

Oil & Natural Gas Technology

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Progress Report

Water Management Strategies for Improved Coalbed Methane Production in the Black Warrior Basin

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EXECUTIVE SUMMARY

The primary objective of this research is to analyze and develop strategies for water management in coalbed methane reservoirs of the Black Warrior basin. Management of produced waters is a subject of increasing environmental scrutiny, and the Geological Survey of Alabama (GSA) is developing a large, high-quality database and GIS that will provide a basis for the development of efficient regulatory frameworks that will protect the environment while ensuring that coalbed methane will be delivered to the marketplace. The Black Warrior basin provides a wealth of data and experience that can be used to evaluate water management practices across a spectrum of reservoir conditions and operational situations. Accordingly, the concepts and methods developed during this study will be applicable to other regions. These concepts and methods include optimizing water and gas production throughout the operational life cycle, forming strategies to minimize environmental impact, and identifying beneficial uses for produced water.

This project is employing an integrated, multidisciplinary approach to the evaluation and development of water management strategies for coalbed methane reservoirs. Work has commenced with an evaluation of reservoir geology and basin hydrology, which control fluid composition and yield. This project considers the full range of geologic and hydrologic variables that affect coalbed methane reservoirs, including stratigraphy, structural geology, petrology, fluid chemistry, reservoir pressure, and basin hydrodynamics. As the hydrogeologic framework is developed, work will shift toward characterizing reservoir performance and the life cycle of coalbed methane operations. The study will conclude by developing a comprehensive approach to produced water management that emphasizes environmental protection, optimization of reservoir performance, and beneficial use of produced water. A vigorous technology transfer program will be conducted throughout the study that will include assembly of a project advisory committee, development of a project web page, and dissemination of project results through the internet, publications, presentations, and workshops.

This project is proceeding according to schedule and budget.

RESULTS OF WORK DURING REPORTING PERIOD

Approach

The Black Warrior basin is a cradle of the modern coalbed methane industry that has provided a wealth of experience and has guided coalbed methane development around the globe. More than 2.2 Tcf of coalbed gas has been produced from the basin, and 4,869 wells are active in 17 coalbed methane fields (fig. 1). Annual gas production has been between 105 and 121 Bcf since 1993, and although the basin is considered mature, exploration and drilling operations are highly active. Cumulative water production now exceeds 1,340 MMbbl, and annual production was higher than 78 MMbbl in 2007. Water production has been rising since 2001 in response to renewed expansion of the coalbed methane industry in Alabama, and so water management issues continue to be of high concern.

The hydrologic and geochemical complexity of coalbed methane reservoirs in the Black Warrior basin favors the application of diverse technologies for produced water management, yet the coalbed methane industry is reliant mainly upon instream disposal, which is a subject of increasing environmental scrutiny. Currently, no integrated system for water management exists that can be used to optimize production operations, manage instream and subsurface disposal, and identify opportunities for beneficial use. A basic need is an integrated analysis of water chemistry, basin hydrology, and operational infrastructure that can be used to make decisions about produced water management. GIS technology, moreover, is an ideal vehicle for the synthesis of this analysis that facilitates the construction of a robust and effective water management plan.

To assist the coalbed methane industry in filling this need, the Geological Survey of Alabama (GSA) is conducting a three-year study that provides a conceptual framework for the management of produced water from coal. This study employs an integrated, life-cycle approach that draws on a spectrum of geologic disciplines (fig. 2). This investigation employs a spectrum of geologic, hydrologic, geochemical, petrologic, GIS, and other computational techniques to characterize the reservoir geology and basin hydrology of the Black Warrior basin to develop new water management strategies that ensure environmental protection, foster beneficial use of produced waters, and improve reservoir performance. The wealth of data and the geological diversity of the Black Warrior basin provides an unparalleled opportunity to evaluate water management strategies across a spectrum of reservoir conditions. Accordingly, this research will help natural gas producers develop basic geologic, hydrologic, and water management concepts that can be applied to coalbed methane plays throughout the world.

