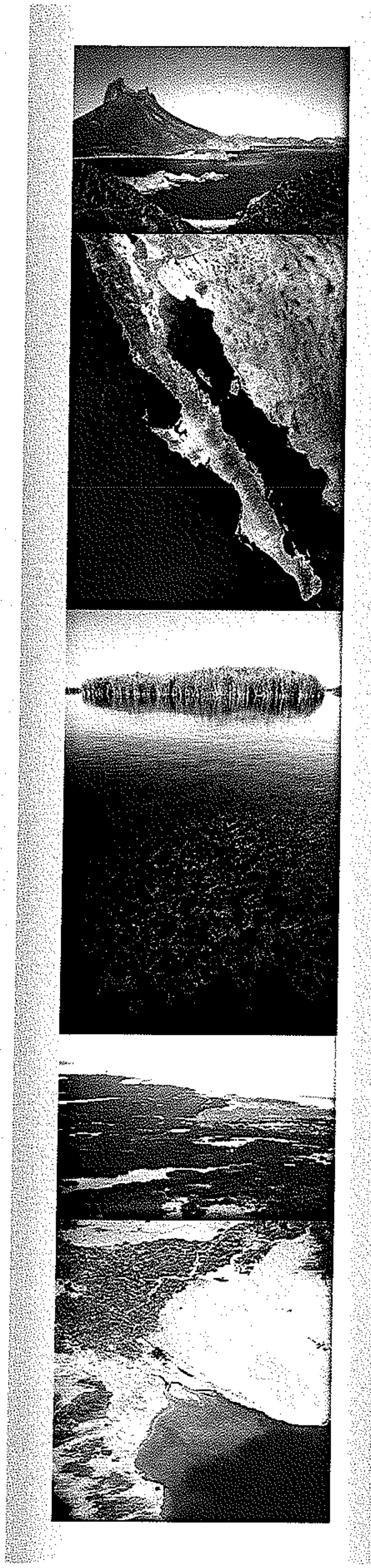

Investigation of Binational Desalination for the Benefit of Arizona, United States, and Sonora, Mexico

FINAL REPORT

June 5, 2009

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Project Numbers
87873 and 87874

CAP
CENTRAL ARIZONA PROJECT

SRP®

Investigation of Binational Desalination for the Benefit of Arizona, United States, and Sonora, Mexico

FINAL REPORT

Registered Professional Engineer (Civil)
CERTIFICATE NO.
46661
TONY
MARDAM
Date Signed 06/04/09
ARIZONA U.S.A.

Registered Professional Engineer (Civil)
CERTIFICATE
45613
GUY W.
CARPENTER
Date Signed 06/05/09
ARIZONA U.S.A.

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EXECUTIVE SUMMARY

Introduction

It is generally recognized that development of new water resources will be necessary to meet municipal, industrial, environmental, recreational, and other demands associated with expected growth in Arizona, United States, and Sonora, Mexico. These two states have similar water resource challenges and a shared dependence on the Colorado River basin for a large portion of their water supplies. It is mutually advantageous for the governments of Sonora and Arizona to collaboratively secure their long-term water futures.

Since at least the 1960s, the U.S. and Mexican governments have recognized that desalinated seawater from the Gulf of California is one possible solution to the demand for water in the Arizona-Sonora region. Salt River Project (SRP) and Central Arizona Project (CAP), in consultation with the Arizona Department of Water Resources (ADWR), United States Bureau of Reclamation (USBOR), and the Comision Estatal del Agua, Sonora (CEA), have determined it is in the best interest of Arizona and Sonora to conduct an investigation of this possible water supply. To this end, CAP and SRP contracted with HDR Engineering, Inc. (HDR), to initiate the planning of a water supply development project in coordination with officials from Sonora and the Mexican federal government, as well as with local officials and consultants associated with near-term plans to design and construct a seawater desalination plant in and for the municipality of Puerto Peñasco. A summary of the Puerto Peñasco study is provided on page ES-7.

Purpose

The purpose of this study is to determine opinions of cost for a potential new water supply for Arizona and Sonora in support of water related initiatives developed and driven by the Arizona Mexico Commission (AMC in the United States) and the Comision Sonora Arizona (CSA in Mexico). The purpose is to provide conceptual-level information and opinion of cost data to provide decision makers and stakeholders a basis for beginning meaningful discussions and for conducting additional studies. The water supply volumes evaluated are somewhat arbitrary, in that they are not tied to rigorous demand determinations, but were chosen to provide a range of costs for discussion purposes.

Scenarios

A number of water supply scenarios and associated annual volumes and availability dates were considered during the study. Ultimately, conceptual level cost estimates were developed for the following two scenarios:

- Arizona-Sonora Scenario: 120,000 acre-feet per year (AFY) (107 MGD or 0.4M m^3/day) of desalinated seawater from the Gulf of California (Puerto Peñasco) delivered to Imperial Dam.

- Regional Scenario: 1.2 million AFY (1,070 MGD or 4 M m^3/day) of desalinated seawater from the Gulf of California (Puerto Peñasco) delivered to Imperial Dam

The focus of the study is on large volume sea water desalination. Because of the level of incomplete data and uncertainties, many simplifying assumptions were developed for the study. The project team used conservative estimates for treatment and delivery costs to accommodate the uncertainties. Significant simplifying assumptions are that power would be available to the desalination plant and conveyance facilities at a rate of $0.10/kWh, and that desalination should be based upon membrane treatment, which is the most common desalination technology employed worldwide.

The water supply scenarios used general water demands based on general assumptions. No specific volume of product water is assigned to any particular entity, either in Arizona or Sonora. It is sufficient to know that additional water would benefit Arizona and Sonora, and that benefits could also be realized by California, Nevada, and Mexico through the implementation of the Regional Scenario. It is acknowledged that implementation of either of the water supply scenarios will require many years to implement, including significant levels of effort for planning, permitting, and design.

Two technical memoranda accompany this Executive Summary: one for developing the opinions of cost for treatment, and one for conveyance. The opinions of cost prepared for this study were based on conceptual designs developed for each treatment/conveyance scenario. The conceptual design criteria are documented in each Technical Memorandum. For conceptual-level cost estimates, the Association for the Advancement of Cost Engineering International (AACEI) recommends that an error range of plus 50% to minus 30% be assigned. The capital and operations and maintenance (O&M) costs provided in this report are based on:

- Costs developed by HDR Design-Build, Inc., for specific project elements
- Recent HDR construction cost estimates
- Recent bid tabs/equipment quotes
- A recent 25 MGD MF/UF/RO design report (confidential client)
- Southern Nevada Water Authority 2006 Cost Guide
- USBOR and National Research Council escalation factors
- Input from CAP and SRP technical staff

The results of the study show that capital and O&M cost are significant for developing seawater desalination for the benefit of Arizona and Sonora. The following is a summary of the costs:

Arizona-Sonora Scenario: $2,727/AF ($8.38/1,000gal)
120,000 acre-feet per year (AFY) (107 MGD or 0.4 M m3/day) of desalinated seawater from the Gulf of California (Puerto Peñasco) delivered to Imperial Dam

Regional Scenario: $1,183/AF ($3.63/1,000gal)
1.2 million AFY (1,070 MGD or 4 M m3/day) of desalinated seawater from the Gulf of California (Puerto Peñasco) delivered to Imperial Dam

Seawater Desalination

Seawater has been a source of water supply for more than 50 years. Recent advances in desalination technology are making it more economical for use as a potable water supply. The potential for potable water production is essentially unlimited, depending on the intake design and location. Seawater in the northern Gulf of California (Sea of Cortez) has a total dissolved solids (TDS) concentration range of between 28,000 and 37,000 mg/L. The target finished water TDS concentration for this study was 750 mg/L, which approximates the salinity of the Colorado River at Imperial Dam and which is of sufficient quality for agricultural needs of the region and for potable water.

Ocean source water quality depends on local site factors such as water intake depth, water turbidity, boat traffic, oil contamination, nearby outfalls, wind conditions, tides, and the influence of surface runoff from land. The two major types of desalination technologies are membrane processes and thermal processes. In general, membrane desalination technologies are more sensitive to feed water quality than thermal desalination technologies. Therefore, proper pretreatment of the seawater is a critical factor in the successful operation of seawater membrane desalination systems. This report provides opinions of cost for desalination using membrane technology. With any desalination technology a brine waste must be managed or disposed. For this study, it was assumed that brine would be returned to the Gulf of California through an ocean dispersion system.

Desalination Opinion of Cost

For both scenarios, opinions of cost (capital and O&M) for desalination were developed and translated into cost per produced volume based on a 20-year debt service term.

- Arizona-Sonora Scenario (120,000 AFY): **$995/acre-foot (AF)** ($3.06/1,000gal)
- Regional Scenario (1,200,000 AFY): **$905/AF** ($2.78/1,000gal)

Conveyance of Desalinated Water

The water produced from a binational seawater desalination facility must be conveyed to locations where it can be put to beneficial use. Early in this investigation, it was decided that opinions of cost would be developed for the delivery of desalinated water to Imperial Dam, with the acknowledgment that deliveries would also be made along the route in Mexico at locations to be determined in future studies. Approximately 5.7 MAF (5,083 MGD or 19.3 M m^3/day) of Colorado River water passed through Imperial Dam in 2008 to satisfy water demands in both countries (USBOR 2008). Desalinated water conveyed to Imperial Dam will displace Colorado River water that can then be exchanged to users in Arizona, and possibly the other basin states, which would then divert the additional Colorado River water through their existing, expanded, or new infrastructure.

