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Quarterly Report

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

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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

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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 third quarter of the project, work progressed on schedule, and all project deliverables were submitted on time. The Project Management Plan and Technology Status Assessment were submitted as required, and data collection under Tasks 2.0 and 3.0 was begun. No problems have been encountered to date. There were three milestones scheduled for completion during this quarter and all were 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.

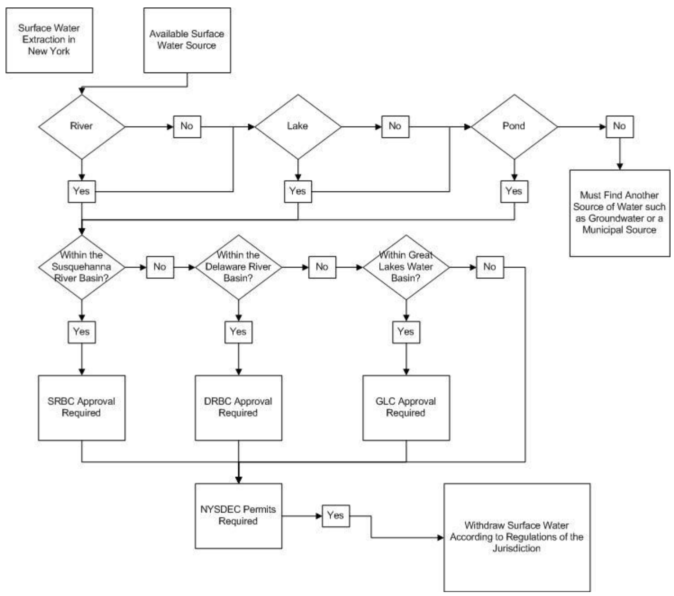
The primary considerations in evaluating water needs are the location of the need, the seasonal timing of the need, the location of available water, and the regulations governing water withdrawals. In general, the Marcellus region has ample precipitation, making water readily available, and withdrawals 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.

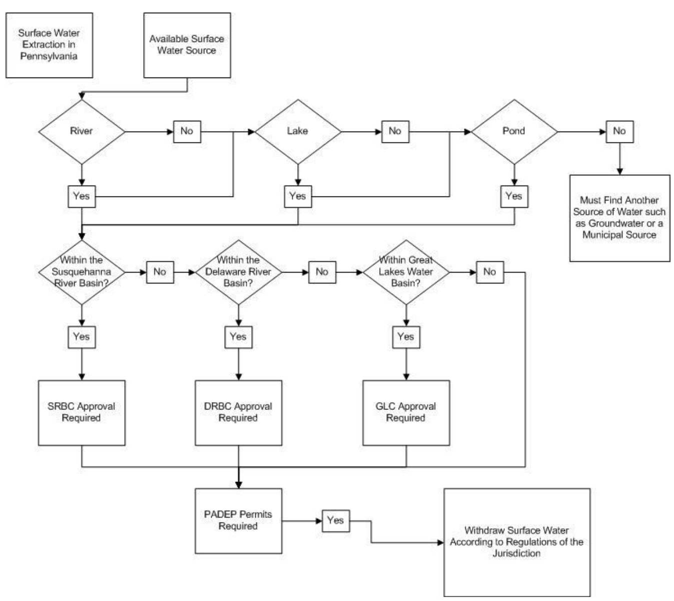
Operators will work to minimize water transportation costs by securing permitted withdrawals as close as possible to their planned development areas. Therefore, it is the groundwater and surface water sources most proximal to the well sites that will be most desirable. Operators may need to evaluate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

