Oil & Natural Gas Technology

DOE Award No.: DE-FE0000797

Quarterly Report

Comprehensive Lifecycle Planning And Management System For Addressing Water Issues Associated With Shale Gas Development In New York, Pennsylvania, And West Virginia

Submitted by:
ALL Consulting, LLC
1718 S, Cheyenne Ave.
Tulsa, OK 74119

Principal Author: J. Daniel Arthur, P.E., SPEC

Prepared for:
United States Department of Energy
National Energy Technology Laboratory

October 27, 2010

Office of Fossil Energy

Acknowledgment:
This material is based upon work supported by the Department of Energy under Award Number DE-FE0000797.

Quarterly Progress Report

Title: **Comprehensive Lifecycle Planning and Management System for Addressing Water Issues Associated With Shale Gas Development in New York, Pennsylvania, and West Virginia**

Recipient: Arthur, Langhus, Layne, LLC, dba ALL Consulting
1718 S. Cheyenne
Tulsa, OK 74019

Principal Investigator: J. Daniel Arthur, P.E., SPEC, darthur@ALL-LLC.com, 918-382-7581

Award No.: DE-FE0000797

Period: July 1, 2010 –September 30, 2010

Executive Summary

The objective of this project is to develop a modeling system to allow operators and regulators to plan all aspects of water management activities associated with shale gas development in the target project area of New York, Pennsylvania, and West Virginia ("target area"), including water supply, transport, storage, use, recycling, and disposal and which can be used for planning, managing, forecasting, permit tracking, and compliance monitoring.

The proposed project is a breakthrough approach to represent the entire shale gas water lifecycle in one comprehensive system with the capability to analyze impacts and options for operational efficiency and regulatory tracking and compliance, and to plan for future water use and disposition. It will address all of the major water-related issues of concern associated with shale gas development in the target area, including water withdrawal, transport, storage, use, treatment, recycling, and disposal. It will analyze the costs, water use, and wastes associated with the available options, and incorporate constraints presented by permit requirements, agreements, local and state regulations, equipment and material availability, etc.

By using the system to examine the water lifecycle from withdrawals through disposal, users will be able to perform scenario analysis to answer "what if" questions for various situations. The system will include regulatory requirements of the appropriate state and regional agencies and facilitate reporting and permit applications and tracking. These features will allow operators to plan for more cost effective resource production. Regulators will be able to analyze impacts of development over an entire area. Regulators can then make informed decisions about the protections and practices that should be required as development proceeds.

To ensure the success of this project, it has been segmented into nine tasks conducted in three phases over a three year period. The tasks will be overseen by a Project Advisory Council (PAC) made up of stakeholders including state and federal agency representatives and industry representatives. ALL Consulting will make the catalog and decision tool available on the Internet for the final year of the project.

In this, the fourth quarter of the project, work progressed on schedule, and all project deliverables were submitted on time. No problems have been encountered to date. There one milestone scheduled for completion during this quarter and it was met as scheduled.

Results of Work During the Reporting Period

Approach

Task 1: Project Management Plan and Technology Status Assessment

Under this task, ALL Consulting completed and submitted the Project Management Plan (PMP) and the Technology Status Assessment (TSA) for this project. The PMP was submitted on October 6, 2008, and the TSA on November 13, 2009. The TSA was revised to incorporate NETL comments on December 2, 2009. Other project management activities planned for this task were also completed. All work is progressing according to schedule.

Task 2: Research Water Issues in the Target Area, Initial System Design, and Establish a Project Advisory Committee

ALL Consulting has completed initial identification of water issues in the Marcellus shale region. ALL is reviewing previous NETL reports and other available literature prior to arranging site visits to get more detailed information on the issues and water management needs. All work was completed according to schedule and the milestone associated with this task (Milestone No. 3, Complete Initial Issue Analysis) was completed on schedule. As part of this effort, ALL identified that the potential impact of water withdrawals on local and regional water resources is one of the most pressing issues facing both regulators and operators. As part of the process of documenting the withdrawal issues and the regulatory processes that must be followed in various jurisdictions, ALL prepared a technical paper that was peer reviewed by the Project Advisory Council (PAC).

The use of horizontal drilling and hydraulic fracturing has focused regulatory and NGO attention on issues surrounding the withdrawal of large volumes of water from sources sufficiently close to the gas exploration sites. While the water volumes needed to drill and stimulate shale gas wells are large, they generally represent a small percentage of the total water resource use in the shale gas basins. Estimates of peak drilling activity in New York, Pennsylvania, and West Virginia indicate that maximum water use in the Marcellus, at the peak of production for each state, assuming 5 million gallons of water per well, would be about 650 million barrels per year. This represents less than 0.8 percent of the 85 billion barrels per year used in the area overlying the Marcellus Shale in New York, Pennsylvania, and West Virginia.

By comparison, the volume required for shale gas is small in terms of the overall water availability in the area. To put shale gas water use in perspective, the consumptive use of fresh water for electrical generation in the Susquehanna River Basin alone is nearly 150 million gallons per day, while the projected total demand for peak Marcellus Shale activity in the same area is only 8.4 million gallons per day. One factor in shale gas water use is that operators need this water when drilling and hydraulic fracturing activities are occurring, requiring that the water be procured over a relatively short period of time, and these activities will occur year-round. Water withdrawals during periods of low stream flow could affect municipal water supplies and industries such as power generation, as well as recreation, and aquatic life. Thus, in order to have adequate water during periods of low streamflow or drought, operators may need to make withdrawals during periods of high stream flow and store the water for later use. Another consideration is that while the region may have abundant water supplies, any given well site may not be near a large stream or lake. To avoid adversely affecting a given water source, operators may need to consider withdrawals from multiple near-by sources or explore other options such as overland piping for more distant sources.

The regulatory framework for water withdrawals is complicated with a combination of states managing water within their state along with commissions (who have authority over entire river basins) that are looking at regional, interstate issues. This requires that water sourcing and use be viewed in the larger context of full lifecycle water management. Gas well operators new to the Marcellus region may find water management planning and permitting challenging because multiple approvals may be required, first by a river basin commission (if one is applicable to the location in question) then by a state agency. Once an operator becomes familiar with the process it should become relatively straightforward; however, the time required for the additional approvals must be factored into an operator's development schedule.