It was assumed that a desalination plant would be located on the Gulf of California, just northeast of the central part of Puerto Peñasco with water delivered to Imperial Dam. Within the Northern Gulf is the Upper Gulf of California/Colorado River Delta Biosphere Reserve, extending from the Delta to a straight line running from approximately San Felipe, Baja California Sur, to a point just a few miles northwest of Puerto Peñasco, Sonora.

The withdrawal of seawater and return of brine for seawater desalination operations was located south of the marine reservation. Delivering water between Puerto Peñasco and Imperial Dam would most likely require conveyance across portions of the 600 mi^2 (155,000 ha) El Pinacate and Gran Desierto de Altar Biosphere Reserve. At this level of study, it was assumed that the route for conveyance with the lowest environmental impact would be along the highway that already exists through the designated reserve. Figure ES-1 depicts the study area, the location of important features, and the conceptual conveyance route.

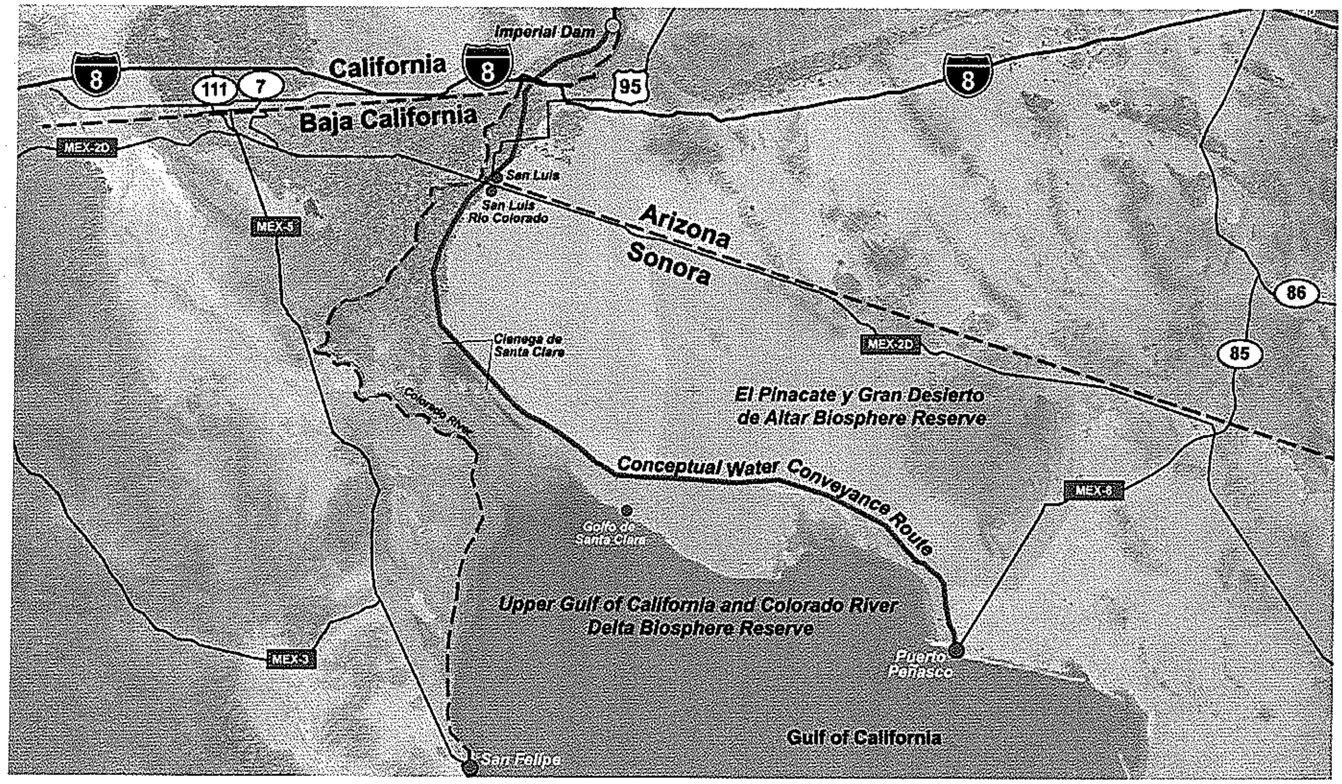

Figure ES-1 Study Area Map

Opinions of cost for conveyance of desalinated ocean water delivered from Puerto Peñasco to Imperial Dam are based on two methods of conveyance: through a pipeline or via a canal for the 120,000 AFY and 1,200,000 AFY scenarios, respectively. The conveyance cost opinions were developed based on a preliminary pipeline/canal route. It is expected that the actual route of the pipeline or canal will vary from that shown based on geologic conditions, soil conditions, environmental factors, and land ownership/right-of-way issues not assessed during this investigation.

The route is generally of low slope, with 181 feet of vertical lift from the treatment site to Imperial Dam, which is a distance of approximately 168 miles. Most of the elevation gain is in the last 30 miles before arriving at Imperial Dam. Based on required vertical lift and distance, a number of pumping stations and associated forebays will be needed to convey the water. No locations for the pumping stations were identified at this level of study. Reservoirs necessary for operational and maintenance flexibility, as well as possibly water availability reliability for points of delivery along the conveyance route, are also factored in.

Conveyance Opinion of Cost

For both scenarios, opinions of cost (capital and O&M) for conveyance were developed and translated into cost per conveyed volume based on a 20-year debt service term.

- Arizona-Sonora Scenario (120,000 AFY): **$1,732/acre-foot (AF)** ($5.32/1,000gal)
- Regional Scenario (1,200,000 AFY): **$278/AF** ($0.85/1,000gal)

Rolled Up Summary of Delivered Desalination Water Costs

1. Arizona-Sonora Scenario (107 MGD; 120,000 AFY)

Arizona-Sonora Scenario	$/AF	$/1,000 gallon
Pipeline	1,732	5.32
SWRO Plant	995	3.06
Total	**$2,727**	**$8.38**

Includes:

- 250 MGD raw water intake structures
- 107 MGD MF/UF/RO plant
- 143 MGD concentrate ocean outfall
- 168-mile; 78-inch-diameter welded steel pipeline
- Four 6,000 hp pumping plants
- 100 MG of system storage

Conveyance represents about 63% of the total cost of water under this scenario. The power capacity requirement for this scenario is 50 MW.

2. Regional Scenario (1.07 BGD; 1,200,000 AFY)

Regional Scenario	$/AF	$/1,000 gallon
Canal	278	0.85
SWRO Plant	905	2.78
Total	**$1,183**	**$3.63**

Includes:

- 2,503 MGD raw water intake structures
- 1,070 MGD MF/UF/RO plant
- 1,433 MGD concentrate ocean outfall
- 143 miles of trapezoidal open canal
- 25 miles of dual, 180-inch welded steel pipeline sections
- Five 15,000 hp pumping plants
- 100 MG of system storage

Conveyance via a canal-based system represents about 24% of the total cost of water. The power capacity requirement for this scenario is 500 MW.

Identified Risks

It is recognized that a number of risks threaten the feasibility of a binational desalination facility and associated conveyance infrastructure, not the least of which are related to environmental, intergovernmental, and cultural resource issues. Additionally, the municipality of Puerto Peñasco is actively planning and is in the early design stages of a desalination facility to provide water service locally. If the local project is well executed, the risks associated with public acceptance of a binational desalination facility would likely decrease. Once the local desalination plant is constructed and operational, additional data will be available to help reduce the uncertainty associated with a binational facility.

Few data are readily available regarding the costs for environmental assessment and mitigation in Sonora. Regulatory permitting requirements and approvals for a desalination facility along the Gulf of California are difficult to ascertain since project implementation would be managed by Mexican administrative agencies. According to the World Bank, the cost of an environmental assessment rarely exceeds 1% of the total project cost. Mitigation measures usually account for three to five percent of total project cost. These figures do not include the cost of environmental damage caused by a project that has not undergone an environmental assessment. The project team has assumed that legal fees associated with each scenario would be 10% of the total capital cost, and the environmental and archeological assessment and mitigation fees would be $20M and $50M for the Arizona-Sonora and Regional scenarios, respectively.

This study assumed that the conveyance infrastructure would cross the Colorado River and connect to the Imperial Dam forebay in California, which would therefore require environmental and construction permitting in California. Because a desalination facility and its appurtenances would encompass a variety of areas and environments (e.g., open ocean, barrier island, bay and marsh habitats, freshwater stream crossings, uplands) and encounter multiple state and federal jurisdictions, project participants should establish communication as early as possible in the permitting process to define jurisdictional boundaries, ascertain major areas of concern, and facilitate overall communication among the regulatory agencies. The most prevalent environmental impediments to this project are anticipated to be the potential impacts associated with the feedwater intake, brine discharge activities, and concerns over impacts to the designated Reserves.

The AMC and CSA, the International Boundary Water Commission, and a number of other binational organizations are involved in improving the quality of life and working on water issues of mutual concern. Government and water agency officials from both sides of the border are actively involved in these groups, and relations are strong.

Cultural resource concerns (archaeological) are well understood in the border region, but less understood in the Reserves identified above. The U.S. National Park Service (NPS) has been proactive in its development of shared responsibility agreements with its counterparts in Mexico regarding the protection of natural and cultural resources. NPS has developed a strong relationship with the Mexican National Institute for Anthropology and History (INAH) to collaborate to protect and preserve mutual interests, which include archeological sites, Native American communities, artifacts, submerged resources, and other sites of shared interest. The procedures for conducting cultural resource evaluations in Sonora and at the border region are not currently well-defined.