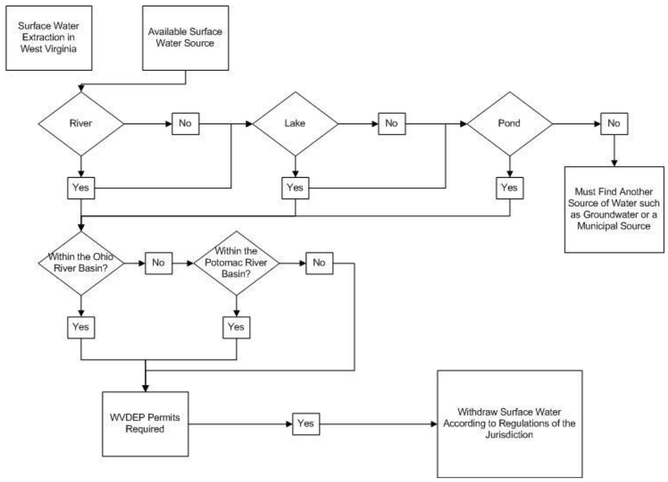
A major consideration in planning water withdrawals will be the regulations governing permitting procedures, especially the passby flow requirements and their impact on the seasonality of permittable withdrawals for the water bodies most proximal to development. This, combined with the fact that water 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.

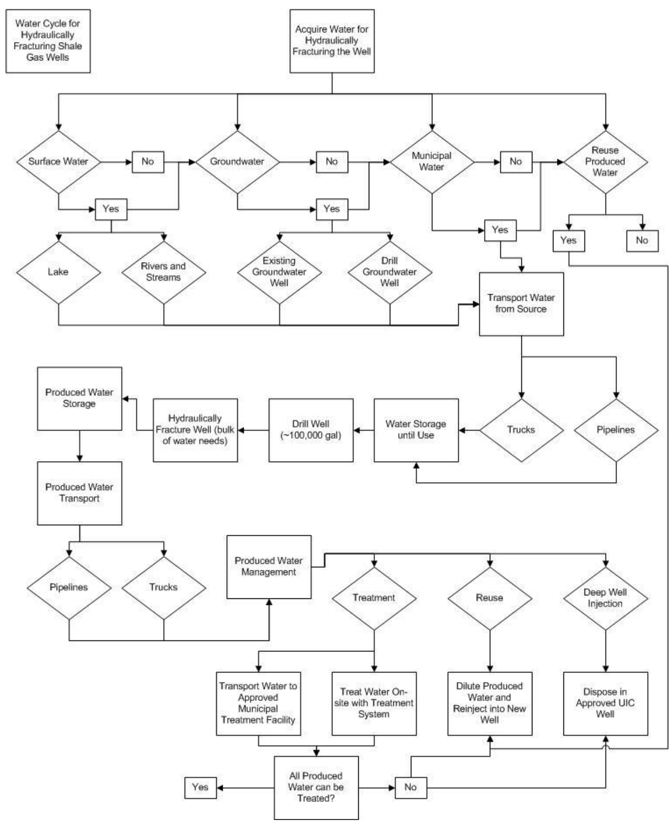
In addition to the paper on water resource issues, ALL also made a presentation at the AIPG meeting in May on the full suite of issues associated with the practice of hydraulic fracturing. The presentation summarized information on water issues throughout the shale gas drilling and production lifecycle 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 being gathered under Task 3 is also being incorporated into the initial system design. 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 emerging practice that can affect many 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 allow 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 state-wide shale gas water demands.

ALL has completed some initial visits with NYSERDA, SRBC, 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 is being incorporated into the initial plans for the model design. ALL will continue to gather information through the end of the budget period and will make additional site visits to well-sites, treatment facilities, disposal facilities and regulatory agencies as they become available and as needed. 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 has also been accepted for publication and presentation at the International Environmental Petroleum and Biofuels Conference to be held in San Antonio August 31-September 2, 2010.

ALL has also worked with NETL site-support contractors to prepare an article about the benefits of and progress on the project for NETL's *E&P Focus* newsletter. ALL is currently preparing a paper on the issues that arise in the other phases of the Lifecycle: transportation and storage, produced water management, and disposal, which would include temporary storage, re-use, treatment for beneficial use or discharge, and injection for disposal.

