

DEMONSTRATED ECONOMICS OF MANAGED IRRIGATION FOR CBM-PRODUCED WATER

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BIOGRAPHICAL SCETCH

Jonathan Paetz is a Senior Project Manager for Cascade Earth Sciences (CES) responsible for the direction and management of CBM production water re-use projects. Jonathan is a Registered Professional Geologist and holds a BS in Geology and an MS in Geophysics. Mr. Paetz is responsible for the development of cost-effective managed irrigation and water management strategies for the re-use of CBM production water. Mr. Paetz recently completed a managed irrigation demonstration project that evaluated the performance and cost effectiveness of multiple water and soil treatments for implementation of managed irrigation using CBM produced water.

Abstract: Coal bed methane (CBM) produced water typically has characteristics that allow for beneficial re-use for crop and vegetation production under proper management. Powder River Basin CBM-produced water has an elevated sodium adsorption ratio (SAR) due to low levels of calcium and magnesium compared to sodium. Water with elevated SAR levels can negatively impact soil and reduce crop and vegetation yields if not managed correctly. However, the produced water and/or the soil can be treated and/or conditioned to lower the SAR and allow this water to be beneficially used in a cost-effective manner. This presentation reviews the economics of an existing managed irrigation system for Powder River Basin CBM-produced water. Based on the evaluation of an actual managed irrigation site with a flow of 12,500 barrels per day (bbl/day), the lifetime cost of a 100-acre system is \$0.005 to \$0.01 per barrel for design and equipment; \$0.04 to \$0.06 per barrel for water amendment; and \$0.02 to \$0.04 per barrel for operation and monitoring for a total project cost of \$0.06 to \$0.11 per barrel. Costs for managed irrigation systems are influenced by water chemistry, soil chemistry, water volume, irrigation season limitations and land management practices.

INTRODUCTION

Managed irrigation of CBM-produced water provides an alternative to direct discharge via the National Pollutant Discharge Elimination System (NPDES) permit process. Managed irrigation provides benefits by allowing for the re-use of the produced water, enhancement of native vegetation and agricultural production. Beneficial re-use of production water is possible when the effects of an elevated SAR are controlled through proper system design and management. Managed irrigation is a cost-effective method of water management if the factors that control cost are understood and managed. The factors that influence the design and resulting cost of a managed irrigation system are presented along with actual project cost to illustrate the relative cost of managed irrigation as a water management strategy.

FACTORS THAT INFLUENCE THE COST OF MANAGED IRRIGATION SYSTEMS

It is critical to understand that all managed irrigation solutions are site specific. The design approach, amendment application rate, and water application equipment selected for a particular project are unique to the water and soil chemistry of the location. The factors that influence the cost of managed irrigation – water chemistry, water volume, soil chemistry and physical properties, and irrigation season limitations – are discussed below.

Water Chemistry

Produced water chemistry is the primary driver in terms of cost for the implementation of a managed irrigation system. CBM production water of the Powder River Basin typically has an elevated SAR due to the high concentration of sodium (Na) relative to calcium (Ca) and/or magnesium (Mg). To compound this water's high SAR, it also contains relatively high amounts of bicarbonate, which in effect raises the SAR of the water even more from the resulting chemical reactions. Bicarbonate (HCO_3^+) concentrations can range from 1,000 to 3,500 mg/l with sodium concentrations ranging from 500 to 1,000 mg/l.

The application of high SAR water can cause soil dispersion. A dispersed soil structure can cause the soil to become almost impermeable to rain or irrigation water. A dispersed soil is sticky when wet, forms a crust, becomes very hard and clod-like when dry, and water infiltration is severely restricted. Dispersion of the soil particles caused by sodium may result in poor physical soil conditions, and water and air can not readily move through the soil, which can in turn cause a reduction in plant growth.

To reduce the dispersive effects of soil caused by the sodium in CBM-produced water, the water chemistry must be adjusted by the addition of amendments. The cost of amendments directly influences the cost of managed irrigation. Higher bicarbonate and sodium concentrations typically result in higher amendment costs for the same soil type. Therefore, each individual water chemistry has a specific amendment rate that influences the final cost of managed irrigation of the water.

Water Volume

A key variable in the production of CBM is the estimation of the volume and rate of decay of produced water required to achieve gas production. The volume and rate of produced water also influences the cost of managed irrigation. The combination of water chemistry and flow rate influences the volume of amendments required, the type of amendment delivery system selected, and the size and cost of the irrigation system.