Puerto Peñasco Desalination Facility

The United States Trade Development Agency (USTDA), part of the United States Department of Commerce, in collaboration with the City of Puerto Peñasco, Sonora, Mexico retained WL Bouchard and Associates (Bouchard) to prepare a technical study evaluating the feasibility of a seawater desalination plant in Puerto Peñasco, on the Gulf of California to serve the local agricultural, municipal, and industrial needs of the City of Puerto Peñasco.

HDR met with Bouchard and on April 9th, 2009 and received the following information on the study:

- Bouchard has submitted the draft of this study to USTDA
- The desalination plant will be built in 500 liters/second (l/s) increments, which is approximately 11.5 mgd, with a total capacity of 2,000 l/s, or approximately 46 mgd.
- The study included 3 components: socio-economic needs analysis, preliminary design, and a request for proposals (RFP) for design-build contractors to build the plant
- The need for the plant is immediate due to salt water intrusion in the regional aquifer and deterioration of groundwater quality
- Bouchard concludes in the study that the project is "economically, politically and financially feasible"
- Bouchard and the City of Puerto Peñasco are currently determining the best method to approach the finance and building industry to construct the project

Since the report was still in Draft form, HDR was not provided an opportunity to review all the assumptions and contents of the Bouchard study.

Next Steps and Concepts to be Analyzed Further

This section of the Executive Summary lists issues that have been raised throughout project development, but that have been deferred for future study. They are captured and provided here for the benefit of continuity and advancing the new water supply concept.

Predesign Issues

1. The water demands for the region and the location of those demands should be reviewed and refined.

2. Alternative conveyance routes should be evaluated in the next phase of the project. Hydraulic profiles should be developed with a focus to optimize the number and location of pump stations and to reduce the length of pressurized sections in the Regional Scenario to manage costs. Topographic and geologic data should be refined as well as rights of way opportunities. Geotechnical, seismic, environmental, cultural resources, and intergovernmental issues (including involving California) need to be more thoroughly analyzed to determine a "best route."

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Technical Memorandum 1: Opinion of Cost for Desalination

HDR | ONE COMPANY *Many Solutions℠*

From: HDR ENGINEERING, INC.	Project: Investigation of Binational Desalination
Date: June 5, 2009	Job No: 87873 and 87874

RE: Investigation of Binational Desalination for the Benefit of Arizona, United States, and Sonora, Mexico

This technical memorandum was developed in support of the project, *Investigation of Binational Desalination for the Benefit of Arizona, United States, and Sonora, Mexico*. It documents the available technologies and estimated costs to desalinate seawater from the Gulf of California to increase available water supplies for Arizona and Sonora.

Source Water

Seawater has been a source of water supply for more than 50 years. Recent advances in desalination technology are making it more economical for use as a potable water supply. The potential is essentially unlimited, depending on the intake design and location. Seawater in the northern Gulf of California (Sea of Cortez) has a total dissolved solids (TDS) concentration range of between 28,000 and 37,000 mg/L. The target finished water TDS concentration for this study was 750 mg/L, which nearly matches the salinity of the Colorado River at Imperial Dam, and which is of sufficient quality for agricultural needs of the region and for potable water. (The secondary maximum contaminant level (MCL) for TDS in drinking water is 500 mg/L. Several municipal water suppliers are serving water around 800 mg/L in Central Arizona.)

Ocean source water quality depends on local site factors such as water intake depth, water turbidity, boat traffic, oil contamination, nearby outfalls, wind conditions, tides, and the influence of surface runoff from land. The two major types of desalination technologies are membrane processes and thermal processes. In general, membrane desalination technologies require better feed water quality than thermal desalination technologies. Therefore, proper pretreatment of the seawater is a critical factor in the successful operation of seawater membrane desalination systems. This report provides opinions of cost for desalination using membrane technology, in this case, reverse osmosis (RO). With any desalination technology commercially available for the flow rates considered, a brine waste must be managed or disposed. For this study, it was assumed that brine would be returned to the Gulf of California through a dispersion system.

Table TM1-1 provides a list of recommended source water analyses (AWWA) that may be performed before the design of an RO desalination system.

Table TM1-1 Source Water Parameters for Reverse Osmosis Design

Temperature	Silt Density Index	Iron
pH	Silica	Manganese
Alkalinity	Hydrogen Sulfide	Chloride
Hardness	Calcium	Fluoride
Turbidity	Sodium	Sulfate
Total Dissolved Solids	Magnesium	Nitrate
Total Suspended Solids	Potassium	Phosphate
Conductivity	Strontium	Carbonate
	Ammonium	Bicarbonate
	Barium	Boron

During normal operation over a period of time, RO membranes are subject to fouling by suspended or soluble constituents that may be present in the source water. Common examples of such foulants are calcium carbonate scale, calcium sulfate scale, metal oxides scale, silica coating, and organic or biological deposits.

The expected average water quality of the northern Gulf of California was determined by accessing data from myriad sources, including the National Oceanographic Data Center; Minerals Management Service; and research vessels, platforms, and buoy monitoring networks. In addition, well-established marine solute proportionalities were used to estimate dissolved salt concentrations based on reported salinities. Table TM1-2 presents a synthesis of various collected water quality parameters.

Tides within the northern region of the Gulf of California cycle diurnally, with elevation variations ranging up to 10 meters in the Colorado River Delta. Tidal currents range between 0.4 and 1.7 knots along the coasts of Sonora and Baja California. Salinity decreases with depth during most of the year. However, during winter months the colder and more saline water sinks to the ocean floor and moves southwardly, affecting the vertical distribution of the water's physical and chemical properties.

Table TM1-2 Average Water Quality in the Northern Gulf of California

Parameter	Unit	Average measured value
Temperature	°C	24
Total dissolved solids	mg/L	34,000
Magnesium	mg/L	1,251
Sodium	mg/L	10,401
Potassium	mg/L	377
Ammonium	mg/L	2.40
Barium	mg/L	0.021
Strontium	mg/L	12.6
Carbonate	mg/L	0
Bicarbonate	mg/L	139
Sulfate	mg/L	2,611

Parameter	Unit	Average measured value
Chloride	mg/L	18,710
Fluoride	mg/L	1.02
Nitrate (N)	mg/L	0.50
Silica	mg/L	3.0
pH		7.9
Calcium	mg/L	401
Iron	mg/L	0.01
Manganese	mg/L	0.002
Boron	mg/L	3.87
Phosphate (P)	mg/L	0.28

Treatment Technologies

The two major types of desalination technologies are membrane processes and thermal processes. Membrane desalination technologies include RO, nanofiltration (NF), electrodialysis, and electrodialysis reversal (EDR). Thermal desalination technologies can be subcategorized as multistage flash distillation (MSF), multieffect distillation (MED), and vapor compression (VC).

Membranes

Several different types of membrane systems that may be used for water treatment fall within the general categories of microfiltration (MF), ultrafiltration (UF), NF, RO, and EDR. However, not all membranes are suitable for desalination.

MF and UF are low-pressure membranes systems used to remove suspended particles and microbial organisms from water. The pore sizes of these membranes are too large to remove dissolved ions from seawater. MF and UF can be used as pretreatment for desalination systems.

NF and RO are high-pressure membrane systems used to remove dissolved ions and minerals. NF membranes are used primarily for softening (a process to remove calcium and magnesium hardness) rather than desalination, which removes chloride and sodium ions. EDR is an electrically driven, rather than pressure-driven, membrane process that can also be used for desalination.

For the membrane alternatives, this evaluation is focused on the use of MF or UF as a pretreatment to desalination using RO membranes. The RO process uses semipermeable membranes and a driving force or pressure in the range of about 800–1,200 psi for seawater desalination. The process can be described as solution/diffusion controlled, because the ions move through RO membranes via the process of diffusion. Salts do permeate the membrane but at permeabilities that are orders of magnitude lower than that of water; thus, the majority of dissolved salts are removed by the process.

As shown in Figure TM1-1, an RO desalination plant essentially consists of four major systems: 1) pretreatment, 2) high-pressure pumps, 3) RO membrane system, and 4) post-treatment. Pretreatment is very important in RO desalination plants because proper pretreatment can reduce RO membrane fouling and thus reduce the operational energy needs and cost. Pretreatment may involve conventional coagulation/filtration processes or membrane processes such as microfiltration or ultrafiltration. The choice of a particular pretreatment process is based on feed water quality, space availability, RO membrane requirements, and other site specific factors.

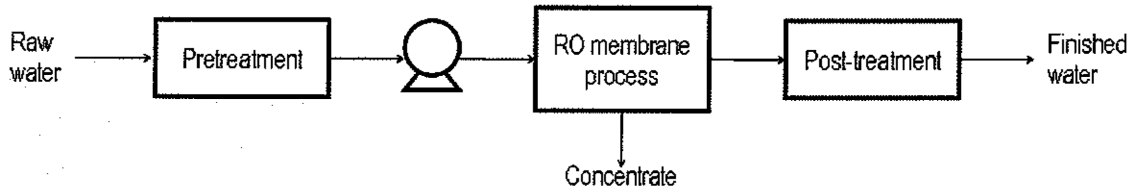

Figure TM1-1 Schematic of a Typical RO Desalination System

RO membranes for desalination generally come in two types: spiral wound and hollow fiber. Currently, the most widely used membrane material is a thin-film composite polymer combining a microporous polysulfone support layer with a thin polyamide layer. The RO membrane assembly consists of a pressure vessel with semipermeable membrane elements inside that permit passage of feedwater. The feedwater, under pressure, flows through the RO elements within the pressure vessel, and the product (desalinated) water is collected in the central tube. As a portion of the water passes through the membrane, the remaining feedwater is discharged without passing through the membrane.