Results

The hydraulic fracturing process is viewed by many in the northeast as requiring immense quantities of water, approximately three to five million gallons per well. This is understandable when looking at just the numbers, but when compared to other uses of water throughout the same area these numbers seem less significant. New York City diverts up to 800 million gallons of water per day from the Delaware River Basin and New Yorkers[1] averaged 125.8 gallons of water per person per day in 2009. This amounts to use of just over one billion gallons of water daily, just in the New York City metro area. [i]

While the water volumes needed to drill and stimulate shale gas wells are large, they 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 five million gallons of water per well, would be about 650 million barrels per year.[ii,iii,iv] 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.[v]

The water lifecycle begins with allocating, or gathering, the water from a source, such as surface streams or groundwater wells. Once the water is collected it must be transported to the well where it will be used, usually done by tanker trucks or temporary above ground pipelines. Once the water is at the well site it is usually stored on site in either a surface impoundment or above ground storage tanks.

Once enough water is available, the drilling and hydraulic fracturing processes begin. After the process is complete, the used water will flow back up the wellbore and the well will produce water from several hours up to two weeks, while in some cases the well may produce water for several months after gas production has begun.[vi] This produced water is stored in another impoundment which is either at the producing well or in a centralized location for the storage of produced water from multiple well sites.

The produced water is now highly saline and contains both, the additives used in the hydraulic fracturing process and other minerals and components acquired from the shale formation. The produced water is now treated, reused/recycled, or disposed. Each process for managing produced water has specific advantages and disadvantages specifically when analyzing individual projects versus cumulative impacts of multiple projects. The lifecycle and cumulative impacts of the water used to development shale gas demonstrate the challenges in extracting this beneficial resource.

Collection and Transportation of Water

Before water is gathered, the operator must receive approval from the appropriate state agency or river basin commission in charge of the area. Exhibit XX is a map showing the jurisdictional boundaries of the three state agencies, two major river basin commissions and one city agency in

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[1] Residents of the New York City metropolitan area

the study area: the New York State Department of Environmental Conservation (NYSDEC), the Pennsylvania Department of Environmental Protection (PADEP), the West Virginia Department of Environmental Protection (WVDEP), the Susquehanna River Basin Commission (SRBC), the Delaware River Basin Commission (DRBC) and the New York City Department of Environmental Protection (NYCDEP).