There are two methods of amendment application: direct surface application and in-line injection. The direct application of amendments to the soil surface is typically used for low flow rates, especially if high rates of amendments are necessary. Higher flow rate systems warrant the use of in-line flow amendment injection systems. Only with the evaluation of the water chemistry and projected flow rate can the proper method of amendment application be determined.

The projected flow rate and rate of decay are important in selecting the proper irrigation equipment to distribute the water across the soil surface in a uniform and controlled manner. The type of irrigation system and the capital and labor cost associated with the system need to be evaluated using the anticipated flow rate and rate of reduction in the water flow. In some cases, phasing of well development can reduce the capital cost of equipment for a managed irrigation system. For example, if new wells are brought online as the flow from earlier wells is

decreasing then the maximum flow managed by the irrigation system is controlled which reduces the size of the system.

A variety of permitting conditions also influence the size and cost of the managed irrigation system. A permitting condition that allows for the application of produced water during the growing season (April through October) and the direct discharge of the produced water during the non-growing season (November through March) is the most favorable scenario in terms of project cost. This condition reduces the size of the system and volume of water requiring amendments.

Other operational scenarios may require the application of water during the growing season with winter storage during the non-growing season. This requires the construction and permitting of a reservoir large enough to contain all water produced during the non-growing season. This results in an increase in the number of acres and equipment required to properly apply the produced water because you are managing the annual flow during a seven-month season, plus the application of amendments for the entire flow.

If permitting conditions do not allow for winter storage of the produced water then year round application can be considered. This results in a need for a large land area and increased water equipment application costs to apply water during freezing conditions. Alternative cropping scenarios utilizing annual grass species should be considered to counter the effects of ice buildup during the winter application season.

Soil Chemistry and Physical Properties

A majority of the soils in the Powder River Basin contain a low “free” calcium concentration. This is a critical factor to evaluate when considering the managed irrigation of a water source with an elevated sodium and bicarbonate concentration. This lack of “free” calcium is the primary reason why amendment addition is critical to the success of managed irrigation. Typically, the addition of a calcium source is required to counter the effects of the sodium in the produced water. The presence of bicarbonate in produced water will tend to form calcite in the soil and limit the availability of the applied calcium. Management of the level of bicarbonate is essential to maintain a sustainable managed irrigation system. Therefore additional amendments are required to control the bicarbonate found in produced water.

Soil type and the associated physical characteristics have a major effect on the overall size and type of water application equipment and therefore a direct effect on the cost of managed irrigation. For example, the rate at which produced water can be applied to the soil is limited to the saturated hydraulic conductivity of the soil (also known as the saturated infiltration rate). Sandy soils with a low clay content are favored over soils with a larger percent of clay simply because sandy soils typically have a higher infiltration rate and are less reactive with the produced water.

Irrigation Season Limitations

The rate at which produced water can be applied is also affected by seasonal variations of temperature, evaporative potential and transpiration by plants. Spring and fall are seasons with lower evapotranspiration rates requiring reduced daily application rates. Summer provides for higher evapotranspiration rates allowing for higher application rates to maintain equivalent soil moisture levels.

A managed irrigation system must be designed around these seasonal variations and the variable flow conditions of the CBM well field to provide for the consistent application of produce water and amendments throughout the year in a cost-effective manner.

MANAGED IRRIGATION PROJECT COST

The development of a managed irrigation system is a step-wise approach that involves evaluating the chemistry of the produced water and site soils, determining the size of the required system based on projected water volumes then selecting appropriate irrigation equipment to distribute the water. Ongoing operation and monitoring of water

amendments, irrigation efficiency, soil chemistry and system maintenance are equally important. The steps and cost of the development, operation and maintenance of a managed irrigation system are outlined below.

Project Development and Design

Conducting a Desktop Evaluation and Field Soil Assessment begins the initial development of a project. These activities can be conducted one at a time or concurrently.

The Desktop Evaluation uses the actual CBM water quality along with reference materials on the site soils and area topographic or photographic maps to develop a preliminary system layout and cost estimate ($\pm 25\%$). The Field Soil Assessment is completed to determine the site-specific characteristics of site soils and identify the most favorable location for the system. A refinement of the project design and cost is also performed after the completion of the soil assessment.