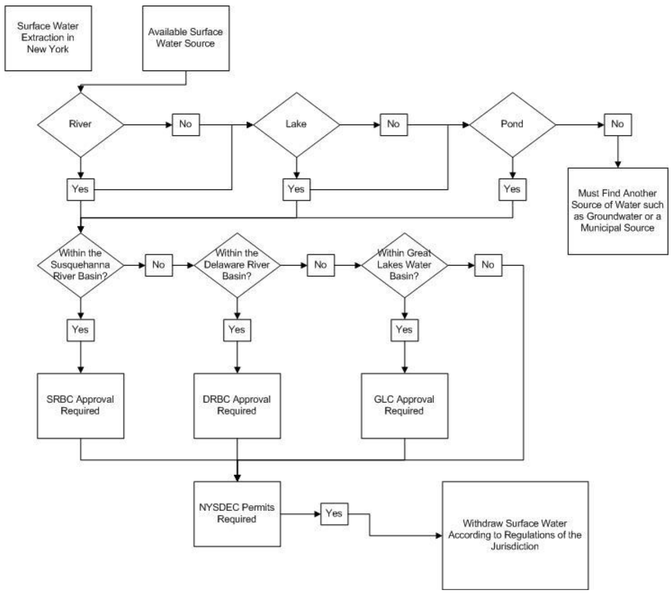
The primary considerations in evaluating water needs are the location of the need, the seasonal timing of the need, the location of available water, and the regulations governing water withdrawals. In general, the Marcellus region has ample precipitation, making water readily available, and withdrawals for shale gas development will be a small part of the overall regional water demand. However, it is important to understand that while shale gas withdrawals may be small on a regional level, withdrawals at any given point must be managed to ensure the ecological health of the water body and to provide for other industrial or recreational uses.

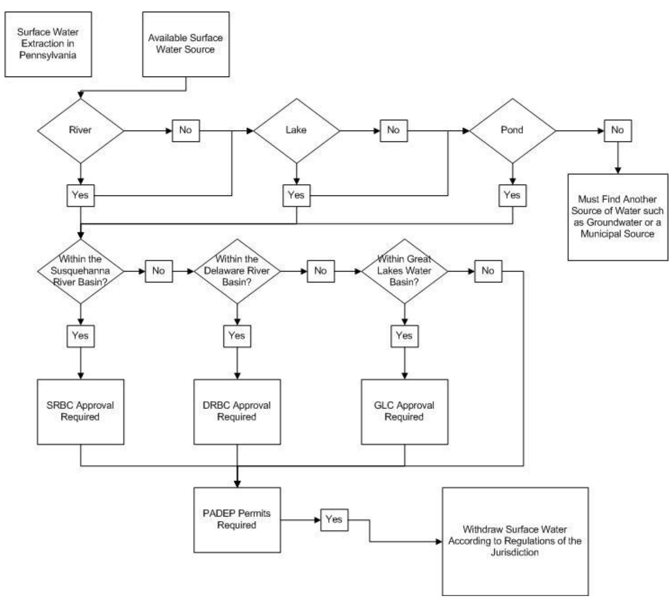
Operators will work to minimize water transportation costs by securing permitted withdrawals as close as possible to their planned development areas. Therefore, it is the groundwater and surface water sources most proximal to the well sites that will be most desirable. Operators may need to evaluate and secure several water sourcing take points in order to minimize environmental impacts while still meeting the water needs of their development plans.

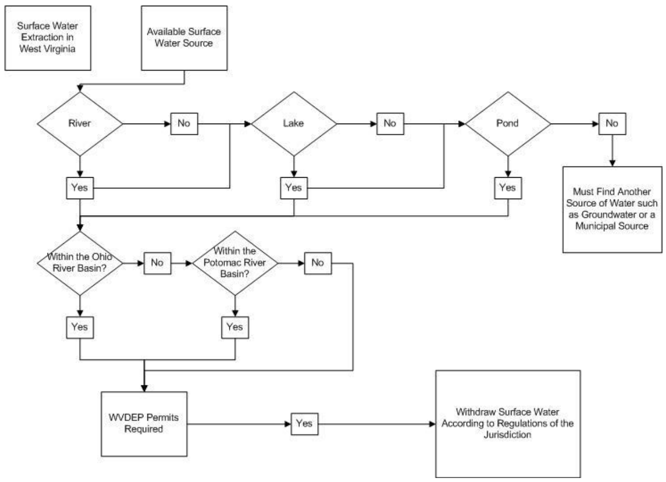
A major consideration in planning water withdrawals will be the regulations governing permitting procedures, especially the passby flow requirements and their impact on the seasonality of permittable withdrawals for the water bodies most proximal to development. This, combined with the fact that water withdrawal permitting is regulated by a matrix of state and interstate regulatory agencies, whose regulations reflect the needs of individual states or watersheds, requires that shale gas operators be keenly aware of the specific permitting requirements for each location.

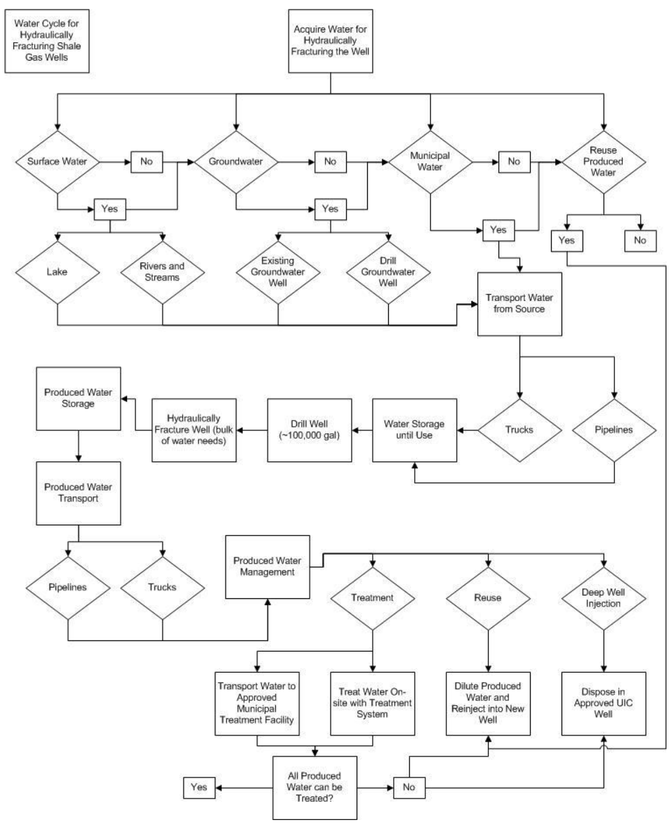
In addition to the paper on water resource issues, ALL also made a presentation at the AIPG meeting in May on the full suite of issues associated with the practice of hydraulic fracturing. The presentation summarized information on water issues throughout the shale gas drilling and production lifecycle including water sourcing, transportation, drilling and fracturing, and produced water management including treatment, re-use, and disposal. The presentation also addressed proposed federal regulation of hydraulic fracturing.