The amount of feedwater discharged as concentrate is about 50% to 55% for seawater desalination. The number of RO elements depends on element size, feedwater salinity, target product water quality, and other factors. For example, the 87-MGD (approximately 330,000-m^3/day) Ashkelon Desalination Plant, Seawater RO Plant in Israel—the world's largest of its type—employs about 40,000 RO membrane elements to desalinate seawater with 40,750 mg/L TDS to approximately 40 mg/L TDS (http://www.water-technology.net/projects/israel/specs.html).

Development of more efficient membranes and the use of energy recovery devices can help RO desalination plants reduce operating costs. Energy recovery devices are typically connected to the concentrate stream and recover energy from the pressure of the concentrate stream as it leaves the pressure vessel. In general, energy recovery devices can recover from 75% to 96% of the input energy in the concentrate stream of seawater RO plants (Sallangos and Kantilaftis 2003).

RO is a feasible technology for seawater desalination. It is a widely used desalting technology with plants in operation and under development in the United States and other parts of the world.

Thermal Desalination

Thermal desalination technologies are the earliest methods used to desalinate seawater on a commercial basis, and thermal processes have been and continue to be a logical regional choice for desalination in the Middle East for several reasons. First, the seas in the region are very saline, hot, and periodically have high concentrations of organics, which are challenging conditions for RO desalination technology. Second, dual-purpose cogeneration facilities were constructed that integrate the thermal desalination process with available steam from power generation, improving the overall thermodynamic efficiency by 10% to 15%. For these reasons, combined with the locally low imputed cost of energy, thermal processes continue to dominate the Middle East. In other parts of the world, where integration of power and water generation is limited and where oil or other fossil fuels must be purchased at market prices, thermal processes are relatively expensive options.

Because the power supply options for desalination plants are still in flux, thermal desalination remains a potential option and is discussed below.

Multistage Flash (MSF) is a thermal distillation process that involves evaporation and condensation of water. Figure TM1-2 presents a schematic of a typical MSF desalination system. The evaporation and condensation steps are coupled so that the latent heat of evaporation is recovered for reuse by preheating the incoming water. To maximize water recovery, each stage of an MSF unit operates at a successively lower pressure. A key design feature of an MSF system is bulk liquid boiling. In most cases, large MSF units are coupled with steam or gas turbine power plants for better utilization of the fuel energy.

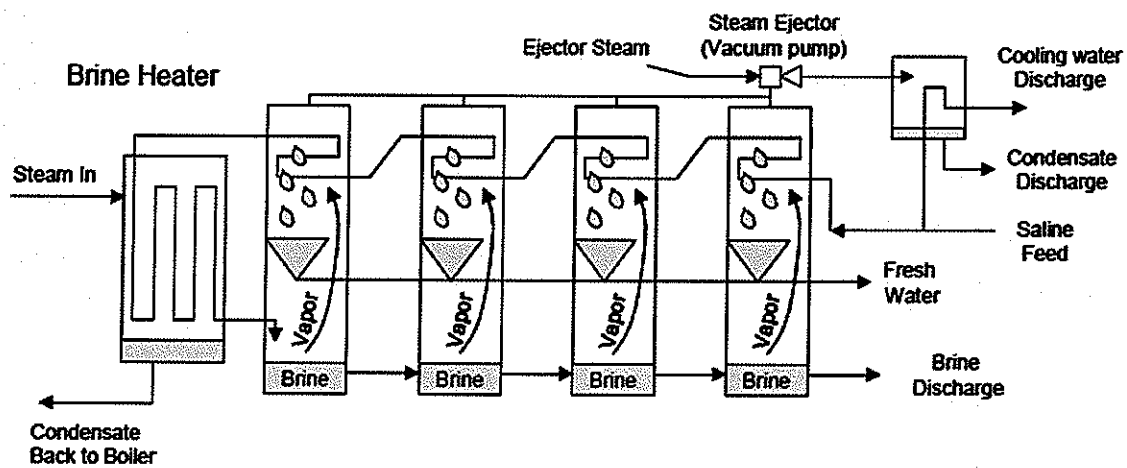

Figure TM1-2 Schematic of a Typical MSF Desalination System (Source: Miller 2003)

Multieffect Distillation (MED) is a thermal distillation process similar to MSF. Figure TM1-3 presents a schematic of a typical MED desalination system. Vapor from each stage is condensed in the next successive stage, thereby using heat to drive more evaporation. Similar to MSF, each stage runs at a successively lower pressure to increase the system performance. MED was developed earlier than MSF, but it has not been widely used because of scaling problems on the heat transfer tubes. Newer plants are designed to limit the scaling problems.

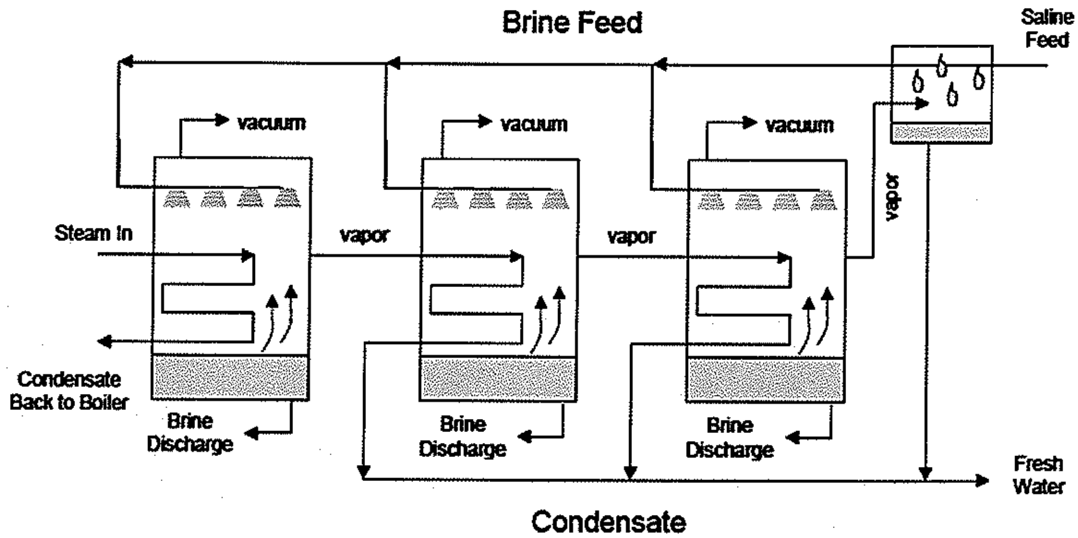

Figure TM1-3 Schematic of a Typical MED Desalination System (Source: Miller, 2003)

The vapor compression (VC) process relies on reduced pressure operation to drive evaporation. Figure TM1-4 presents a schematic of a typical VC desalination system. The heat for the evaporation is supplied by the compression of the vapor, either with a mechanical compressor or a steam ejector. Usually, a mechanical compressor is used to generate the heat for evaporation. The VC process can be used either in combination with other processes, such as MED or by itself for small-size desalination plants.

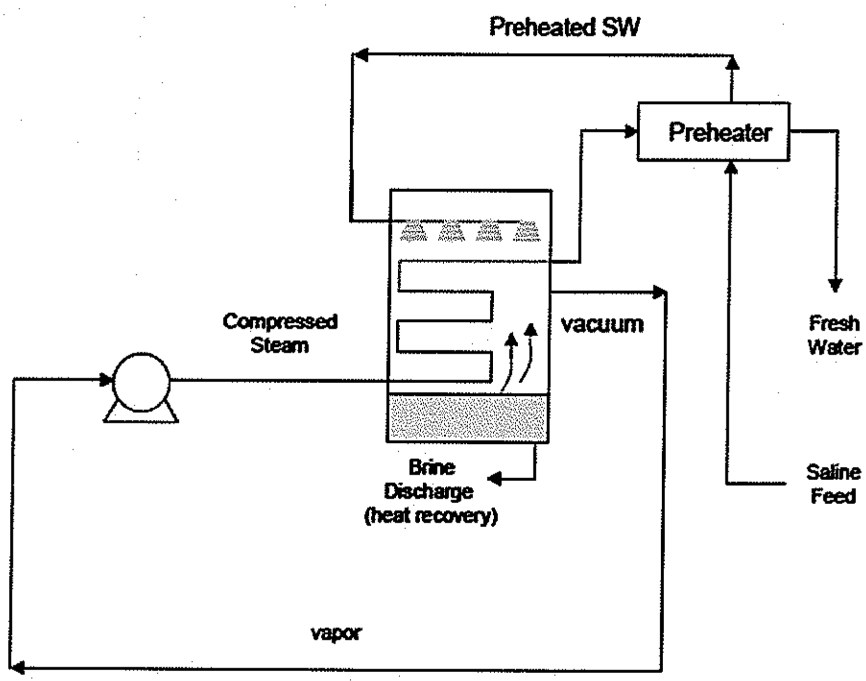

Figure TM1-4 Schematic of a Typical VC Desalination System (Source: Miller, 2003)

Process Selection

An initial screening evaluation was conducted to develop the recommended desalination technology for purposes of generating the cost opinions presented in this technical memorandum. Based on relative general industry treatment costs, technology availability and deployment in North America, power demand and availability, and recent industry trends, this investigation focused on the application of RO in combination with UF or MF pretreatment to desalinate seawater.