System Design

Upon completion of the Desktop Evaluation and Field Soil Assessment, a System Design can be completed. The design involves developing engineering calculations and specifications on the layout and design of the irrigation system including the pipeline and pumping system to deliver water to the irrigation equipment. During the equipment design phase the specific type of irrigation equipment is selected and a system layout developed based on the physical characteristics of the soil identified during the soil assessment. Also, if in-line amendment application systems are appropriate, the system capacity is specified and integrated into the overall design of the irrigation system.

Typical cost for project development and system design effort are \$0.002 to \$0.003 per barrel for a 12,500 barrel a day (17 MBBL lifetime) system over 4 years of operation.

MANAGED IRRIGATION EQUIPMENT OPTIONS

Different types of irrigation equipment can be utilized for the application of CBM-produced water. The volume of water and the soil application rate are the primary variable to be considered in selecting a cost-effective water application system. Various types of irrigation equipment can provide the required application rate at the particular flow requirement but vary greatly in the level of labor required to operate the irrigation system effectively. Understanding the limitations and operational characteristics of various types of irrigation equipment is what achieves a cost-effective managed irrigation system design.

The different types of irrigation equipment utilized for the application of CBM produced water consist of wheel line or side roll, solid set, traveler, and center pivot systems. Each type of irrigation equipment has a different cost related to initial capital investment, ongoing labor, operation and maintenance, and management to achieve the range of application rates necessary to effectively operate a managed irrigation system.

Capital Equipment Cost

The type of irrigation equipment selected is critical to the design of a cost-effective system. Equipment selection is completed during the design stage of the project. The most cost-effective equipment for the application of produced water is selected based on flow rate and anticipated rate of decay; soil physical properties (soil infiltration rate determined during field assessment); and acres required to accept the expected produced water volume. A balance must be struck between the initial equipment cost, ongoing labor cost and required water application rates. The overall objective in the design of a water application system is to achieve the greatest level of uniformity of water application for variable application rates at the lowest equipment and labor cost.

For comparison purposes the initial equipment and operational labor costs are compared for a 100-acre system requiring a 0.25-in/day application rate for a flow rate of 12, 500 bbl/day.

Wheel Line or Side Roll

A wheel line consists of a 4 to 5-inch diameter pipe connected with metal wheels that extend out from a center drive motor. The typical length of a wheel line system is $\frac{1}{4}$ mile with the drive motor positioned in the middle of the system. Sprinklers are positioned along the metal pipeline and the wheel line sits stationary while water is

applied through the system. Once the required volume of water is applied, the wheel line is drained and moved forward by an operator approximately 60 feet to the new location.

Three ¼-mile wheel line systems would be required to meet a design flow rate of 12,500 bbl/day. The per system initial capital cost of \$9,000 to \$12,000 per wheel line is relatively low, but manual moving of the wheel line is necessary after each application event. During the high evapotranspiration summer months, set times can be as great as 10 to 12 hours before the wheel line would need to be moved to a new location. During the spring and fall when evapotranspiration losses are lower, the set times would be limited to as little as 1 hour, which would apply approximately 0.25 in/set. Again, manual labor is required to move the wheel line to the next field position. The cost of labor can range from \$1,500 to \$15,000/month based on the necessary set times to achieve the required (designed) application rate and prevent surface ponding and run-off.

Disadvantages of wheel line systems include; they cannot be operated in freezing conditions without risking damage, uniformity of application is moderate, can not be operated remotely, can over apply if not moved on time and requires more frequent attention to move them. Advantages include; lower initial capital cost and can be moved for field activities (amendment application, harvest, etc.).

Solid Set System

A solid set system consists of a series of pipelines with risers and sprinklers attached to the risers to distribute water across the land surface. Solid set systems can be constructed with aluminum hand line piping, which allows for movement of the system from one field to another, or they can be constructed as a fixed pipeline system for permanent installation. The spacing of the pipeline and sprinklers determines the application rate while increasing or decreasing the operating time controls the volume of application.

Solid set systems range in cost from \$1,500 to \$2,500 per acre. To construct a 100-acre system would require two, 25-acre hand line systems or four, 25-acre fixed lined systems. The total cost of the system would range from \$75,000 to \$250,000. For a movable hand line system consisting of two, 25-acre systems, the labor cost per month would be \$5,000 to \$10,000 to pick up and move the system from location to location for low application rates near 0.25 in/day.

