowback water could be readily adjusted according to the performance of the well and to the needs and capabilities for handling flowback waters of varying quality parameters (using specific conductivity as the primary surrogate measure).

The segregation of shale-gas flowback waters according to specific conductance implies significant potential for recycling flowback water according to its re-use potential for various purposes in well drilling and completion. This could serve to significantly reduce the quantity of fresh water that is presently used to drill and complete shale gas wells and to reduce the quantity of high TDS flowback water that needs to be disposed.

This could lead to significant logistical efficiencies and economic savings with respect to water acquisition, handling, trucking and disposal.

Acknowledgements

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Laboratory analyses were performed by Test America, Inc. TestAmerica Pittsburgh 301 Alpha Drive RIDC Park Pittsburgh, PA 15238. Tel: (412) 963-7058 Fax: (412) 963-2468 www.testamericainc.com .