Principals of Managed Irrigation with Coal Bed Natural Gas Produced Water

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Coal Bed Natural Gas (CBNG) produced water may be characterized as having elevated sodium bicarbonate concentrations with or without an accompanying high salinity level. If untreated or inappropriately managed, the high volumes of CBNG produced water pumped from gas production wells can cause severe impacts to receiving streams under direct discharge scenarios or to soil productivity if applied to land surfaces either as an overland flow or in an irrigation scenario. Given that much of the CBNG drilling being developed is in rural agricultural regions, the water itself would have a high value as a potential irrigation source if the salinity and sodium issues could be economically addressed. In areas with favorable soil conditions (i.e., low to moderate clay content), CBNG produced water with even relatively high sodium adsorption ratios (SAR) and low to moderate salinity concentrations can be successfully managed as an irrigation source using appropriate application technology and soil amendments (e.g., sulfur and gypsum) applied to the field's surface thus avoiding the need for more expensive in-line water treatment processes. This paper reviews the principal challenges and solutions to utilizing CBNG produced water as source water for irrigated agricultural.

A land-based CBNG production water management system, often referred to as land application, is a cost-effective, natural way to reuse CBNG production water in a soil/crop system by applying the water in a controlled manner. Due to the unique water quality (elevated sodium, salinity, and bicarbonate concentrations) of CBNG produced water, proper site selection and water chemistry evaluations are necessary in order to design land application systems to help ensure that soil impacts are minimized and that the land where the irrigation occurs remains productive (i.e., the overall soil structure is not destroyed to the point where the land cannot support the native biomass community).

Land-based treatment systems can be effectively used as a part of an overall CBNG water management strategy. However, for land-based management to be successful, the CBNG produced water quality and soil characteristics must be assessed and appropriately managed to minimize the impacts to soil structure and productivity. The primary concerns with the irrigation of CBNG production water include *salinity* and *sodium adsorption ratio* impacts to the soil, which can result in decreased infiltration, soil sealing, and reduced vegetative growth.

Salinity

Salinity is a measure of the mineral salts present within either the soil or water of interest. The salinity of water can be expressed in many different ways but is most commonly referenced as either electrical conductivity (EC) or total dissolved solids (TDS). The EC

$$EC = \frac{TDS}{0.64}$$

and TDS are very closely related and can be related by the following equation:

where:

EC = electrical conductivity (μmhos/cm)

TDS = total dissolved solids (mg/L).

Note: The conversion factor of 0.64 may vary slightly based on specific water chemistries, but generally averages 0.64.

High salinity water used for irrigation can cause the soil salinity to increase to levels that can impact crop growth and yields. Usually, the salinity of the irrigation water is not a problem until the cumulative amount of water-applied increases the salinity of the soil to a point where the concentration in the soil decreases crop productivity (Ayers and Westcot, 1985). This decrease in crop productivity is related to the osmotic effects that the elevated salt levels in the root zone exhibit on the crop. This osmotic stress on the crop inhibits the individual plant from extracting water from the soil efficiently (Hanson et al. 1999). Irrigated crop yields tend to be more affected by the average root zone salinity (EC_e) than that of the irrigation water salinity (EC_w) itself (Ayers and Westcot, 1985). However, the salinity of the irrigation water directly affects the salinity of the soil and there has been considerable research to determine the productivity impacts based on the irrigation water EC_w levels (Ayers and Westcot, 1985; Hanson et al., 1999; Ludwick et al., 2002). This research illustrates that most agricultural crops can withstand a soil EC_e of 3.0 mmhos/cm (3,000 μmhos/cm) while many of the forage grass crops have tolerance levels as high as 5 or 6 mmhos/cm.

In a CBNG managed irrigation scenario, the salts are handled primarily by leaching salts out of the root zone and, to a much lesser extent, crop uptake. The quantity of leaching that is required for maintaining a soil at a desirable salinity level can be calculated as

$$LR = \frac{ECw}{5ECe - ECw}$$

shown in the following formula:

where:

LR = leaching requirement as a percentage of total irrigation water

EC_w = salinity of the applied water

EC_e = soil salinity tolerated by the crop

Please note that if the salinity concentration is too great, the leaching requirement becomes increasingly large and may not be achievable with normal irrigation activities. Also, it is much more efficient to design for annual leaching of accumulated salts over the entire season than to try and attain the leaching requirements in one single event.