As issues have been identified and information about water management requirements has been gathered, ALL has begun work on the initial system design. Work to date consists of flow charts that follow the water withdrawal process in each of the states and other applicable regulatory jurisdictions in the target area. Flow charts were developed for each state, incorporating the River Basin Commission requirements as well as the state regulatory requirements. Once the flow diagrams for each individual state were constructed, an overall depiction of the process for anywhere in the target area was created. It is anticipated that these flow diagrams will serve as the basic framework for the logic flow of the withdrawal module of the model. ALL is following a similar process for creating the logic flow of the remaining phases of the lifecycle of water management issues. The flow charts developed to date are shown below.









Information gathered under Task 3 has also been incorporated into the initial system design. The initial system design is described in detail in a topical report submitted separately.

A key element of water management that appears to be gaining favor with regulators, operators, and the public is the re-use of the initial volumes of produced water, sometimes referred to as flowback, in subsequent hydraulic fracture treatments. To incorporate this aspect of produced water re-use, ALL has developed a simple mixing model that will allow users to evaluate the TDS concentration that would result from mixing a certain volume of fresh water with a certain volume of produced water. ALL expects to incorporate this mixing model into the larger Life-cycle Model to allow users to evaluate the volume of produced water that can be used to create a fracture fluid with a specified TDS level. Consequently, both operators and regulators can evaluate the impact that various re-use scenarios will have on the volume of water withdrawals that will be needed for a project, a region, or a state. Regulators can use this information to evaluate cumulative withdrawal impacts and operators can use it to evaluate the potential for reduced withdrawals, transportation-related costs and impacts, and disposal requirements.

In addition, ALL has established the PAC to consist of the project partners, New York State Energy Research and Development Authority (NYSERDA), the Susquehanna River Basin Commission (SRBC), and the Delaware River Basin Commission (DRBC). The PAC has been instrumental in gathering information and identifying issues to be analyzed. The PAC was also enlisted to review the technical paper that was prepared. Other regulatory agencies such as the New York Department of Environmental Conservation, the Pennsylvania Department of Environmental Protection, and the West Virginia Department of Environmental Protection, Office of Oil and Gas (WV OOG) as well as several shale gas operators have expressed a willingness to participate in the PAC. New members will be added to the PAC as the project progresses and needs for guidance and review are identified.

Task 3: Data Gathering and Field Site Assessments

ALL Consulting has begun to gather data on water management options and requirements in the Marcellus shale region. ALL has talked with operators about the water management issues and the approaches that operators use, as well as some of the decision points that accompany these different approaches. As part of its information gathering process, ALL has identified the re-use of produced water for subsequent fracturing jobs as an emerging practice that can affect the entire water management lifecycle. By re-using produced water, operators reduce the volume of fresh water that must be obtained and transported. This reduces potential withdrawal impacts to surface water, reduces truck traffic and the associated impacts to traffic congestion, dust, emissions, and roads. Re-use also reduces the operators' costs for obtaining the water and transporting it.

In addition to reducing water sourcing issues, re-use also addresses a number of issues associated with produced water management. By re-using the water, operators have less, or no, water to dispose of through injection, commercial plants or other means. Thus, re-use alleviates concerns with impacts to streams that receive the effluent from treatment plants and reduces operator costs for transporting produced water, Class II injection, and for potentially treating the water to reduce the volume that must be injected.

As more experience has been gained, operators and service companies are finding that higher TDS fracture fluids can be used, which allows operators to mix high TDS produced water with fresh water to create blended water that can still be used in fracture fluid. By incorporating a simple mixing model into the Lifecycle model, ALL hopes to encourage expanded use of this practice by allowing operators to evaluate the amount of produced water that can be re-used, and the resulting reductions in sourcing, transportation, treatment, and disposal costs. In addition, this will allow regulators to quickly evaluate the impact of re-use on local, regional, and statewide shale gas water demands.

ALL has completed site visits with NYSERDA, SRBC, DRBC, and shale gas well-sites to gather information on shale gas water issues and management approaches. Commercial water disposal facilities in the Marcellus are limited. These facilities rely on dilution of the produced water prior to discharge to surface water bodies. While other potential treatment technologies for shale gas produced water exist, there is limited experience actually treating shale gas water that limited experience exists almost completely in shale basins other than the Marcellus. For information on other water treatment facilities, ALL has incorporated information from another DOE project. As part of that other project, visits to water treatment facilities have been conducted at well sites in other shale plays, and information from these visits has been incorporated into the initial plans for the model design. All work is progressing according to schedule.

Task 4: Technology Transfer

ALL Consulting established a project web-site that is structured to provide updates to project team members, the PAC, and others. The project website can be accessed at http://www.all-llc.com/projects/shale_water_lifecycle/ . In addition to a project overview and basic information about the project, the site has a page for the issues identified and page with a list of project-related reports, papers, and presentations. ALL will continue to update this site throughout the project and will use the site to distribute information to the PAC and solicit feedback. The site can also be accessed by the NETL project officer at any time as a way to follow the latest project activities and results.