Basis for Treatment Cost Opinions

To generate the treatment cost opinion, a conceptual treatment concept was developed as shown in Figure TM1-5. It is important to note that this conceptual process is not a final recommended design and it has not been optimized based on detailed source water and finished water quality analyses. Rather, it serves as an early conceptual feasibility study benchmark for planning purposes.

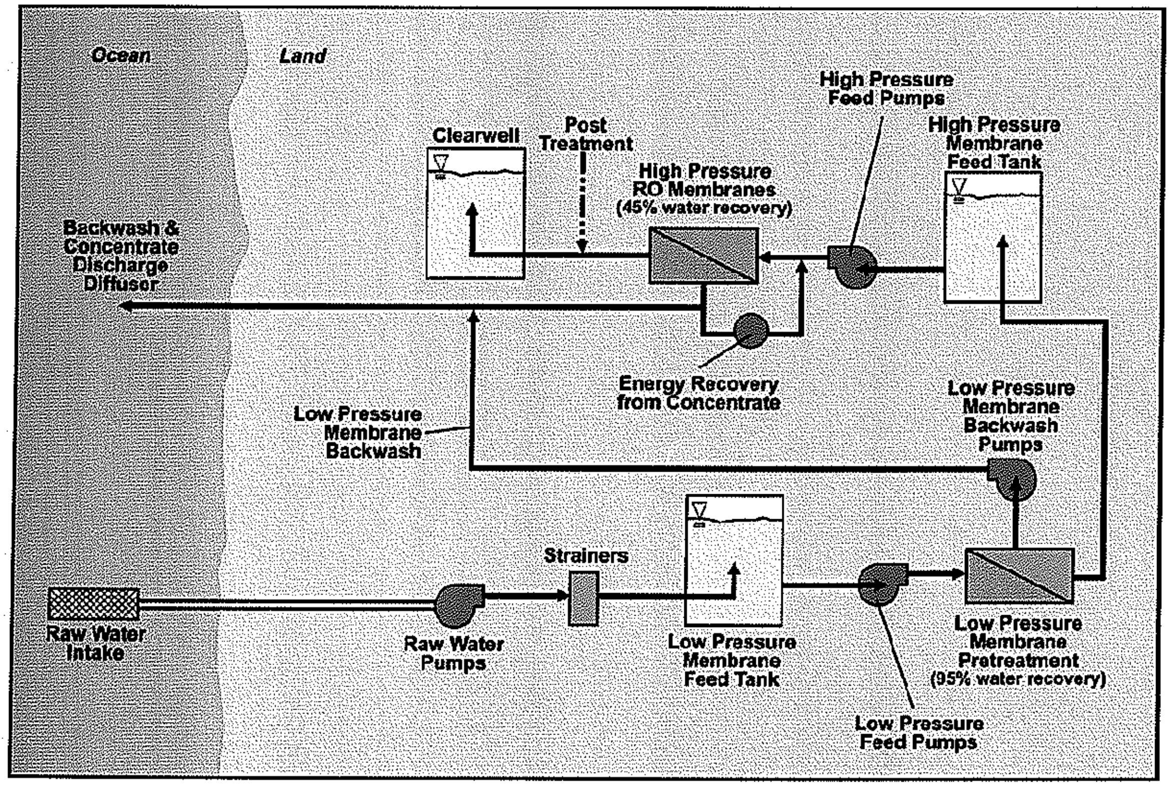

Figure TM1-5 Conceptual Treatment Plant Layout for Cost Opinion

Raw Water

Seawater for the facility can either be drawn directly from the ocean water column with an intake structure or from a near-shore well field. For the purpose of this evaluation, it is assumed that an open water intake will be used because land-side intakes depend on the local geology, the number of wells required to meet the "Regional Scenario" volume is prohibitive, and such "beach wells" are not feasible in all locations. The seawater is pumped to a reservoir or series of storage tanks that serve as the feed reservoir for the low-pressure membrane system. The feedwater storage is sized to store a volume of water equivalent to 5% of the design flow rate.

The raw water supply system will deliver substantially more water than the desalination facility generates as finished product water. Process recovery of 95% was assumed for the low-pressure membranes, while recovery of 45% was assumed for the high-pressure (RO) membrane systems. In total, the source water feed volume needs to be 2.34 times the targeted product water volume using these assumed recovery percentages.

Pretreatment

An effective and reliable pretreatment system is essential to the successful operation of a desalination facility. RO membrane systems require high-quality feedwater to reduce the magnitude and frequency of fouling and the time between cleanings, and to extend membrane life.

Low-pressure membranes (MF or UF) have become increasingly popular for pretreatment prior to RO membranes. The primary advantage of this treatment approach is that the low-pressure membrane process removes contaminants that may pass through conventional treatment processes and that could foul RO membranes. This is particularly true of conventional treatment processes that routinely employ alum (aluminum sulfate) as a coagulant. Alum has been identified as a constituent that can accelerate the degradation of RO membranes over time.

Chemicals are sometimes needed to enhance the physical filtration capabilities of the low-pressure membrane system and polish the effluent for subsequent RO treatment. The use of a coagulant or activated carbon supplement is not expected to be necessary based on the anticipated low concentrations of organics and suspended solids in the seawater. Thus, seawater will be directly applied to and filtered by the low-pressure membrane system.

Reverse Osmosis Membrane Process

After appropriate feedwater pretreatment conditioning, dissolved salts and other constituents are removed by the RO membranes. To properly maintain the function of the RO membranes, various chemicals and ancillary facilities are necessary to adjust the feedwater pH and clean the RO membranes to prevent or remove foulants. These facilities include an acid feed system for pH adjustment and a clean-in-place (CIP) system to remove any foulants.

Post-treatment

Reverse osmosis permeate (product water) often requires various post-treatment strategies in addition to disinfection. An integrated membrane system removes virtually all pathogens, particles, natural organic matter, salts, and solutes. The resultant permeate is typically corrosive due to the absence of solutes and the chemicals added ahead of the RO membranes to depress the feedwater pH to prevent scaling.

Post-treatment must provide corrosion control, disinfection, and creation of finished product water that complies with all applicable regulations. The post-treatment sequence assumed in this technical memorandum includes alkalinity and hardness addition, and free chlorine disinfection. Most pathogens are removed by integrated membrane systems so that the microbiological quality of RO product water is excellent. Nevertheless, disinfection is still a standard post-treatment process that provides an additional barrier of protection against pathogens and microbial organisms and ensures the persistence of a disinfectant residual in the conveyance system. Several alternatives or combinations of disinfectants are available to disinfect the RO permeate during post-treatment, including chlorine, chlorine dioxide, ozone, and ultraviolet radiation. Chlorine was selected as the preferred disinfection method based on a long history of successful and reliable application.

Concentrate

Microfiltration/Ultrafiltration Residuals Management

The low pressure membrane filtration system produces two primary residual streams that may contain chemicals, particulates, or biomass. Normal backwashing accounts for the majority of the disposal flow produced by the pretreatment process. This flow would constitute approximately 5% of the low-pressure system design flow and would contain solids including sediments and organic matter but no pretreatment chemicals. It is proposed that the backwash water be discharged with the RO concentrate away from sensitive habitat.

Chemical cleaning solution represents the other pretreatment residual. This flow comprises pretreatment chemical agents used to clean and enhance the performance of the membrane system. It is proposed that chemically cleaning waste be stored, neutralized, and discharged with the RO concentrate. The high chlorine residual waste would be neutralized by sodium bisulfite and the acid cleaning solution would be neutralized with sodium hydroxide.

Reverse Osmosis Residuals Management

The RO membrane filtration system produces two primary residual streams that may contain chemicals, minerals, or biomass. The pressurized concentrate stream containing the rejected solutes accounts for the majority of the waste flow produced by the RO process. This flow would constitute approximately 55% of the RO system design flow and would contain concentrated dissolved constituents, but no cleaning chemicals.

CIP waste represents the other residual flow. This flow comprises chemical agents used to clean and enhance the performance of the RO system. It is proposed that CIP waste be stored, neutralized, and then slowly released in the RO concentrate dispersion system discussed below.

Concentrate Disposal System

The concentrate disposal system discharges the pretreatment waste and RO concentrate streams back into the sea below (downstream/down current) the source water intake system. The chemical composition and concentration of the waste streams generated by these processes is expected to vary according to the source water quality and the specific treatment process chosen. The discharge system must employ an environmentally acceptable disposal technique that will meet the requirements of several regulatory agencies.

The concentrate disposal system should be designed to mitigate adverse effects of discharge and facilitate regulatory compliance while minimizing associated capital and operation and maintenance costs. Key factors for consideration include chemical composition and daily volume of concentrate produced. Options would also be influenced by the location of the desalination facility in relation to the quality and dilution or dispersive capabilities of the receiving water. Rapid mixing of the concentrate through diffusers (or other mixing systems) is desired to quickly dilute the discharge.

Operationally, backwash and cleaning wastes from the low-pressure membrane system would be mixed with the RO concentrate stream for subsequent release into the open ocean. A pipeline would be necessary to convey the combined membrane systems discharge to the open ocean and away from sensitive marine life. Additionally, the use of fewer and less harmful treatment chemicals, if possible, as well as proper neutralization prior to disposal would reduce adverse effects caused by the discharge.

Dilution may be promoted through the use of diffusers or multiport outfalls that distribute the discharge over a larger area, thereby reducing the discharge plume to environmentally acceptable concentrations. Dilution may be further enhanced by providing a dilution mixing stream for the concentrate from the raw water intake system prior to open ocean discharge. Special care should be taken in locating the concentrate outfall to avoid surrounding biota that might be vulnerable or sensitive to changes in water quality.