Sodium Adsorption Ratio

The sodium adsorption ratio (SAR) is the ratio of sodium to calcium and magnesium. It is used as a measure of the impacts that irrigation water might have on soil permeability. The SAR is sometimes referred to as a relative scale of water sodicity. Unlike high salinity in the soil, elevated SAR levels do not directly affect plant growth or yield. However, elevated soil SAR will cause clay particles to swell and disperse. This swelling and dispersion of the soil clay particles will reduce the permeability and the available water holding capacity of the soil, which ultimately reduces the amount of soil water that is available for the plants. The SAR is typically calculated as follows:

$$SAR = \frac{Na}{\sqrt{\frac{Ca + Mg}{2}}}$$

where:
Na = sodium concentration (meq/L)
Ca = calcium concentration (meq/L)
Mg = magnesium concentration (meq/L)

Since the soil profile will be driven to reach ionic equilibrium with the irrigation water, any irrigation water with elevated sodium concentrations will have a tendency to replace the soil particle ionic sites with sodium, leading to the swelling and dispersion of clay particles. If the water or soil profile is dominated by calcium and/or magnesium, the impacts from sodium are reduced (i.e., soluble calcium will compete very effectively against sodium for the negatively charged sites on soil clay particles - refer to Figure 1 below).

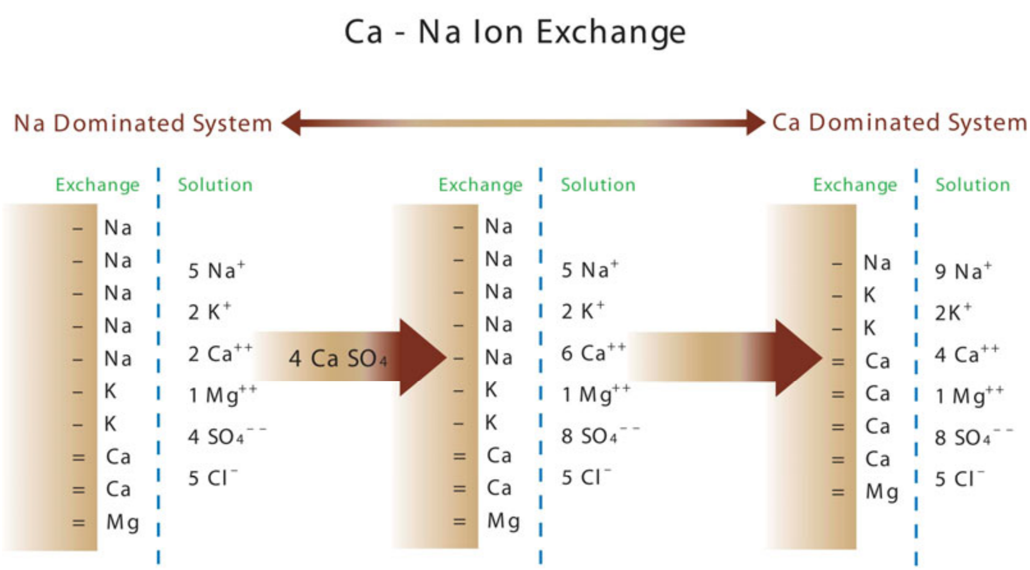
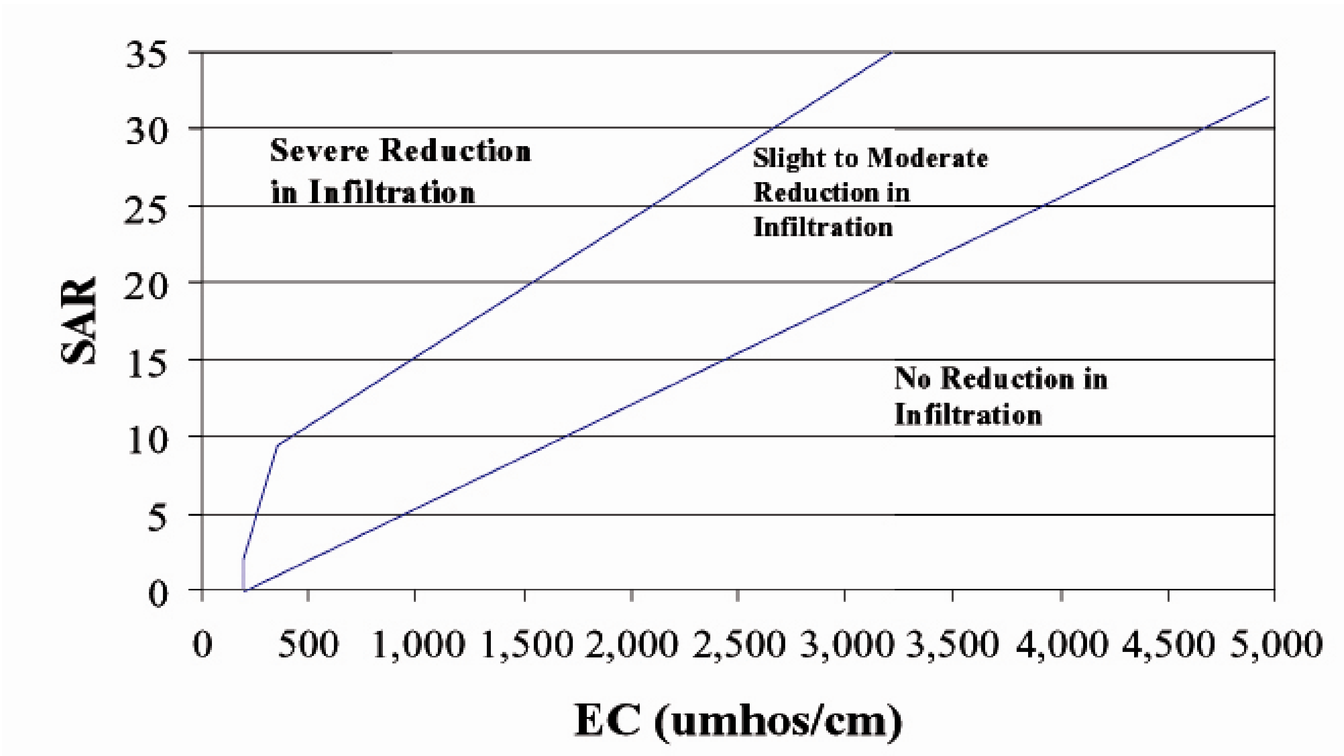


