TECHNICAL EVALUATION OF OPTIONS FOR LONG-TERM AUGMENTATION OF THE COLORADO RIVER SYSTEM

COALBED METHANE PRODUCED WATER

BY:
DOUG ELDER
SENIOR WATER TREATMENT PROCESS ENGINEER
BLACK & VEATCH

Q/C:
DAN ROBINETTE, SENIOR ENGINEER
WATER AND WASTEWATER
CH2MHILL

Final: August 2007
Released: March 2008

TABLE OF CONTENTS

1.1 Summary and Purpose 1
1.2 Background 1
1.3 Overview of Option 1
1.4 History/Viability of Obtaining Water From This Source 2
1.5 Location of Supply 3
1.6 Amount of Water 3
1.7 Water Quality 6
1.8 Technical Issues 6
  1.8.1 Availability 6
  1.8.2 Proximity to Colorado River and Major Tributaries 7
  1.8.3 Treatment Requirements 7
  1.8.4 Useful Life of Treatment and Conveyance Facilities 8
1.9 General Reliability of Supply 8
1.10 Environmental Issues 9
1.11 Permitting 9
1.12 Costs 9
1.13 References 10
1.14 Conclusion 11

TABLES

Table 1 Potential CBM Produced Water Sources within Colorado River Basin 3
Table 2 Unit Water Production Data for Rocky Mountain Region Coal Basins 5
Table 3 Projected Costs for Desalination of CBM Produced Water 10
Table 4 Summary of Findings Related to Coalbed Methane Produced Water Option 12

FIGURES

Figure 1 Coalbed Methane Resources within the Colorado River Basin 4

ACRONYMS

AFY	acre-feet per year
CBM	coalbed methane
CRWC	Colorado River Water Consultants
gpm	gallons per minute
MAF	million acre-feet
MCF	thousand cubic feet
mgd	million gallons per day
mg/L	milligrams per liter
NPDES	National Pollutant Discharge Elimination System
O&M	operations and maintenance
PRB	Powder River Basin
psig	pounds per square inch gage
RO	reverse osmosis
SAR	sodium adsorption ratio
Seven States	Seven Colorado River Basin States
TCF	trillion cubic feet
TDS	total dissolved solids
U.S.	United States
USEPA	United States Environmental Protection Agency
USGS	United States Geological Survey

1.0 COALBED METHANE PRODUCED WATER

Doug Elder, Senior Water Treatment Process Engineer
Black & Veatch

1.1 SUMMARY AND PURPOSE

This discussion of coalbed methane (CBM) produced water is one of a series of White Papers being prepared for the Seven Colorado River Basin States (Seven States). The purpose of the White Papers is to present evaluations of potential options to provide long-term augmentation of the water supply of the Colorado River system. This White Paper presents background information on the overall evaluation program, followed by a preliminary evaluation of the CBM produced water option.

1.2 BACKGROUND

The Seven States have authorized Colorado River Water Consultants (CRWC) to provide a technical evaluation of long-term options. The States will supplement the technical evaluations with legal, administrative, and/or institutional considerations.

The White Papers are the first step in an iterative process to develop, screen, and evaluate options. Evaluation parameters will be applied progressively and will be developed in increasing detail as selected options become more promising. In parallel with White Paper development, the CRWC research team will meet with representatives of the Seven States and will refine the White Papers/develop new White Papers based on their input. White Paper results will be reviewed with a Technical Steering Committee comprised of delegates from the Seven States.

Each White Paper will present a brief overview of the option being evaluated, followed by discussions of history and viability of obtaining additional water from the source, location of supply, quantity of water potentially available, water quality, technical issues, general reliability of supply, environmental issues, permitting issues, and project costs. A list of reference documents for each White Paper will be included, and general findings and conclusions will be provided.

1.3 OVERVIEW OF OPTION

CBM is natural gas associated with coal deposits. While the presence of methane gas in coal deposits has been documented for many years, methods for economically collecting the gas have only existed since the early 1980s. Initial large-scale efforts to obtain CBM gas occurred primarily in the Powder River Basin area of Wyoming and Montana in 1987. The five Rocky Mountain States of Colorado, Montana, New Mexico, Utah, and Wyoming have long led the United States (U.S.) in production of CBM, and additional wells continue to be constructed as both the demand for and the cost of natural gas in the U.S. have increased. Methane is generally considered a cleaner form of energy than traditional oil and coal; exploration costs for CBM are relatively low, and wells used to extract CBM are very cost-effective to develop.