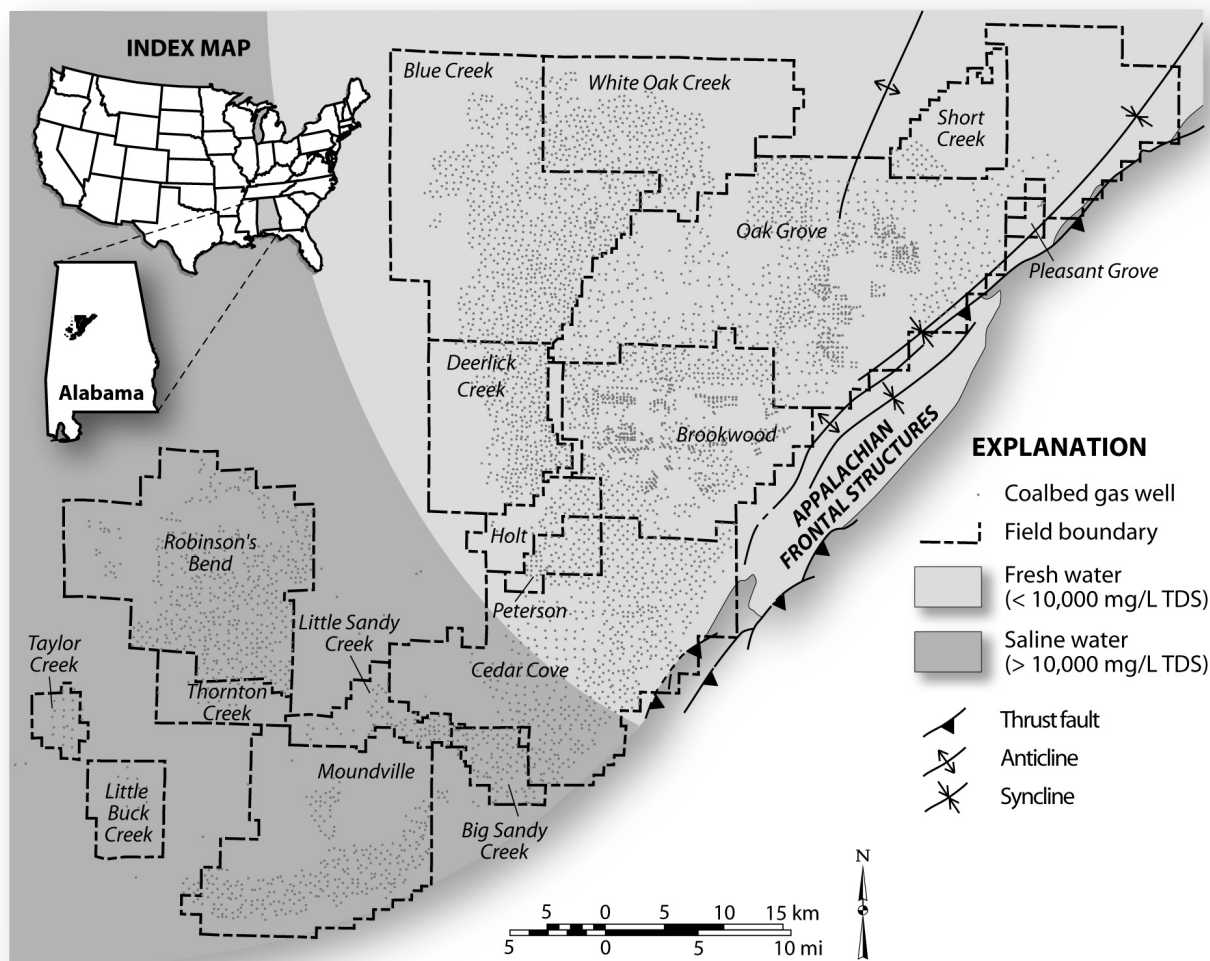


Figure 1.—Coalbed methane fields of the Black Warrior basin, west-central Alabama.

Results and Discussion

Work on this project is coordinated into a series of tasks aimed at project management, technology transfer, and the performance of technical activities (fig. 3). Task 1.0 focuses on project management, whereas Task 2.0 encompasses all technology transfer activities associated with this project. Tasks 4.0 through 9.0 include all technical activities required to meet the goals of this research. Work is in progress on Tasks 2.0 and Tasks 6.0 through 9.0, and this report summarizes the progress made during the most recent quarter of study.