ALL has made several project presentations and completed a paper, peer-reviewed by our project partners, that summarizes our findings regarding the water sourcing issues in the Marcellus Shale states of New York, Pennsylvania, and West Virginia. Project presentations have been made at the 2009 GWPC Water and Energy Symposium and the IOGA NY 2009 Annual Meeting. The paper, entitled *Water Resources and Use for Hydraulic Fracturing in the Marcellus Shale Region* was sent to NETL on May 14, 2010, and was posted on the project web-site as well as the ALL Consulting website. In addition, the paper was presented at the AIPG Marcellus Shale Hydraulic Fracturing Conference in Pittsburgh on May 5, 2010, and it was also presented at the International Environmental Petroleum and Biofuels Conference that was held in San Antonio, TX on August 31- September 2, 2010.

ALL also worked with NETL site-support contractors to prepare an article about the project that was published in NETL's *E&P Focus* newsletter.

Results

The analysis for work completed in this quarter addresses the management of water used throughout each stage of development in the Marcellus Shale Play in the states of New York, Pennsylvania, and West Virginia, hereinafter referred to known as the "target area".

Water management involves addressing the entire lifecycle of water used by operators including: water requirements for development; water sourcing; transportation of fresh, recyclable and disposal water; water storage; and disposal, treatment or reuse of produced water. The different stages of shale gas development present unique challenges for both operators and regulators.

Water is the key to releasing the vast quantities of natural gas trapped in the Marcellus Shale. Water is used for shale gas development to both drill and stimulate a formation. Drilling a well involves combining water with additives to cool and lubricate the drill bit while also moving drill cuttings to the surface. Horizontal drilling and hydraulic fracturing are the two key processes which allow an unconventional natural gas resource, like the Marcellus Shale, to be economically developed.

Horizontal drilling involves drilling vertically, until reaching a point above the target formation where the drill bit is then turned through a 90-degree arc to allow advancing the borehole horizontally through the target ("pay") formation. This approach allows for a greater contact length between the wellbore and the producing formation than is traditionally achieved through vertical drilling. Because of this increased exposure to the pay zone, a volume of gas similar to what can be produced by numerous vertical wells can potentially be produced by significantly fewer horizontal wells.[1] Once a horizontal well is drilled it is then hydraulically fractured to increase production of natural gas.

The hydraulic fracturing process used for shale gas development uses a water based fluid, mixed with a friction reducer, which is then pumped into the borehole under pressure to create fractures. In addition to the fluid, a proppant, usually sand, is also pumped into the formation with the water to fill in the fractures that have been created. The fracturing fluid may contain other chemical additives in addition to the proppant and friction reducer which are designed to perform tasks needed to maintain the production of water and natural gas from the well. These additives may include: a biocide to prevent microorganism growth which reduces biofouling of the fractures; scale inhibitors which prevent mineral scale from clogging the open space in the fractures and piping; and corrosion inhibitors which prevent corrosion of the metal pipes used to construct the well.[2]

After the fracture fluid is pumped into the formation it is allowed to sit under pressure for several days while the proppant settles into place. After several days the pressure from the fracturing process is released. Once the pressure is released, water begins to flow back up the well bore to the surface. The produced water that flows back during the early time period has a similar chemical composition to the water that was pumped during the fracture treatment, however over time the produced water that flows to the surface contains constituents acquired from the shale formation. Components of produced water may include hydraulic fracturing additives, metals, high levels of total dissolved solids (TDS), mineral scales, suspended solids (clays, silts and other sediments) and naturally-occurring radioactive material (NORM).[3]

As the water is produced to the surface, the water is captured and stored prior to being disposed or otherwise managed. Initially, the water is stored on the surface in tanks or specialized impoundments. Produced water is generally managed by a combination of three methods: disposal, reuse, or treatment.

Marcellus Shale Water Needs

Horizontally drilling a shale gas well requires smaller quantities of water than the hydraulic fracturing process. Once the water has been collected and stored on-site, approximately one hundred thousand gallons are used for drilling a well and between three and five million gallons are used when hydraulically fracturing a well. Recent data suggests an approximate average of 3.8 million gallons of water per well are required to completely drill and stimulate a well in the Marcellus Shale, as shown in Exhibit 1[4]. This amount of water is not insignificant but is less than other comparable water uses in the target area.

Marcellus Shale Water Requirements per Well (gallons per well)	
Drilling	~84,000
Hydraulic Fracturing	~3,780,000
Total	**~3,864,000**

Exhibit 1. Water Needs for Drilling and Hydraulic Fracturing

Projected total demand for peak Marcellus Shale activity in the Susquehanna River Basin is approximately 8.4 million gallons per day.[5] This is comparable to other energy producing water uses in the same area. The consumptive use of fresh water for electrical generation in the Susquehanna River Basin is approximately 150 million gallons per day.[6] Other water consumers that also affect water use in some parts of the Marcellus Shale include golf courses and agricultural producers; each golf course requires between 100,000 and 1,000,000 gallons of water per week.[7] Exhibit 2[8,9,10] compares some of the current water demands in the target area with current well development trends in Pennsylvania.

Current trends in Pennsylvania indicate key areas of shale gas development in the northeast and southwestern portions of the state. This indicates the areas where water demand will be highest and may give an approximation of the areas where water will continue to be in high demand for the immediate future. This map can also be expounded to areas in northern West Virginia and southern New York as an indicator of where water will be and currently is in higher demand. New York currently has no active Marcellus wells being drilled but by looking at the demands in Pennsylvania we can see the areas in New York which may become in high demand when drilling is allowed to move forward.