Design Capacity

The overall desalination system capacity and performance is a function of several variables, including:

- Source and finished water quality
- Recovery rates of the low and high pressure membrane systems
- Temperature

As mentioned in the previous section, system recoveries of 95% and 45% were assumed for the low- and high-pressure membrane systems, respectively. These performance assumptions mean that the pretreatment feed flow rates will be 250 and 2,503 MGD to sustain corresponding finished water rates of 107 and 1,070 MGD.

Raw water would be pumped into raw water feed tanks to provide equalization storage prior to being pumped through the low-pressure membranes to the RO feed tanks. The RO feed tanks will provide water for backwash and system cleaning of the low-pressure system as well as equalization storage for the high-pressure system. All feed tanks were sized to accommodate 10 minutes of storage capacity, with an assumed sidewater depth of 16 feet.

Assumptions

Based on the general conceptual design assumptions above, an opinion of cost was developed. This opinion is a Class 5 estimate as defined by the Association for the Advancement of Cost Engineering (AACE). Class 5 estimates are generally prepared based on very limited information and subsequently have wide accuracy ranges. The expected accuracy range for Class 5 estimates are -20% to -50 % on the low side and

+30% to +100% on the high side. This estimate is also referred to as an "order of magnitude" estimate by ANSI. It is typically accurate within -30% to +50%.

Foreigners cannot acquire direct ownership (title) of real estate in Mexico within 50 kilometers of the coast (restricted areas). A property trust can be established and used by foreigners to utilize property in restricted areas. Rights acquired through a property trust are very broad, similar to the acquisition of the property, without covering the direct dominion of the trustee (typically a credit institution or bank). Property trusts can be used for tourist, residential, industrial, or dwelling purposes. Provisions governing property trusts are contained in Mexico's Foreign Investment Law of 1973. No land cost was assumed for the purpose of developing an opinion of cost for each scenario. It is assumed that actual land prices would be negotiated between the future parties of a binational project in association with the benefits gained from a new water resource.

The following general assumptions were used in developing the treatment costs documented in this technical memorandum:

- Source water TDS: 34,000 mg/L
- Product water TDS: 750 mg/L
- Energy costs: $0.10/kWh—provided by CAP and SRP. These costs would be refined as power options are reviewed and optimized.
- Adequate energy supply available from power grid
- Membrane life: 5 years
- Low-pressure membrane recovery: 95%
- High-pressure membrane recovery: 45%
- Plant capacity assumes continuous operation, 24 hours a day, 365 days per year
- Construction costs are based on base flow
- Operations costs are based on base flow
- Base flow used for unit costing: 107 MGD
- Capital cost of connecting piping and valves: 20% of raw water intake and pump equipment, MF/UF membranes, RO membranes, and chemical feed equipment costs
- Capital cost of buildings and ancillary equipment: 7.5% of raw water intake and pump equipment, MF/UF membranes, RO membranes, and chemical feed equipment costs
- Capital costs of electrical and instrumentation: 20% of raw water intake and pump equipment, MF/UF membranes, RO membranes, and chemical feed equipment costs
- Treatment system installation cost: 28% of raw water intake and pump equipment, MF/UF membranes, RO membranes, and chemical feed equipment costs
- Concentrate disposal pipeline: 1 mile in length
- Brine diffuser: 3,000 linear feet
- Mobilization: 3% of equipment, materials, and installation costs
- Insurance: 1.5% of equipment, materials, and installation costs
- Contractor overhead and profit: 15% of equipment, materials, and installation costs
- Engineering, legal, and contingency: 40% of total costs
- Environmental and cultural resources (impact studies and permitting [local, state, federal, and international]): assumed at $10 million for 107 MGD plant

- Environmental and cultural resources (impact studies and permitting [local, state, federal, and international]): assumed at $30 million for 1,070 MGD plant
- For the Regional Scenario (1,070 MGD): conveyance system is a canal that would need to be shut down for 2 weeks of maintenance. The 1,070 MGD plant would not be increased in capacity to account for the shut down
- Capital cost escalation (minus the concentrate disposal line) from 107 MGD to 1,070 MGD is based on a multiplier of 8 because of economies of scale (National Research Council and U.S. Bureau of Reclamation [USBOR])
- Capital cost escalation for the concentrate disposal line items ranges from a multiplier of 4 (U.S. Bureau of Reclamation) to 8 (National Research Council)
- O&M cost escalation from 107 MGD to 1,070 MGD is based on a multiplier of 9 (National Research Council) because of economies of scale. The USBOR multiplier is 10 which assumes no economies of scale. Both factors are used to present a range of costs
- The multipliers above are provided by the National Research Council and the USBOR. However, the sources do not include facilities of the 1,070 MGD facility capacity (because no such facility exists)
- Total capital costs: annualized based on a 4% discount rate and 20-year duration
- Annual costs determined using four times the costs of a similar 25 MGD facility (prepared by HDR for a confidential client on a very similar project), multiplied by 90%
- No land or right-of-way costs were included

Conceptual Opinion of Cost for Desalination

Table TM1-3 details the costs for each scenario.

Table TM1-3 Opinion of Cost for 107 MGD and 1,070 MGD Desalination Plants

	Cost Opinion 107 MGD	Cost Opinion 1,070 MGD (NRC)	Cost Opinion 1,070 MGD (USBOR)
Equipment, Materials, and Installation Capital Costs			
Treatment System			
Raw Water Intake and Pumps	$14,925,000	$119,400,000	$119,400,000
Low Pressure Membrane Pretreatment	$42,403,000	$339,224,000	$339,224,000
High Pressure Reverse Osmosis Desalination	$104,805,000	$838,440,000	$838,440,000
Chemical Feed	$3,722,000	$29,776,000	$29,776,000
Connecting Piping and Valves	$33,171,000	$265,368,000	$265,368,000
Buildings and Ancillary Equipment	$12,439,000	$99,513,000	$99,513,000
Electrical and Instrumentation	$33,171,000	$265,368,000	$265,368,000
Subtotal Installed Equipment and Materials Capital Cost	$244,636,000	$1,957,089,000	$1,957,089,000
Treatment System Installation Cost	$68,498,000	$547,985,000	$547,985,000
Treatment System Capital Cost	$313,134,000	$2,505,074,000	$2,505,074,000
Concentrate Transmission and Disposal Systems			
Concentrate Disposal Discharge Pipeline (1 mile)	$17,424,000	$104,544,000	$69,696,000
Brine Diffuser (3000 ft)	$2,234,000	$11,170,000	$8,936,000
Concentrate Transmission and Disposal Systems Capital Cost	$19,658,000	$115,714,000	$78,632,000
Subtotal Equipment, Materials, and Installation Capital Cost	$332,792,000	$2,620,788,000	$2,583,706,000
Mobilization (3%)	$9,984,000	$78,624,000	$77,511,000
Insurance (1.5%)	$4,992,000	$39,312,000	$38,756,000
Contractor's Overhead and Profit (15%)	$49,919,000	$393,118,000	$387,556,000
Total Construction Cost	$397,687,000	$3,131,842,000	$3,087,529,000
Engineering, Legal Costs and Contingencies (40%)	$159,075,000	$1,252,737,000	$1,235,012,000
Environmental & Archaeology Studies and Mitigation	$10,000,000	$30,000,000	$30,000,000
Total Project Capital Cost	**$566,762,000**	**$4,414,579,000**	**$4,352,541,000**
Annual Costs			
Debt Service (4%, 20 years)	$41,703,000	$324,832,000	$320,268,000
Operations and Maintenance			
Treatment System Maintenance (incl. membrane replacement)	$8,752,000	$78,768,000	$87,520,000
Transmission and Concentrate Maintenance	$620,000	$5,580,000	$6,200,000
Operations Staff	$5,547,000	$49,923,000	$55,470,000
Treatment Chemicals	$10,909,000	$98,181,000	$109,090,000
Energy (at $0.10/kW-hr)	$51,852,000	$518,520,000	$518,520,000
Total Annual Costs	$119,383,000	$1,075,804,000	$1,097,068,000
Available Project Yield (acre-ft/yr)	120,000	1,200,000	1,200,000
Available Project Yield (MGD)	107	1,070	1,070
Annual Cost of Water ($ per acre-ft)	**$995**	**$897**	**$914**
Annual Cost of Water ($ per 1,000 gallons)	**$3.06**	**$2.75**	**$2.81**

The total treatment system capital cost opinion for the 107 MGD scenario is $567 million. The annual costs, including debt service in the capital, O&M, chemicals, and power, are $119 million per year over the 20 year life of the project (constant dollars). This results in a unit cost for treatment of **$995 per acre-foot** ($3.06 per 1,000 gallons).

The total treatment system capital cost opinion for the 1,070 MGD scenario is $4.3 to $4.4 billion depending on the factors used for capital costs multipliers. The annual costs, including debt service in the capital, O&M, chemicals, and power, are approximately $1.0 billion per year over the 20-year life of the project (constant dollars).This results in an average unit cost for treatment of about **$905 per acre-foot** ($2.78 per 1,000 gallons).

For context, information for large seawater RO facilities (greater than 50 MGD) world-wide is provided in Table TM1-4. The average cost of desalinated seawater is **$968 per acre-foot** ($2.97 per 1,000 gallons) for these facilities.