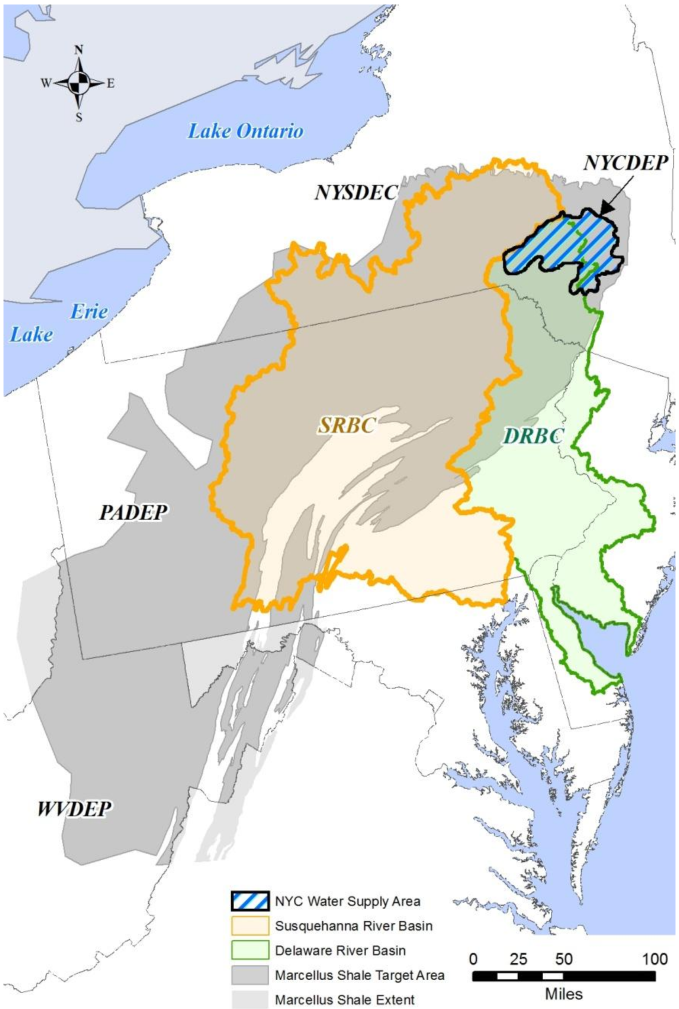

Exhibit 1 – Map of Regulatory Bodies in Jurisdictional Boundaries

Water, in most cases, must be acquired from sources close to the well site; the reduction in the total distance traveled in turn reduces the cumulative impacts associated with air emissions from tanker trucks. In the Susquehanna River Basin there are multiple water take points already approved and being utilized by local operators.

Exhibit 1 shows a map of these take points and well sites for which they are approved. Once a take point has been approved an operator is allowed to allocate water for use at any of their leased well sites, so long as they document where the water will be used and do not take more water than they are permitted by the SRBC.[vii]

This allows operators to use the water nearest to their operations which saves fuel costs while also reducing cumulative air emissions released into the environment 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 infrastructure, as well as reduced noise, dust, and traffic.

MAP - SRBC water take points

To reduce many of the impacts associated with truck transport, water can be gathered and transported over short distances directly from a take point to a well site. This can be done with the use of temporary above ground pipelines, also known as “fastlines.” These are used efficiently throughout other shale basins in the United States.

Fastlines require energy for pumps used to withdraw and transport water through the pipelines. Exhibit 2 displays some of the pumps which may be used in the Marcellus Shale. These pumps use less energy than the diesel engines in tanker trucks and emit less cumulative air pollution. Exhibit 3 is a table comparing diesel engines used in tanker trucks to the engines used to pump the water through temporary water pipeline systems. Temporary water pipeline reduce the overall impacts associated with truck traffic but do require using land area. Paths are generally cleared to place the pipelines along the routes of shortest distance from water take point to well site.


Exhibit 2 - Industrial Pumps for Transporting Water via Temporary Pipelines

	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 3 – Comparison Table of Diesel Tanker Truck Impacts versus Industrial Water Pump Impacts

Temporary pipelines may be a better option when comparing air emission totals and cumulative impacts but they are not viable in all situations, particularly in areas with higher population densities. Trucks are more useful for longer distances, they can be used efficiently in densely populated areas, and in many cases may be the more cost effective option.

Storage of Fresh Water

Once the fresh water has been gathered for the hydraulic fracturing process, it must be stored until needed. Operators in the Marcellus Shale either utilized 500-barrel steel tanks at the well site or large excavated impoundments.[viii] The impoundments are constructed by excavating a large pit which is then lined to prevent infiltration.[ix] Larger central impoundments are more desirable for supplying multiple well pads in a single area; further reducing travel times from water take points to well sites.

When using larger centralized impoundments the water is generally transported from the impoundment to the well pad by temporary water pipelines. These centralized impoundments may hold several million gallons of water and have a surface area of up to five acres.[x] This allows for large quantities of water to be stored on or near a well site for use during drier months of the year

when the local rivers and streams have lower flow rates.[xi] Regulations prohibit removal of water from rivers and streams when the streams are at predetermined low-flow rates.
Regulations also require permits to be issued by the states in which the impoundments are built if the impoundments exceed predetermined thresholds established by the state. In New York, for example, a permit is required if the impoundment has a height equal to or greater than fifteen feet in height[2] or a maximum impoundment capacity equal to or greater than three million gallons[3], but is exempt if the height is less than six feet regardless of capacity or if the capacity does not exceed one million gallon regardless of height.[xii]

Management of Produced Water

Once the water has been collected and stored on-site, it will be used for first, drilling and then hydraulically fracturing the well. During the hydraulic fracturing process a proppant, usually in the form of sand, and additives will be added to the water to increase the effectiveness of the process. The additives perform various tasks needed in the process such as prevention of micro-organism growth to reduce biofouling of the fractures, decrease the surface tension of the water and prevent corrosion from forming on the metal pipes used in the process.[xiii]

After completion of the hydraulic fracturing process the pressure is released and the water flows back to the surface and is captured as produced water. This produced water not only contains the additives from the fracturing process but also 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).[xiv]

Now that the water has been produced by the well it needs to be managed. Initially, the water must be stored on the surface in tanks or specialized impoundments before it can be managed. There are three general means for managing produced water: disposal, reuse, or treatment.