Disadvantages of solid set systems include; they cannot be moved for field activities if fixed, uniformity of application is moderate when properly designed, can over apply if left on too long and requires higher initial capital cost. Advantages include, less labor required if they are fixed, can be operated in freezing conditions if designed correctly, and can be operated remotely.

Traveler System

The traveler system consists of a big volume gun attached to a flexible pipeline on a large reel. The flexible pipeline is rolled out and the big gun is retracted on the reel. This system requires the reel and big gun to be repositioned and rolled out along separate irrigation lanes. Each traveler unit costs approximately \$25,000 to \$35,000 and a flow rate of 12,500 bbl/day would require four units. Labor cost typically range from \$2,500 to \$5,000 per month. Low application rates such as 0.25 in/day require that the system be designed initially for a low application rate and the unit frequently repositioned.

Disadvantages of Traveler Systems include; they can not be operated in freezing conditions, have the potential to over apply if not moved on time, can not be operated remotely, and uniformity of application is lower than other options. Advantage include, they are easily moved from site to site and can be moved out of the way for field activities.

Center Pivots

Center pivots consists of a sprinkler line supported on wheeled towers and electrically self-propelled around a central pivot point. Two, 50-acre center pivots at \$1,125/acre including installation would cost approximately \$112,500 for a 100 acre-system. The center pivots would be designed to apply water at the instantaneous application rate of the soil and would be capable of applying water over a wide range of application rates. Labor and maintenance for a center pivot system is approximately \$500 per month independent of application rate. The

uniformity and application rate control from a center pivot is high compared to the other types of equipment evaluated.

Disadvantages include; moderate to high initial capital cost and are not easily transportable from site to site unless towable units are utilized. Advantages include; remote operation possible, can be operated in freezing conditions, can be moved for field activities, and are least likely to exceed application rate.

System Operation and Monitoring and Maintenance

The operation of a managed irrigation system requires the development of irrigation schedules and the regular monitoring of soil and produced water quality. The cost of operation, monitoring and maintenance is approximately \$0.02 to \$0.04 cents per barrel of produced water.

MANAGED IRRIGATION PROJECT EXAMPLE

To illustrate the relative lifetime project cost of a managed irrigation, an example of an existing managed irrigation project with the following characteristics is evaluated:

- Current flow rate of 12,500 bbl/day (365 gpm)
- Water quality – HCO₃ of 3,000 mg/l, Na of 600 mg/l, SAR of 25
- Soil – sandy loam
- 100-Acre system utilizing four center pivots
- Field applied amendments (sulfur and gypsum)
- Amendments field applied for every 6 to 7 inches of produced water applied.

The site began operation in September 2001 and has operated for approximately one year with an amendment cost of approximately \$0.05 to \$0.06 per barrel. Amendments have been field applied with a tractor and spreader. The projected amendment cost at the end of four years of operation (December 2006), assuming a reduction in the flow rate of 25% beginning in 2004, yields a per barrel cost for amendments of approximately \$0.04. The cost of design, development, equipment, operation and monitoring adds approximately \$0.02 to \$0.04 per barrel, resulting in an overall cost of \$0.06 to \$0.08 per barrel. The final cost will be dependent on the total volume of water and the rate at which the flow rate decreases.

Amendment cost per barrel stays constant with the decrease in flow rate; operation and monitoring cost decreases with reduced flow. Irrigation equipment that is no longer required due to a decreased flow can be transferred to other sites or sold, further reducing the cost of the managed irrigation system.

The cost of this project would be less per barrel if: the produced water contained less bicarbonate; the site soils contained a higher percentage of sand; the site topography was smoother; a forage crop was produced, harvested, and sold.

CONCLUSIONS

Based on the evaluation of an actual managed irrigation site with a flow of 12,500 bbl/day, the lifetime cost of a 100-acre system is \$0.005 to \$0.01 per barrel for design and equipment, \$0.04 to \$0.06 per barrel for amendments, and \$0.02 to \$0.04 per barrel for operation and monitoring, for a total project cost of \$0.06 to \$0.11 per barrel. Cost for the example system is \$0.06 to \$0.08 per barrel.

Managed irrigation of CBM-produced water provides a cost-effective alternative to direct discharge and provides for a beneficial use of a valuable resource. The development of a managed irrigation system is a step-wise process, which evaluates the site-specific water and soil chemistry, anticipated water volume and irrigation equipment to develop a site-specific solution.