Figure 1. Ca - Na Ion Exchange Illustration (Ayers and Westcot, 1985)

This relationship is reflected in the SAR formula, which shows that if calcium and magnesium concentrations are low and sodium is high, then the SAR will be high, as is the case for most CBNG produced water. Conversely, if calcium and/or magnesium concentrations increase relative to sodium, then the SAR will decrease. Irrigation water with an elevated SAR will have a greater effect on heavier soils (i.e., those having a higher concentration of clay) as compared with lighter soils (e.g., sandy soils).

The overall impact from sodium, as measured by SAR, can be mitigated to a certain degree by increases in EC_e. In other words, the higher the salinity of the water, the higher the SAR that can be accepted without impairing soil permeability since clay particles are less likely to swell and disperse under elevated salinity situations. The graphical relationship between SAR and EC_e is illustrated in the following graph taken from Hanson et al., 1999.



The acceptable irrigation water SAR level for any given site is therefore dependent upon the irrigation water, soil salinity, soil texture (i.e., clay content), and the amount of calcium and/or magnesium present, or which needs to be added, to the soil profile.

Sodium Management

There are several approaches or combination of approaches that can be used for the mitigation of the sodium impacts to soil associated with the irrigation of CBNG produced water. The first approach is to maintain a balance between the EC_e and the SAR so that the EC_e remains below the crop tolerance level yet is high enough to offset the impacts resulting from the irrigation of water with an elevated SAR. The second approach is to reduce the SAR in the soil profile by adding calcium or magnesium in sufficient quantities to reduce the overall SAR in the soil. This can be accomplished by either adding calcium and/or magnesium to the irrigation water itself or by incorporating it into the soil. At most sites developed for the irrigation of CBNG produced water, calcium is typically surface applied in the form of gypsum with an acid source (e.g., sulfur) provided to consume the bicarbonate alkalinity of the produced water (i.e., lower the pH) so that the added calcium will be dissolved. However, this approach will cause the EC_e to increase and may be limited if the EC_e has to be increased in excess of the crop tolerance level to compensate for the SAR. The third approach is to remove the sodium or salinity from the water prior to irrigation. Unfortunately, this approach has typically been shown to be costly and usually produces a brine water side stream that requires off-site transportation and disposal.