Technology transfer activities last quarter included manuscript submission and preparation. A manuscript has been submitted to a special volume of the *International Journal of Coal Geology* that is being edited by Daniel Soeder of the U.S. Department of Energy National Energy Technology Laboratory and Mark Engle of the U.S. Geological Survey. The volume focuses on the potential environmental impacts of unconventional fossil energy development. The paper is entitled, "Interrelationships Between Water and Gas Chemistry in Mature Coalbed Methane Reservoirs of the Black Warrior Basin" and is authored by Jack Pashin of Oklahoma

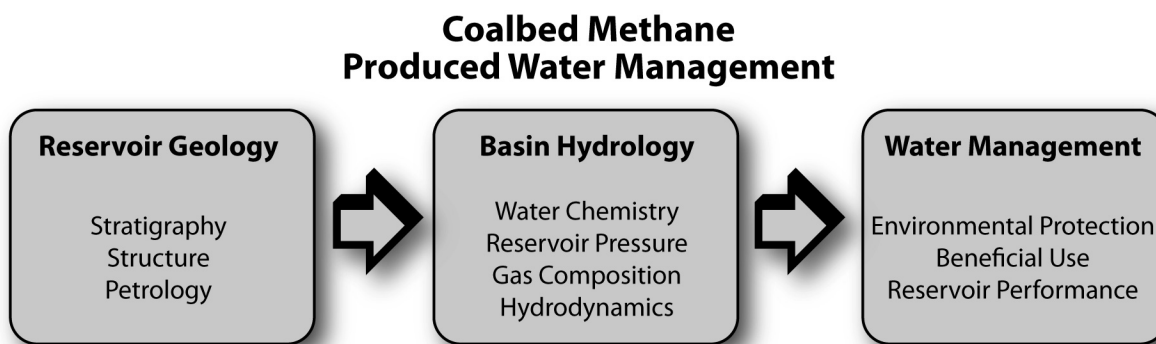


Figure 2.—Conceptual framework outlining proposed study of the relationships among reservoir geology, basin hydrology, and water management strategies in coalbed methane reservoirs.

State University, Marcella McIntyre-Redden and Steve Mann of the Geological Survey of Alabama, and Matthew Varonka and Bill Orem of the U.S. Geological Survey. Another manuscript is being prepared for the Unconventional Resources Technology Conference, which will be held in Denver during August 2013. The paper is entitled, “Dynamics of Thermogenic and Late-Stage Biogenic Gas Generation in Coalbed Methane Reservoirs of the Black Warrior Basin,” and considers the effects of burial, unroofing, and changing water chemistry on the generation, migration, and chemistry of hydrocarbons in bituminous coal. Dr. Pashin also has been invited to make a presentation in a workshop on produced water issues that is being organized by the Petroleum Technology Transfer Council. The workshop will be held in Morgantown, West Virginia, and is tentatively scheduled for August 22-23, 2013.

Sampling of coalbed methane wells under Gas Composition (Task 6.0) was completed on schedule, and as mentioned last quarter, Petrology (Task 7.0) was completed well ahead of schedule. Samples were obtained from 23 wells operated by Kavanaugh Petroleum, Chevron U.S.A., and Saga Petroleum. Important relationships between water chemistry and gas composition were discovered during the last quarter. The produced water is rich in ammonium and ammonia, and the concentrations of these substances correlates strongly with salinity. This relationship suggests that ammonium was derived from feldspar, mica, and clay minerals. Deionization of ammonium to ammonia, along with biodegradation of organic matter, appears to have been an important source of hydrogen that helped drive late-stage microbial methanogenesis. Anaerobic oxidation of ammonia, moreover, appears to be an important source of nitrogen, which is the only significant impurity in the produced gas.

Activity performed under Reservoir Performance (Task 8.0) last quarter focused on Decline Curve Analysis (Subtask 8.1), and Production Mapping (Subtask 8.2) was completed last quarter. Under Subtask 8.1, decline curves from more than 400 wells throughout the coalbed methane producing areas have been compiled and analyzed. Numerous types of production decline have been identified, and some types of decline curves are characteristic of specific producing areas. For example, areas with high initial water production typically exhibit hyperbolic decline of water rate coupled with exponential decline of gas rate. After about a decade of production, however, gas production flattens, reflecting a transition from production driven by pressure reduction to production that is dominated by steady-state diffusion of gas from coal matrix.