Marcellus Shale Water Demand Comparisons	
Electrical Power Generation	60.9 Billion Bbls/yr
Industrial and Mining	13.7 Billion Bbls/yr
Public Water Supply	10.2 Billion Bbls/yr
Golf Course Maintenance [a]	0.148 Billion Bbls/yr
Agricultural Irrigation	0.102 Billion Bbls/yr
Marcellus Shale Gas Development [b]	0.077 Billion Bbls/yr
Total Water Withdrawal in Marcellus Shale Play Area	**85 Billion Bbls/yr**

Exhibit 2. Comparison of Peak Drilling Water Demands versus Other Common Withdrawals in the Marcellus Shale Play Area (Billion Oil Barrels/Year)

[a] Assuming 1,000,000 gallons of water per week and only during 44 weeks per year.
[b] Based on projected wells drilled in Marcellus Shale Formation in Pennsylvania assuming 840 wells drilled per year

Water Sourcing

Water used in shale gas development is currently gathered from surface water, groundwater, or other less conventional sources, such as acid mine drainages (AMD), wastewater treatment plant

(WWTP) effluents or reused produced water. Surface water sourcing is the most widely available option and is generally collected from rivers, lakes and streams. Groundwater sourcing requires pumping water from currently available groundwater wells or by drilling a groundwater well near a well pad location. Other water sources, like AMD and WWTP effluents, have been utilized by operators in the target area as source water for shale gas development. AMD is a good source for reducing impacts from areas currently affected by the highly acidic water flowing into the local environment. WWTP is an excellent source, if available, as it is viewed as a wastewater though it is viable for numerous applications which do not require high quality water. Cost benefits provided by state and regional agencies make these water sources more economical to use while simultaneously reducing environmental degradation. All of these water sources require approval from state and federal agencies and may require additional permits from regional water basin commissions.

Another water source, which is now being utilized by most operators in the Marcellus Shale, is simply reusing water produced from previously stimulated wells. Approximately fifteen to thirty percent of water going down a Marcellus Shale well will return as produced water within the first few weeks and may continue to produce water through the life of the well.[11] Exhibit 3[12,13] shows the various water sources and includes general availability of the water source, water quality, and treatment required before use in hydraulic fracturing as well as some comments on water management.

Sources of Water for Drilling and Hydraulic Fracturing				
Source	**Availability**	**Quality**	**Treatment Before Use**	**Comments on Water Management**
Surface Water	Abundant	High	Minimal	Must be properly managed to avoid environmental impacts
Groundwater	Abundant but requires access to water wells	High	Minimal	Must be properly managed to avoid environmental impacts
Acid Mine Drainage	Localized	Very Low (High acidity, High dissolved metals[1])	Treatment required	Good source for reducing impacts from areas currently affected by the highly acidic water flowing into the local environment.
Waste Water Treatment Plant Effluent	Localized	Median (Non-Potable)	Minimal	Excellent source, if available, as it is viewed as a wastewater though it is viable for numerous applications other than use as drinking water.
Brackish and Saline Water	Localized	Low (High TDS Levels)	Treatment may be Required	Proper handling to avoid spills and post-treatment disposal of concentrated brine or solid waste is required.
Reuse of Produced Water	Abundant	Low (High TDS Levels[2])	Treatment may be Required	Proper handling to avoid spills and post-treatment disposal of concentrated brine or solid waste is required.

Exhibit 3. Chart Displaying Various Water Sources Being Used for Hydraulic Fracturing Operations in the Marcellus Shale

Water Transportation

Water, in most cases, is acquired from sources close to the well site. Acquiring water locally reduces the total distance trucks travel transporting this water. In the Susquehanna River Basin the SRBC has multiple water take points already approved and being utilized by local operators.[14]

At an approved take point an operator is allowed to allocate water for use at any of their leased well sites, so long as the operator documents where the water will be used and does not take more water than permitted.[15] The permits allow operators to use the water nearest to their operations which can save fuel costs while reducing air emissions from diesel powered tanker trucks. Also, by reducing travel time from take point to the well site there is less of an impact on the local road infrastructure, as well as reduced noise, dust, and traffic. Exhibit 4[16] shows the estimated total truck trips needed per stage of shale gas well development.

Estimated Number of Truck Trips per Stage of Shale Gas Development[1]	
Stage of Development	**Truckloads**
Drill Pad and Road Construction Equipment	10 – 45
Drilling Rig	30
Drilling Fluid and Materials	25 – 50
Drilling Equipment (casing, drill pipe, etc.)	25 – 50
Completion Rig	15
Completion Fluid and Materials	10 – 20
Completion Equipment – (pipe, wellhead)	5
Hydraulic Fracture Equipment (pump trucks, tanks)	150 – 200
Hydraulic Fracture Water	400 – 600
Hydraulic Fracture Sand	20-25
Flow Back Water Removal	200 – 300

Exhibit 4. Average number of truck trips per Stage of Shale Gas Development

To further reduce impacts associated with truck transport, water can be gathered and transported over short distances directly from a take point to a well site. Operators accomplish this with the use of temporary above ground pipelines, also known as "fastlines." Fastlines are used efficiently throughout other shale basins in the United States. [17]

Fastlines require energy for pumps used to withdraw and transport water through the pipelines. Exhibit 5 is a photograph, taken by ALL Consulting, of pumps that are used to move water through fastlines in the Fayetteville Shale Play. Exhibit 6 compares diesel engines used in tanker trucks to engines used to pump water through temporary water pipeline systems. Temporary water pipelines may reduce overall impacts associated with truck traffic, while also occupying a relatively small land area during their use. Pathways usually need to be cleared to place the pipelines along the routes from take point to well site, generally utilizing the smallest distance feasible to transport the water.

Fastlines may provide reduced air emissions and cumulative impacts but fastlines are not viable in all situations. Fastlines are not typically compatible in areas with higher population densities, areas with large elevation changes, areas with dense vegetative cover, long distances or where the natural landscape is broken by valleys. Trucks are more appropriate for transporting water over long distances. Trucks can be used efficiently in densely populated areas, and in some cases may be the more cost effective option.

In some instances, operators may have a third option in which permanent water pipelines are used for transport of water from source to well site. Permanent water pipeline systems are less common than fastlines and truck transport but may become more common as the Marcellus Shale Play develops over time.