Table TM1-4 Unit Cost Data for Seawater Reverse Osmosis Facilities

Plant	Year of estimate	Water cost ($/1,000gal)	Capacity (MGD)	Product water salinity (mg/L TDS)
Taweelah C, UAE (est)	2000	2.73	86	<500
Ashkelon, Israel	2008	2.95	86	300
Hamma, Algeria	2005	3.10	53	500
Shuqaiq, Saudi Arabia	2006	3.90	56	110
Carlsbad, California (est)	2007	2.91	50	N/A
Hadera, Israel	2008	3.26	87	20 mg/L chlorides, 0.3 mg/L boron
Ad Dur, Bahrain	2008	3.52	58	N/A
Mactaa, Algeria (bid)	2008	2.12	132	<500
Tenes, Algeria	2008	2.23	53	<500
Average		2.97	73	
Maximum		3.90	132	
Minimum		2.12	50	

(Source: Water Desalination Report)

In 2008, the largest desalination plant in the world, the Shoaiba 3 plant in Saudi Arabia with a production capacity of 232.4 MGD, was commissioned. It produces approximately 260,391 AFY, or 0.88 M m^3/day. The Regional Scenario, if implemented, would represent the largest seawater desalination project in the world—at approximately 4.5 times the size of the Shoaiba 3 plant. However, global water demand projections indicate that facilities of such size are within the realm of possibility within the next few decades. Desalination technologies have progressed to the point where such facilities are feasible, and advances in water and energy efficiency and productivity are expected to continue into the future.

HDR | ONE COMPANY *Many Solutions*℠

From: HDR ENGINEERING, Inc.	Project: Investigation of Binational Desalination
Date: June 5, 2009	Job No: 87873 and 87874

RE: Investigation of Binational Desalination for the Benefit of Arizona, United States, and Sonora, Mexico

This technical memorandum was developed in support of the project, *Investigation of Binational Desalination for the Benefit of Arizona, United States, and Sonora, Mexico*. It documents the conveyance infrastructure (pipeline or canal, storage, and pumping plants) to deliver desalinated ocean water from the Gulf of California to Imperial Dam in California.

Water Conveyance Concept

Water produced from a binational seawater desalination facility must be conveyed to locations where it can be put to beneficial use. Opinions of cost would have been developed for the delivery of desalinated water to Imperial Dam, with the acknowledgment that deliveries would also be made along the route in Mexico at locations to be determined in future studies. Approximately 5.7 MAF (5,083 MGD or 19.3 M m^3/day) of Colorado River water passed through Imperial Dam in 2008 to satisfy water demands in both countries (United States Bureau of Reclamation [USBOR] 2008). Desalinated water conveyed to Imperial Dam would displace Colorado River water that could then be exchanged to users in Arizona or even the other basin states, which would then divert the additional Colorado River water through their existing, expanded, or new infrastructure.

To conceptualize the infrastructure needs and associated costs to convey water to Imperial Dam, it was assumed that a desalination plant would be located on the Gulf of California, just northeast of the central part of Puerto Peñasco. Within the Northern Gulf is the Upper Gulf of California/Colorado River Delta Biosphere Reserve, extending from the Delta to a straight line running from approximately San Felipe, Baja California Sur, to a point just a few miles northwest of Puerto Peñasco, Sonora. Because this is an environmentally sensitive area, the withdrawal of seawater and return of brine for seawater desalination operations was located south of the marine reservation. Delivering water between Puerto Peñasco and Imperial Dam would most likely require conveyance across portions of the 600-mi^2 (155,000-ha) El Pinacate and Gran Desierto de Altar Biosphere Reserve. At this level of study, it was assumed that the route for conveyance with the lowest environmental impact would be along the highway that already exists through the designated reserve. A conceptual water conveyance route is depicted on Figure TM2-1.

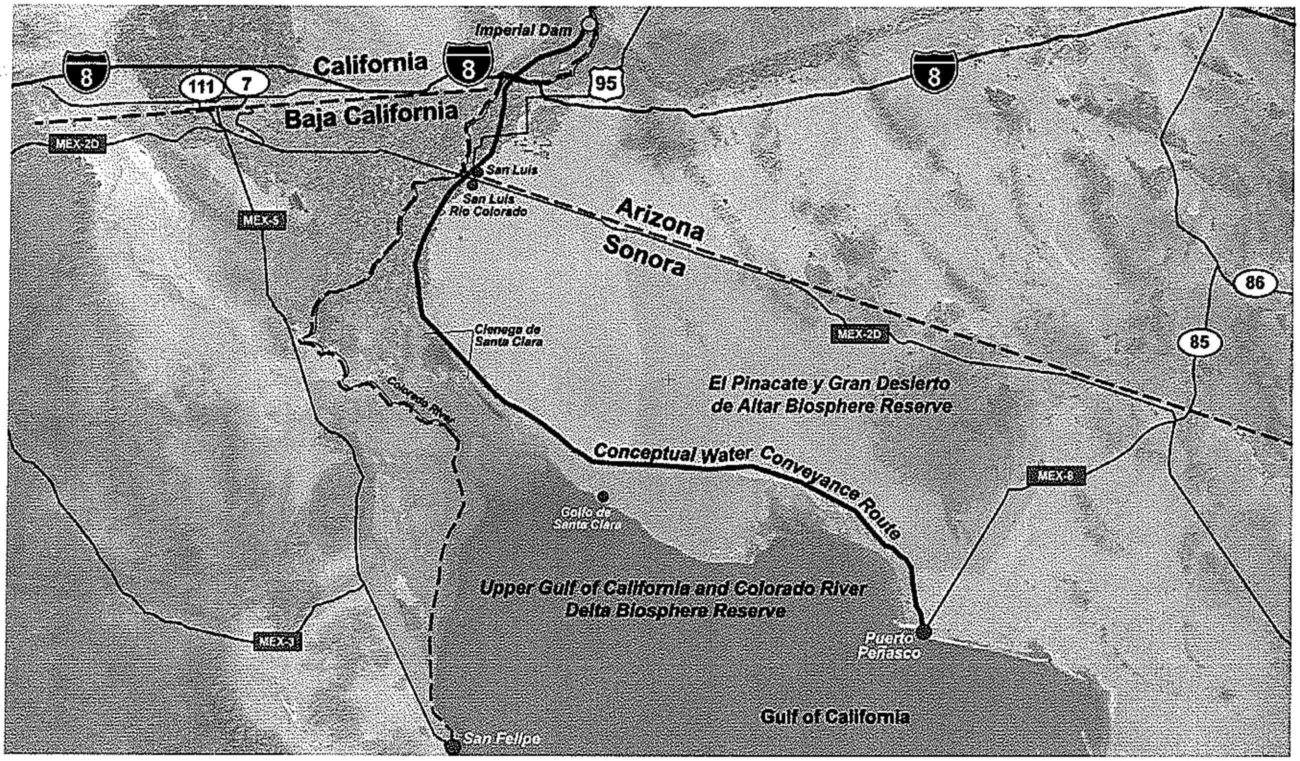

Figure TM2-1 Conceptual Water Conveyance Route

Opinions of cost for conveyance of desalinated ocean water delivered from Puerto Peñasco to Imperial Dam are based on two methods of conveyance: through a pipeline or via a canal for the 120,000 AFY and 1,200,000 AFY scenarios, respectively. The conveyance cost opinions were developed based on a preliminary route. It is expected that the actual route of the pipeline or canal would vary from that shown above, based on geologic conditions, soil conditions, environmental factors, and land ownership/right-of-way issues not assessed during this investigation.

The route is generally of low slope with 181 feet of vertical lift from the treatment site (sea level) to Imperial Dam. The length of the conceptual conveyance route is approximately 168 miles.

Assumptions

Based on the concept described above, an opinion of cost was developed. This opinion is a Class 5 estimate as defined by the Association for the Advancement of Cost Engineering (AACE). Class 5 estimates are generally prepared based on very limited information and subsequently have wide accuracy ranges. The expected accuracy range for Class 5 estimates are -20% to -50 % on the low side and +30% to +100% on the high side. This estimate is also referred to as an "order of magnitude" estimate by ANSI. It is typically accurate within -30% to +50%.

This technical memorandum assumed welded steel pipe for all pipeline sections. Alternatives such as HDPE, concrete cylinder, and fiberglass-based materials should be evaluated for feasibility in the next phase of this project. Each pumping plant includes a single discharge manifold that feeds the pressure pipes provided to reach the next open canal section. The actual configuration of the pumping plant discharges should be optimized for cost, ease of maintenance, and operability. For example, it may be advantageous to construct parallel discharge manifolds such that each individual pipeline is fed by its own discharge header and set of pumps. This optimization would occur during a later phase of the design.

Foreigners cannot acquire direct ownership (title) of real estate in Mexico within an area of 100 kilometers along the borders with neighboring countries or 50 kilometers along the coast (restricted areas). A property trust can be established and used by foreigners to utilize property in restricted areas. The rights acquired through the property trust are very broad, being similar to the acquisition of the property, without covering the direct dominion of the trustee (typically a credit institution or bank). Property trusts can be used for tourist, residential, industrial, or dwelling purposes. The provisions governing property trusts are contained in the Mexican Foreign Investment Law of 1973. A land cost of $5,000 per acre was assumed for the purpose of developing an opinion of cost for each scenario. This is an arbitrary value, and it is assumed that actual land prices would be negotiated between the future parties of a binational project in association with the benefits gained from a new water resource.