4.1 Storage of Produced Water

Produced water is stored on the surface in tanks or impoundments. Tanks have advantages over impoundments due to the fact that the produced water is in a contained closed vessel. Above ground tanks are less complicated to repair should a leak occur and have fewer occurrences of leaks when compared to impoundments.[xv] Some disadvantages of tanks include: they require space at the actively producing well site; they are initially more expensive; and they may not have the necessary capacity to hold all of the water initially flowing back to the surface from the well.

Impoundments, alternatively, have a much higher capacity, are cheaper to acquire, and may be placed at a location away from the well site for use as a large centralized holding area from multiple well sites. However, impoundments are open to the air and some of the produced water and volatile constituents are lost during evaporation. Impoundments typically have two layers of po-

[2] Maximum height is measured as the height from the downstream [outside] toe of the dam at its lowest point to the highest point at the top of the dam.
[3] Maximum impounding capacity is measured as the volume of water impounded when the water level is at the top of the dam.

lyethylene geomembranes with a fill material and leak detection devices in-between. However, if a leak were detected the entire impoundment would have to be drained and relined at the added expense of the operator.

4.2 Disposal of Produced Water

There are two means of disposing of produced water; an operator may choose a zero-liquid discharge or an operator may choose to inject the produced water into an approved Class II injection well.

A zero-liquid discharge, or crystallization, disposal removes the water from the solids generally through evaporation. This can be accomplished by several means and there are multiple companies with patented techniques for accomplishing this procedure. Once the water has been removed the only material which needs to be disposed are the solids in the form of salt crystals left behind. This is an effective disposal option but can be more expensive than other alternatives, such as injection of the produced water underground.

At a large amount of shale gas sites in the U.S., produced water is disposed through injection onsite or nearby. "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."[xvi]

However, in the Marcellus Shale there is limited use of Class II injection wells as a means of disposal.[xvii] There is some disposal using injection in West Virginia but little, if any, in New York or Pennsylvania. Some 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 diluting the produced water so it can be used again.[xviii]

4.3 Reuse of Produced Water

Reuse of produced water is a widely used application in shale gas basins across the United States. Many operators either dilute the produced water with fresh water or they treat the produced water on-site to a concentration clean enough for reuse and then dispose of the concentrated waste. Many well sites in shale gas development have multiple wells on a single pad. This eliminates a 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.

Reuse of produced water reduces the need for constant sources of fresh water for each hydraulic fracturing operation. Many of the wells drilled in the Marcellus Shale are done so during summer months. Unfortunately, this is also the lowest flow periods during average years for river and streams. Reuse of produced water gives operators an alternative source of water and decreases the amount of fresh water required for each well. This decreases environmental impacts associated with water withdrawals. Exhibit 4 is a simple mixing model demonstrating the amount of fresh water needed to mix with produced water to allow it to be reused.

Parameter	Shallow Ground Water	Flow Back Water	Produced Water	IWS Prod. Water	Units	Mixed Water	
pH	7.78	7.71	6.77	7.53		7.7	
TDS	2,938	8,610		27,323	(mg/l)	10452.25	
Total Hardness as CaCO3	114	505	1573	2481	(mg/l)	803.5	
Chloride	1,293	5,911	10,288	15,717	(mg/l)	6053.5	
Calcium	48.5	189	303.9	478	(mg/l)	191	
Magnesium	82.2	154.3	197.9	334	(mg/l)	163.175	
Barium	25	18.42	27.3	33.86	(mg/l)	25.57	
Sodium	464	2682		9474	(mg/l)	3271	
Sulfate	189	509.8	20.84	6.81	(mg/l)	223.6525	
Bicarbonate Alkalinity	358	1763	1753	1257	(mg/l)	934	**Actual Mix TDS**
Iron	2.1	8.62	29.01	17.56	(mg/l)	7.595	**(Sum of Mixed**
Strontium			58.92	83.34	(mg/l)	20.835	**Water Totals)**
Calculated Sum for TDS	2,462	11,236	12,679	27,402		10890.33	**10890.3275**
Percent of Water in Mix	**50.00%**	**25.00%**	**0.00%**	**25.00%**			