	Diesel Powered Tanker Trucks		Diesel Powered Industrial Water Pumps	
Impacts	*Localized Impacts*	*Cumulative Impacts*	*Localized Impacts*	*Cumulative Impacts*
Air Emissions	High	Moderate	High	Low
Traffic	Moderate to High	Moderate to High	Low	Low
Noise	High	Moderate to Low	High	Low
Dust	Moderate	Low	Low	Low
Infrastructure	Moderate to Low	Low	Low	Low

Exhibit 6. Comparison Table of Diesel Tanker Truck Impacts versus Industrial Water Pump Impacts

Water Storage

Exhibit 5. Industrial Pumps for Transporting Water via Temporary Pipelines

Once water has been gathered for the hydraulic fracturing process, it is stored on or near the well pad until needed. Operators in the Marcellus Shale either utilized large steel tanks capable of storing hundreds of barrels of water at the well site or in large surface impoundments.[18]

In the Marcellus Shale more operators are utilizing 500-barrel steel tanks for water storage than those storing water in open pit impoundments. Some operators are utilizing open pit impoundments for freshwater storage while using steel tanks for produced water storage. One advantage tanks have over impoundments is the fact that produced water is contained in a closed vessel. Above ground tanks are less complicated to repair should a leak occur and have fewer occurrences of leaks when compared to impoundments.[19] Some disadvantages of tanks include: tanks occupy surface space at the well site; tanks are initially more expensive; and tanks have a much lower capacity so multiple tanks will need to remain onsite during the flow back period. Steel tanks reduce the potential for evaporation decreasing the concern of emissions being released when produced water is stored in open impoundments.

Impoundments, alternatively, have a much higher capacity, are typically cheaper to construct for the storage capacity compared to purchasing tanks, and may be constructed off the well site or as large centralized holding areas from multiple well sites. However, impoundments are open to the air and some produced water and volatile compounds can be lost due to evaporation. Impoundments may also disturb a large land surface area and have a higher potential for leaks while also being more costly to repair if a leak should occur. Exhibit 7[20,21] displays a comparison of the relative surface areas disturbed by either method of water storage.

Water Storage Comparisons		
Storage Options	**Surface Area Footprint**	**Capacity**
Surface Impoundments	1-5 acres per impoundment	~1,000,000 – 16,000,000 gallons[1]
Storage Tanks	~2 acres for 240 tanks (0.0088 acres per tank[2])	~5,000,000 gallons (21,000 gallons per tank)

Exhibit 7. Comparison Chart of Surface Disturbance for Storage Tanks versus Holding Ponds

Produced Water Disposal

Produced water from the Marcellus Shale can range in quality with TDS concentrations over 250,000 mg/L. The low quality of this water means disposal options are typically limited to: discharging the treated water, either at a commercial treatment plant or a municipal wastewater treatment facility; utilizing a zero-liquid discharge system; or injecting the produced water into an approved Class I or Class II Underground Injection Control (UIC) well.

A zero-liquid discharge, or crystallization, disposal involves the treatment of produced water to separate the water from the solids generally by the process of evaporation.[22] Zero-liquid discharge can be accomplished by multiple technologies and there are multiple companies offering these services in the Marcellus Shale production area with various designs such as the unit in Exhibit 8.[23] These processes evaporate water from the produced water solution, limiting disposal to the mineral solids remaining in the form of salt crystals. Zero liquid discharge is an effective disposal option but may be more expensive than other alternatives.

Exhibit 8. Evras Zero Discharge System for Produced Water

In the U.S., the oil and gas industry has been utilizing underground injection disposal of produced water since the 1930's.[24] "Underground injection has traditionally been the primary disposal option for oil and gas produced water. In most settings, this may be the best option for shale gas produced water. This process uses salt water disposal wells to place the water thousands of feet underground in porous rock formations that are separated from treatable groundwater by multiple layers of impermeable rock thousands of feet thick."[25]

However, in the Marcellus Shale there is limited use of injection wells as a means of disposal.[26] There are some disposals using injection in West Virginia but few UIC wells have historically been permitted in the Marcellus Shale producing areas of New York and Pennsylvania. Some of the produced water from the Marcellus is being transported and injected into disposal wells in other states nearby but a more widely used option is some manner of treating the produced water so it can be reused.[27]

Produced Water Reuse

Reuse of produced water is an increasing management option in shale gas basins across the United States. Many operators dilute produced water with fresh water or treat produced water to achieve a concentration clean enough for reuse. The concentrated waste product after treatment is then disposed of via injection or crystallization disposal. Many shale gas well sites have multiple wells on a single pad. Reuse of produced water on a multi-well site eliminates the need to transport the produced water to new location. Much of the water produced from one well on-site can then be reused for the next well on the same well pad.

Re-use of produced water also reduces the volume of fresh water needed for hydraulic fracturing operations. Reuse decreases environmental impacts associated with water withdrawals and can be used in times of low surface water flows to augment withdrawals during low flow periods.

Though reuse of produced water is an increasingly used option for produced water management, water which cannot be reused must be disposed or treated. Many of the components of produced water must be removed before discharge to river can occur.

Produced Water Treatment

Produced water treatment can be done on-site or be transported to a municipal or industrial treatment facility. Treatment systems for on-site treatment are available from multiple companies specializing in patented systems, designed specifically for treating produced water.[28]

Municipal wastewater treatment facilities have been used in the past for management of produced water in the Marcellus Shale. These facilities generally use a combination of treatment and dilution of the produced water to create a resultant concentration which can be discharged back to surface water bodies. The smaller scale of these facilities may not be an appropriate option for many operators considering large volumes of produced water requiring proper treatment. Smaller municipal wastewater treatment facilities may not fully treat the water before release, potentially causing risk to the environment. This was the case in Pennsylvania when produced water was linked to elevated TDS levels in the Monongahela River in 2008.[29] Incidents like these have also led to proposed changes in the regulation of produced water in Pennsylvania.

A more viable option, to prevent environmental risk, is to transport the produced water to larger commercial treatment facilities which have the capacity to handle this type of wastewater. These commercial wastewater treatment systems may pose less of a risk for produced water to be released without complete treatment.

Exhibit 9 displays some of the pros and cons of the different options available for produced water treatment, disposal, and reuse.