Scenario 1: Pipeline for the Arizona-Sonora Scenario – 120,000 AF/year

The following general assumptions were used in developing the pipeline costs documented in this technical memorandum:

- 120,000 AFY of flow, equivalent to 107 million gallons per day (MGD)
- Length of pipeline: 168 miles (Puerto Peñasco to Imperial Dam)
- Electrical grid power would be available along the entire pipeline route
- Power costs: $0.10/kW-hr
- Four 6,000 hp pumping plants, each with five 1,200 hp duty pumps, and one 1,200 hp back-up pump. Land requirement for each pumping plant: estimated at 8 acres
- Pump efficiency: 85%
- Pump motor efficiency: 90%
- 1.1 MG forebays with volume of individual forebays equal to 15 minutes of full flow. Land requirement for each forebay: estimated at 8 acres
- Factor of safety of 1.2 on total dynamic head (TDH) to account for losses through pump station and appurtenances
- Maximum discharge pressure from pumping plant: 110 psi => 241 feet of total dynamic head (TDH); typical operating pressure of approximately 100 psi
- 78-inch-diameter welded steel pipe
- Maximum water velocity in pipeline, V_{max} of 5 feet per second (fps)
- 10% of the conveyance route would be through hard rock while the remaining 90% of the route would allow for normal excavation
- Pipe buried with 5 feet of cover
- 100-foot right-of-way for pipeline
- Pipeline has isolation valves every mile
- Fully enclosed buildings for pumping plant
- Uninterrupted Power Supply only for SCADA, monitoring, instrumentation
- Approximately 1-day storage or 100 MG—four 25 MG reservoirs, each requiring 8 acres, along pipeline route to aid in service reliability, maintenance, and deliveries to users along the pipeline route

- Distribution infrastructure is the responsibility of the end user
- Environmental impact studies and permitting (local, state, federal, international) estimated at $10M
- O&M for the pumping stations: estimated at 3% of construction costs/year
- All projects would be delivered on a design-bid-build basis

The conceptual cost opinion for the pipeline (Arizona-Sonora Scenario) is presented in Table TM2-1.

Table TM2-1 Cost Opinion for 168-Mile Pipeline Conveyance System

	Cost Opinion
Equipment, Materials, and Installation Capital Costs	
Pipeline (78-inch)	
General Requirements and Special Equipment (Division 1)	
Trenching, Bedding, Backfill, Access Road, Fencing (Division 2)	
78-inch Welded Steel Pipe (0.35-inch wall)	
Freight	
Appurtenances	
Temporary Facilities and Miscellaneous Equipment	
Pipeline Capital Cost	$887,000,000
System Storage/Forebays	
4, 25 MG Flow Management Reservoirs	
4, 1.1 MG Forebays (One located at each pump station)	
System Storage/Forebays Capital Cost	$79,400,000
Pump Stations (4 Total)	
General Requirements, Site Work, and Furnishings (Divisions 1-2 and 12)	
Concrete, Masonry, Construction Materials (Divisions 3-6)	
Roofing, Openings, Finishes, and Specialties (Divisions 7-10)	
Equipment: Pumps, Drivers, Appurtenances (Division 11)	
Instrumentation and Controls (Division 13)	
Conveying and Mechanical (Divisions 14-15)	
Electrical (Division 16)	
Pump Stations Capital Cost	$81,600,000
Subtotal Equipment, Materials, and Installation Capital Cost	$1,048,000,000
Mobilization (3%)	$31,400,000
Insurance (1.5%)	$15,700,000
Contractor's Overhead and Profit (20%)	$209,600,000
Total Construction Cost	$1,304,700,000
Engineering, Legal Costs and Contingencies (40%)	$521,900,000
Land Acquisition for Pipeline Corridor and Reservoir Sites	$10,500,000
Environmental & Archaeology Studies and Mitigation	$10,000,000
Total Project Capital Cost	**$1,847,100,000**
Annual Costs	
Debt Service (4%, 20 years)	$135,900,000
Operations and Maintenance	$55,400,000
Energy (at $0.10/kW-hr)	$16,500,000
Total Annual Costs	**$207,800,000**
Available Project Yield (acre-ft/yr)	120,000
Available Project Yield (MGD)	107
Annual Cost of Water ($ per acre-ft)	**$1,732**
Annual Cost of Water ($ per 1,000 gallons)	**$5.32**

The following general assumptions were used in developing the canal costs documented in this technical memorandum:

- 1.2 million AFY of flow, equivalent to 1,070 MGD
- Length of conveyance system: 168 mi (Puerto Peñasco to Imperial Dam)
- Average slope of existing grade: 181 ft/ (5,280 feet/mile * 168 miles) = 0.000204
- Electrical grid power would be available along the entire canal route
- Power costs: $0.10/kW-hr
- Conveyance system: 143 miles of open channel, 25 miles of closed channel (pressure pipes), and five pumping plants
- Open channel: canal with trapezoidal section, 24-foot bottom width, 10 feet overall depth, 8 feet water depth, 1.5H (horizontal):1V (vertical) canal side slopes
- Canal lining: 3.5-inch-thick concrete with wire mesh reinforcement
- Berm: 3.5 feet high with 3H:1V side slopes
- 10% of the conveyance route would be through hard rock while the remaining 90% of the route would allow for normal excavation
- Spoils: would provide sufficient material for berm
- Twenty-foot-wide road crossing approximately every 25 miles (plus five locations in urban areas) via a 20-foot-wide, 70-foot-long steel truss bridge
- Maximum water velocity in canal: approximately 5 fps
- Subcritical flow in canal
- Closed channel system: two welded steel pipes, each 180 inches in diameter
- Maximum water velocity in pipeline, V_{max} of 5 fps
- Pipe buried with 5 feet of cover
- Five 15,000 hp pumping plants, each with five 3,000 hp duty pumps and one 3,000 hp standby pump
- Each of the five pumps plus the backup pump would discharge via a common discharge header manifold. From the common manifold header there would be two discharge pipes that would feed into two individual penstocks
- Pump efficiency: 85%
- Pump motor efficiency: 90%
- Factor of safety of 1.2 on total dynamic head (TDH) to account for losses through pump station and appurtenances
- Discharge pressure from pumping plants: approximately 26 psi => approximately 58 feet of total dynamic head (TDH)
- Five 11.1 MG forebays required along the route (one at each pump station)
- Volume of impoundments equal to 15 minutes of full flow
- 200-foot-wide right-of-way (ROW) for channel
- Fully enclosed buildings for pumping plant
- Uninterrupted power supply only for SCADA, monitoring, instrumentation
- Approximately 100 MG of in-channel storage divided into four 25 MG storage areas. In-channel storage consists of a widening of the channel to a 200-foot bottom width for a length of 2,000 feet. Each of these storage areas requires approximately 18 acres along pipeline route to aid in service reliability, maintenance, and deliveries to users along the pipeline route. ROW will increase to 400 feet in these areas
- Distribution infrastructure is the responsibility of the end user
- Environmental impact studies and permitting (local, state, federal, international) estimated at $20M

- O&M for the pumping stations is estimated at 3% of construction costs/year
- All projects would be delivered on a design-bid-build basis

The conceptual cost opinion for the canal (Regional Scenario) is presented in Table TM2-2.

Table TM2-2 Cost Opinion for 168-Mile Canal Conveyance System

	Cost Opinion 1,070 MGD Canal System
Equipment, Materials, and Installation Capital Costs	
Canal Structures	
Normal Excavation - Scrapers, No Ripping (90% of canal length)	
Hard Excavation - Scrapers, with Ripping (10% of canal length)	
Furnish and Install 3.5" Canal Liner	
Canal Check Structures	
Inverted Siphon at All-American Canal	
Access Bridges	
Service Roads	
Fencing	
Temporary Facilities, MOB/DEMOB, Miscellaneous Equipment	
Canal Capital Cost	$357,300,000
System Storage/Forebays	
4, 25 MG Flow Management Reservoirs	
5, 11.1 MG Forebays (One Located at each Pump Station)	
System Storage/Forebays Capital Cost	$130,500,000
Pump Stations (5 Total)	
General Requirements, Site Work, and Furnishings (Divisions 1-2 and 12)	
Concrete, Masonry, Construction Materials (Divisions 3-6)	
Roofing, Openings, Finishes, and Specialties (Divisions 7-10)	
Equipment: Pumps, Drivers, Appurtenances (Division 11)	
Instrumentation and Controls (Division 13)	
Conveying and Mechanical (Divisions 14-15)	
Electrical (Division 16)	
Discharge Manifolds	
Connector Pipelines (5, 114-inch Welded Steel Pipes per Connection)	
Pump Stations Capital Cost	$1,130,700,000
Subtotal Equipment, Materials, and Installation Capital Cost	$1,618,500,000
Mobilization (3%)	$48,600,000
Insurance (1.5%)	$24,300,000
Contractor's Overhead and Profit (20%)	$323,700,000
Total Construction Cost	$2,015,100,000
Engineering, Legal Costs and Contingencies (40%)	$806,000,000
Land Acquisition for Canal Corridor and Reservoir Sites	$19,500,000
Environmental & Archaeology Studies and Mitigation	$20,000,000
Total Project Capital Cost	**$2,860,600,000**
Annual Costs	
Debt Service (4%, 20 years)	$210,488,000
Operations and Maintenance	$85,800,000
Energy (at $0.10/kW-hr)	$37,100,000
Total Annual Costs	$333,388,000
Available Project Yield (acre-ft/yr)	1,200,000
Available Project Yield (MGD)	1,070
Annual Cost of Water ($ per acre-ft)	**$278**
Annual Cost of Water ($ per 1,000 gallons)	**$0.85**

The unit cost to convey the treated water to Imperial Dam under the Arizona-Sonora Scenario (120,000 AFY) via pipeline is **$1,732 per acre-foot** ($5.32 per 1,000 gallons). The unit cost to convey treated water to Imperial Dam under the Regional Scenario (1,200,000 AFY) via canal is **$278 per acre-foot** ($0.85 per 1,000 gallons).