CBM is held in place by the hydrostatic pressure of the water that fills factures (cleats) within the coal deposit. To produce gas from CBM wells, it is first necessary to reduce the hydrostatic pressure within the coal seam by pumping of some of the water from the gas-bearing coal seams. As water is pumped out of the formation and the hydrostatic pressure drops, the gas desorbs from the coal into the cleats and migrates into the well. Eventually, as pressure and water production decline, gas production increases, and a well may have a long productive period with relatively high gas production and little or no water production. Generally, as the depth of the coal deposit increases, less water is present, but the salinity/total dissolved solids (TDS) of the water is higher than for more shallow deposits.

The rate of CBM gas production is a product of several factors that vary widely from basin to basin. These factors include fracture permeability development, type of coal, coal maturation and distribution/burial depth, geologic structure, produced water management practices and extent/duration of prior CBM production within the basin. While estimates of CBM availability and production vary widely, approximately 1.5 trillion cubic feet (TCF) of CBM was reportedly produced during 2004 in the five Rocky Mountain States. This volume represented approximately 6 percent of the total U.S. natural gas supply. Estimates of total readily-available CBM within the Rocky Mountain States show values as high as 63 TCF. (Various estimates cite total in-place CBM resources for the entire U. S. as approximately 700 TCF, but less than 100 TCF of this total is likely economically recoverable.) The United States Geological Survey (USGS) estimates that approximately 50 TCF of CBM is present in the Powder River, San Juan, Uinta, Piceance, and Raton basins that could be extracted using current technology.

1.4 HISTORY / VIABILITY OF OBTAINING WATER FROM THIS SOURCE

The CBM industry has generally viewed and treated the produced water associated with gas recovery as a waste product that must be disposed at the least possible cost, rather than as an asset that could potentially be used beneficially. Therefore, experience with beneficial use of the produced water, and particularly for stream flow augmentation, is currently very limited. For example, in Montana, only one untreated direct discharge of CBM produced water to a surface water supply has been permitted, that being the Tongue River between the Wyoming state line and the Tongue River Reservoir; permitted discharge rate is reported to be 1600 gallons per minute (gpm), or 2,581 acre-feet per year (AFY).

Current beneficial uses of produced waters include wildlife and livestock watering, irrigation, and discharge to groundwater recharge basins. However, in most cases, CBM produced waters are currently disposed by injection into Class II underground injection wells.

1.5 LOCATION OF SUPPLY

Based on review of recent CBM development data and production estimates, potential sources of CBM produced water within the Colorado River Basin and associated CBM reserves are summarized in Table 1, and approximate CBM basin locations relative to the Colorado River and its major tributaries are shown on Figure 1.

Table 1
Potential CBM Produced Water Sources Within Colorado River Basin[1]

Basin / Location (state[s])	CBM Produced (TCF)[2]	CBM Reserves (TCF)[3]		Current Development Status
		Proved[4]	Total Est.[5]	
San Juan (CO, NM)	9.464	8.547	10.2	Highly developed
Piceance (CO)	0.039	1.801	5.5	Moderate development
Uinta (UT, CO)	0.413			Moderate development
Greater Green River (WY, CO)	0.002	0.162	2.5	Little development

[1]Source: Energy Information Administration (February 2004)
[2]Cumulative CBM production through December 2002.
[3]CBM not yet recovered, based on information through December 2002.
[4]Gas quantities demonstrated “with reasonable certainty” to be recoverable in future years.
[5]Most likely estimates of undiscovered, recoverable, and marketable volumes

1.6 AMOUNT OF WATER

Projections regarding the amount of both currently-available and potential future CBM produced water volumes vary widely. Some projections suggest that produced water volumes of as much as 40 million acre feet (MAF) could be realized within the western United States over the next 15 to 20 years. A number of sources suggest that management and disposal of approximately 250,000 AFY could potentially be required in the Powder River Basin alone over the next 10 to 15 years.

In contrast to conventional gas/oil wells, where water is produced in highest quantities during the later portion of the well’s life as production rates decline, CBM well water production is normally greatest immediately after the well is brought on line. When first placed online, a CBM well typically produces significant amounts of water (10 to 20 gpm), with little or no gas production. Within several months of initial operation, gas production is initiated, and water production begins to decrease as the coal seams become dewatered. After one to two years of operation, water production rates per well can fall to as little as a few barrels of water per day as overlapping cones of depression for individual wells form in the producing area, while gas production rates may increase to several hundred thousand cubic feet per day.