Produced Water Disposal and Treatment Options Comparison		
	Pros	**Cons**
On-Site Water Treatment	Numerous systems for treatment. Treatment can occur on-site reducing the need to transport Produced Water elsewhere.	Difficult for regulatory monitoring. Improper surface discharges may occur.
Zero Liquid Discharge Treatment	Evaporative method where only solids remain, allowing for reduced transportation costs.	Evaporative methods are viewed as emission sources.
Commercial Wastewater Treatment Facility	Properly treats Produced Water to remove contaminants before discharge back to surface water.	Discharges water back to surface water sources as opposed to taking the water out of the system entirely. Limited availability.
Municipal Wastewater Treatment Facility	Treats Produced Water before discharging back to surface water source. Numerous facilities available.	May not properly treat Produced Water. May not be a large enough facility to handle the extra demand from Produced Water.
Underground Injection Disposal	Completely removes wastewater from the system by injecting it into subsurface geology.	Not available, due to inadequate geology, in New York and Pennsylvania. Some Underground Injection Control (UIC) wells are available in West Virginia and Ohio.
Reuse of Produced Water	Reuses Produced Water that is mixed with fresh water to hydraulically fracture new shale gas wells. Keeps the wastewater produced during shale gas development out of the hydrologic system.	Management of the liquid must be closely monitored to avoid spills from leaks or accidental release.

Exhibit 9. Pros and Cons of Treatment and Disposal Options for Produced Water

Summary

The Marcellus Shale offers a vast domestic supply of natural gas which the United States has the technology to extract. This unconventional energy source is available with the use of horizontal drilling and hydraulic fracturing but presents us with challenges in the treatment and disposal of produced water. However, produced water is manageable with current commercial treatment facilities and disposal through underground injection.

Future development of the Marcellus Shale Play will present further challenges on both water needs and produced water disposal. Water demands will change as reuse of produced water becomes more common. Trends appear to indicate reuse of produced water will continue to become normal operating procedure for operators in the Marcellus. It is also apparent that underground injection and commercial treatment facilities will be utilized for disposing produced water which cannot be reused for future development of the Marcellus Shale.

---

[1] GWPC, *Modern Shale Gas Development in the United States: A Primer*, 2009

[2] ALL Consulting and the Groundwater Protection Council (GWPC), "Modern Shale Gas Development in the United States: A Primer," prepared for the U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory, Washington, D.C. (April 2009), Pg. 61.

[3] New York State Department of Environmental Conservation (NYSDEC), Division of Mineral Resources, "Well Permit Issuance for horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," in *Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program* (September 2009), Section 5.11.3 Pgs. 5-100 - 5-101, available at http://www.dec.ny.gov/energy/58440.html.

[4] Derived from ALL Consulting, "Produced Water Issues with Shale Gas Production," presented at Society of Petroleum Engineers (SPE) Tight Gas Completions Workshop, Denver, Colorado, April 28, 2010, http://all-llc.com/publicdownloads/ArthurSPE-ATW-042810.pdf (accessed September 27, 2010).

[5] A. Gaudlip, L. Paugh (SPE, Range Resources Appalachia LL), and T. Hayes (Gas Technology Institute), "Marcellus Shale Water Management Challenges in Pennsylvania," presented at the SPE Shale Gas Production Conference, November 2008.

[6] A. Gaudlip, L. Paugh (SPE, Range Resources Appalachia LL), and T. Hayes (Gas Technology Institute), "Marcellus Shale Water Management Challenges in Pennsylvania," presented at the SPE Shale Gas Production Conference, November 2008.

[7] Alliance for Water Efficiency, "Golf Course Water Efficiency Introduction" (2009), http://www.allianceforwaterefficiency.org/golf_course.aspx (accessed April 2010).

[8] Derived from ALL Consulting, LLC, "Lifecycle Water Management Considerations & Challenges for Marcellus Shale Gas Development," presentation before the Independent Oil & Gas Association of New York, July 8, 2009, http://all-llc.com/publicdownloads/Arthur%20IOGA%20LifecycleWtr%20070609.pdf (accessed September 2010) with barrels meaning a standard oil barrel equal to 42 gallons.

[9] Alliance for Water Efficiency, "Golf Course Water Efficiency Introduction" (2009), http://www.allianceforwaterefficiency.org/golf_course.aspx (accessed April 2010) assuming 1,000,000 gallons of water per week and only during 44 weeks per year.

[10] ESRI, United States Geological Survey, Tele Atlas North America, Inc., "USA Golf Courses," *ArcGIS.com* (June 10, 2010), http://www.arcgis.com/home/item.html?id=97fe792109004dc5a6596d34d35ff7dd (accessed September 2010) assuming 142 golf courses in overlying the Marcellus Play area.

[11] ALL Consulting, "An Environmental Discussion of Hydraulic Fracturing in the Marcellus Shale," presentation for American Institute of Professional Geologist (AIPG), Pittsburgh, Pennsylvania, May 5-6, 2010, http://www.all-llc.com/publicdownloads/ALLConsulting-HVHFMAY62010.pdf (accessed October, 2010).

[12] Evan Hansen Downstream Strategies, "A Technical Analysis of Acid Mine Drainage Total Maximum Daily Loads for West Virginia's Buckhannon River and Tenmile Creek," prepared for the West Virginia Rivers Coalition, West Virginia Highlands Conservancy, and Ohio Valley Environmental Coalition (August 17, 1998) http://www.wvrivers.org/articles/BuckhannonRivAMDTMDL.pdf (accessed September 2010).

[13] Tom Hayes, GTI, "Gas Shale Produced Water," presented at the RPSEA/GTI Gas Shales Forum (June 4, 2009) http://www.rpsea.org/attachments/contentmanagers/429/Gas_Shale_Produced_Water_-_Dr._Tom_Hayes_GTI.pdf (accessed October 1, 2010).

[14] Susquehanna River Basin Commission, "Approved Source List," *www.srbc.net* (October 6, 2010), http://www.srbc.net/downloads/ApprovedSourceList.pdf (accessed October, 2010).

[15] Susquehanna River Basin Commission (SRBC), "Standards Conditions Contained in Gas Well Surface Dockets," http://www.srbc.net/programs/docs/Standard%20SW%20Docket%20Conditions%20for%20Gas%20Wells%20.PDF (accessed July14, 2010)

[16] [1] NTC Consultants, "Impacts on Community Character of Horizontal Drilling and High Volume Hydraulic Fracturing in Marcellus Shale and Other Low-Permeability Gas Reservoirs," prepared for the New York State Energy Research and Development Authority, Albany, New York (September 2009), 10.