Year 1 (10/1/09-9/30/10)				Year 2 (10/1/10-9/30/12)				Year 3 (10/1/12-9/30/13)			
Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4	Q1	Q2	Q3	Q4
Task 1.0 Project Management Plan											
Task 2.0 Technology Transfer											
Task 4.0 Geologic Framework											
Task 5.0 Basin Hydrology											
Subtask 5.1 Water Chemistry											
Subtask 5.2 Reservoir Pressure											
				Task 6.0 Gas Composition							
				Subtask 6.1 Bulk Composition							
				Subtask 6.2 Isotopic Analysis							
				Task 7.0 Petrology							
				Subtask 7.1 Authigenic Mineralization							
				Subtask 7.2 Isotopes and Trace Elements							
				Task 8.0 Reservoir Performance							
				Subtask 8.1 Decline Curve Analysis							
				Subtask 8.2 Production Mapping							
								Task 9.0 Water Management Strategies			
								Subtask 9.1 Production Strategies			
								Subtask 9.2 Beneficial Uses			
Project Milestones								Milestones 3-7 are critical path milestones			
Milestone 1								Milestone 7			
Milestone 2								Milestone 6			
Milestone 3				Milestone 4				Milestone 5			

Figure 3.—Gantt chart showing scheduling and relationships among project tasks and milestones.

In areas with little or no water production, many wells can maintain a constant gas production rate from initial production onward. Many wells have erratic production histories, which tend to reflect two major factors. The first is frequent well maintenance related to coal fines and scaling. The second factor is related to management of pumping rates. In this case, where wells cannot be pumped to full capacity, water pumping rates are commonly changed several times over the life of a well, resulting in erratic production histories. Inability to pump a well to capacity, moreover, commonly results in reduced production rate. In cases where water pressure cannot be reduced sufficiently, the result is inefficient gas recovery.

Work continued last quarter on Water Management Strategies (Task 9.0). The Black Warrior coalbed methane industry is currently dependent solely on instream disposal of produced water, which limits production in some areas where coalbed methane reservoirs yield large volumes of

hypersaline brine. Discharge points where processed water is issued into the Black Warrior River have been identified and have been incorporated into a geographic information system that is being used to compile and synthesize the vast amount of data collected during this project.

Salinity is the principal variable that dictates water management practice in the Black Warrior coalbed methane fields and precludes the direct use of the produced water for beneficial purposes. Concentrations of lead and mercury, as well as other metallic and nonmetallic constituents that can affect human health, are minimal and therefore are not of major concern for water management. Aside from sodium chloride, organic compounds and ammonia are the main substances worthy of consideration for water management. Organic compounds, which include a variety of extractable hydrocarbons, are nearly identical to those identified in coal of the Powder River Basin. Many of these substances can impact human health, but the low concentrations pose little risk of acute exposure. The effects of long-term exposure are unknown, but the need to remove chlorides makes the likelihood of long-term exposure moot. A system of storage and treatment ponds is used to manage produced water. Synthetic membrane liners and monitoring wells ensure the integrity of impoundments. Pollutants are removed by suspension settling and aeration, which are crucial for mitigating environmental impact. Settling removes fine particles, such as clay and silt. Aeration enables oxidation and flocculation of metallic compounds and facilitates the evaporation, oxidation, and degradation of organic compounds in the produced water. The fate of the ammonia is unclear, but concentrations are lower than 24 milligrams per liter and are thus unlikely to have significant environmental impact.

Next quarter, research will continue on Technology Transfer (Task 2.0) and Water Management Strategies (Task 9.0). All other project tasks have been completed, and the project is on track to be completed according to schedule.

Conclusion

This project is proceeding according to schedule and budget. Technology transfer activities last quarter (Task 2.0) included submission of a manuscript to the International Journal of Coal Geology and preparation of a manuscript for the Unconventional Resources Technology Conference. Sampling of fluids from coalbed methane wells was completed this quarter under Task 6.0. Investigation of Petrology (Task 7.0) has been completed ahead of schedule. Reservoir Performance (Task 8.0) also has been completed and is revealing complex relationships among water and gas production. Completion of Tasks 6.0 through 8.0 means that the Critical Path Milestone scheduled for this quarter has been met according to plan. Accordingly, all project activities have now shifted toward Water Management Strategies (Task 9.0), and efforts will focus on Tasks 2.0 and 9.0 for the remainder of the project. Progress on Task 9.0 indicates that salinity is the primary variable that dictates water management practice in the Black Warrior coalbed methane fields. Aside from chlorides, organic compounds and ammonia are the main substances worthy of consideration for water management. Produced water is processed by suspension settling and aeration. Settling removes fine particles, such as clay and silt. Aeration facilitates the evaporation, oxidation, and degradation of organic compounds in the produced water. The fate of the ammonia is unclear, but the low concentrations in the produced water are unlikely to have significant environmental impact.