The San Juan Basin, which extends from southwest Colorado into northwest New Mexico, is reportedly the most productive source of CBM in North America. Recent CBM water production rates in the San Juan Basin are reported to be approximately 3000 AFY (977.5 billion gallons per year, or 2.68 million gallons per day [mgd]). However, very little CBM produced water is used for beneficial purposes, in part because

Figure 1
Coalbed Methane Resources Within the Colorado River Basin

the quality of the water is too poor for most uses that require a sizeable and relatively continuous supply of water. Most of the produced water is currently disposed by injection into Class II underground injection wells.

Produced water volumes associated with CBM development typically exhibit exponential decline over time. One example is wells in the Powder River Basin. While initial production rates per well may be as high as 15 gpm, rapid declines in production occur over the first one to two years of operation, and by year six, rates of less than 2.5 gpm (4 AFY) are typically experienced. For all wells (both new and extended production time wells), normalized average well lifetime production rates over approximately 10 years are reported to be between 2.5 and 4 gpm (4 to 6.4 acre-feet per year). (ALL, 2003)
An important factor in evaluating potential produced water availability is the historical unit water production per well, which also varies considerably across the major coal basins. Table 2 summarizes available data on produced water on a unit basis (water obtained per MCF (1000 cubic feet) of CBM production).

Table 2
Unit Water Production Data for Rocky Mountain Region Coal Basins

Location (States)	Typical Production per CBM Well[1]			
	Water Barrels/day	Gas MCF/day	Unit Water Production Per MCF of CBM	
			Barrels	Gallons
Powder River Basin (MT, WY)	400	145	2.75	116
Raton Basin (NM, CO)	266	200	1.34	56
Uinta Basin (UT)	215	625	0.34	14
San Juan Basin (NM, CO)	25	833	0.03[2]	1.3[2]

[1]Source: James Bauder Presentation (October 19th 2005)
[2]More recent data suggest that actual values may be closer to 0.05 – 0.06 barrels/MCF, or 2.1 to 2.5 gallons per MCF

As shown in Table 2, unit produced water volumes for the Uinta and San Juan Basins are considerably lower than for wells located in the Powder River and Raton Basins. The San Juan Basin, while one of the most productive areas in terms of CBM gas production, is also the lowest in terms of produced water. This reflects the fact that CBM development within the San Juan Basin is at a relatively mature stage, with many of the existing wells having been in service for a considerable period, and thus producing large amounts of gas and relatively little water. Unit water production within the Powder River Basin, where considerable new development (and thus wells producing relatively large amounts of water) continues to occur, are much higher than for current CBM production areas within the Colorado River Basin.

Using the CBM reserves data presented in Table 1, and a conservative unit water production of 5 to 10 gallons per MCF of CBM gas, total potential produced water volumes for the four major coal basins located within the Colorado River Basin (in addition to volumes associated with current CBM production) can be projected. Projected values range from approximately 161,000 to 322,000 acre-feet (53 to 106 billion gallons) based on “proved” reserves, and from approximately 279,000 to 558,000 acre-feet (91 to 182 billion gallons) based on “total estimated” reserves.

1.7 WATER QUALITY

The quality of the produced water varies considerably from basin to basin, within a particular basin, from coal seam to coal seam, and over the lifetime of a CBM well. In general, CBM produced water is characterized by moderate-to-high concentrations of dissolved solids, particularly high levels of sodium, bicarbonate, chloride, iron, and barium. CBM produced water typically exhibits relatively low sulfate concentrations, as the chemical conditions within the coal beds favor conversion of sulfate to sulfide. As much of the currently available produced water is discharged to surface drainage or used for soil irrigation, another water quality parameter of concern is sodium adsorption ratio (SAR), defined as the ratio of the sodium concentration to the sum of the calcium and magnesium concentrations (all expressed in meq/L).

The quality of CBM produced water within the Powder River Basin varies across the basin. At the basin extremities, where coal seam aquifers are recharged with fresh water, the quality of the produced water is relatively good and may be suitable for human consumption, irrigation, livestock water, or stream flow augmentation without significant treatment. However, for the interior portions of the basin, the produced water becomes more saline, with relatively high TDS (>3,000 milligrams per liter [mg/L]), which renders the water less suitable for irrigation, and unsuitable for consumption or stream flow augmentation without treatment to reduce TDS concentrations. Data developed for the Powder River Basin by Marathon Oil Company indicate that "typical" TDS concentrations for produced water are approximately 1,750 mg/L, with bicarbonate and sodium concentrations of 1920 mg/L and 619 mg/L, respectively, and an SAR value of 25.5.