[17] Impact Energy Services, "Water Management and Flowback Services," *Selectenergyweb.ipower.com* (n.d.), http://selectenergyweb.ipower.com/brochures/impact_datasheet_101110.pdf (accessed October 2010)

[18] New York State Department of Environmental Conservation (NYSDEC), Division of Mineral Resources, "Well Permit Issuance for horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," in *Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program* (September 2009), Section 5.7 Pg. 5-75, available at http://www.dec.ny.gov/energy/58440.html.

[19] New York State Department of Environmental Conservation (NYSDEC), Division of Mineral Resources, "Well Permit Issuance for horizontal Drilling and High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs," in *Draft Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program* (September 2009), Section 7.1.7.4 Pg. 7-55, available at http://www.dec.ny.gov/energy/58440.html.

[20] Bureau of Oil & Gas Regulation New York State Department of Environmental Conservation (NYSDEC) Division of Mineral Resources, *DRAFT Supplemental Generic Environmental Impact Statement on the Oil, Gas and Solution Mining Regulatory Program Well Permit Issuance for Horizontal Drilling And High-Volume Hydraulic Fracturing to Develop the Marcellus Shale and Other Low-Permeability Gas Reservoirs*, digital edition (Albany, New York) September 2009, Table 5-13, page 5-118.

[21] Grizzly Manufacturing, Inc., "500 Barrel Corrugated Wall Frac Tank – Specifications," *www.grizzlymfg.net* (n.d.) http://www.grizzlymfg.net/pfprod.html (accessed October 1, 2010).

[22] Intevras Technologies, Layne Christensen-Intevras Products, "Evras Zero Discharge System," *www.intevras.com* (2008) Austin, TX http://www.intevras.com/evras.html

[23] Intevras Technologies, Layne Christensen-Intevras Products, "Evras Zero Discharge System," *www.intevras.com* (2008) Austin, TX http://www.intevras.com/evras.html

[24] Clark, J.E., D.K. Bonura, and R.F. Van Voorhees, "An Overview of Injection Well History in the United States of America", in Developments in Water Science, Volume 52. 2005. Pages 3-12.

[25] ALL Consulting and the Groundwater Protection Council (GWPC), "Modern Shale Gas Development in the United States: A Primer," prepared for the U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory, Washington, D.C. (April 2009), Pg. 68.

[26] ALL Consulting and the Groundwater Protection Council (GWPC), "Modern Shale Gas Development in the United States: A Primer," prepared for the U.S. Department of Energy Office of Fossil Energy and National Energy Technology Laboratory, Washington, D.C. (April 2009), Exhibit 39, Pg. 69.

[27] Veil, John A., "Water Management Technologies Used by Marcellus Shale Gas Producers," prepared for the U.S. Department of Energy National Energy Technology Laboratory, Washington, D.C. (July 2010), Pg. 14.

[28] Intevras Technologies, Layne Christensen-Intevras Products, "Integra," *www.intevras.com* (2008) Austin, TX http://www.intevras.com/integra.html

[29] Sapien, Joaquin, "With Natural Gas Drilling Boom, Pennsylvania Faces Flood of Wastewater," *ProPublica*, (October 5, 2009) http://www.scientificamerican.com/article.cfm?id=wastewater-sediment-natural-gas-mckeesport-sewage&page=5 (accessed July 16, 2010)

Milestone Status

In September 2010, ALL Consulting recognized that completing Milestone 6, "Deliver topical report" as scheduled would require preparation of the report before all of the Budget Period 1 activities were completed. ALL contacted the DOE Project Officer and rescheduled the milestone completion date for 10/30/2010.

Milestone Status Table

Budget Period	Milestone Description	Status	Planned Completion Date	Actual Completion Date
I	Completion of PMP	Completed	12/04/09	12/01/09
	Completion of Technology Status Assessment	Completed	11/14/09	11/14/09
	Develop project web-site	Completed	12/04/09	12/04/09
	Completion of Initial Issue Analysis	Completed	03/30/10	03/29/10
	Complete Site Visits	Completed	09/30/10	9/26/10
	Deliver topical report	On Track	10/30/10	On Track

COST/PLAN STATUS

Baseline Reporting Quarter	YEAR 1 Start:10/01/09 End: 09/30/10 Q1	Q2	Q3	Q4	YEAR 2 Start: 10/01/10 End: 09/30/11 Q1	Q2	Q3	Q4	YEAR 3 Start: 10/01/11 End: 09/30/12 Q1	Q2	Q3	Q4
Baseline Cost Plan (from SF-424A)												
Federal Share	114,998	114,998	114,998	114,998	83,511	83,511	83,511	83,511	64,652	34,546	34,546	34,552
Non-Federal Share	29,281	29,281	29,281	29,281	21,232	21,232	21,232	21,232	16,708	11,025	11,025	11,025
Total Planned (Federal and Non-Federal)	144,279	144,279	144,279	144,279	104,743	104,743	104,743	104,743	81,360	45,570	45,570	45,570
Cumulative Baseline Cost	144,279	288,558	432,839	577,115	504,169	644,912	749,655	854,398	935,758	1,017,118	1,098,478	1,179,838
Actual Incurred Costs												
Federal Share	140,061	14,462	106,276	199,129								
Non-Federal Share	1,260	40,000	12,858	77,858								
Total Incurred Cost-Quarterly (Federal and Non-Federal)	141,321	54,462	119,134	276,987								
Cumulative Incurred Costs	141,321	195,783	314,917	591,904								
Variance												
Federal Share	(25,063)	100,536	8,722	(84,131)								
Non-Federal Share	28,021	(10,719)	16,422	(48,578)								
Total Variance-Quarterly (Federal and Non-Federal	2,958	89,817	25,145	(142,708)								
Cumulative Variance	2,958	92,775	117,919	(14,789)								

National Energy Technology Laboratory

626 Cochrans Mill Road
P.O. Box 10940
Pittsburgh, PA 15236-0940

3610 Collins Ferry Road
P.O. Box 880
Morgantown, WV 26507-0880

13131 Dairy Ashford, Suite 225
Sugarland, TX 77478

1450 Queen Avenue SW
Albany, OR 97321-2198

2175 University Ave. South
Suite 201
Fairbanks, AK 99709

Visit the NETL website at:
www.netl.doe.gov

Customer Service:
1-800-553-7681