Salts and pH are typically managed using soil amendments and controlled leaching. Controlled leaching is a management tool that allows us to percolate a set amount of water out of the root zone and into the geologic profile for storage. This process must be closely managed because excess leaching can lead to groundwater impacts. As such, it is critical that the land application system have an irrigation system where the water can be fully controlled (e.g., center pivot mechanical irrigation as opposed to flood irrigation, which is highly uncontrolled). Because of this, land application is not the same as just placing water in an irrigation ditch for use by others. It is a well-managed treatment approach designed to maximize the treatment potential of a soil/crop system. The following diagram summarizes the various processes that are incorporated with land application:

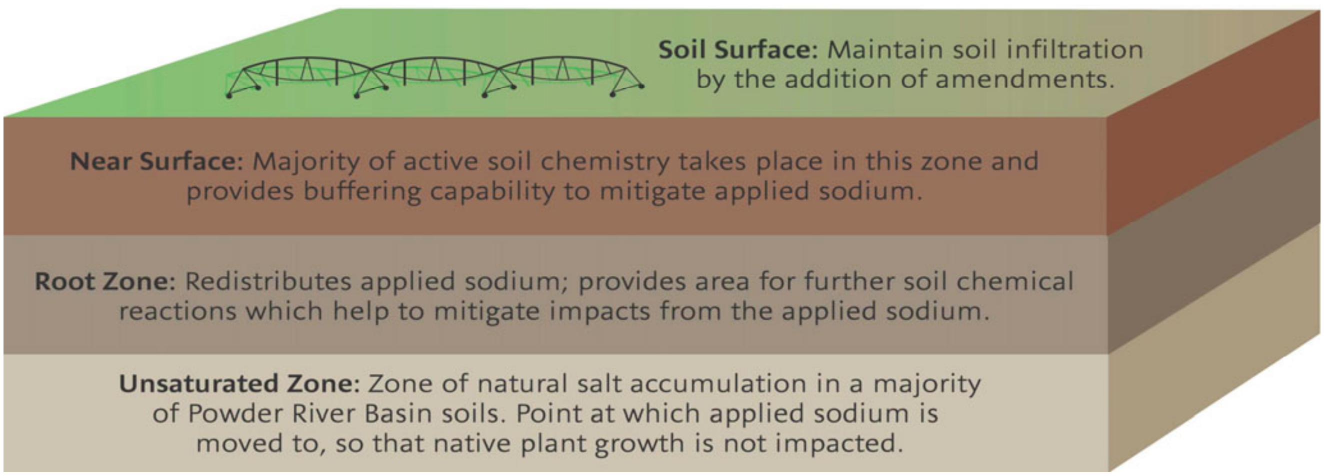


Figure 3. CBNG Irrigation Soil Profile (courtesy Cascade Earth Sciences)

Operational Requirements

The operation and monitoring of a land application system is dependent upon the CBNG production water quality, site soil characteristics, amendment application scheduling, crop characteristics, application system (e.g., pivot, subsurface drip, etc.) and regulatory requirements. The CBNG production water flow and application rate is typically monitored on a weekly basis in order to determine the loading volume on a per acre basis at each application site. The CBNG production water itself is usually monitored on a monthly basis if the quality has high variability, but as little as once per quarter if the quality parameters are considered stable.

Most systems have at least a part-time operator who is responsible for operating the irrigation system(s) and determining weekly irrigation schedules to ensure that a site is adequately irrigated, but is not overloaded with constituents (salts). This individual is also responsible for performing routine maintenance on the equipment. Site monitoring requirements can include groundwater monitoring at sites with shallow aquifers, soil moisture monitoring to determine the depth of irrigation penetration, and crop quality (health and harvest scheduling, etc.).

The system is usually assessed at least annually to determine crop adjustments, water trends, and soil amendment adjustments. Much of this information is summarized in an annual report to show that the system is being operated and managed as proposed and to make adjustments to the operation or amendment schedule to address any corrective actions that need to be implemented to maintain the productivity of the site. Land application systems are very resilient so most imbalances can be corrected by changing the irrigation rate or making adjustments to the soil amendment rates within a season or two.