Relatively little water quality information exists for CBM development areas outside the Powder River Basin (PRB), where the majority of CBM development has occurred over the past 15-20 years. However, the information developed thus far suggests that the quality of the produced water in other areas may be significantly worse than CBM produced water in the PRB. Reported average water quality data for two of the CBM production areas closest to the Colorado River watershed (the San Juan Basin and the Piceance Basin) indicates that TDS concentrations for produced water varies from 1,000 to 15,000 mg/L for the San Juan basin, and is approximately 15,000 mg/L for produced water within the Piceance Basin (ALL, 2003)

1.8 TECHNICAL ISSUES

1.8.1 Availability

Considering the wide spacing of individual CBM wells (typically one per 80 to 160 acres), and relatively low productivities per well (2 to 4 gpm normalized over an average well life of 8-10 years), available CBM produced water supplies may be too dispersed to easily and economically manage collectively. Transporting CBM produced water from where it is generated to where it can be used may be expensive in many cases and could present a significant impediment to feasibility for stream flow augmentation.

1.8.2 Proximity to Colorado River and Major Tributaries

A key issue in considering the feasibility of using CBM produced water to augment flows within the Colorado River Basin is proximity of the supply to, and ability to readily convey the water to, the intended discharge point. For example, most of the CBM development within the Uinta Basin in Utah is located in an area approximately 50 – 70 miles west of nearest major tributary to the Colorado River (Green River), which may reduce its attractiveness as a means of augmenting flows in the Colorado River. Similarly, most of the CBM development within the Greater Green River Basin in Wyoming has occurred at points approximately 100 miles east of the Green River. However, CBM development within the Piceance and San Juan River Basins has occurred in relatively close proximity to the Colorado River and the San Juan River, respectively.

1.8.3 Treatment Requirements

As discussed in section 1.7 above, CBM produced water typically exhibits moderate to high concentrations of TDS (1000 to 15,000 mg/L for the San Juan and Piceance Basins, based on limited available data). Water quality criteria for flows discharged to surface water supplies are typically established by individual states. However, it is reasonable to assume that essentially any future permitted discharge to the Colorado River and/or its major tributaries will have to comply with requirements developed to minimize the potential for exceedances of established salinity criteria for the lower stem of the Colorado River. Current salinity criteria (as measured as total dissolved solids) are as follows:

- Below Hoover Dam = 723 mg/L
- Below Parker Dam = 747 mg/L
- At Imperial Dam = 879 mg/L

Considering these criteria, essentially any CBM produced water would need to be treated to reduce TDS concentrations prior to direct discharge to a tributary to the Colorado River. The most practical means of reducing TDS concentrations for highly saline supplies currently available is use of reverse osmosis (RO) membrane technology. RO conversion rates of 70 to 90 percent may be achievable, depending on feedwater TDS concentrations and the overall composition of the water to be treated. Required membrane feedwater pressure requirements would range from approximately 150 to 250 pounds per square inch gage (psig) for low TDS waters (less than 1,500 – 2,000 mg/L) to as high as 800 to 1,000 psig for waters with high TDS concentrations (>10,000 mg/L). Initial attempts to use RO for treatment of CBM produced waters revealed operational problems associated with rapid fouling of membrane surfaces. This suggests that substantial pre-treatment may be required for some feedwaters to control inorganic constituents that form precipitates upon concentration and to remove free and dissolved oils and soluble hydrocarbons to ensure effective long-term system operation.

Use of electrodialysis (an electrically-driven membrane separation process in which ions are transferred through ion-selective membranes upon application of direct-current voltage) is also reportedly being investigated as a potential means of treating CBM produced water to obtain finished water suitable for direct discharge. However, results of previous evaluations of electrodialysis suggest that waters with TDS concentrations exceeding approximately 2,000 mg/L may be more economically treated in most cases using RO.

1.8.4 Useful Life of Treatment and Conveyance Facilities

Considering the typical dispersed layout of CBM production wells and the limited effective production life of the wells, any facilities constructed to convey raw and treated water and to treat the water may have a relatively limited useful life before the wells are no longer productive and are removed from service. Selection of plant sites that would facilitate centralized treatment of produced waters collected over large areas would be necessary to maximize effective life of treatment and conveyance facilities.