COST STATUS

Table 1. Comparison of costs budgeted for Budget Period 3 and actual expenditures through March 30, 2013.

Category	Budgeted Costs			Actual Expenditures		
	DOE*	Participant	Total	DOE	Participant	Total
Personnel	\$77,180	\$41,592	\$118,772	\$22,896.08	\$22,896.06	\$45,792.14
Fringe Benefits	26,241	14,141	40,382	7,555.71	7,555.70	15,111.41
Travel	6,197	0	6,197	1,726.65	0	1,726.65
Equipment	0	0	0	0	0	0
Supplies	968	0	968	909.83	0	909.83
Contractual	0	0	0	0	0	0
Construction	0	0	0	0	0	0
Other	51,460	0	51,460	3,933.70	0	3,933.70
Total Direct Charges	162,046	55,733	217,779	37,021.97	30,451.76	67,473.73
Indirect Charges	46,802	25,221	72,023	13,730.78	13,730.77	27,461.55
Totals	\$208,848	\$80,954	\$289,802	\$50,752.75	\$44,182.53	\$94,935.28

SCHEDULE STATUS

This project is moving ahead according to schedule and budget (fig. 3, tables 2 and 3). Critical Path Milestone 6 (table 3) has been met on schedule, and the remainder of the project will focus on completing Task 9.0.

Table 2. Status of project schedule by task and subtask.

Task	Anticipated completion	Actual completion	Status
Task 1.0 Project Management Plan	11/15/09	11/13/09	Complete
Task 2.0 Technology Transfer	9/30/13		In progress
Task 4.0 Geologic Framework	9/30/12	9/28/12	Complete
Task 5.0 Basin Hydrology	9/30/12	9/28/12	Complete
Subtask 5.1 Water Chemistry	9/30/12	9/28/12	Complete
Subtask 5.2 Reservoir Pressure	3/31/12	3/31/11	Complete
Task 6.0 Gas Composition	3/31/13	3/31/13	Complete
Subtask 6.1 Bulk Composition	3/31/13	3/31/13	Complete
Subtask 6.2 Isotopic Analysis	3/31/13	3/31/13	Complete
Task 7.0 Petrology	3/31/13	3/31/13	Complete
Subtask 7.1 Authigenic Mineralization	3/31/13	3/31/13	Complete
Subtask 7.2 Isotopes and Trace Elements	3/31/13	3/31/13	Complete
Task 8.0 Reservoir Performance	3/31/13	3/31/13	Complete
Subtask 8.1 Decline Curve Analysis	3/31/13	3/31/13	Complete
Subtask 8.2 Production Mapping	3/31/13	3/31/13	Complete
Task 9.0 Water Management Strategies	9/30/13		In progress
Subtask 9.1 Production Strategies	9/30/13		In progress
Subtask 9.2 Beneficial Uses	9/30/13		In progress

Table 3. Milestone schedule. Milestones 3 through 7 are critical path milestones.

Milestone	Description	Scheduled completion	Actual completion
1	Completion of initial Project Management Plan and Technology Status Assessment (Task 1.0)	11/15/09	11/13/09
2	Posting of project web site on internet (Task 2.0).	12/31/09	12/24/09
3	Completion of design of databases for Task 4.0, Geologic Framework, and Task and 5.0, Basin Hydrology	3/31/10	3/19/10
4	Characterization of reservoir pressure complete (Subtask 5.2)	3/31/11	2/18/11
5	Tasks 4.0 and 5.0 complete.	9/30/12	9/28/12
6	Completion of analysis of Gas Composition (Task 6.0), Petrology (Task 7.0), and Reservoir Performance (Task 8.0)	3/31/13	3/31/13
7	Completion of Water Management Strategies (Task 9.0).	9/30/13	

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