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xhibit 4 – Simple Mixing Model

Reused water is a well used option for produced water management. Water which cannot be reused must be disposed or treated and discharged back to a river system. Much of the components of produced water must be removed before discharge to river can occur.

4.4 Treatment of Produced Water

Produced water treatment can be done on-site or the water can 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.

Municipal wastewater treatment facilities generally dilute the produced water down to a level which is treatable. The smaller scale of these facilities may not be an appropriate option for many operators with large volumes of produced water. A more viable option in these cases is to transport the water to larger commercial treatment facilities which have the capacity to handle this type of wastewater. These commercial wastewater treatment systems pose less of a risk for produced water to be released without complete 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.[xix] Incidents like these have also led to proposed changes in Pennsylvania's regulations of produced water.

[i] New York City Department of Environmental Protection (NYCDEP), "History of Drought and Water Consumption," Table titled Consumption, http://www.nyc.gov/html/dep/html/drinking_water/droughthist.shtml (accessed July 14, 2010)
[ii] 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), available at http://www.dec.ny.gov/energy/58440.html.
[iii] T. Considine, R. Watson, R. Entler, and J. Sparks, "An Emerging Giant: Prospects and Economic Impacts of Developing the Marcellus Shale Natural Gas Play," The Pennsylvania State University College of Earth & Mineral Sciences, Department of Energy and Mineral Engineering (July 24, 2009), Pg. 29.
[iv] ALL Consulting, "Projecting the Economic Impact of Marcellus Shale Gas Development in West Virginia: A Preliminary Analysis Using Publicly Available Data," (accessed March 31, 2010), Pg. 27, available at http://www.netl.doe.gov/energy-analyses/refshelf/detail.asp?pubID=305.
[v] J. Satterfield, M. Mantell, D. Kathol, F. Hiebert, K. Patterson, and R. Lee, "Managing Water Resource's Challenges in Select Natural Gas Shale Plays," presented at the GWPC Annual Meeting, (September 2008).
[vi] 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. 66.
[vii] 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)
[viii] 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.
[ix] 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. 5-76, available at http://www.dec.ny.gov/energy/58440.html.
[x] 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. 5-76, available at http://www.dec.ny.gov/energy/58440.html.
[xi] 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.
[xii] 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 5.7.2.1 Pg. 5-79, available at http://www.dec.ny.gov/energy/58440.html.
[xiii] 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.
[xiv] 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.
[xv] 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.
[xvi] 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.
[xvii] 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.
[xviii] 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.
[xix] 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 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	On Track	09/30/10	On Track
	Deliver topical report	On Track	09/30/10	On Track

COST/PLAN STATUS

Baseline Reporting Quarter	YEAR 1 Start:10/01/09 End: 09/30/10				YEAR 2 Start: 10/01/10 End: 09/30/11				YEAR 3 Start: 10/01/11 End: 09/30/12			
	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	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	19,733									
Non-Federal Share	1,260	40,000	30,756									
Total Incurred Cost-Quarterly (Federal and Non-Federal)	141,321	54,462	50,489									
Cumulative Incurred Costs	141,321	195,783	246,272									
Variance												
Federal Share	(25,063)	100,536	95,265									
Non-Federal Share	28,021	(10,719)	(1,475)									
Total Variance-Quarterly (Federal and Non-Federal	2,958	89,817	93,790									
Cumulative Variance	2,958	92,775	186,564									

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