1.9 GENERAL RELIABILITY OF SUPPLY

CBM wells are unreliable as long-term sources of water due to their declining flow rates as the coal seams are dewatering and gas production increases, and to their limited useful life. Therefore, available produced water supplies will decline unless development of new well fields continues to occur. It should be noted that considerable controversy exists in many areas regarding the impacts of continued CBM well development; issues of concern typically include:

- Long-term effects of pumping of CBM wells on aquifer recharge and groundwater resources.
- Construction impacts and dust emission from drilling, roads and pipelines, and water disposal facilities.
- Potential effects of seepage from unlined impoundments on both groundwater and surface water supplies.
- Where disposal by surface discharge is employed, long-term effects of application of moderately to highly saline produced waters on soil condition and future land use.

While the impact of public opinion on continued ability to develop new CBM resources is uncertain, development rates in some areas have declined in recent years due in part to public opposition. It is therefore unknown whether the rapid pace of new CBM development experienced in many areas over the past 5-10 years can or will be sustained. While development within the Powder River Basin continues at a rapid pace, it is believed by some that development within the San Juan Basin has reached a level where CBM production and associated produced water volumes may not increase significantly above current levels.

1.10 ENVIRONMENTAL ISSUES

Potential environmental issues associated with collection, treatment, and conveyance of produced water for augmentation of flows within the Colorado River Basin would include the following:

- Ground disturbance and dust development for construction of access roads, raw and treated water pipelines, and pumping and treatment facilities.
- Equipment operation noise.
- Wildlife habitat changes.
- Disposal of high TDS treatment residual flows from required treatment processes.

1.11 PERMITTING

If produced water is discharged to streams or other surface water bodies within the Colorado River Basin, the discharge must be authorized by a permit issued under the National Pollutant Discharge Elimination System (NPDES). Individual NPDES permits can be issued to specific facilities, or general NPDES permits that address all similar activities in the same geographic area can be issued. Most states have been delegated authority to administer the NPDES program, and thus permits must follow both federal regulations and any state-specific requirements. NPDES permits typically specify numerical effluent limits for one or more constituents and associated monitoring requirements. The three key CBM producing states in U. S. Environmental Protection Agency (USEPA) Region 8 (Colorado, Montana, and Wyoming) have received primacy to administer the NPDES program at the state level, and follow USEPA guidance in developing discharge requirements.

Both Colorado and Wyoming have issued numerous NPDES permits for discharge of CBM produced waters; however, it is unknown if any of the permits issued are for direct discharge to the Colorado River or its major tributaries.

1.12 COSTS

As discussed above, desalination of CBM produced water would likely be required prior to surface discharge within the Colorado River Basin for flow augmentation purposes. Desalination construction and operating costs would be highly site-specific and dependent upon factors such as feedwater TDS concentration and temperature, treatment capacity provided, pre-treatment and post-treatment required, etc.. Projected construction and annual operation and maintenance (O&M) costs for a 500 gpm RO-based treatment facility are presented in Table 3. As required RO system feedwater pressures increase with increasing feedwater TDS concentrations, O&M costs are presented for a range of potential feedwater TDS concentrations that reflect levels that could be experienced with produced waters within the Colorado River Basin. A finished water TDS concentration goal of 500 mg/L was used for this evaluation, which reflects a level that would be acceptable for discharge while maintaining the salinity criteria discussed in Section 1.8.3

above, as well as other beneficial uses such as municipal and/or industrial water supply, shallow reinjection, etc..

In addition to costs associated with desalination treatment of the produced water prior to discharge, other costs associated with this option would include the following:

- Collection and transmission of produced water from individual well sites to a central treatment facility.
- Pumping and transmission of the treated water to the discharge point.
- Disposal of the high-TDS desalination process residual stream (likely deep-well injection).
- Land acquisition costs for construction of pipelines and treatment facilities.
- Permit fees.