Benefits of Land Application

There are many economic and environmental benefits of land applying CBNG production water. The benefits of using land application, when possible, versus other treatment and discharge methods include:

- Lower energy costs – A land application system requires much less energy to operate and maintain than a typical water treatment system design to remove salts. The highest energy use component of a land application system is usually associated with the pumping of production water from the collection point to the land application site. While a water treatment system would require similar cost to pump the production water from the collection point to the treatment system, the net energy requirements for irrigation is less than a water treatment system.

- Brine disposal elimination – A water treatment system utilizing any type of membrane filtration or ionic removal process (e.g., reverse osmosis) will require backflushing or the creation of a decant stream. This side stream, which carries the waste ions (Na, Ca, Mg, B, etc.) in solution, will require on-site storage and eventual disposal. No waste disposal streams are generated with the use of a land application system. The ions present in the production water are managed throughout the irrigation process by the application of amendments and controlled leaching.

- Reduced system upsets/compliance issues - Land application systems have the resiliency to recover from short-term overloads and upsets. An upset at a water treatment system usually allows non-treated or under-treated production water to enter the environment at the discharge point. This does not occur with land application since it is, in affect, a zero-discharge system and the permit, if one is needed, is based on a monthly or annual mass loading approach rather than on a concentration basis (e.g., maximum soil SAR limits instead of a maximum SAR or TDS concentration at the discharge outfall).

Overall, a land application system can accept much higher solids, temperature, and nutrient levels than a surface discharge allows.

- Potential opportunities for local revenue improvement - By reusing production water as an irrigation source, landowners or operators have the opportunity to save on irrigation water and pumping costs while maximizing crop productivity.

- Net water savings - Reusing production water for irrigation can reduce the net demand on freshwater resources. This is especially important in areas facing water scarcity problems.

- Net capital savings - Land applications systems are typically less expensive than water treatment systems that remove sodium and other ions from the production water prior to discharge. Land application systems can be easily expanded (e.g., just add more land compared to construction of additional ponds or mechanical treatment systems). The same holds true for adding land application to an existing water treatment system to alleviate additional discharge requirements if the existing system is routinely being overloaded.

Potential Risks of Land Application

While the benefits of land application might appear numerous, there are a number of risks associated with this process that should be considered.

- Excess Hydraulic Loading - One potential risk is excess hydraulic loading (i.e., over-irrigation). Over irrigation will cause deep percolation, which has the potential of carrying constituents (salts) to an underlying aquifer. It is therefore extremely important for the irrigation to be conducted in a controlled manner (e.g., sprinkler irrigation using center pivots or linear move systems) and the site routinely monitored (e.g., soil conditions, soil moisture, crop productivity, shallow groundwater, etc.). As such, flood irrigation is not considered a usable approach for the land application of CBNG production water.

- Constituent Loading - The greatest risk associated with the land application of CBNG production water is the potential impact to crop productivity due to the reduction in soil infiltration rates. Sustained or even limited irrigation with water containing a high SAR can and will seal the surface soils which will prevent any water from percolating into the soil profile. This will be the case if the proper assessment, design, monitoring, and management of a land application system are not conducted. While the land application of CBNG production water can be successful designed and managed to minimize the impacts to soil structure and productivity, soil sealing and increased salinity must always be monitored and managed.

- Site Selection - It must be stated that land application is not suitable for all situations. Some site specific soil conditions (high clay content) and production water qualities (extreme sodium concentrations) do not allow for land application to be the most cost effective water management solution. Pumping and piping costs can become prohibitive if the production water must be transported over long distances to deliver the water to a location with favorable soil characteristics. Finally, care should be taken to assess groundwater resources in the area. Sites with shallow aquifers should be avoided since the goal is to precipitate the salts in the geological zone below the crop root zone but above the nearest aquifer (refer to Figure 3).

Conclusions

Land application is a cost-effective approach to managing CBNG produced water. While the benefits associated with land application are great (e.g., lower energy costs, no by-product disposal requirements, reduced system upsets, lower operating and capital costs, and regional water savings), a land application system must be well designed and operated so as to avoid the inherent risks associated with this water management approach (e.g., soil sealing, salinity impacts, groundwater pollution, etc.). Given favorable site conditions, a properly designed and operated land application represents one of the least expensive methods for managing CBNG produced water.

References

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