Table 3
Projected Costs for Desalination of CBM Produced Water
(500 mg/L Finished Water TDS)

Feedwater TDS, mg/L	Construction Cost[1] $	Unit O&M Cost[2]	
		$ per 1000 gals	$ per Acre foot
1,500	2,000,000 – 2,500,000[3]	0.50 – 0.60	163 – 195
3,000		0.75 – 0.80	244 – 261
10,000	3,500,000 – 4,000,000[4]	1.50 – 1.60	489 – 521
15,000		1.85 – 1.95	603 – 635

[1]Costs based on 500 gpm treatment unit (feedwater flow), operating at 80% recovery. Costs include membrane skids, feedwater pumps, cartridge filters, cleaning system, building, electrical/instrumentation, and 20% contingency allowance.
[2]Costs based on finished water flow following blending of raw and permeate flows to yield 500 mg/L TDS in finished water, unit power cost = $0.10 per kwh.
[3]Assumes brackish water membrane elements.
[4]Assumes seawater membrane elements required.

These costs will be highly site-specific, and cannot be readily predicted without more specific information on CBM well field configuration and location relative to potential treated water discharge points.

Private contractors responsible for treatment and disposal of water produced during extraction of coalbed methane cite costs of 12 to 60 cents per barrel of water ($900 to $4,600 per acre-foot).

1.13 REFERENCES

ALL Consulting (July 2003). *Handbook on Coal Bed Methane Produced Water: Management and Beneficial Use Alternatives.* Prepared for Ground Water Protection Research Foundation, U.S. Department of Energy, National Petroleum Technology Office, Bureau of Land Management.

Bank, Gregory C., Kuuskraa, Vello A. (January 2006). *The Economics of Powder River Basin Coalbed Methane Development.* Prepared for U.S. Department of Energy.

Bauder, James (October 19th, 2005). *CBM and the Issue of Water Management Associated with CBM Extraction.* Presentation at Montana Energy Symposium; Montana State University.

Energy Information Administration, "Coalbed Methane in the US" (February 2004)
Hayes, Tom (Summer 2004). *The Electrodialysis Alternative for Produced Water Management.*

Matthews, Mark (March 12, 2007). Coalbed Methane Producers Have Some New Options. Engineering News-Record.

Ruckleshaus Institute of Environment and Natural Resources (December 2005). *Water Production from Coalbed Methane Development in Wyoming: A Summary of Quantity, Quality, and Management Options.* Prepared for The Office of the Governor, State of Wyoming.

S. S. Papadopulos & Associates, in conjunction with Colorado Geological Survey (February 2006). *Coalbed Methane Stream Depletion Assessment Study – Northern San Juan Basin, Colorado.* Prepared for State of Colorado Department of Natural Resources, Division of Water Resources, and the Colorado Oil and Gas Conservation Commission.

United States Geological Survey (February 2003). *Coal-Bed Gas Resources of the Rocky Mountain Region.* USGS Fact Sheet FS-158-02.

Western Governors' Association (April 2006). *Coal Bed Methane Best Management Practices: A Handbook.*

1.14 CONCLUSION

White Paper findings are summarized in Table 4.

Table 4 Summary of Findings Related to Coalbed Methane Produced Water Option	
Parameter	**Findings**
Location of Supply	At least 4 major CBM producing areas are located within the Colorado River Basin.
Quantity of Water Potentially Available	Projections vary significantly, but range from 3,000 to 20,000 AFY.
Water Quality	High TDS concentrations (typically 2,000 – 15,000 mg/L) will necessitate treatment prior to discharge to the Colorado River system.
Technical Issues	Additional collection, treatment, and delivery systems will be required to implement this option. Wide spacing of wells and distance from the Colorado River and major tributaries are factors in some locations. Limited useful life of conveyance and treatment facilities may be an issue unless centralized treatment can be economically implemented.
General Reliability of Supply	Supply is reliable only if development of new CDM wells continues. Individual wells have limited life (~10 years) and low water production (2-4 gpm per well) after first 1-2 years of operation
Environmental Issues	Typical issues related to construction and operation of water conveyance and treatment facilities. Disposal of high TDS treatment residuals is required.
Permitting Issues	Ability to readily obtain NPDES permits for direct discharge to Colorado River and/or major tributaries is unknown.
Costs	Highly site-specific; dependent upon water quality and location of source relative to intended discharge point(s). Desalination system operating costs (not including conveyance of the produced water to and from the treatment facility, nor disposal of the high TDS treatment residual stream) may range from approximately $160 to $650 per acre foot, depending upon initial TDS concentrations, power and chemical costs, etc. Amortized capital costs for desalination facilities may range from $300 to $650 per-acre foot (10 years, 5% interest). Private contractors quote costs for treatment and disposal of $900 to $4,600 per acre-foot.